Power Engineering Guide

5th Edition

Answers for energy.

SIEMENS

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Forword

This fundamentally revised and updated new edition of the established Power Engineering Guide is a manual for everyone who is involved in the generation, transmission and distribution of electrical energy – from system planning, to implementation and control. Our guide is designed to assist engineers, technicians, planners and advisors and support students, trainees, electrical engineering teachers and energy technology teachers (including university lecturers). Beyond that, we hope Power Engineering Guide will also be useful as a reference work for technical questions and in supporting continuing education in technical fields.

Our guide is organized by product and function, covering the entire portfolio of Siemens products for the transmission and distribution of electrical power – including high, medium and low voltage, switching substations and transformers and switchgear. It also covers solutions in the areas of automation, energy management and network communication, as well as service and support. The guide's most important terms and abbreviations are explained in a handy appendix, and Internet addresses are provided for additional in-depth information.

Siemens' products, systems and integrated, complete solutions benefit customers by meeting a wide range of different, local requirements. They represent the key technologies of the future and set global standards. The connecting theme of all developments and innovations – which also affect methods and processes – are efficiency, environmental compatibility, reliability and economy.

Siemens AG is a global leader in electronics and electrical engineering with 400,000 employees and branches in 190 countries. The Power Transmission and Power Distribution divisions of the Siemens Energy Sector are product suppliers, system integrators total solution providers and service providers for power transmission and distribution systems from the power plant to the end consumer.

To help our customers achieve success and further growth, we are always in the process of selectively strengthening and optimizing our portfolio. As a result, in addition to "classic" products for power transmission and distribution, today's portfolio includes many additional products. It offers network operators, electricity customers, planners and builders of electrical systems the additional benefits of integrated communications and automation technology. Our range of services includes the planning, maintenance and repair of entire power supply networks.

Thanks to our many years of experience managing projects around the world, we can provide power supply and industrial companies with optimum, cost-efficient solutions to quickly meet their needs anytime, anywhere – you can count on us. If you find, as you read through the Power Engineering Guide, that you have questions or need any assistance choosing the right product, please don't hesitate to contact us. The staff at your local Siemens sales location is there to help you. You will find their e-mail addresses at www.siemens.com/energy.

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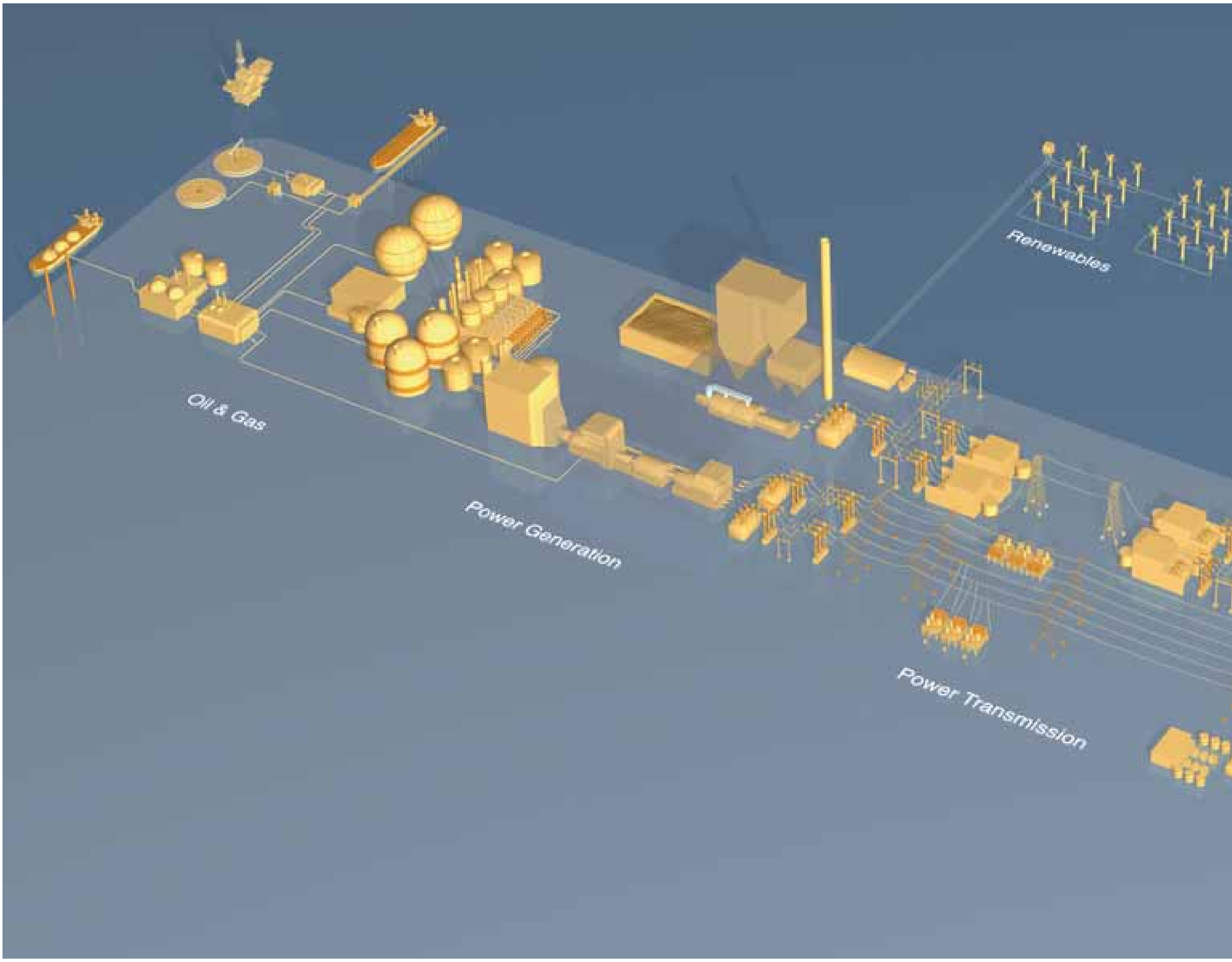


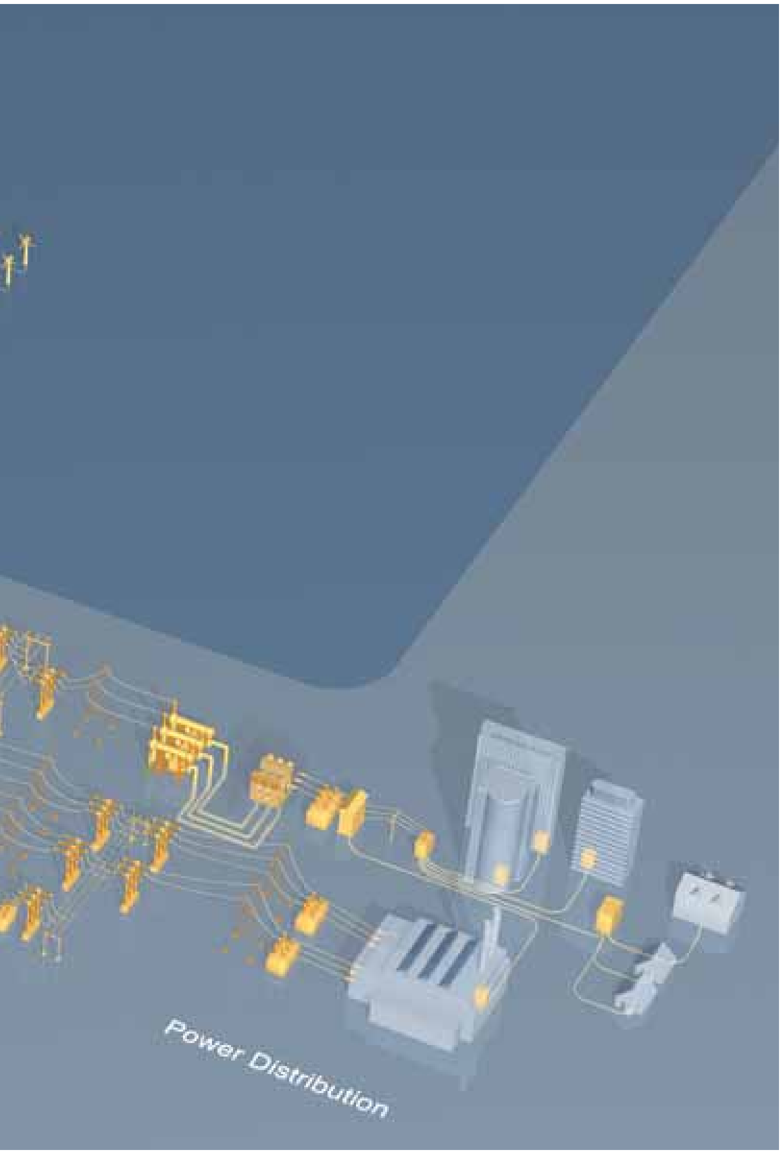
Fig. 1-1: **Siemens is offering complete communications solutions to build a smart grid for power utilities**

1. Introduction

In today's world, electrical energy is the backbone of all economies and supports every aspect of social and cultural life throughout the world. Seen on a global scale, however, the comfort of always having electricity available is anything but a matter of fact – particularly in view of the major challenges the world faces in providing sufficient power generation, transmission and distribution capacity.

The global demand for energy is steadily rising, not least because of the world's rapid population growth and generally longer lives. The demand for electricity is growing at an annual rate of three percent, faster than the two percent annual increase in the global demand for primary energy. The process of urbanization is continuing to accelerate, and ever larger amounts of electricity must be transported to heavily populated areas, usually over long distances. At the same time, the density and complexity of urban power grids are increasing (fig. 1-1).

On the other hand, fossil energy sources are getting scarcer and the exploration and production of oil and gas, in particular, are becoming more expensive. Worldwide, growing efforts to slow the threatening climate change demand the reduction of CO_2 emissions. For power grids, this means an increasing integration of renewable energy sources such as hydro, wind and solar. At the same time, it also means further increasing the energy efficiency of the power grids in order to contribute to environmental and climate protection efforts and help keep energy costs under control. The growing international trade in



energy, fueled by the liberalization of energy markets, and the supraregional integration of power grids increasingly requires additional transmission lines to ensure the stability of the grids and guarantee power supplies.

To meet all of these challenges, one must utilize innovative technologies to upgrade and expand the power grids in developing and emerging countries. It is also necessary to optimize the power infrastructures of industrialized nations. In the highly populated countries of Asia and America, for example, Siemens has introduced advanced solutions in recent years that will provide a model for planning in other countries and on other continents. Altogether, four nations – China, India, the U.S. and Brazil – make up about 50 percent of the world's population. They also rank among the world's ten biggest regions in terms of energy consumption and installed power plant capacity.

With its dynamic economic growth and rapid urbanization, China currently faces the greatest challenges in satisfying its rapidly growing energy needs. Enormous amounts of energy have to be transported long distances, in some cases up to 2,000 kilometers (1,250 miles). Increasingly, hydro power and coal-generated power produced in the interior of the country is used by the coastal region's large urban centers. Local coal deposits also supply coal electrification.

High-voltage direct-current transmission, with its high capacity, stability and low rate of loss, is the best way to ensure highly efficient, long-distance power transmission. Siemens is currently building some of the highest capacity HVDC transmission lines in the world, in China and India. These include a 5,000-MW capacity transmission system. For the first time, we are also providing a transmission voltage of 800 kV between the southwest provinces of Yunnan and the southern province of Guangdong. Without this Ultra-High-Voltage Direct-Current (UHV DC) system, the renewable hydro energy source in Yunnan could not be used. This new transmission line will help save over 30 million metric tons of CO_2 emissions a year.

Technically seen, such ultra-high-voltage transmission lines require pioneering developments in HVDC technology and all of the related components. For instance, the weight and size of the transformers and the high level of test voltages are unprecedented. The key engineering challenges here are the dielectric dimensioning – in particular for controlling ultra-high voltage fields while ensuring the reliability of the insulation in the polarity reversals.

In land area, Brazil is the fifth largest country in the world. Like China, it relies on hydro power and it transports energy over long distances to consumption centers. In Brazil, however, network operators take a different approach. They have boosted the capabilities of the alternating-current transmission system by using uncontrolled (FSC) and controlled series compensators (TCSC) to increase transmission capacities (flexible alternating current transmission systems (FACTS) technology. Series compensators reduce line impedance through series-connected capacitors. They increase the long-distance transmission capacity of overhead power lines. Controlled compensators also improve system stability. Thanks to a Siemens thyristor-controlled series compensator in Serra da Mesa, for example, the transmission capacity can now be increased to 1,300 MW. In the 550-kV transmission line, this compensator also dampens up to 500 network swings per day, successfully stabilizing Brazil's northern and southern grids.

A highly industrialized country such as the U.S. has to meet other challenges. Here, extreme burdens on the nation's power transmission grids and distribution systems, particularly in the large urban centers, make the networks susceptible to blackouts. To remedy this situation, the existing power grids have to be strengthened, upgraded and optimized, and new ways of transporting energy to consumption centers must be found. Since the available space for power infrastructure in megacities such as New York is extremely limited, Siemens is placing high-voltage switching stations completely underground. Gas-insulated power lines also make it possible to build underground power grids and at the same time reduce magnetic field burdens to a minimum.

Where little space is available, one generally needs efficient alternatives to standard technologies. In areas with smaller transformer stations or in industrial sites, in particular, one depends on space-saving outdoor switching stations. With its products SIMOVER and SIMOBREAKER, Siemens offers two station versions for providing secure and economical power supplies. In the SIMOVER system, for example, all of the high-voltage switchgear components are integrated into a single unit. The complete station needs only roughly 45 percent of the room normally required for a standard outdoor switching facility. In addition to these conventional air-insulated solutions, Siemens also offers a combined air- and gas-insulated unit: the highly integrated switchgear (HIS) combines the advantages of conventional solutions with those offered by gas-insulated switchgear.

For coastal cities, power supplies running under the sea offer another alternative. Long Island, a densely populated residential area on the outskirts of New York, and San Francisco, on the Pacific coast, are two examples where such applications are the ideal solution. Both rely on HVDC submarine cable links. San Francisco uses the new, self-commutated power converter technology, HVDC Plus. In comparison to conventional grid technology, the converter station requires only half the space. In addition, HVDC Plus allows the use of favorably priced and robust extruded marine cables. Compared with other self-commutated power converter topology, the multi-point topology of HVDC Plus makes it possible to generate virtually the same sinusoidal voltage wavelengths, which means lower losses and no or only minor need for filters. The use of overhead lines is also possible.

Population centers need large amounts of distributable energy. Given their proximity to human habitation, technical facilities should be not only invisible, but also inaudible. To meet those requirements, Siemens has developed a calculation model that can predict a power transformer's noise level. The model has already been used successfully in the U.S. to design low-noise "whisper" transformers.

In order to control the growing number of short-circuit currents in increasingly overloaded power grids, short-circuit limiters based on proven FACTS technology and power electronics solutions are available (SCCL, or Short Circuit Current Limiter). They are also already being used in some areas of the U.S.

Our vast experience and new, proven technologies will allow us to meet similar challenges that Europe will be facing in the not too distant future. In order to cut CO_2 emissions and reduce dependence on certain imports, the EU plans to exploit renewable energy – in the form of wind power – more

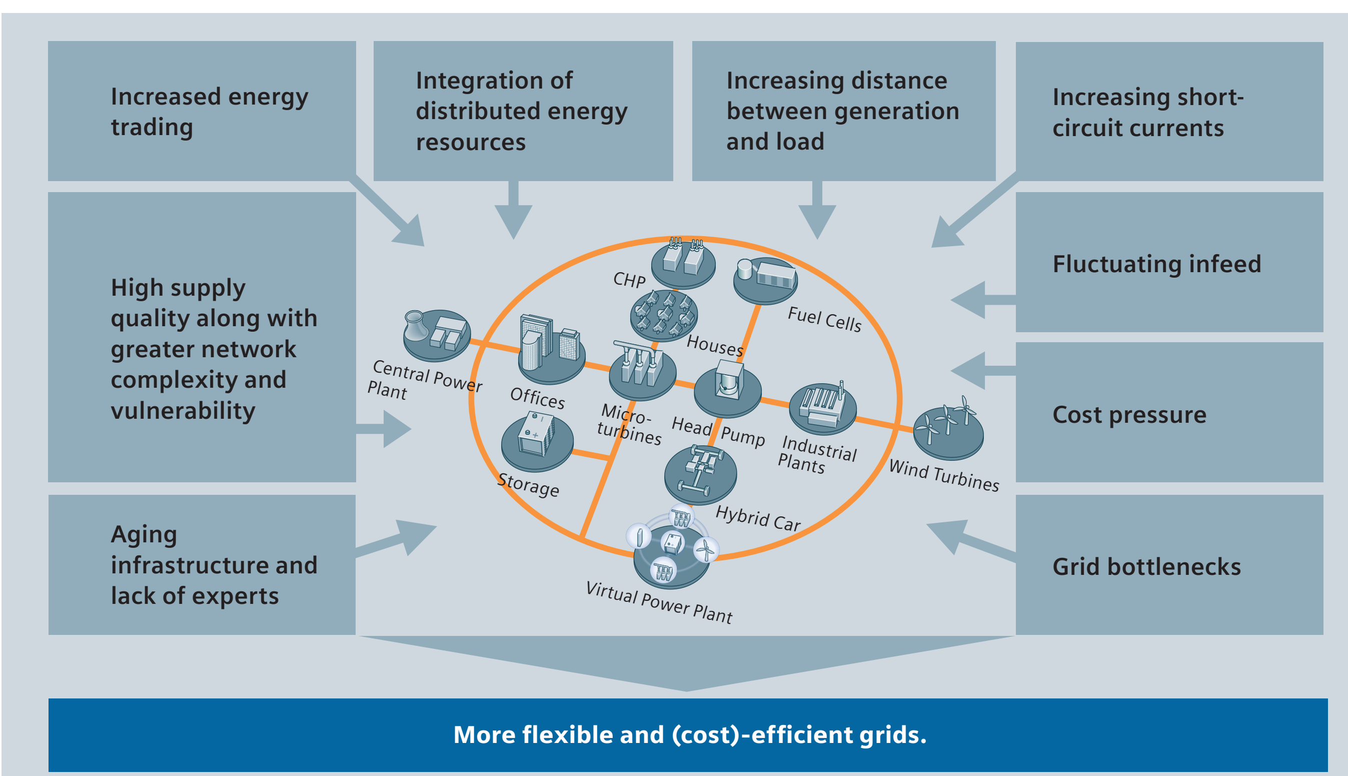


Fig. 1-2: **Future grids require more flexibility**

intensively. As a political goal, the EU is also aiming to create a more competitive trans-European energy market. Both objectives require expanding transport capacity.

The growth in energy trading is also causing additional network loading, which is leading to bottlenecks at cross-border network interconnection points. Meanwhile, as wind power with its fluctuating input is fed into the grid, power grids must be designed to handle two different situations. They must be able to accommodate both strong wind phases as well as low wind phases when conventional power plants have to compensate for the reduced renewable feed-in. Highly populated areas are experiencing increases in short-circuit currents. Although substantial investments in network upgrading in the past have solved problems with the short-circuit current carrying capacities, given the costs, power utilities should consider using short-circuit limiters in the future.

Both HVDC transmission and series compensation can play an important role in developing the supraregional transport network in Europe. The two options are capable of controlling load flow fluctuations that arise from the growth in decentralized power generation. They can also stabilize supply networks which are generally becoming more complex. Finally, supply reliability should not be sacrificed for the sake of flexibility and dynamism. Synchronous, interconnected three-phase networks demonstrate the obvious advantages of HVDC transmission technology. The technology acts as a firewall between three-phase networks. In the event of a fault, HVDC transmission technology suppresses interference and decouples the two connected networks. The new, self-commutated HVDC technology, HVDC PLUS, also works very well for connecting offshore wind parks; it provides an economical and space-saving solution.

Increasing energy demands require the comprehensive expansion of the network. Load management systems are also needed to maintain a dynamic equilibrium between controllable power generation, the increasing feed-in of wind energy (with its fluctuating grid input), and power consumption. In the absence of available, cost-effective energy storage technology, electrical energy could be used in peak load periods. For example, it could be used in the transport sector (for hybrid vehicles), for heating buildings and to replace increasingly scarce fossil energy sources. Today it is already possible to use electrical energy via heat pumps for heating buildings and thus help reduce CO_2 emissions.

New equipment, based on power electronics solutions from the HVDC and FACTS modules, enable load flows in both transmission grids as well as medium-voltage networks to be regulated. This makes cross-border energy trading possible with highly efficient and easily regulated interconnecting stations and ensures dynamic system perturbation without jeopardizing the security of the power supply.

Today, innovative power system management can help combine several decentralized power providers into a larger unit – a so-called virtual power plant (VPP). Intelligent grid automation systems can bring together different generating plants – such as block heating power plants or wind power plants – to form a virtual balancing circuit that can be planned and controlled more effectively than its individual components. The energy management systems already in use in the distribution networks could also be expanded to incorporate a large number of small power generating sources. However, the reliability of the power supply and the maintenance of relevant quality criteria would not meet the high demands of the grid operators. Therefore, specialized automated systems will be used in smaller medium-voltage systems and in local grid stations to measure the quality of the electricity and make necessary adjustments to voltages.

As power supply systems become larger and more complex, they become increasingly vulnerable to faults such as blackouts. Given those vulnerabilities, a power system control center must be able to react quickly and effectively to minimize the impact of a fault. Modern power management systems record the precise state of the supply network, and, before problems occur, analyze it and suggest the best operational solutions in critical situations. Some response tactics can even be automated.

The eventual replacement of standard, periodic network maintenance with condition-based maintenance will help cut operating costs. It will also play a role in keeping energy prices competitive. Thanks to the increasingly automatic analysis of both the importance and the condition of the network (including the consequences of a possible failure), we can carry out maintenance activities with minimum costs and maximum availability. All of these measures are part of the SmartGrid concept that is designed to meet today's energy supply challenges with efficient, flexible and secure solutions (fig. 1-2).

In the future, all possibilities will be exploited in energy supply systems to fulfill the demands for primary energy efficiency and the reduction of greenhouse gas emissions under the most economical conditions. Large centralized power plants will also continue to play a dominating role in ensuring reliable energy supplies. Wind parks and large photovoltaic installations will also make growing power contributions that are fed into the main power grids.

The operators of distributed grids have to prepare for the growing demand that will burden even well-developed grids to the limits of their capacity. Especially problematic are the peak loads in certain parts of the day that have to be compensated in order to avoid investments that are too expensive simply to meet peak demands for a few hours a day. The answer is to utilize all measures that allow a shifting of demand to help ensure more economical grid operation – such as by monitoring the real-time demand rate. Grid operators will manage the loads of private customers as well. In these efforts, it will be especially important to provide bi-directional communication between the grid operator and the electronic household meters feeding from the grid. This will make "smart metering" possible and will allow grid operators to gain valuable data about the momentary condition and load of their power grids, monitor the maintenance of voltage levels, and exert influence on the central power plants or grid loads.

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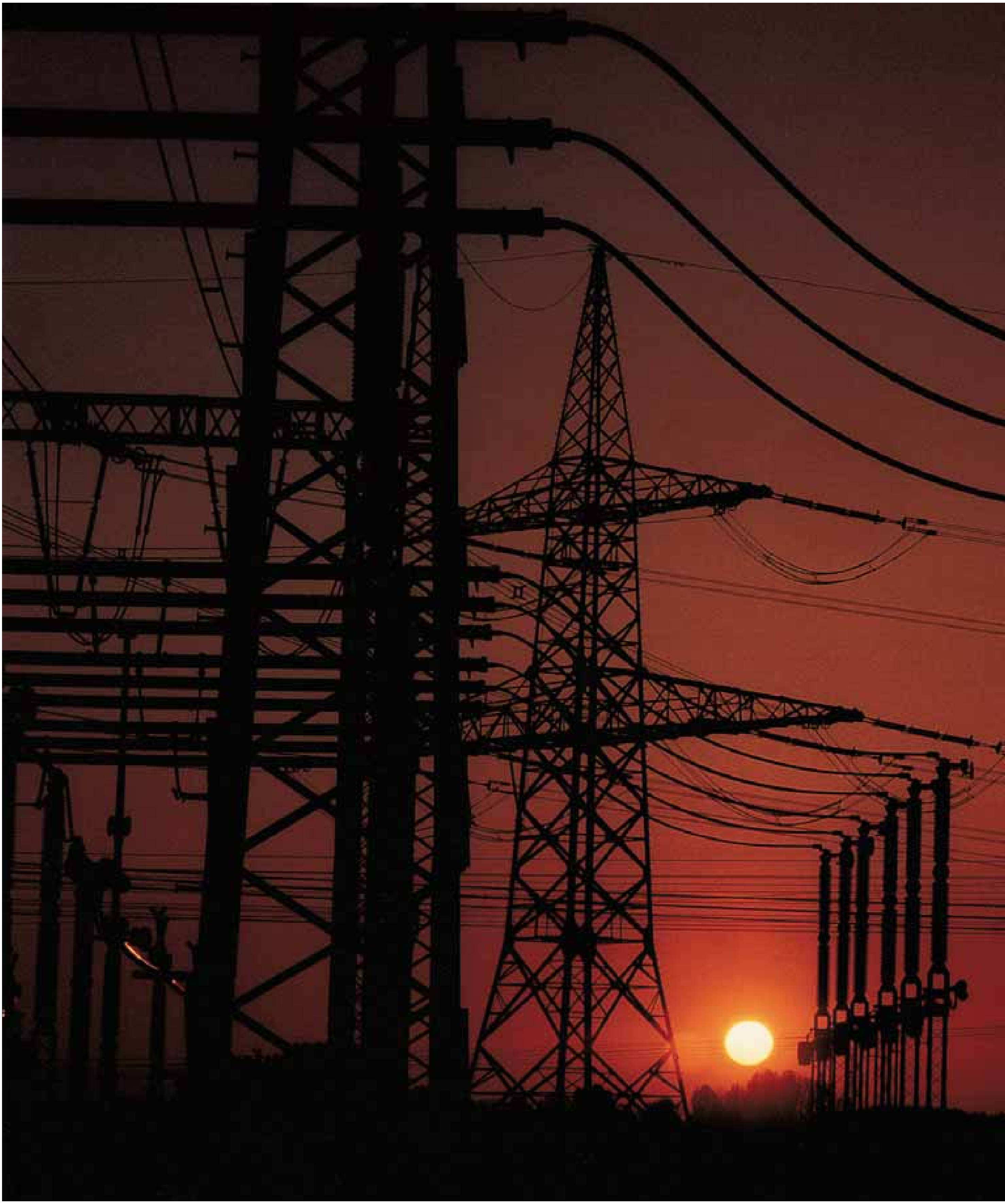

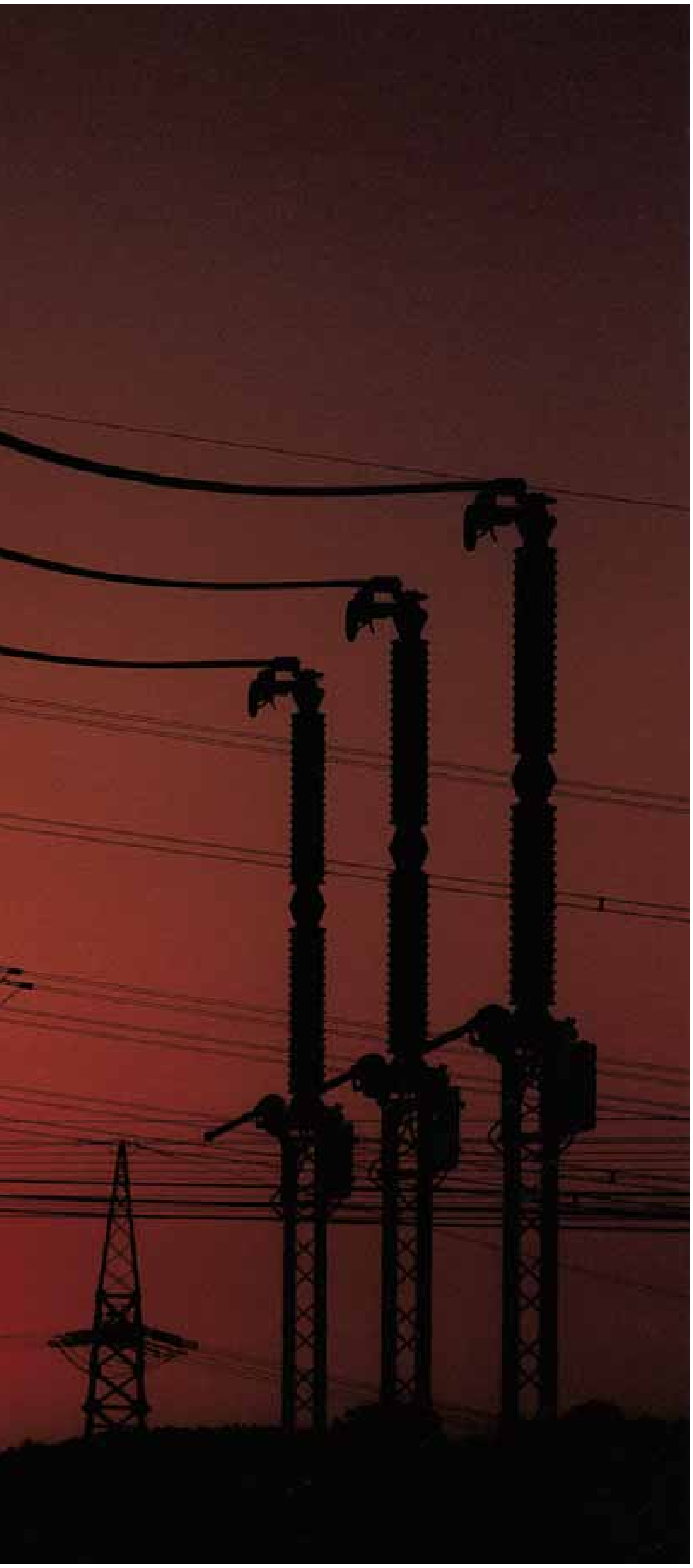

Power Transmission and Distribution Solutions

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2 Power Transmission and Distribution Solutions

2

2.1 Overview of Technologies and Services

Feeding the power generated at different locations over long distances into power systems often calls for extraordinary power transmission and distribution solutions. Despite the challenges it poses, however, interconnecting of different regions, countries or even continents remains a viable option for providing these areas with economical access to power (fig. 2.1-1). As a solution provider with extensive experience in every aspect of power transmission and distribution, Siemens has already implemented a large number of projects linking power systems or connecting decentralized generating units to the grid. In each case, conditions were unique. And because Siemens strives to provide its customers with the most cost-efficient results, the implemented solutions using different technologies were also unique.

2.1.1 AC/DC Transmission and Distribution

HVDC, FACTS and SIPLINK

Today's power transmission systems have the task of transmitting power from point A to point B reliably, safely and efficiently. It is also necessary to transmit power in a manner that is not harmful to the environment. Siemens offers comprehensive solutions, technical expertise and worldwide experience to help customers meet these challenges.

For each application and technical transmission stage, Siemens offers optimized solutions with SIPLINK, HVDC transmission or FACTS (Flexible AC Transmission Systems) for the most efficient use of AC power systems and lines.

Typical applications for FACTS include fast voltage control, increased transmission capacity over long lines, power flow control in meshed systems, and power oscillation damping. With FACTS, more power can be transmitted within the power system. When technical or economical feasibility of conventional three-phase technology reaches its limit, HVDC will be the solution (fig. 2.1-2). Its main application areas are economical transmission of bulk power over long distances and interconnection of asynchronous power grids. Siemens's latest innovation in high-voltage direct current technology is HVDC PLUS. The advantages of the new system, which employs voltage-sourced converters, include a compact layout of the converter stations and advanced control features such as independent active and reactive power control, and black start capability.

For medium-voltage DC transmission, Siemens offers the SIPLINK (Siemens Multifunctional Power Link) system. Depending on the application and the configuration of the existing system, SIPLINK will reduce investment, system and lifecycle costs. The system controls the active power and optimizes voltage stability by providing reactive power (section 2.3).

Power lines

Since the very beginning of electric power supply, overhead lines have constituted the most important component for transmission and distribution systems. Their portion of the overall length of electric circuits depends on the voltage level and on local conditions and practice. When environmental or structural factors make overhead lines impossible, Siemens's "underground" transmission path is the ideal solution. Siemens gas-insulated transmission lines (GIL) are an economically viable alternative to conventional power cables (section 2.5).

Grid access

Decentralized generating units are custom-engineered, which involves reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution. Specific attention is paid to intelligently designing the "collection systems" at the medium-voltage level, which is followed by the high-voltage transmission system offering the grid access. By relying on both transmission technologies, Siemens can offer AC as well as DC solutions at both the high and medium-voltage levels (section 2.6).

Solar power

As an alternative power supply for rural electrification, Siemens integrates solar power in the low-voltage distribution system for private consumers, as stand-alone systems or even with grid connection (section 2.7).

2.1.2 Managing Entire Projects

Project management

Supplying power is more than just combining a number of individual components. It calls for large-scale projects, such as transmission systems or industrial complexes, especially in countries where the demand for power is growing at an accelerated pace. The best partner to handle such large projects is an expert who can carefully analyze the demand, take an integrated approach to project planning and consider all the general conditions. A qualified project partner is one that can provide high-quality components and services for both power transmission tasks and power system management. Such a partner also can ensure that the systems are installed expertly.

Turnkey solutions

Siemens's many years of experience allow it to offer turnkey power transmission solutions that are tailored to individual requirements. Siemens supplies all components, including power plants, AC or DC transmission systems and high-voltage

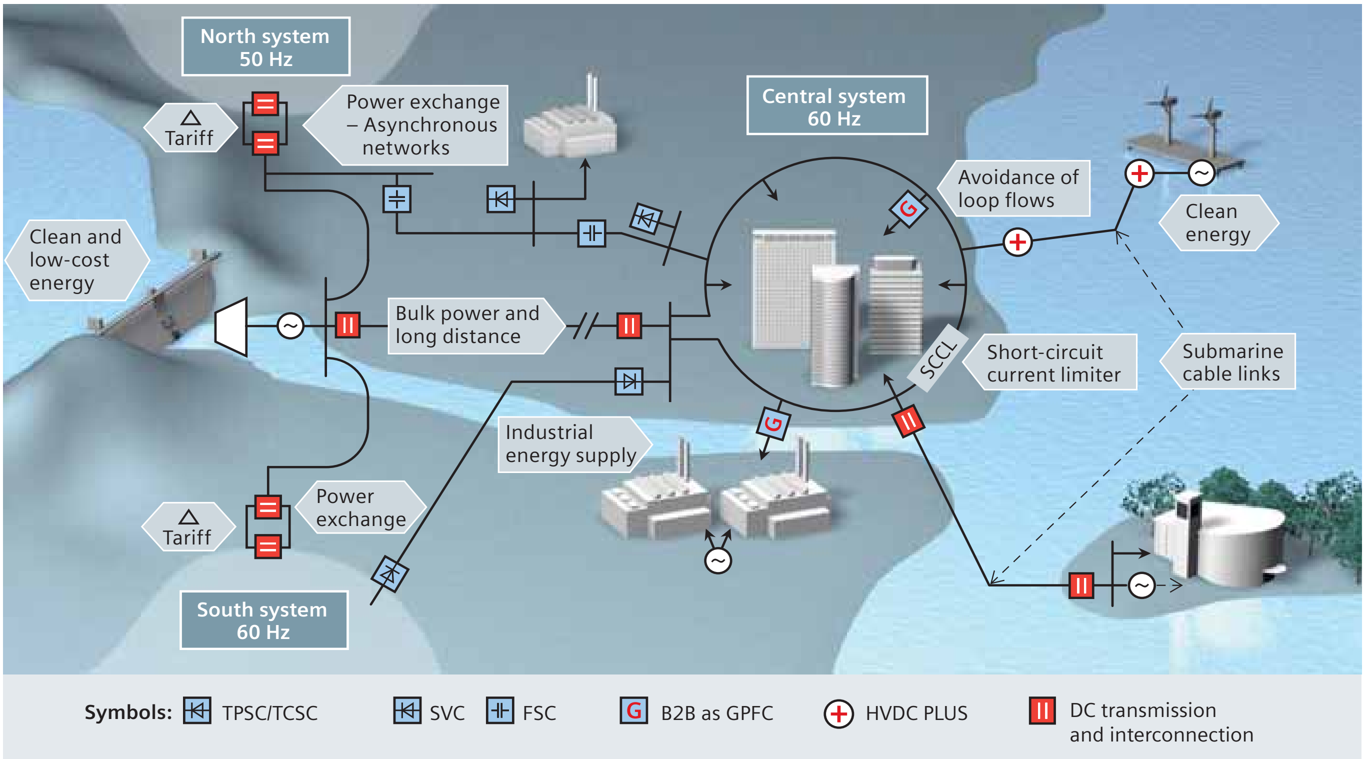

Fig. 2.1-1: **Power transmission and distribution solutions**

interconnected power systems with high, medium and low voltage that finally reach the individual customers. What makes these turnkey solutions so attractive is that one party is responsible for coordinating the entire project, thereby reducing the number of interfaces between system operator and supplier to a bare minimum. Turnkey projects also reduce the operator's own share in project risks, since Siemens is responsible for delivering a system that is ready for operation.

Engineering, procurement, production and construction

In addition to comprehensive planning and management services, engineering is one of Siemens's special strengths. Siemens can produce or procure all necessary components and perform all construction work up to testing, commissioning and putting an entire system into operation. With Siemens as a partner, companies can benefit from Siemens's extensive manufacturing expertise and from the work of experienced Siemens engineers who have already participated in a wide range of projects worldwide. Working on this basis, Siemens can provide the best technology for projects based on proprietary Siemens components and additional hardware purchased from reputable vendors. Siemens experts have the important task of determining which of the various technical options are best suited for implementing the project. They consider transmission capacity, transmission efficiency and the length of the transmission line, and after the best technical solution has been determined, they assess its long-term cost efficiency for the operator. Only then can the actual implementation begin for installation and on-time commissioning.

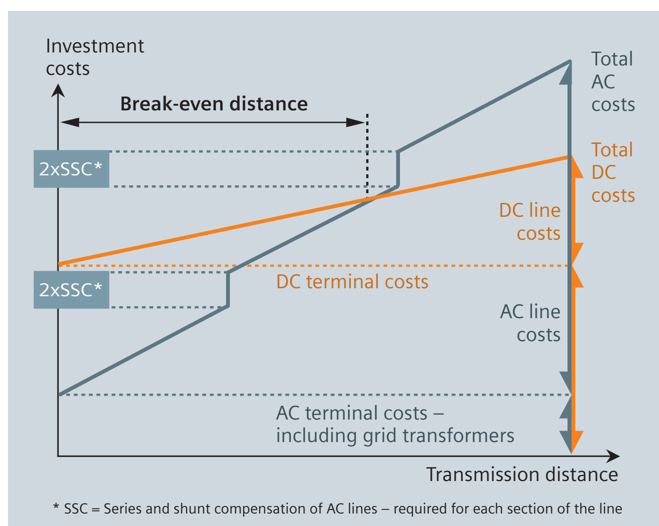

Fig. 2.1-2: **AC versus DC transmission cost over distance. The break-even distance amounts to 600 km for a power transmission of 1,000 MW**

Maintenance
Systems will operate at their best, when equipment lasts a long time and provides continuous trouble-free operation. The Siemens maintenance service ensures that all components are always running safely and reliably. Siemens continuously maintains operator systems through regular inspections including all switchgear and secondary technology. If a malfunction occurs during operation, Siemens is immediately on the job; support is available 24 hours a day, 365 days a year. And with the increased use of state-of-the-art online monitoring and remote diagnosis systems, Siemens offers additional possibilities for keeping operating costs to a minimum.

Optimization and modernization
No company can replace its equipment and systems fast enough to keep pace with technological progress. But all companies can take advantage of the latest technological opportunities through the variety of optimization options provided by the Siemens retrofit and upgrade service. This fast and economical solution allows customers to invest their capital wisely and take full advantage of Siemens's experience in adapting older systems to new technical standards.

2.1.3 Partners Throughout the System Life Cycle

Siemens is with system operators every step of the way to help them develop their projects, to create financing solutions and to provide project management (fig. 2.1-3), and supports them beyond engineering, production and construction. This support continues as the system is commissioned, as customers need maintenance services and even when it is time to modernize. The partnership between Siemens and the system operators does not stop when a turnkey job is finished: Siemens accompanies the system operators throughout the entire life cycle of their systems, offering a wide range of services with products of the highest quality that are always based on the most durable technologies.

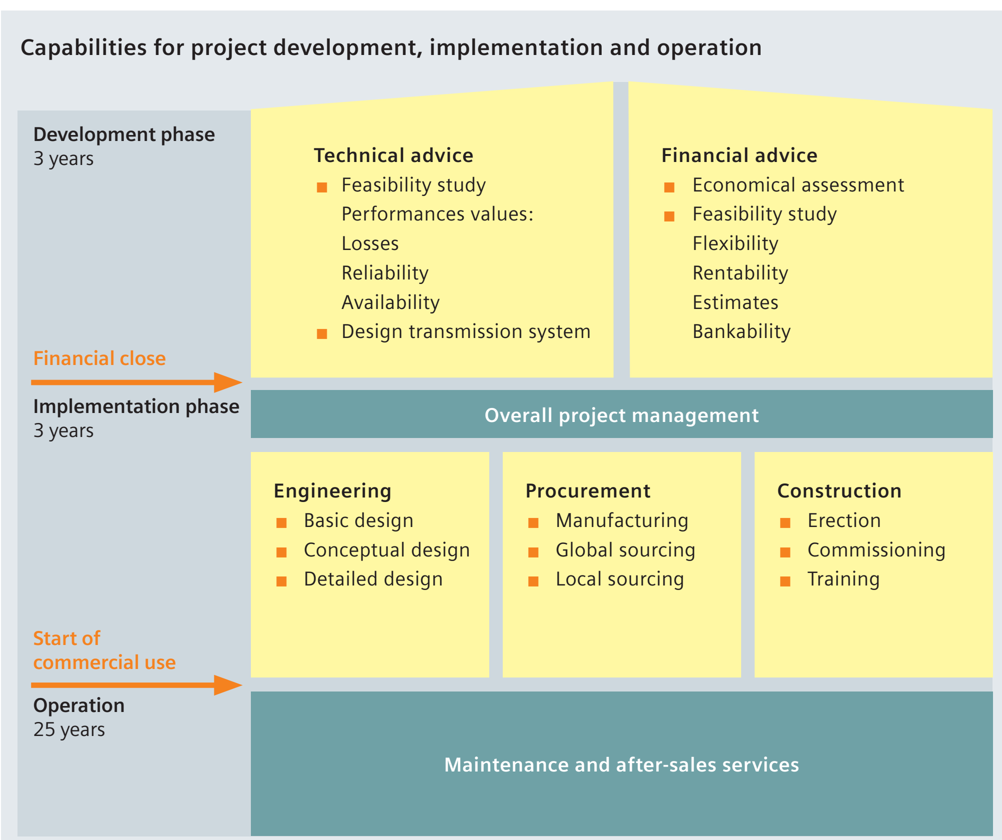

Fig. 2.1-3: **Siemens services for the entire system life cycle**

2.2 High-Voltage Direct current Transmission

When technical and/or economical feasibility of conventional high-voltage AC transmission technology reach their limits, HVDC transmission is the best solution. HVDC systems connect two separated high-voltage AC systems via a DC link. The basic principle of operation of an HVDC system is the conversion of AC to DC and vice versa by means of converter valves comprising power thyristors.

The primary application areas are:

- Economical transmission of bulk power over long distances
- Interconnection of asynchronous power grids without increase in short-circuit power
- Submarine DC cable transmission
- Hybrid integration of HVDC into a synchronous AC system for stability improvement
- Increase in transmission capacity by conversion of AC lines into DC lines

The advantages are:

- DC links do not increase the short-circuit power
- DC links offer fast control of power flow, which is beneficial for sharing spinning reserve and supplying peak power
- The DC interconnection is like a firewall in case of cascading disturbances
- Blackout prevention
- DC link controllability is beneficial for:
  - Exact control of power flow in either direction
  - Enhancement of AC system stability
  - Reactive power control support of AC voltage
  - Frequency control
  - Overload capability
  - Emergency power function
  - Power oscillation damping

2.2.1 HVDC Systems

Main types of HVDC schemes

The main types of HVDC converters are distinguished by their DC circuit arrangements (fig. 2.2-1), as follows:

- Back-to-back:
  Indicates that the rectifier and inverter are located in the same station. These converters are mainly used:
  - To connect asynchronous high-voltage power systems or systems with different frequencies
  - To stabilize weak AC links or to supply even more active power where the AC system reaches the limit of short-circuit capability
  - Grid power flow control within synchronous AC systems
- Cable transmission:
  The most feasible solution for transmitting power across the sea with cables to supply islands/offshore platforms from the mainland and vice versa

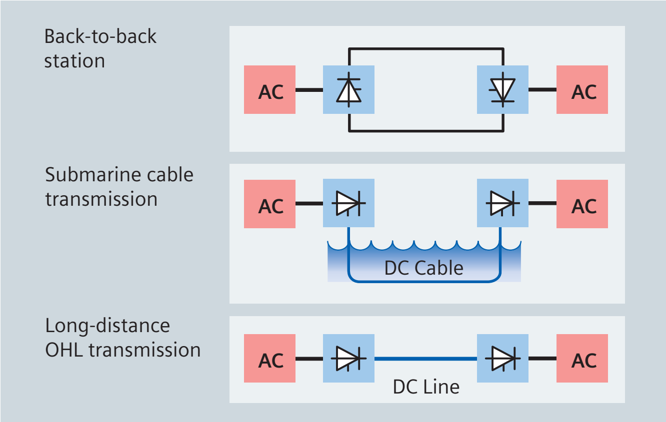

Fig. 2.2-1: **Overview – advanced power transmission systems with HVDC**

Fig. 2.2-2: **Earthquake-proof and fire-retardant thyristor valves in long-distance transmission in Guizho-Guangdong, China**

- Long-distance transmission:
  For transmission of bulk power over long distances (beyond approximately 600 km, considered as the break-even distance)

Special features

Valve technology

The thyristor valves perform the conversion from AC into DC and thus make up the central component of any HVDC converter station. Advantages of the valves are:

- Simple mechanical design, easy-to-maintain
- Use of fire-retardant, self-extinguishing material (fig. 2.2-2)
- Minimum number of electrical connections and components; avoidance of potential sources of failure
- "Parallel" cooling for the valve levels
- De-ionized cooling water
- Direct light-triggered thyristors (LTT) with wafer-integrated overvoltage protection. The standard solution for transmission ratings up to 5,000 MW
- Electrically-triggered thyristors for bulk power transmission up to 7,200 MW

Control system

In the Siemens HVDC control system SIMATIC Win TDC, high-performance components with proven records in many other standard fields of application have been integrated, thus adding to the overall reliability of the system:

- Use of ultra-fast 64 bit RISC processor systems with highly flexible interfaces
- Redundant design for fault-tolerant systems

Filter technology

- 1-tuned, 2-tuned, and 3-tuned as well as high-pass passive filters, or any combination thereof, can be installed.
- Active AC and DC filters for highest harmonic performance.
- Wherever possible, identical filters are selected so that the performance does not significantly change when one filter has to be switched off.

Typical ratings

Typical ratings for HVDC schemes include the following:

- Back-to-back: up to 1,200 MW
- Cable transmission: up to 1,000 MW per cable
- Long-distance transmission: 300 to 7,200 MW

Studies during contract execution are conducted on:

- Power system stability, transient studies
- Load-flow optimization
- HVDC systems basic design
- System dynamic response
- Harmonic analysis and filter design
- Insulation and protection coordination
- Radio and PLC interference
- Special studies, if any

Service offerings

The following set of services completes the Siemens offering spectrum.

Turnkey service

Experienced staff are prepared to design, install and commission the whole HVDC system on a turnkey basis.

Project financing

Siemens is in a position to assist its customers in finding proper project financing, too.

General services

Extended support is provided to customers of Siemens from the very beginning of HVDC system planning, including:

- Feasibility studies
- Drafting the specification
- Project execution
- System operation and long-term maintenance
- Consultancy on upgrading/replacement of components/redesign of older schemes, e.g., retrofit of mercury-arc valves or relay-based controls

Fig. 2.2-3: **Basslink converter station (Queensland, Australia), cable transmission**

Fig. 2.2-4: **UHV DC bushing at the test lab**

Fig. 2.2-5: **UHV DC thyristor valve**

Fig. 2.2-6: **UHV DC transformer**

2.2.2 DC Transmission Lines

DC transmission lines could be part of the overall HVDC transmission contract, either within a turnkey package or as separately contracted stand-alone item that is later integrated into an HVDC link (fig. 2.2-3). Such DC transmission lines are mechanically designed as is common practice for normal AC transmission lines; the main differences are:

- Conductor configuration
- Electric field requirements
- Insulation design

Siemens has all the design and engineering capabilities in-house that are required for a successful construction and erection of the DC transmission line, in addition to the HVDC converter stations (section 2.5.2).

2

2.2.3 Ultra-HVDC Transmission (UHV DC)

Siemens is an innovative supplier of HVDC systems. One outstanding innovation is the 800 kV UHV DC long-distance transmission scheme. In 2007, Siemens was awarded the world's first contract for a ± 800 kV ultra-high-voltage direct current (UHV DC) system with 5,000 MW in China Southern Power Grid. Commercial operation will begin in 2010. The Siemens ± 800 kV systems are designed to transmit up to 7,200 MW electrical power over long distances. Special attention has to be paid to the corresponding AC networks that have to supply or absorb such high amounts of electric power. The special design of transformers, bushings and thyristor valves, now equipped with either 5"- or 6"-thyristors depending on the transmission rating, have been the greatest challenges during the R&D process (fig. 2.2-4, fig. 2.2-5, fig. 2.2-6).

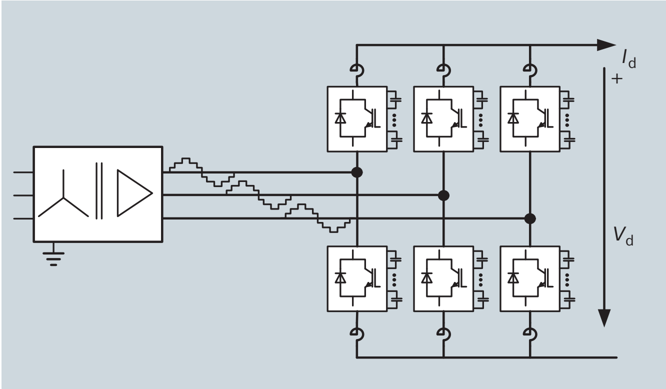

Fig. 2.2-7: **HVDC PLUS arrangement with multi-level IGBT voltage-sourced converter technology**

2.2.4 HVDC PLUS

With another innovation, Siemens sets a new direction for HVDC transmission: the HVDC PLUS with voltage-sourced converter (VSC) technology. Using the latest modular IGBT (Insulated Gate Bipolar Transistor) technology in a pioneering modular multi-level converter (MMC) design (fig. 2.2-7), Siemens engineers have developed a landmark product in the evolution of HVDC transmission.

Advantages

This new technology provides numerous technical and economical advantages over conventional HVDC links. Particular features are:

- HVDC technology in the smallest possible space:
  Even when space is limited, HVDC PLUS enables the use of highly efficient HVDC technology.
- Optimal connection of distributed generation:
  The scalability of HVDC PLUS means that remote energy sources such as offshore wind farms can be connected to the power grid in the most suitable way.
- Operational benefits:
  Minimum time and costs for maintenance and high operational reliability make HVDC PLUS a particularly economical solution.
- Potential environmental protection tool for CO_2 reduction:
  With HVDC PLUS, islanded networks such as oil and gas platforms, as well as mines, can be connected without the need for local generation, which is less efficient. This feature allows for CO_2 reduction.
- Fast and cost-efficient project execution:
  Due to the standardized modular design of HVDC PLUS, time and resources are saved during both planning and implementation.
- Support of AC system stability:
  HVDC PLUS offers extended stabilization of the AC voltage in weak grids. In addition, it is possible to feed passive networks without generation by means of black-start capability.

Fig. 2.2-8: **Design of an HVDC PLUS system**

Applications

There are no technical restrictions on the use of HVDC PLUS – it can be applied in all existing fields of HVDC. However, each project will have its own imperatives, and the advantages of HVDC PLUS will be most apparent in circumstances that require the following capabilities:

1. DC cable transmission
2. Back-to-back transmission
3. Overhead line transmission
4. Composite DC cable/overhead line transmission

Available ratings

The design of HVDC PLUS is optimized for high-power applications. The basic single converter design has a rating in the power range of 30 MW up to 1,000 MW (fig. 2.2-8).

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2.3 Medium-Voltage DC Links with SIPLINK

Just like HVDC systems in transmission networks, medium-voltage distribution networks with different frequency, voltage or phase can also be interconnected flexibly. An innovative medium-voltage link of this type for distribution networks is the Siemens Multifunctional Power Link (SIPLINK). This converter-based back-to-back link (fig. 2.3-1, fig. 2.3-2) is able to selectively control energy flows between subnetworks, and at the same time can improve the voltage quality by providing reactive power.

SIPLINK provides a means of interlinking different power generators or networks with different frequency or power capacity without impairing system stability or increasing the fault currents. Integration of distributed and independent power generators in existing networks is also improved. SIPLINK can cut investment, system and lifecycle costs for the following applications in particular:

- Connection of ships berthed in port to the more environment-friendly shoreside power supply system (SIHARBOR shore-to-ship connection)
- Energy transfer between different distribution networks (urban networks) through interconnected operation
- Increasing the availability and voltage quality of industrial networks

2.3.1 Shore-to-Ship Connection

Cost pressure and increasingly stringent environmental regulations are forcing many ports to supply ships in port with electrical power from an onshore source. To address this need, Siemens has developed SIHARBOR, a shore-to-ship connection system that meets the requirements of port operators, shipping companies, dockyards and power supply companies. Thanks to SIHARBOR, ships can shut down their diesel generating sets that

Fig. 2.3-1: **SIPLINK with opened cabinet doors**

would otherwise be needed, and that not only produce electricity but also produce exhaust gases, soot, fine dust and noise, thus contributing to "harbor smog" (fig. 2.3-3).

SIPLINK is the core element of this supply system. It consists of two self-commutated IGBT pulse-controlled converters that are interconnected through a DC intermediate circuit. The converters are connected on one side to the local power supply network and on the other side to the ship's onboard system. SIPLINK is thus able not only to feed the onboard system from the distribution network, but also to match the various different parameters to one another and to interlink them. Up to 5 MVA of power can be transmitted with a medium-voltage plug and socket connection.

Both the port and the ship must be equipped with such a plug-in connection system in order to use SIHARBOR. After connecting the plug-in connector in the ship, the automation system installed on shore automatically initiates the system start-up. The user dialog for this process is conducted from the ship. The ship's power supply is not interrupted. SIPLINK is self-synchronizing and takes over the power supply within a few minutes. The diesel generators for the onboard power supply can then be shut down, and the complete onboard network can be supplied in an environmentally friendly way from the shore-based power distribution system.

Advantages of this system include:

- Flexible connection of all types of onboard systems, regardless of voltage or frequency
- A single MV cable connection instead of several LV connections
- Electrical separation of shoreside and onboard network, to keep the respective protection schemes and avoid galvanic corrosion

The system also takes into account the different types of ships, such as passenger ships, container ships and ferries. Thanks to its modular basis, any combination of 50 Hz and 60 Hz power supply systems is possible, as are all voltage levels.

2.3.2 Power Transfer Between Distribution Networks

Another application area for SIPLINK is the linking of distribution networks (urban networks) where SIPLINK controls the exchange of electrical energy between independent networks. The particular advantage here is that in the event of supply bottlenecks in one network, available power reserves in another network can be used to make up for the shortfall (fig. 2.3-4). The amount of costly energy that needs to be brought in "from outside," especially during periods of peak demand is decreased. This allows significant cost savings. Other advantages, aside from minimizing energy purchases, include the following:

- The reliability of the supply and voltage quality are improved.
- Especially in population centers, SIPLINK offers an alternative to extending the network and thus saves investment costs.

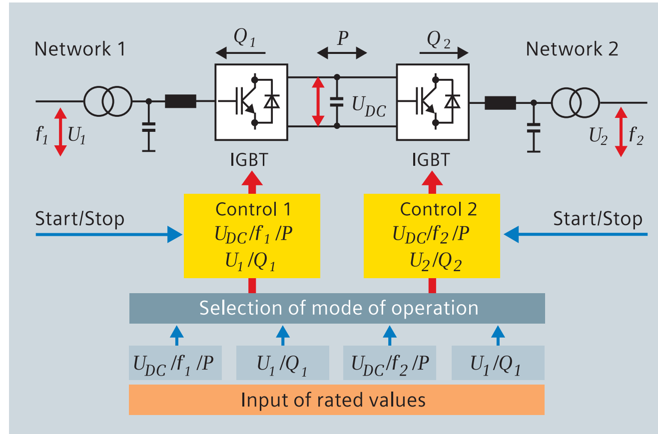

Fig. 2.3-2: **System configuration of SIPLINK with two self-commutated IGBT pulse-controlled converters for controlling the active power flow and for rapid reactive power regulation**

Fig. 2.3-3: **An innovative solution to counter "harbor smog": Siemens technology supplies ships in port with environmentally friendly electricity from the public network**

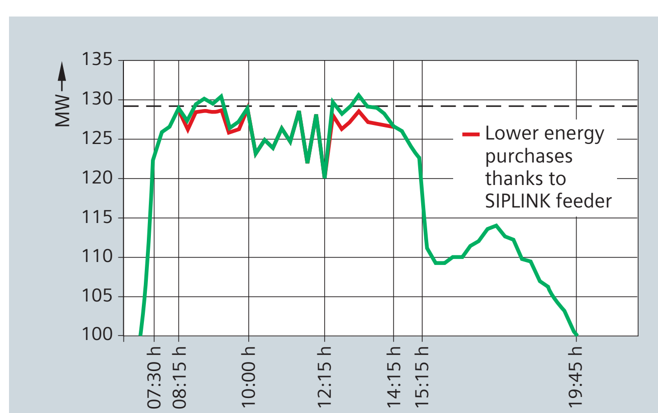

Fig. 2.3-4: **Lower daily peaks in the distribution system of a population center as a result of procuring power from another distribution network linked via SIPLINK**

2

2.3.3 High Availability of Industrial Networks

SIPLINK can also provide a reliable power supply to complex plants and equipment, for example, in the oil and gas industry or chemical industry.

SIPLINK provides unlimited options for switching electricity between two or more networks at a medium-voltage level exactly according to the individual requirements in the particular network. This capability ensures improved supply reliability and better voltage quality at the distribution level. The protection afforded acts in both directions. Sensitive loads are protected against "unclean" networks, and conversely, networks are protected against problematical consumers. Power generation costs can also be reduced substantially through intelligent resource management, thanks to SIPLINK. It is possible under certain circumstances to avoid using additional diesel generators to cover peak loads if less power is needed in another subnetwork at that particular moment. Using SIPLINK cuts costs and reduces pollution of the environment.

A high-availability power supply is essential for certain industrial processes. In such cases, two independent incoming feeders can jointly supply one load (Y-circuit). If one of these feeders fails, the second takes over without interruption so that the changeover is not noticeable at the consumer load (fig. 2.3-5). It is also possible to divide the load between the two feeders in any desired ratio, thus balancing the two feeders.

The SIPLINK Multi Feed configuration is specially suitable for industrial processes where a high-availability power supply is needed but very short interruptions in the millisecond range are permissible (no voltage dips > 70 ms allowed) (fig. 2.3-6). In the case of a short circuit or other fault in one of the power feeding busbars, SIPLINK seamlessly takes over the power supply. SIPLINK is short-circuit-proof and feeds its rated power to short circuit. At the same time, an OPEN command is sent to the normal feeding switch on the busbar. As soon as the contacts of the switch are opened (about 50 ms), the voltage on the busbar increases immediately to the rated voltage (fig. 2.3-7). The Multi Feed configuration is simpler in design than the Y-circuit and is used where short voltage dips are acceptable.

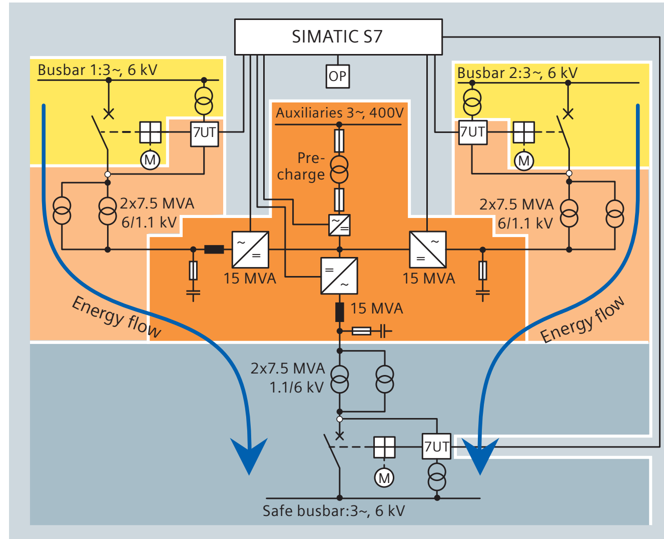

Fig. 2.3-5: **With the fault-tolerant energy supply, the safe busbar (or consumer) is connected simultaneously to two feeding busbars**

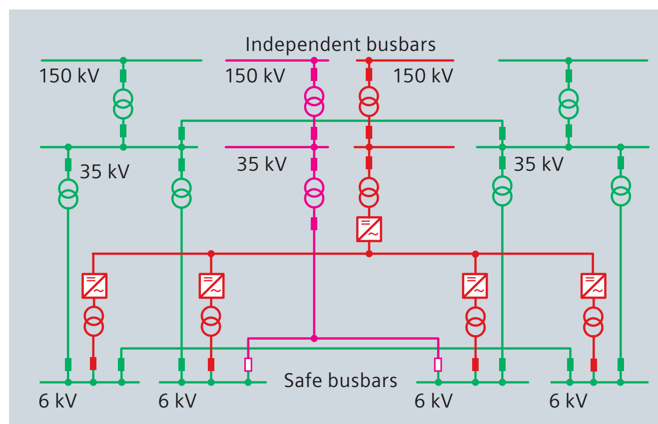

Fig. 2.3-6: **With the SIPLINK Multi Feed circuit arrangement, each of the safe busbars is connected simultaneously to three busbars and an independent feeder**

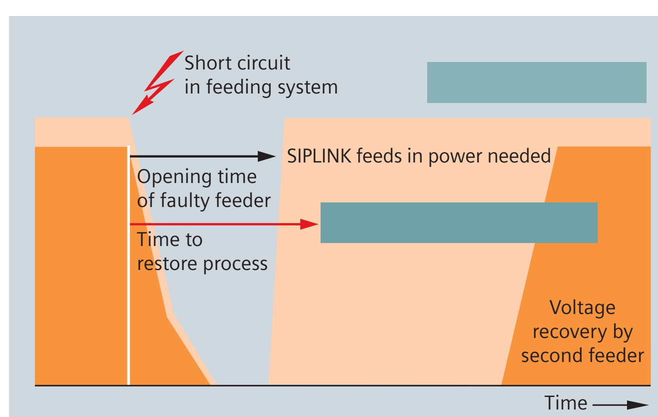

Fig. 2.3-7: **Voltage curve on the busbar in the case of a short circuit in the feeding system with support by SIPLINK**

2.4 Flexible AC Transmission Systems

Flexible AC Transmission Systems (FACTS) have been evolving to a mature technology with high power ratings. The technology, proven in various applications, became a first-rate, highly reliable one. FACTS, based on power electronics, have been developed to improve the performance of weak AC systems and to make long distance AC transmission feasible. FACTS can also help solve technical problems in the interconnected power systems.
FACTS are available in parallel connection:

- Static Var Compensator (SVC)
- Static Synchronous Compensator (STATCOM)

or in series connection:

- Fixed Series Compensation (FSC)
- Thyristor Controlled/Protected Series Compensation (TCSC/TPSC)

2.4.1 Parallel Compensation

Parallel compensation is defined as any type of reactive power compensation employing either switched or controlled units that are connected in parallel to the transmission network at a power system node.

Mechanically Switched Capacitors/Reactors (MSC/MSR)
Mechanically switched devices are the most economical reactive power compensation devices (fig. 2.4-1a).

- Mechanically switched capacitors are a simple but low-speed solution for voltage control and network stabilization under heavy load conditions. Their utilization has almost no effect on the short-circuit power but it increases the voltage at the point of connection.
- Mechanically switched reactors have exactly the opposite effect and are therefore preferable for achieving stabilization under low load conditions.
- An advanced form of mechanically switched capacitor is the MSCDN. This device is an MSC with an additional damping circuit for avoidance of system resonances.

Static Var Compensator (SVC)
Static Var compensators are a fast and reliable means of controlling voltage on transmission lines and system nodes (fig. 2.4-1b, fig. 2.4-2). The reactive power is changed by switching or controlling reactive power elements connected to the secondary side of the transformer. Each capacitor bank is switched ON and OFF by thyristor valves (TSC). Reactors can be either switched (TSR) or controlled (TCR) by thyristor valves.

Fig. 2.4-2: **Static Var Compensator (SVC) installation**

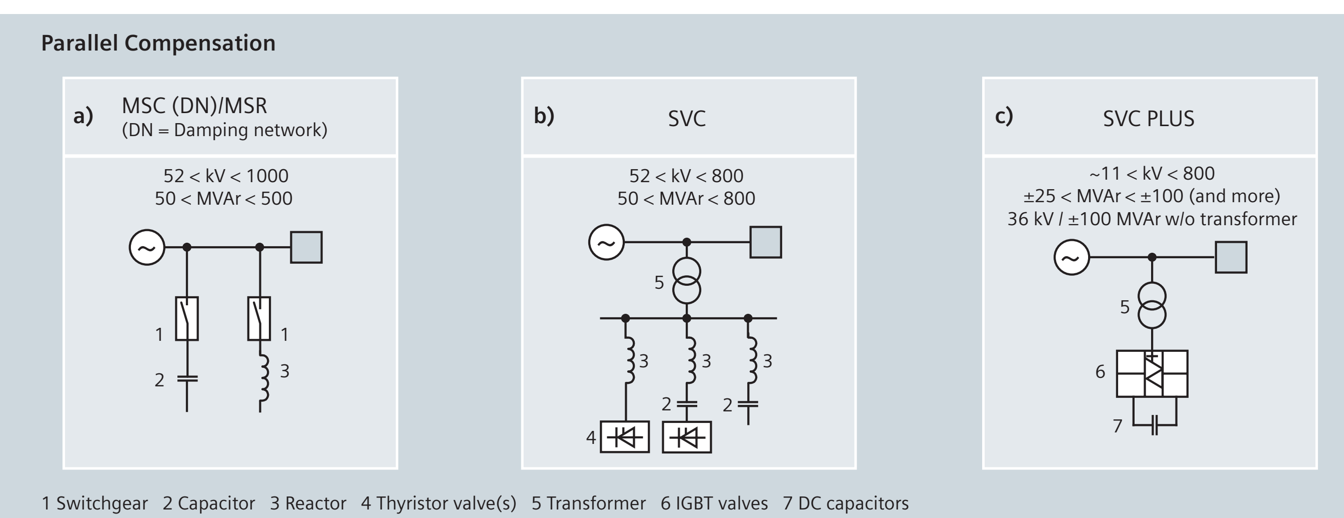

Fig. 2.4-1a: **Mechanically switched capacitors (MSC) and mechanically switched reactors (MSR) connected to the transmission system**
Fig. 2.4-1b: **Static Var compensator (SVC) with three branches (TCR, TSC, filter) and coupling transformer**
Fig. 2.4-1c: **SVC PLUS connected to the network**

When system voltage is low, the SVC supplies capacitive reactive power and rises the network voltage. When system voltage is high, the SVC generates inductive reactive power and reduces the system voltage.

Static Var Compensators perform the following tasks:
- Improvement in voltage quality
- Dynamic reactive power control
- Increase in system stability
- Damping of power oscillations
- Increase in power transfer capability
- Unbalance control (option)

The design and configuration of an SVC, including the size of the installation, operating conditions and losses, depend on the system conditions (weak or strong), the system configuration (meshed or radial) and the tasks to be performed.

SVC PLUS
The modular SVC PLUS is equipped with an IGBT multilevel converter and a storage capacitor on the DC side.

From approximately ± 25 MVAr to ± 50 MVAr, all of the main equipment, including the IGBT converter, the control and protection system and the converter cooling system of the SVC PLUS, is installed in a container and factory pretested so that it is ready to be installed outdoor at the site. For indoor installations, converter modules with approximately ± 100 MVAr are available.

Parallel operation of converter modules is also possible, resulting in higher ratings.

The footprint of an SVC PLUS installation is smaller than a conventional SVC installation of the same rating (fig. 2.4-1c, fig. 2.4-3).

Fig. 2.4-3: **IGBT converter of the SVC PLUS**

2.4.2 Series Compensation

Series compensation is defined as insertion of reactive power elements into transmission lines. The most common application is the fixed series capacitor (FSC). Thyristor-valve controlled systems (TCSC) and thyristor-valve protected systems (TPSC) may also be installed.

Fixed Series Capacitor (FSC)
The simplest and most cost-effective type of series compensation is provided by FSCs. FSCs comprise the actual capacitor banks, and for protection purposes, parallel arresters (metal-oxide varistors, MOVs), spark gaps and a bypass switch for isolation purposes (fig. 2.4-4a).

Fixed series compensation provides the following benefits:
- Increase in transmission capacity
- Reduction in transmission angle

Thyristor-Controlled Series Capacitor (TCSC)
Reactive power compensation by means of TCSCs can be adapted to a wide range of operating conditions. It is also possible to control the current and thus the load flow in parallel transmission lines, which simultaneously improves system stability. Further applications for TCSC include power oscillation damping and mitigation of subsynchronous resonance (SSR), which is a crucial issue in case of large thermal generators.

Additional benefits of thyristor-controlled series compensation:
- Damping of power oscillations (POD)
- Load-flow control
- Mitigation of SSR (subsynchronous resonances)
- Increase in system stability

Thyristor-Protected Series Capacitor (TPSC)
When high power thyristors are used, there is no need to install conventional spark gaps or surge arresters. Due to the very

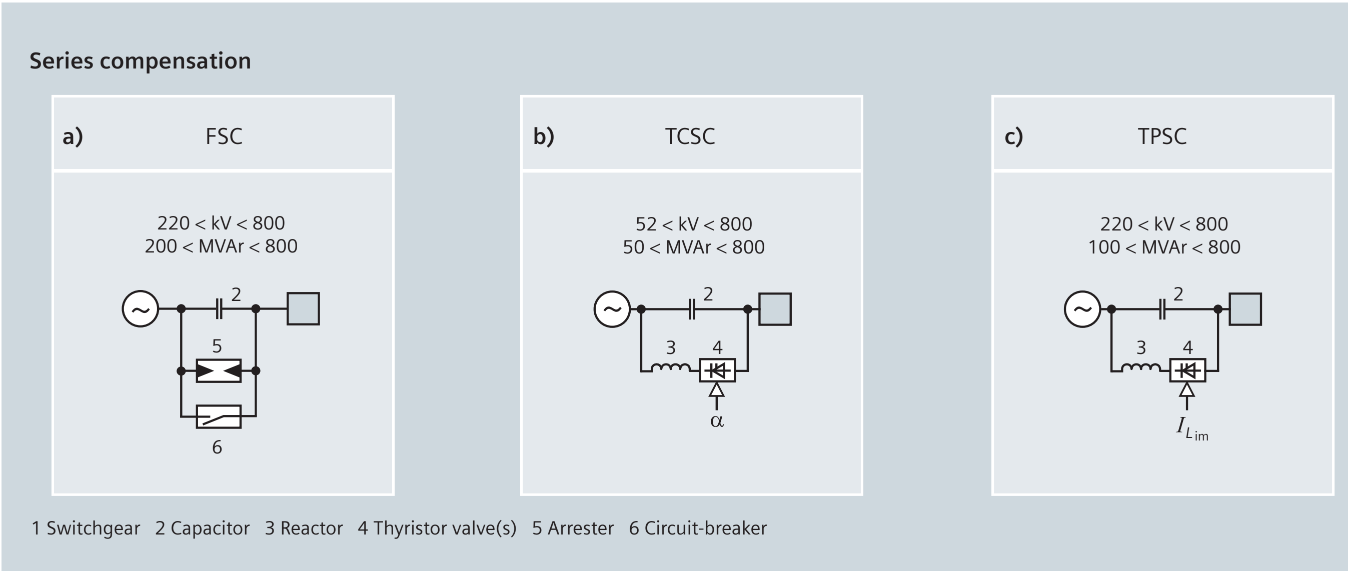

Fig. 2.4-4a: **Fixed series compensation (FSC) connected to the network**
Fig. 2.4-4b: **Thyristor-controlled series capacitor (TCSC) connected to the network**
Fig. 2.4-4c: **Thyristor-protected series capacitor (TPSC) connected to the network**

short cooling-down times of the special thyristor valves, TPSCs can be quickly returned to service after a line fault, allowing the transmission lines to be utilized to their maximum capacity.

TPSCs are the first choice whenever transmission lines must be returned to maximum carrying capacity as quickly as possible after a failure (fig. 2.4-4c).

Short-Circuit Current Limitation (SCCL)
Extensions of HV AC networks, coupling of independent grids and adding of new generation increase the existing short-circuit power in many cases. If the designed short-circuit level of the existing equipment is exceeded, an extension of the network, without extremely costly replacement of the existing equipment, is not possible. This no-go criteria can be avoided by using the Siemens short-circuit current limiter.

By combining the TPSC with an external reactor, this combination can now be used as a short-circuit current limiter (SCCL).

In case of a system fault, the thyristor valve will be fired, bypassing the series capacitor. The corresponding short-circuit current will be limited by the reactor to the design values (fig. 2.4-6).

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Fig. 2.4-5: **View of a TCSC system**

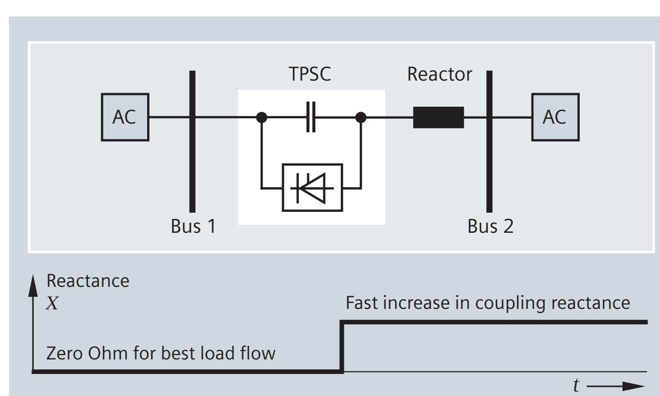

Fig. 2.4-6: **Fast short-circuit current limitation (SCCL) with high-power thyristor**

2.5 Power Transmission Lines

2.5.1 Gas-Insulated Transmission Lines

For high-power transmission systems where overhead lines are not suitable, alternatives are gas-insulated transmission lines (GIL). GIL exhibit the following differences from cables:

- High-power ratings (transmission capacity up to 3,000 MVA per system)
- High overload capability
- Autoreclosure functionality
- Suitable for long distances (100 km and more without compensation of reactive power)
- High short-circuit withstand capability (including internal arc faults)
- Possibility of direct connection to gas-insulated switchgear (GIS) and gas-insulated arresters without cable entrance fitting
- Non-flammable; no fire risk in case of failures

The latest innovation of Siemens GIL is the buried laying technique for GIL for long-distance power transmission. SF_6 has been replaced by a gas mixture of sulphur hexafluoride (SF_6) and nitrogen (N_2) as an insulating medium.

Siemens's experience

When SF_6 was introduced in the 1960s as an insulating and switching gas, it became the basis for the development of gas-insulated switchgear. On the basis of its GIS experience, Siemens started to develop SF_6 gas-insulated lines to transmit electrical energy. In the early 1970s initial projects were planned and implemented. GIL were usually used within substations as busbars or bus ducts to connect gas-insulated switchgear with overhead lines. The aim was to create electrical lines with smaller clearances than those that were obtainable with air-insulated overhead lines. Implemented projects include laying GIL in tunnels, in sloping galleries, in vertical shafts and in open-air installations. Flanging as well as welding has been applied as a jointing technique.

The gas-insulated transmission line technique is highly reliable in terms of mechanical and electrical failures. After a system is commissioned and in service, it runs reliably without any dielectrical or mechanical failures, as experience over the course of 30 years shows. For example, one particular Siemens GIL now in service did not have to undergo its scheduled inspection after 20 years of service, because there were no indications of any weak point. Fig. 2.5-1 shows the arrangement of six phases in a tunnel.

Basic design

In order to meet mechanical stability criteria, gas-insulated lines comprise considerable cross-sections of enclosure and conductor. Herewith high-power transmission ratings are given. Because the insulating medium is gas, low capacitive loads are given so that compensation of reactive power is not needed, not even for longer distances. A further important requirement taken into account is the situation of an earth fault with a high current of up to 63 kA to earth.

Reduction of SF_6 content

Several tests have been carried out in Siemens facilities and in other test laboratories worldwide over the course of many years (fig. 2.5-2). Results of these investigations show that the bulk of the insulating gas for industrial projects involving a considerable amount of gas should be nitrogen, a non-toxic natural gas. However, another insulating gas should be added to nitrogen in order to improve the insulating capability and to minimize size and pressure. An N_2/SF_6 gas mixture with high nitrogen content (and SF_6 content as low as possible) was finally chosen as the insulating medium. The characteristics of N_2/SF_6 gas mixtures show that with an SF_6 content of only 20 % and a slightly higher pressure, the insulating capability of pure SF_6 can be attained. Additionally, the arcing behavior is improved using this mixture. Tests have proven that there would be no external damage or fire caused by an internal fault. The technical data of the GIL is shown in table 2.5-1.

Jointing technique

In order to improve gas tightness and to facilitate laying of the lines, flanges have been avoided as a jointing technique. Instead, welding has been chosen to connect the various GIL construction units. The welding process is highly automated, with the use of an orbital welding machine to ensure high quality of the joints. This orbital welding machine contributes to high productivity in the welding process and therefore speeds up laying the lines. The reliability of the welding process is controlled by an integrated computerized quality assurance system.

Laying

The laying technique must be as compatible as possible with the landscape and must take the change of seasons of the year into

Fig. 2.5-1: **GIL arrangement in the tunnel of the pumped storage station in Wehr, Southern Germany (4,000 m length; in service since 1975)**

account. The laying techniques for pipelines have been improved over many years, and these techniques are applicable for GIL as a ”pipeline for electrical current“, too. However, GIL need slightly different treatment, and the pipeline technique has to be adapted. The laying process is illustrated in fig. 2.5-3.

The assembly area needs to be protected from dust, particles, humidity and other environmental factors that might disturb the dielectric system. Clean assembly, therefore, plays an important role in setting up cross-country GIL under normal environmental conditions. A high level of automation of the overall process makes clean assembly and enhanced productivity possible.

Anti-corrosion protection

The most recently developed Siemens GIL are also designed for directly buried laying. Directly buried gas-insulated transmission lines will be safeguarded by a passive and active corrosion protection system. The passive corrosion protection system comprises a coating and ensures at least 40 years of protection. The active corrosion protection system provides protection potential in relation to the aluminum sheath.

Testing

The GIL has been tested according to IEC 61640 (1998) “Rigid high-voltage, gas-insulated transmission lines for voltages of 72.5 kV and above” (fig. 2.5-2, fig. 2.5-4).

Long-term performance

The long-term performance of GIL for long-distance installations has been proven by the independent test laboratory IPH, Berlin, Germany, and the former Berlin power utility BEWAG (now, Vattenfall Europe) using long-term test procedures for power cables. This result confirms more than 30 years of field experience with GIL installations worldwide. The test procedure consisted of load cycles with doubled voltage and increased current as well as frequently repeated high-voltage tests. The assembly and repair procedures under realistic site conditions were also examined. The Siemens GIL was the first in the world to have passed these tests, without any problems. Fig. 2.5-2 shows the test setup arranged in a tunnel of 3 m diameter.

References

Siemens has gained experience with gas-insulated transmission lines at rated voltages of up to 550 kV and with phase lengths totalling more than 40 km (2008). The first GIL stretch built by Siemens was the connection of the turbine generator pumping motor of a pumped storage station with the switchyard. The 420 kV GIL is laid in a tunnel through a mountain and has a single-phase length of 4,000 m (fig. 2.5-1). This connection was commissioned in 1975 at the Wehr pumped storage station in the Black Forest in Southern Germany.

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Fig. 2.5-2: **Long-term test setup at IPH, Berlin**

Technical data	
Rated voltage	Up to 550 kV
Rated current	2,000 – 4,000 A
Transmission capacity	1,500 – 3,500 MVA
Capacitance	≈ 60 nF/km
Typical length	1–100 km
Gas mixture SF_6/N_2	20 %/80 %, 60 %/40 %, 100 % SF_6
Laying	Directly buried
	In tunnels, sloping galleries, vertical shafts
	Open-air installation

Table 2.5-1: **GIL technical data**

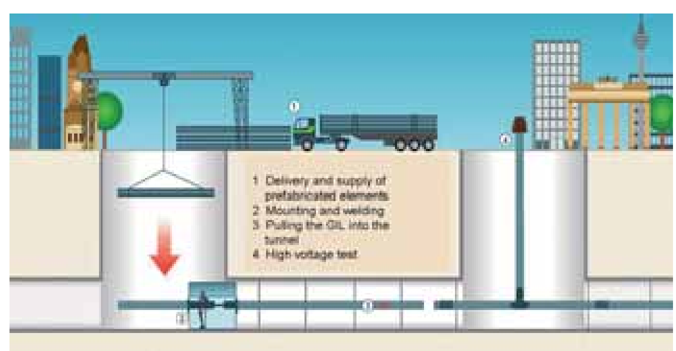


Fig. 2.5-3: **GIL laying technique**

Fig. 2.5-4: **Siemens lab prototype for dielectric tests**

2

2.5.2 Overhead Lines

Since the very beginning of electric power generation, overhead transmission lines (OHL) have constituted the most important component for transmission and distribution of electric power. The portion of overhead transmission lines within a transmission and distribution network depends on the voltage level as well as on local conditions and practice. In densely populated areas like Central Europe, underground cables prevail in the distribution sector, and overhead power lines in the high-voltage transmission sector. In other parts of the world, for example, in North America, overhead lines are often also used for distribution purposes within cities. Siemens has planned, designed and erected overhead power lines for all important voltage levels in many parts of the world.

Selection of line voltage
For the distribution and transmission of electric power, standardized voltages according to IEC 60038 are used world-wide. For 3-phase AC applications, three voltage levels prevail:

- Low voltage (up to 1 kV AC)
- Medium voltage (between 1 kV and 36 kV AC)
- High voltage (between 52 kV and 765 kV AC) and higher

Low-voltage lines serve households and small business consumers. Lines on the medium-voltage level supply small settlements, individual industrial plants and large consumers; the transmission capacity is typically less than 10 MVA per circuit. The high-voltage circuits up to 145 kV serve for subtransmission of the electric power regionally, and feed the medium-voltage network. This level is often chosen to support the medium-voltage level even if the electric power is below 10 MVA. Moreover, some of these high-voltage lines also transmit the electric power from medium-sized generating stations, such as hydro plants on small and medium rivers, and supply large-scale consumers, such as sizable industrial plants or steel mills. They constitute the connection between the interconnected high-voltage grid and the local distribution networks. The bandwidth of electrical power transported corresponds to the broad range of utilization, but rarely exceeds 100 MVA per circuit, while the surge impedance load is 35 MVA (approximately).

In Central Europe, 245 kV lines were used for interconnection of power supply systems before the 420 kV level was introduced for this purpose. Long-distance transmission, for example, between the hydro power plants in the Alps and consumers, was done by 245 kV lines. Nowadays, the importance of 245 kV lines is decreasing due to the existence of the 420 kV transmission network. The 420 kV level represents the highest operation voltage used for AC transmission in Central Europe. It typically interconnects the power supply systems and transmits the energy over long distances. Some 420 kV lines connect the national grids of the individual European countries enabling interconnected network operation (UCTE = Union for the Co-ordination of Transmission of Electricity) throughout Europe. Large power plants such as nuclear stations feed directly into the 420 kV network. The thermal capacity of the 420 kV circuits may reach 2,000 MVA, with a surge impedance load of approximately 600 MVA and a transmission capacity up to 1,200 MVA.

Overhead power lines with voltages higher than 420 kV AC will be required in the future to economically transmit bulk electric power over long distances, a task typically arising when utilizing hydro, wind and solar energy potentials far away from consumer centers. Fig. 2.5-5 depicts schematically the range of application for the individual AC voltage levels based on the distance of transmission and the power rating. The voltage level has to be selected based on the task of the line within the network or on the results of network planning. Siemens has carried out such studies for power supply companies all over the world.

High-voltage direct current
However, when considering bulk power transmission over long distances, a more economical solution is the high-voltage direct current (HVDC) technology. Siemens is in the position to offer complete solutions for such interconnections, starting with network studies and followed by the design, assistance in project development and complete turnkey supply and construction of such plants. For DC transmission no standard is currently available. The DC voltages vary from the voltage levels recommended in the above-mentioned standardized voltages used for AC.

HVDC transmission is used for bulk power transmission and for system interconnection. The line voltages applied for projects worldwide vary between ± 300 kV, ± 400 kV, ± 500 kV, ± 600 kV and recently (2007), ± 800 kV. The selection of the HVDC line voltage is ruled by the following parameters:

- Amount of power to be transferred
- Length of the overhead power line
- Permissible power losses
- Economical conductor size

The advantages of DC transmission over AC transmission are:

- A DC link allows power transfer between AC networks with different frequencies or networks that cannot be synchronized.
- Inductive and capacitive parameters do not limit the transmission capacity or the maximum length of a DC overhead transmission line.
- The conductor cross-section can be more or less fully utilized because there is no skin effect caused by the line frequency.
- DC overhead power lines are much more economical to built and require less right-of-way.

Economical considerations/evaluation of DC voltages
Fig. 2.5-6 shows the economical application of DC voltages in relation to overhead transmission line length and transmitted power. This graph must be seen as a general guideline. Any project should be separately evaluated on a case-by-case basis. The budgets established for this evaluation are based on 2007 figures.

Conclusions:

- 300 kV voltage level:
  The range of 750 and 1,000 km with a power transfer of 600 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per MW power and km of transmission line. The result shows that for long-distance HVDC transmission, the 300 kV voltage level is not the optimal solution (refer to 400 kV below). However, this voltage level is useful in short HVDC interconnectors such as the Thailand-Malaysia Interconnector, which has a line length of 113 km.
- 400 kV voltage level:
  The range 750, 1,000 and 1,500 km with a power transfer of 600, 1,000 and 2,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 400 kV voltage level is a suitable solution for line lengths of 750 to 1,000 km with transmitted power of 600 to 1,000 MW.
- 500 kV voltage level:
  The range 1,000 and 1,500 km with a power transfer of 1,000, 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 500 kV voltage level is a suitable solution for the line lengths of 1,000 km to 1,500 km with transmitted power of 1,000 to 2,000 MW. However, the 400 kV voltage level can also be competitive in this range of power and line length.
- 600 kV voltage level:
  The range 1,500, 2,000 and 3,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line length. The result shows that the 600 kV voltage level is a suitable solution for the line lengths of 1500 km to 3,000 km with transmitted power of 2,000 MW, and 3,000 MW for lines up to 2,000 km. However, the 500 kV voltage level can still be competitive in parts of this range.
- 800 kV voltage level:
  The range 2,000, 3,000 and 4,000 km with a power transfer of 2,000 and 3,000 MW has been evaluated. The line and converter costs have been added, and transferred into a cost factor per megawatt power and kilometer of transmission line. The result shows that the 800 kV voltage level is a suitable solution for the line lengths of 2,000 km and above with transmitted power of 2,000 and 3,000 MW. However, shorter line lengths of 1,500 to 3,000 km with power rating of 3,000 to 7,000 MW can be economically covered with an 800 kV solution.

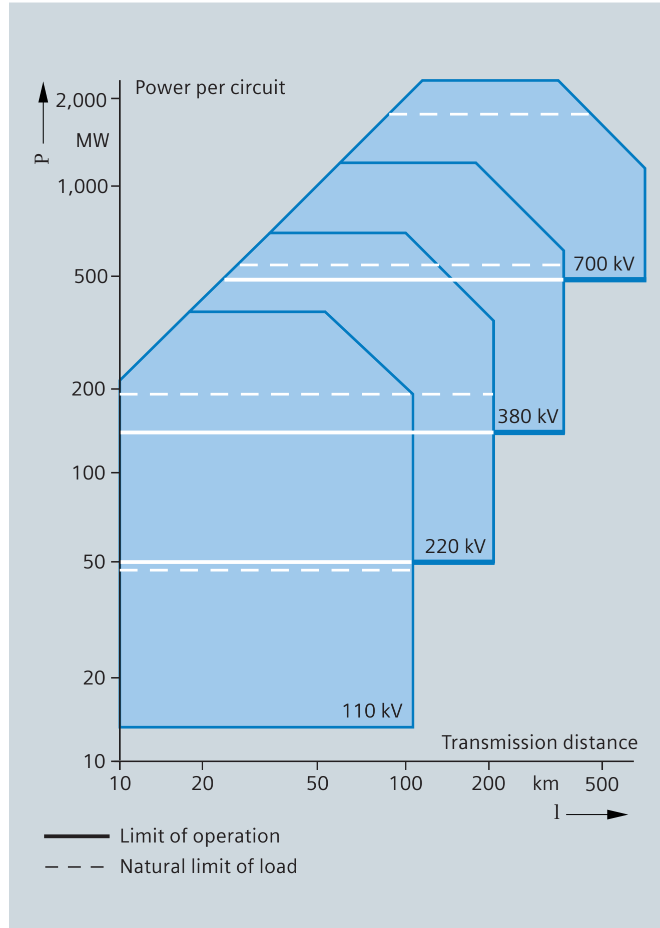


Fig. 2.5-5: **Selection of rated voltage for power transmission**

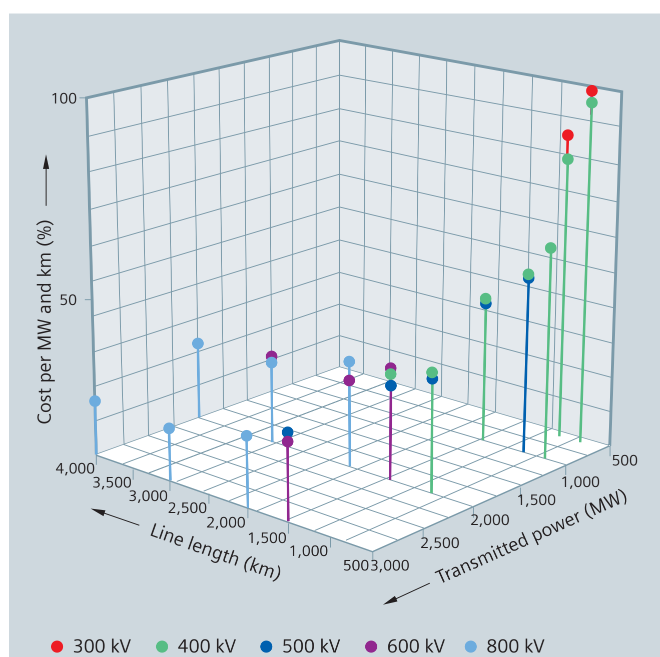


Fig. 2.5-6: **Economical application of DC voltages in relation to overhead transmission line length and transmitted power**

Selection of conductors and earth wires

Conductors represent the most important component of an overhead power line because they have to ensure economical and reliable transmission and contribute considerably to the total line costs. For many years, aluminum and its alloys have been the prevailing conducting materials for power lines due to the favorable price, the low weight and the necessity of certain minimum cross-sections. However, aluminum is a very corrosive metal. But a dense oxide layer is formed that stops further corrosive attacks. Therefore, up to a certain level, aluminum conductors are well-suited for areas in which corrosion is a problem, for example, a maritime climate.

For aluminum conductors, there are a number of different designs in use. All-aluminum conductors (AAC) have the highest conductivity for a given cross-section; however, they possess only a low mechanical strength, which limits their application to short spans and low tensile forces. To increase the mechanical strength, wires made of aluminum-magnesium-silicon alloys are adopted. Their strength is approximately twice that of pure aluminum. But single-material conductors like all-aluminum and aluminum alloy conductors have shown susceptibility to eolian vibrations. Compound conductors with a steel core, so-called aluminum conductor, steel-reinforced (ACSR), avoid this disadvantage. The ratio between aluminum and steel ranges from 4.3:1 to 11:1. An aluminum-to-steel ratio of 6.0 or 7.7 provides an economical solution. Conductors with a ratio of 4.3 should be used for lines installed in regions with heavy wind and ice loads. Conductors with a ratio higher than 7.7 provide higher conductivity. But because of lower conductor strength, the sags are bigger, which requires higher towers.

Experience has shown that ACSR conductors, just like aluminum and aluminum alloy conductors, provide the most economical solution and offer a life span greater than 40 years. Conductors are selected according to electrical, thermal, mechanical and economic aspects. The electric resistance as a result of the conducting material and its cross-section is the most important feature affecting the voltage drop and the energy losses along the line and, therefore, the transmission costs. The cross-section has to be selected so that the permissible temperatures will not be exceeded during normal operation as well as under short-circuit condition. With increasing cross-section, the line costs increase, while the costs for losses decrease. Depending on the length of the line and the power to be transmitted, a cross-section can be determined that results in the lowest transmission costs. The heat balance of ohmic losses and solar radiation against convection and radiation determines the conductor temperature. A current density of 0.5 to 1.0 A/mm^2 based on the aluminum cross-section has proven to be an economical solution in most cases.

High-voltage results in correspondingly high-voltage gradients at the conductor's surface, and in corona-related effects such as visible discharges, radio interference, audible noise and energy losses. When selecting the conductors, the AC voltage gradient has to be limited to values between 15 and 17 kV/cm. Since the sound of the audible noise of DC lines is mainly caused at the positive pole and this sound differs from those of AC lines, the subjective feeling differs as well. Therefore, the maximum surface voltage gradient of DC lines is higher than the gradient for AC lines. A maximum value of 25 kV/cm is recommended. The line voltage and the conductor diameter are one of the main factors that influence the surface voltage gradient. In order to keep this gradient below the limit value, the conductor can be divided into subconductors. This results in an equivalent conductor diameter that is bigger than the diameter of a single conductor with the same cross-section. This aspect is important for lines with voltages of 245 kV and above. Therefore, so-called bundle conductors are mainly adopted for extra-high-voltage lines. Table 2.5-2 shows typical conductor configurations for AC lines.

From a mechanical point of view, the conductors have to be designed for everyday conditions and for maximum loads exerted on the conductor by wind and ice. As a rough figure, an everyday stress of approximately 20 % of the conductor rated tensile stress can be adopted, resulting in a limited risk of

Rated voltage	[kV]	20		110		220		380		700
Highest system voltage	[kV]	24		123		245		420		765
Nominal cross-section	[mm^2]	50	120	150	300	435	bundle 2x240	bundle 4x240	bundle 2x560	bundle 4x560
Conductor diameter	[mm]	9.6	15.5	17.1	24.5	28.8	2x21.9	4x21.9	2x32.2	4x32.2
Ampacity (at 80 °C conductor temperature)	[A]	210	410	470	740	900	1,290	2,580	2,080	4,160
Thermal capacity	[MVA]	7	14	90	140	340	490	1,700	1,370	5,400
Resistance at 20 °C	[Ω/km]	0.59	0.24	0.19	0.10	0.067	0.059	0.030	0.026	0.013
Reactance at 50 Hz	[Ω/km]	0.39	0.34	0.41	0.38	0.4	0.32	0.26	0.27	0.28
Effective capacitance	[nF/km]	9.7	11.2	9.3	10	9.5	11.5	14.4	13.8	13.1
Capacitance to earth	[nF/km]	3.4	3.6	4.0	4.2	4.8	6.3	6.5	6.4	6.1
Charging power	[kVA/km]	1.2	1.4	35	38	145	175	650	625	2,320
Earth-fault current	[A/km]	0.04	0.04	0.25	0.25	0.58	0.76	1.35	1.32	2.48
Surge impedance	[Ω]	360	310	375	350	365	300	240	250	260
Surge impedance load	[MVA]	–	–	32	35	135	160	600	577	2,170

Table 2.5-2: **Electric characteristics of AC overhead power lines (data refer to one circuit of a double-circuit line)**

conductor damage. The maximum working tensile stress should be limited to approximately 40 % of the rated tensile stress.

Earth wires, also called shieldwire or earthwire, can protect a line against direct lightning strikes and improve system behavior in the event of short-circuits; therefore, lines with single-phase voltages of 110 kV and above are usually equipped with earth wires. Earth wires made of ACSR conductors with a sufficiently high aluminum cross-section satisfy both requirements.

Since the beginning of the 1990s, more and more earth wires for extra-high-voltage overhead power lines have been executed as optical earth wires (OPGW). This type of earth wire combines the functions just described for the typical earth wire with the additional facility for large data transfer capacity via optical fibers that are integrated into the OPGW. Such data transfer is essential for the communication between two converter stations within an HVDC interconnection or for remote controlling of power stations. The OPGW in such a case becomes the major communication link within the interconnection. OPGW are mainly designed in one or more layers of aluminum alloy and/or aluminum-clad steel wires. One-layer designs are used in areas with low keraunic levels (small amount of possible lightning strikes per year) and small short-circuit levels.

Selection of insulators

Overhead line insulators are subject to electrical and mechanical stresses, because they have to isolate the conductors form potential to earth and must provide physical supports. Insulators must be capable of withstanding these stresses under all conditions encountered in a specific line.

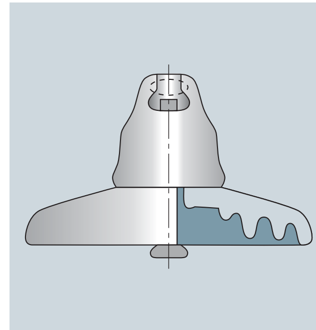
The electrical stresses result from:

- The steady-state operating power-frequency voltage (highest operation voltage of the system)
- Temporary overvoltages at power frequency
- Switching and lightning overvoltages

Insulator types

Various insulator designs are in use, depending on the requirements and the experience with certain insulator types:

- Cap-and-pin insulators (fig. 2.5-7) are made of porcelain or pre-stressed glass. The individual units are connected by fittings of malleable cast iron or forged iron. The insulating bodies are not puncture-proof, which is the reason for a relatively high number of insulator failures.
- In Central Europe, long-rod insulators made from aluminous porcelain (fig. 2.5-8) are most frequently adopted. These insulators are puncture-proof. Failures under operation are extremely rare. Long-rod insulators show superior behavior, especially in polluted areas. Because porcelain is a brittle material, porcelain long-rod insulators should be protected from bending loads by suitable fittings.
- Composite insulators are the third major type of insulator for overhead power line applications (fig. 2.5-9). This insulator type provides superior performance and reliability, particularly because of improvements over the last 20 years, and has been in service for more than 30 years.



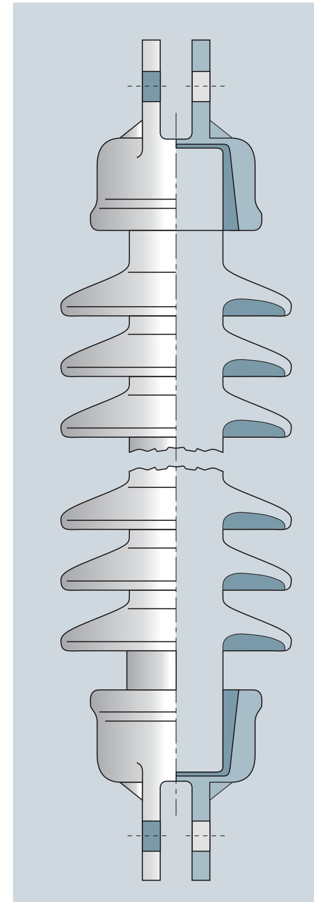


Fig. 2.5-7: **Cap-and-pin insulator (above)**
Fig. 2.5-8: **Long-rod insulator with clevis caps**

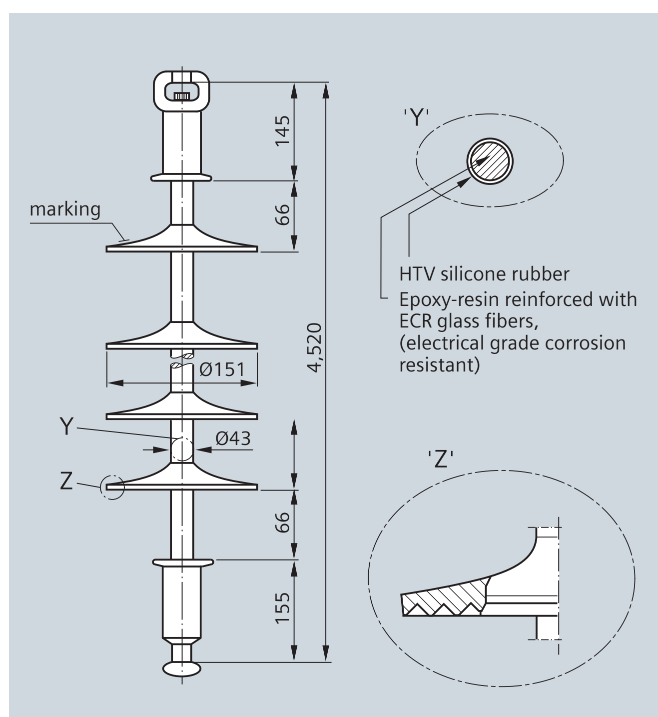


Fig. 2.5-9: **Glass fiber reinforced composite insulator with ball and socket fittings (lapp insulator)**

The composite insulator is made of a glass fiber reinforced epoxy rod. The glass fibers applied are ECR glass fibers that are resistant to brittle fracture (ECR = electrical grade corrosion resistant glass fibers). In order to avoid brittle fracture, the glass fiber rod must additionally be sealed very carefully and durably against moisture. This is done by application of silicone rubber. Nowadays, high temperature vulcanized (HTV) silicone is used.

The silicone rubber has two functions within this insulator type:
- Sealing the glass fiber rod
- Molding into insulator sheds to establish the required insulation

Metal fittings are compressed onto the glass fiber rod at both ends of the insulator, either with a ball socket or clevis connection fitting. Since the 1980s, compression fittings have been the prevailing type. The sealing of the area between fitting and silicone housing protecting the rod is most important, and is nowadays done with special silicone elastomer, which offers after vulcanization the characteristic of a sticky solid, similar to a fluid of high viscosity.

Advantages of the composite long-rod insulator are:
- Light weight, less volume and less damages
- Shorter string length compared to cap-and-pin – and porcelain long-rod – insulator strings
- Up to 765 kV AC and 600 kV DC, only one unit of insulator (practical length is only limited by the ability of the production line) is required
- High mechanical strength
- Vandalism resistance
- High performance in polluted areas, based on the hydrophobicity (water repellency) of the silicone rubber

Advantages of hydrophobicity are:
- Silicone rubber offers outstanding hydrophobicity over the long term; most other polymeric housing material will loose this property over time
- Silicone rubber is able to recover its hydrophobicity after a temporary loss of it
- The silicone rubber insulator is able to make pollution layers on its surface water-repellent, too (hydrophobicity transfer)
- Low surface conductivity, even with a polluted surface and very low leakage currents, even under wetted conditions.

Insulator string sets

Suspension insulator sets carry the conductor weight, including additional loads such as ice and wind, and are arranged more or less vertically. There are I-shaped (fig. 2.5-10a) and V-shaped sets in use. Tension insulator sets (fig. 2.5-10b, fig. 2.5-10c) terminate the conductors and are arranged in the direction of the conductors. They are loaded by the conductor tensile force and have to be rated accordingly. Multiple single, double, triple or more sets handle the mechanical loadings and the design requirements.

Design of creepage distance and air gaps

The general electrical layout of insulation is ruled by the voltages to be withstood and the pollution to which the insulation is subjected. The standards IEC 60071-1 and IEC 60071-2 as well as the technical report IEC 60815, which provides four pollution classes (the new version will have five classes), give guidance for the design of the insulation.

Because IEC 60815 is applicable to AC lines, it should be noted that the creepage distances recommended are based on the phase-to-phase AC voltage ($U_{L\text{-}L}$). When transferring these creepage distances recommended by IEC 60815 to a DC line, it should be noted that the DC voltage is a pole-to-earth value ($U_{L\text{-}E}$). Therefore, these creepage distances have to be multiplied by the factor $\sqrt{3}$. Furthermore, it should be noted that the AC voltage value refers to a mean value, while the DC voltage is comparable to a peak value, which requires a further multiplication with factor $\sqrt{2}$.

Insulators under DC voltage operation are subjected to a more unfavorable conditions than they are under AC, due to a higher collection of surface contamination caused by the constant unidirectional electric field. Therefore, a DC pollution factor has to be applied. Table 2.5-3 shows specific creepage distances for different insulator materials under AC and DC application, and is based on industry experience published by power supply companies in South Africa and China. The results shown were confirmed by an experienced insulator manufacturer in Germany. The correction factors shown are valid for porcelain insulators only. When taking composite insulators into consideration, an additional reduction factor of 0.75 can be applied. The values for a DC system must be seen as a guideline only, that must be verified on a case-by-case basis for new HVDC projects.

To handle switching and lightning overvoltages, the insulator sets have to be designed with respect to insulation coordination according to IEC 60071-1 and IEC 60071-2. These design aspects determine the gap between the earthed fittings and the live part. However, for HVDC application, switching impulse levels are of minor important because circuit-breaker operations from AC lines do not occur on DC back-to-back lines. Such lines are controlled via their valve control systems. In order to coordinate the insulation in a proper way, it is recommended to apply and use the same SIL and BIL as is used for the equivalent AC insulation (determined by the arcing distance).

Selection and design of supports

Together with the line voltage, the number of circuits (AC) or poles (DC) and type of conductors, the configuration of the circuits poles determines the design of overhead power lines. Additionally, lightning protection by earth wires, the terrain and the available space at the tower sites have to be considered. In densely populated areas like Central Europe, the width of right-of-way and the space for the tower sites are limited. In the case of extra-high-voltages, the conductor configuration affects the electrical characteristics, the electrical and magnetic field and the transmission capacity of the line. Very often there are contradicting requirements, such as a tower height as low as

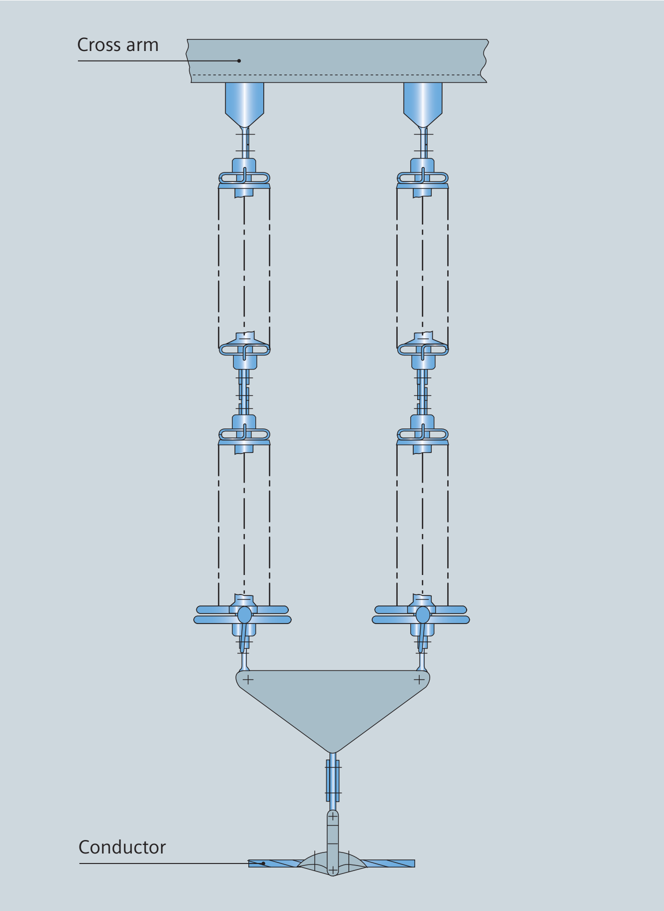


Fig. 2.5-10a: **I-shaped suspension insulator set for 245 kV**

IEC 60815 level		Porcelain and glass insulators		Composite insulators	
		AC system	DC system	AC system	DC system
I Light	[mm/kV]	16	39	12	29
II Medium	[mm/kV]	20	47	15	35
III Heavy	[mm/kV]	25	59	19	44
IV Very Heavy	[mm/kV]	31	72	24	54

Table 2.5-3: **Guideline for specific creepage distances for different insulator materials**

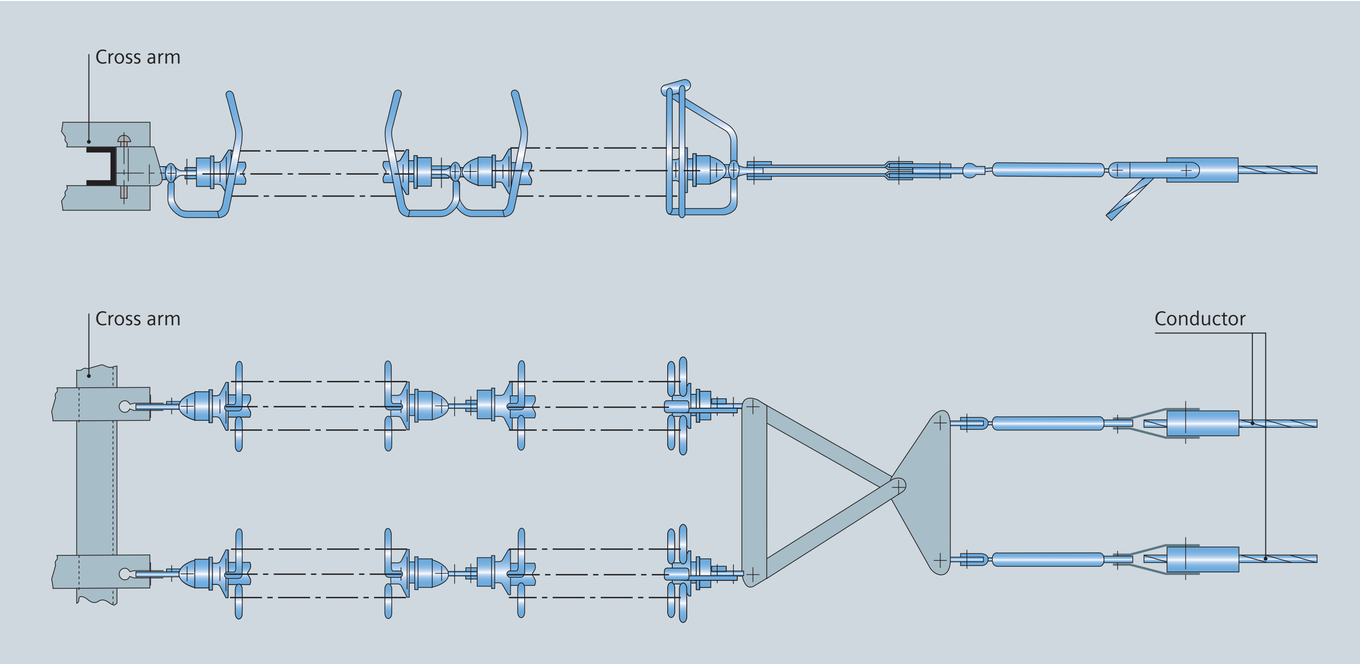


Fig. 2.5-10b: **Double tension insulator set for 245 kV (elevation, top)**
Fig. 2.5-10c: **Double tension insulator set for 245 kV (plan, bottom)**

possible and a narrow right-of-way, which can only be met by compromises. The minimum clearance of the conductors depends on the voltage and the conductor sag. In ice-prone areas, conductors should not be arranged vertically, in order to avoid conductor clashing after ice shedding.

For low-voltage and medium-voltage lines, horizontal conductor configurations prevail; these configurations feature line post insulators as well as suspension insulators. Poles made of wood, concrete or steel are preferred. Fig. 2.5-11 shows some typical line configurations. Earth wires are omitted at this voltage level.

For high-voltage and extra-high-voltage power lines, a large variety of configurations are available that depend on the number of circuits (AC) or poles (DC) and on local conditions. Due to the very limited right-of-way, more or less all high-voltage AC lines in Central Europe comprise at least two circuits. Fig. 2.5-12 shows a series of typical tower configurations. Arrangement "e" is called the "Danube" configuration and is often adopted. It represents a fair compromise with respect to width of right-of-way, tower height and line costs.

For AC lines comprising more than two circuits, there are many possibilities for configuring the supports. In the case of circuits with differing voltages, those circuits with the lower voltage should be arranged in the lowermost position (fig. 2.5-12g).

DC lines are mechanically designed according to the normal practice for typical AC lines. The differences from AC Line layout are the:

- Conductor configuration
- Electric field requirements
- Insulation design

For DC lines, two basic outlines (monopole and bipole), with variations should be considered. Fig. 2.5-12i–l show examples for HVDC line configurations that are valid for all voltage levels.

The arrangements of insulators depend on the application of a support within the line. Suspension towers support the conductors in straight-line sections and at small angles. This tower type offers the lowest costs; special attention should therefore be paid to using this tower type as often as possible. Angle towers have to carry the conductor tensile forces at angle points of the line. The tension insulator sets permanently transfer high forces from the conductors to the supports. Finally, dead-end towers are used at the terminations of a transmission line. They carry the total conductor tensile forces on the line side (even under unbalanced load condition, e.g., when conductors of one tower side are broken) and a reduced tension into the substations (slack span).

Various loading conditions specified in the respective national and international standards have to be met when designing towers. The climatic conditions, the earthquake requirements and other local environmental factors are the next determining factors for the tower design.

When designing the support, a number of conditions have to be considered. High wind and ice loads cause the maximum forces to act on suspension towers. In ice-prone areas, unbalanced

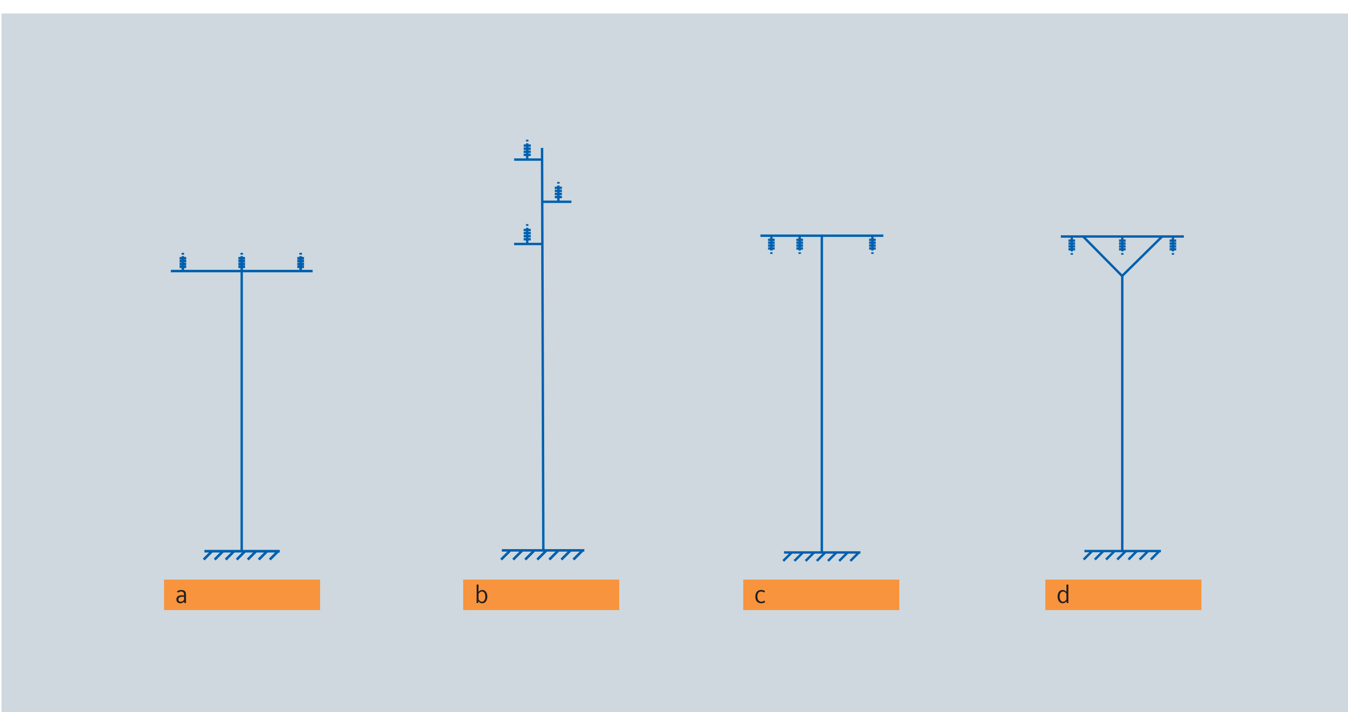


Fig. 2.5-11: **Configurations of medium-voltage supports**

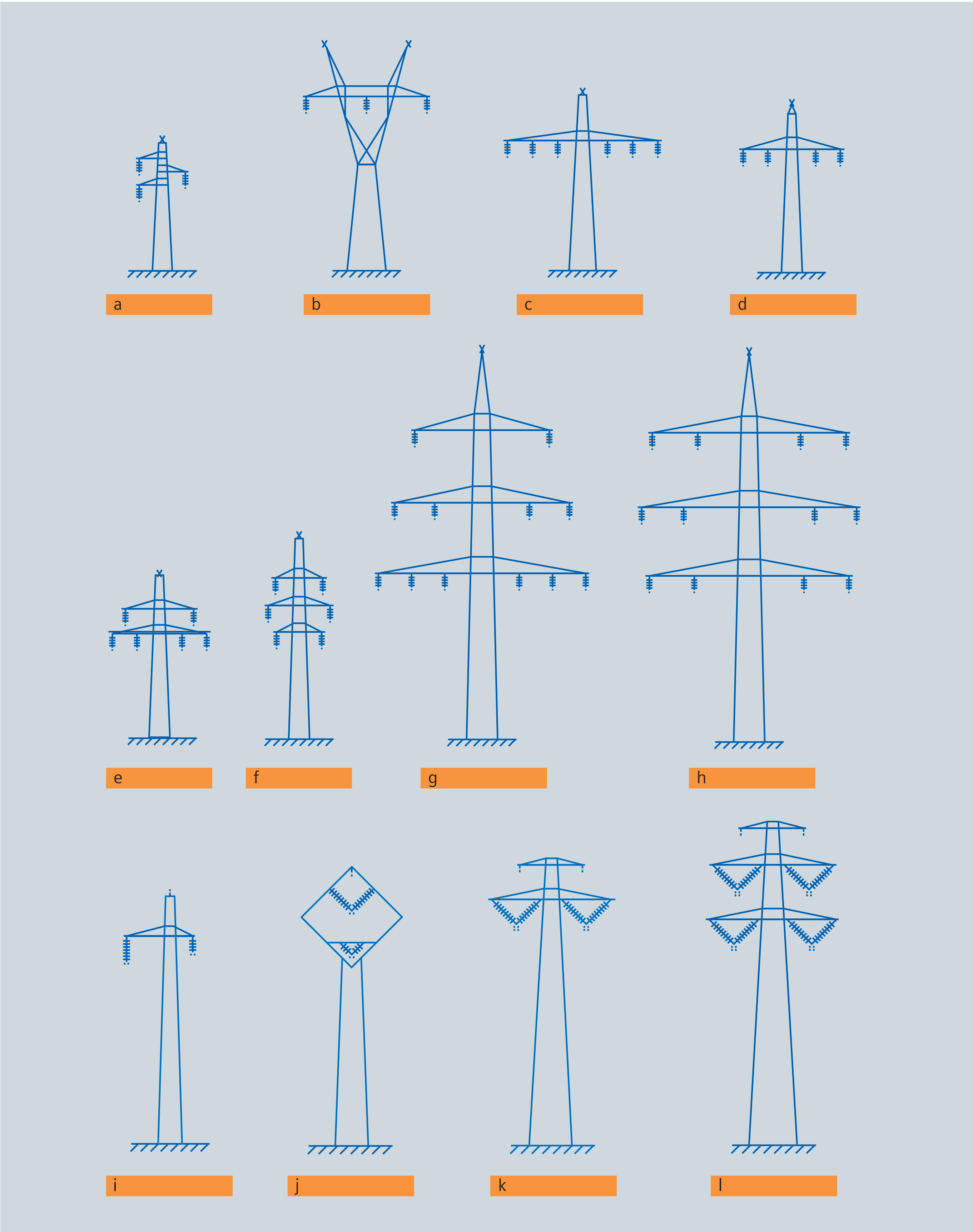


Fig. 2.5-12: **(a–h): tower configurations for high-voltage lines (AC); (i–l): tower configurations for high-voltage lines (DC)**

conductor tensile forces can result in torsional loading. Additionally, special loading conditions are adopted for the purpose of failure containment, that is, to limit the extent of damage. Finally, provisions have to be made for construction and maintenance.

Depending on voltage level and the acting forces of the overhead line, differing designs and materials are adopted. Poles made of wood, concrete or steel are very often used for low-voltage and medium-voltage lines. Towers with lattice steel design, however, prevail at voltage levels of 110 kV and above (fig. 2.5-13). Guyed lattice steel structures are used in some parts of the world for high-voltage AC and DC lines. Such design requires a relatively flat topography and a secure environment where there is no threat from vandalism and theft. Guyed lattice steel structures offer a substantial amount of cost savings with respect to tower weight and foundation quantities. However, a wider right-of-way has to be considered.

Foundations for the supports

Overhead power line supports are mounted on concrete foundations. The foundations have to be designed according to the national or international standard applicable for the particular project.

The selection of foundation types and the design is determined by the:

- Loads resulting from the tower design
- Soil conditions on the site
- Accessibility to the line route
- Availability of machinery
- Constraints of the particular country and the site

Concrete blocks or concrete piers are in use for poles that exert bending moments on the foundation. For towers with four legs, a foundation is provided for each individual leg (fig. 2.5-14). Pad and chimney and concrete block foundations require good bearing soil conditions without groundwater.

Driven or augured piles and piers are adopted for low-bearing soil, for sites with bearing soil at a greater depth and for high groundwater level. In case of groundwater, the soil conditions must permit pile driving. Concrete slabs can be used for good bearing soil, when subsoil and groundwater level prohibit pad and chimney foundations as well as piles.

Route selection and tower spotting

Route selection and planning represent increasingly difficult tasks, because the right-of-way for transmission lines is limited and many aspects and interests have to be considered.

Route selection and approval depend on the statutory conditions and procedures prevailing in the country of the project. Route selection nowadays involves preliminary desktop studies with a variety of route alternatives, environmental impact studies, community communication hearings and acceptance approval from the local authorities.

Fig. 2.5-13: **Typical Central European AC line design with different voltage levels**

After the route design stage and approval procedure, the final line route is confirmed. Following this confirmation and approval, the longitudinal profile has to be surveyed, and all crossings over roads, rivers, railways, buildings and other overhead power lines have to be identified. The results are evaluated with a specialized computer program developed by Siemens that calculates and plots the line profile. The towers are spotted by means of the same program, which takes into account the conductor sags under different conditions, the ground clearances, objects crossed by the line, technical data of the available tower family, specific cost for towers and foundations and cost for compensation of landowners.

The result is an economical design of a line that accounts for all the technical, financial and environmental conditions. Line planning forms the basis for material acquisition and line erection. Fig. 2.5-15 shows a line profile established by computer.

Siemens's activities and experience

Siemens has been active in the overhead power line field for more than 100 years. The activities comprise design and construction of rural electrification schemes, low-voltage and medium-voltage distribution lines, high-voltage lines and extra-high-voltage installations.

To give an indication of what has been carried out by Siemens, approximately 20,000 km of high-voltage lines up to 245 kV and 10,000 km of extra-high-voltage lines above 245 kV have been set up so far. Overhead power lines have been erected by Siemens in Germany and Central Europe as well as in the Middle East, Africa, the Far East and South America.

Outstanding AC projects have been:

- The 420 kV transmission lines across the Elbe River in Germany comprising four circuits and requiring 235 m tall towers
- The 420 kV line across the Bosphorus (Crossing II) in Turkey (1983) with a crossing span of approximately 1,800 m (fig. 2.5-16).
- The 500 kV Suez Crossing (1998); height of suspension tower 220 m
- The 420/800 kV Bosporus Crossing III in Turkey (1999)

Furthermore, Siemens has constructed two HVDC interconnectors as turnkey projects that include HVDC overhead transmission lines. The two projects are the 300 kV HVDC interconnector from Thailand to Malaysia (bipole transmission line, fig. 2.5-17) and the 400 kV HVDC Basslink project in Australia (monopole transmission line, fig. 2.5-18a–c).

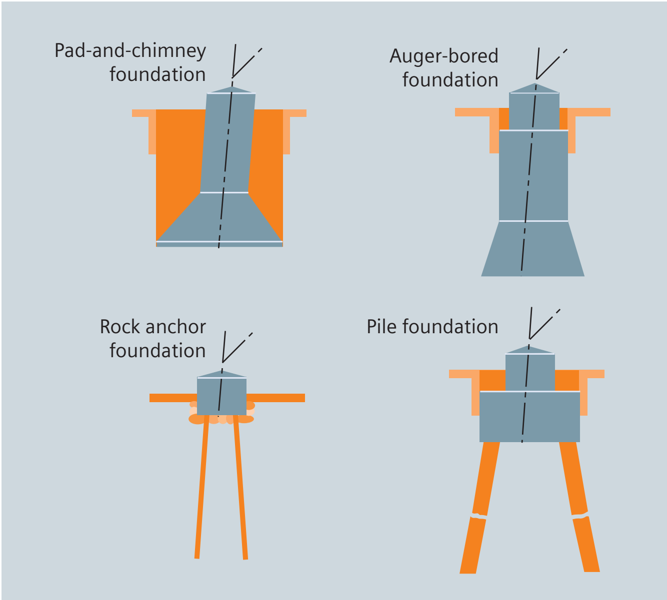


Fig. 2.5-14: **Foundations for four-legged towers**

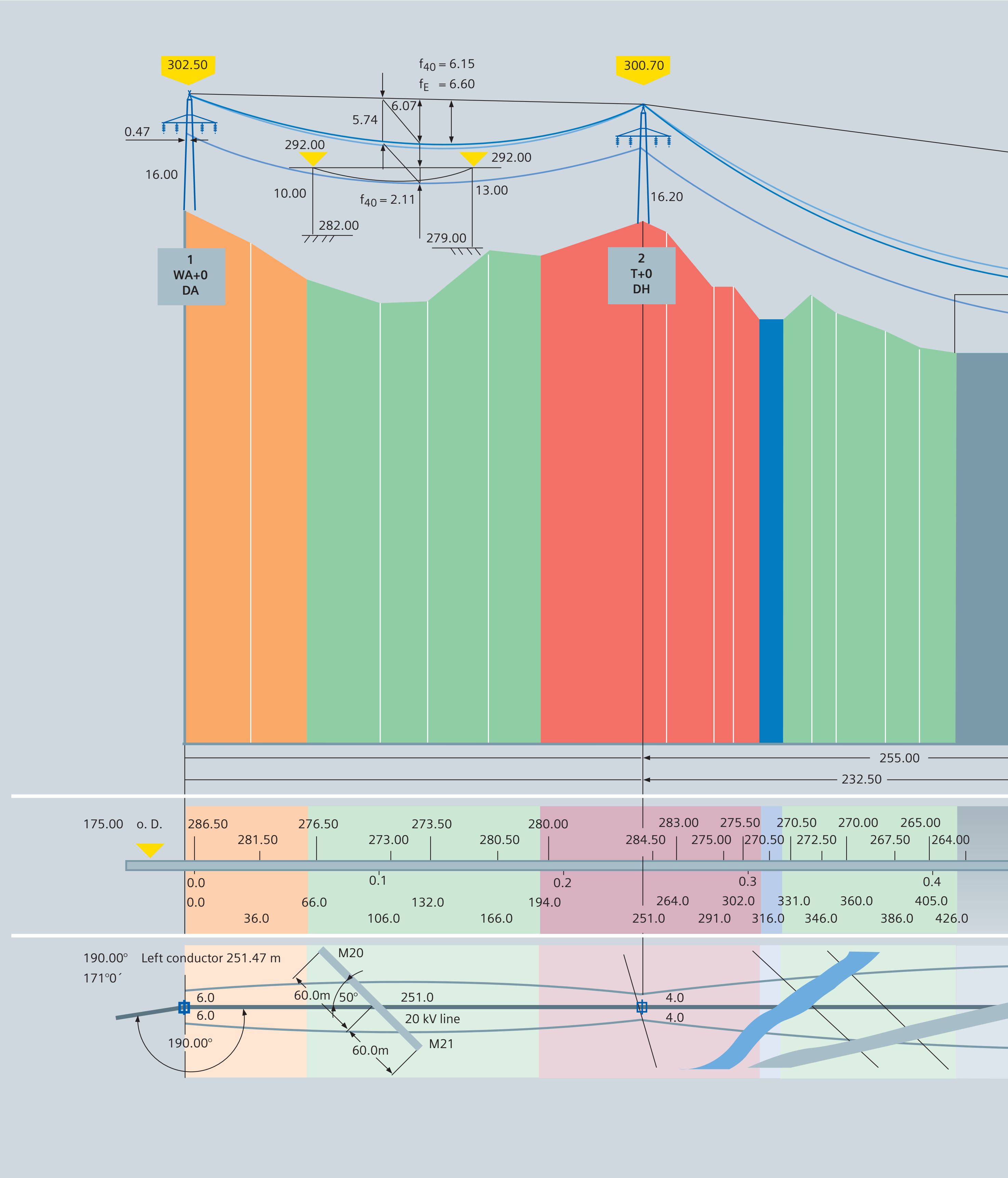
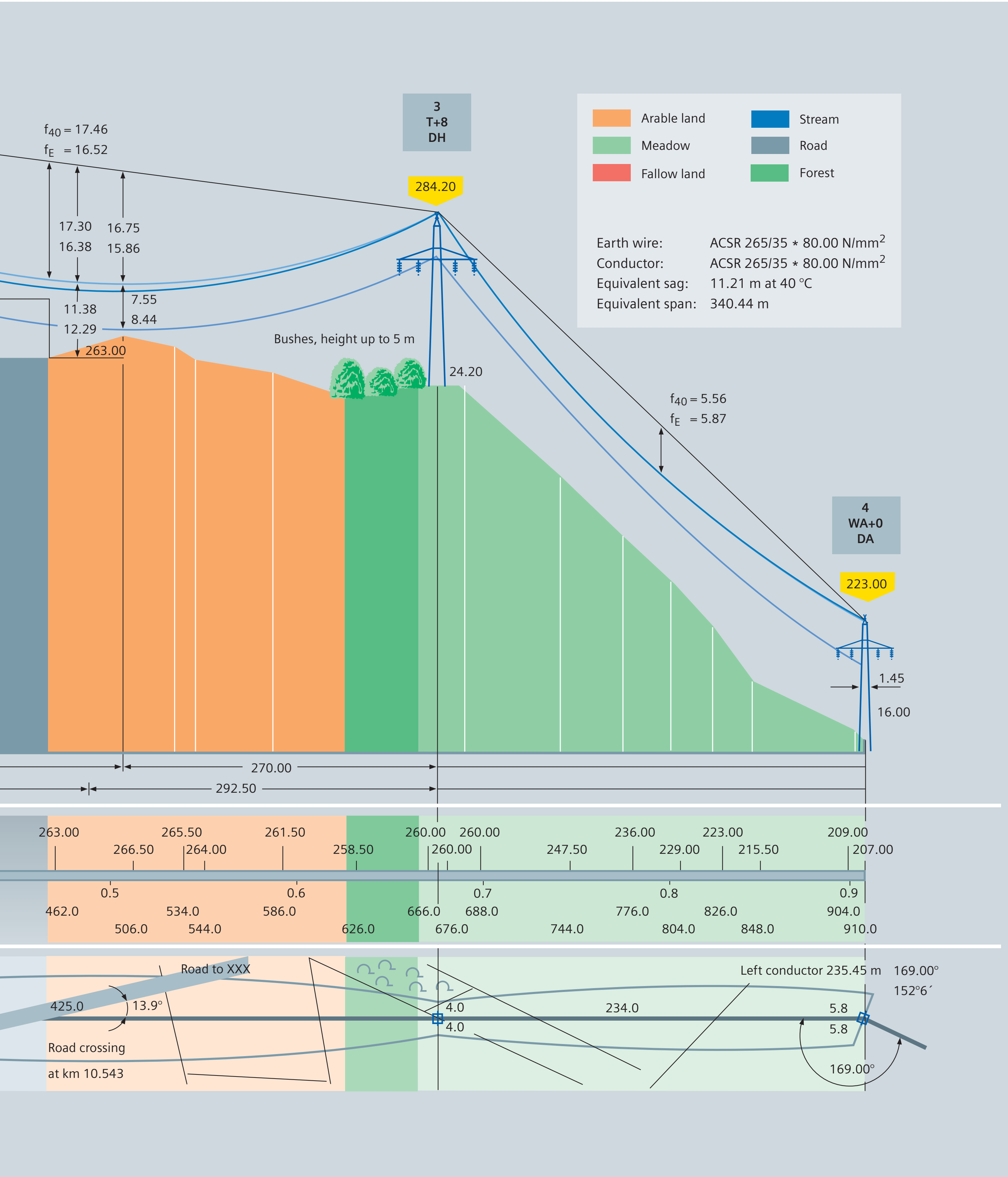


Fig. 2.5-15: **Line profile established by computer**



3
T+8
DH
284.20
Arable land
Meadow
Fallow land
Stream
Road
Forest
Earth wire: ACSR 265/35 * 80.00 N/mm2
Conductor: ACSR 265/35 * 80.00 N/mm2
Equivalent sag: 11.21 m at 40 °C
Equivalent span: 340.44 m
f40 = 17.46
fE = 16.52
17.30
16.38
16.75
15.86
11.38
12.29
7.55
8.44
263.00
Bushes, height up to 5 m
24.20
f40 = 5.56
fE = 5.87
4
WA+0
DA
223.00
1.45
16.00
270.00
292.50
263.00
265.50
261.50
260.00
260.00
236.00
223.00
209.00
266.50
264.00
258.50
260.00
247.50
229.00
215.50
207.00
0.5
0.6
0.7
0.8
0.9
462.0
534.0
586.0
666.0
688.0
776.0
826.0
904.0
506.0
544.0
626.0
676.0
744.0
804.0
848.0
910.0
Road to XXX
425.0
13.9°
Road crossing
at km 10.543
4.0
4.0
234.0
Left conductor 235.45 m
169.00°
152°6´
5.8
5.8
169.00°

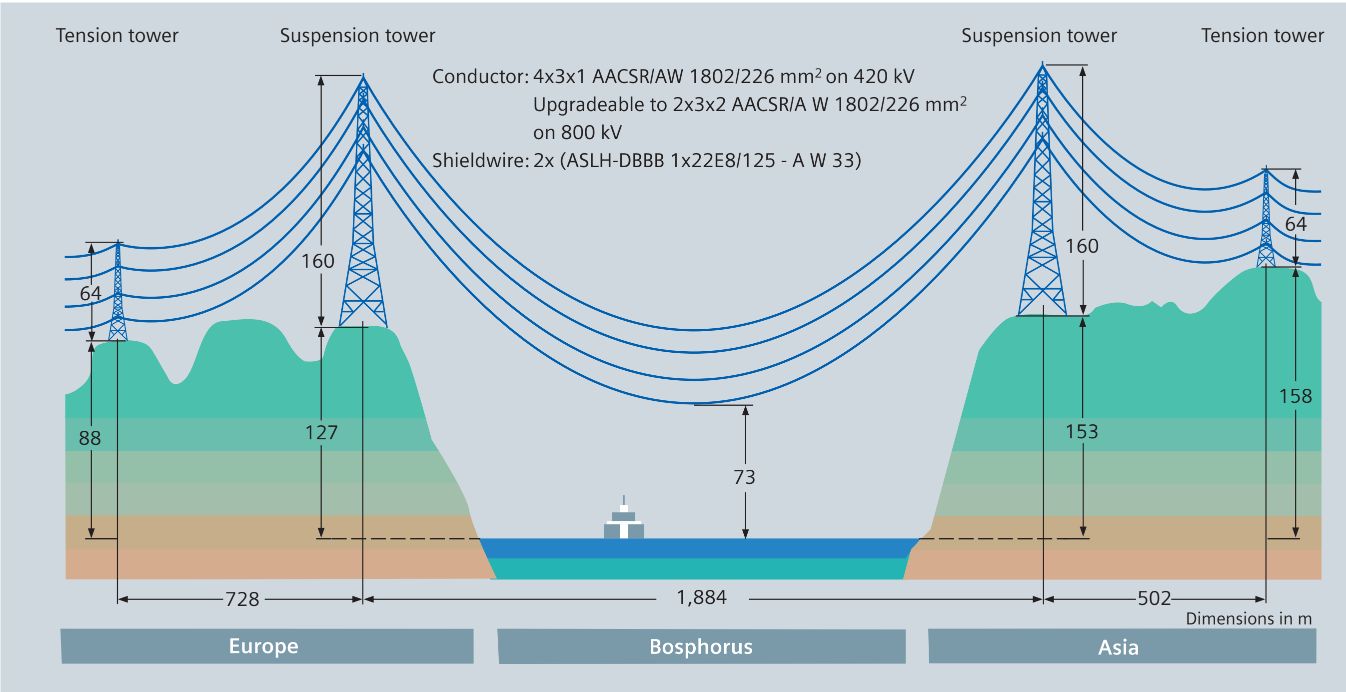


Fig. 2.5-16: **420/800 kV line across the Bosphorus, longitudinal profile**

Fig. 2.5-17: **300kV HVDC interconnector from Thailand to Malaysia (bipole transmission line)**

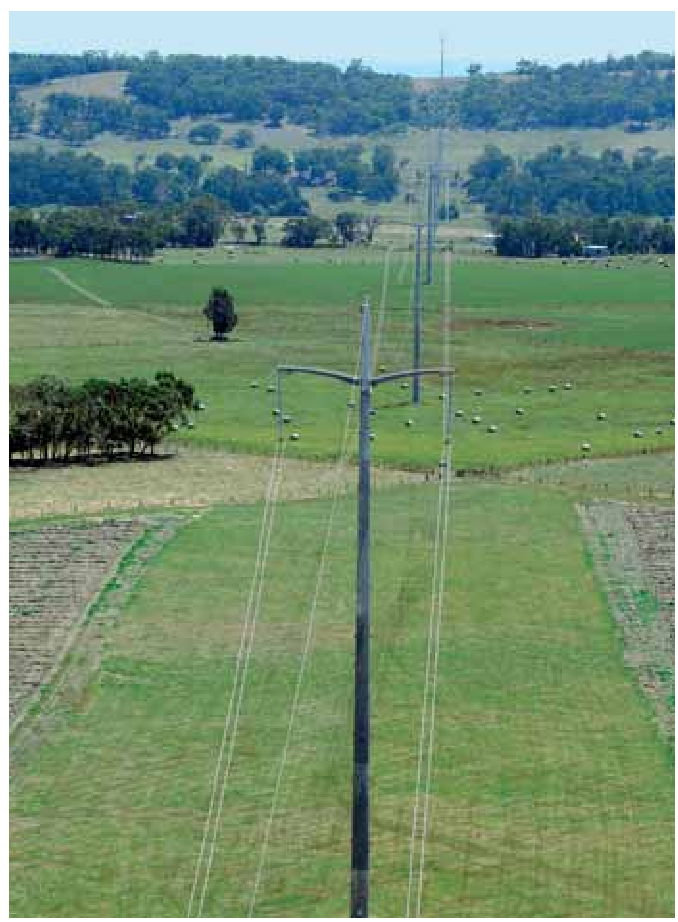


Fig. 2.5-18a: **400 kV HVDC Basslink project in Australia (monopole transmission line)**

Fig. 2.5-18b, c: **400 kV HVDC Basslink project in Australia (monopole transmission line)**

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2

2.6 Grid Access Solutions for Decentralized Power Generation

Grid access solutions are decentralized generating units and remote loads that are custom-engineered. They involve reconciling contrasting parameters, such as high reliability, low investment costs and efficient transmission, in the best possible solution (fig. 2.6-1). Specific attention is paid to intelligently designing the collection systems at the medium-voltage level, which is followed by the designing of the high-voltage transmission system offering the grid connection.

Turnkey approach and project execution
By relying on both AC and DC transmission technologies, Siemens can offer solutions for a broad range of requirements. The technical constraints of a decentralized generating unit or remote loads in connection with AC cables or a DC transmission system are well known and addressed accordingly. Siemens's engineering expertise includes everything from the conceptual and basic design to digital and real-time simulation. Siemens also assumes responsibility for presenting the solution to the grid owner.

Essential for a turnkey project is the responsibility of the contractor for the system and design work in order to provide the most reliable solution and meet the grid code requirements.

System and design studies, engineering
The most important steps in planning and executing grid access solutions are:

1. Defining the most economic wind park or distribution network and grid connection.
2. Defining layout and specify components of the entire grid connection.
3. Load flow studies and short-circuit calculations of the entire system (including the relevant transmission grid).
4. Defining the system earthing concept and performing insulation coordination for the entire grid connection.
5. Proving the static and dynamic performance and defining static and dynamic reactive power compensation.
6. Deriving the resonance behaviors driven by the cables, transformers, reactors and wind turbines.
7. Proving the conformity with the grid code.
8. Creating the basic design of the entire grid connection.
9. Designing the protection, control SCADA and communication systems.
10. Evaluating the overall losses for various scenarios.
11. Evaluating the electromagnetic interferences for the grid connection (if required).
12. Indicating potentials in optimizing availability and reliability.

Engineering, purchasing, delivery, erection and commissioning
Based on the system and design work just described, the project will be executed, for example, based on an "engineering, procurement and construction" (EPC) contract (fig. 2.6-2, fig. 2.6-3).

Fig. 2.6-1: **Embedding decentralized or remote generators such as wind farms require customized solutions for grid access**

The benefits for the project owner are a single:

- Entity
- Responsibility
- Source
- Performance warranty

These benefits are based on:

- High reliability
- Quality of grid code compliance
- Easier cash flow management
- Overall responsibility for professional indemnity

Fig. 2.6-2: **Based on an EPC contract (engineering, procurement, construction) the project will be executed**

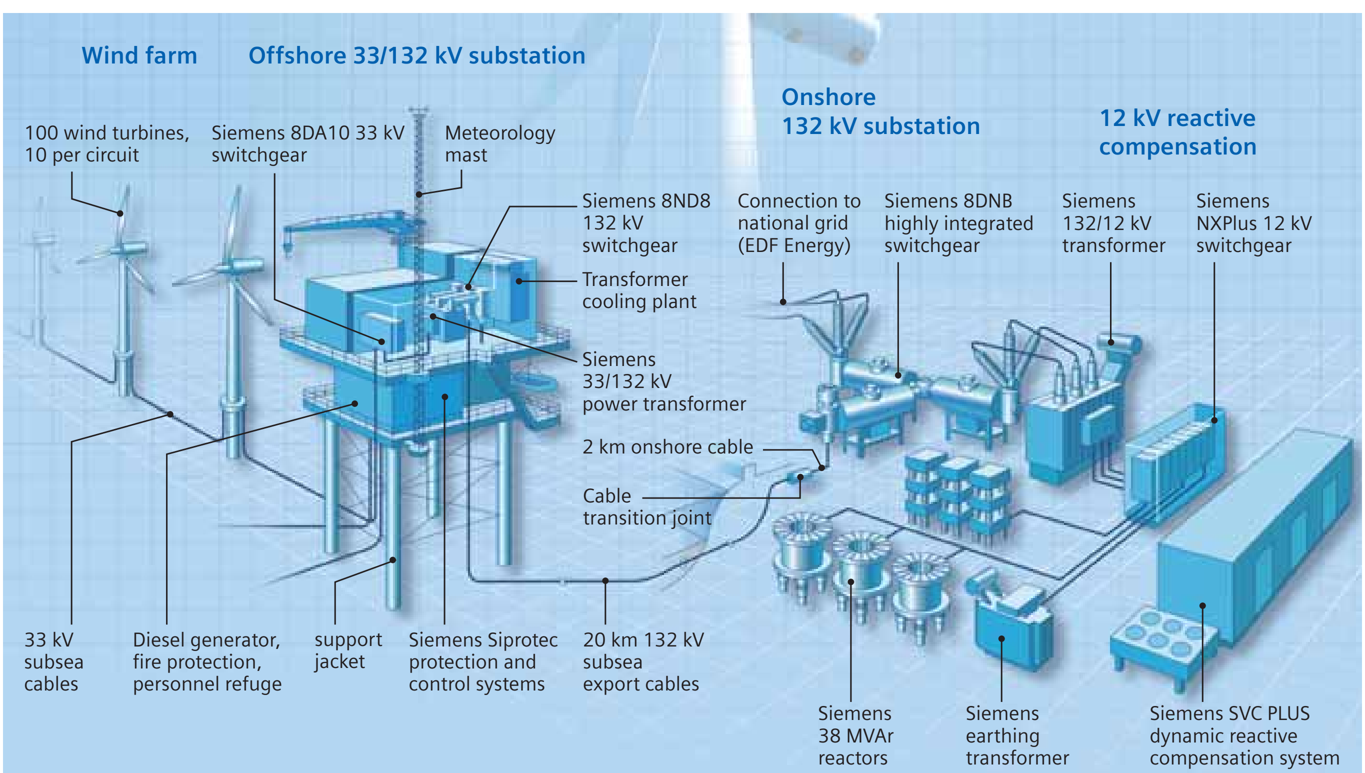

Fig. 2.6-3: **Electrical design of the 300 MW offshore grid connection for the an offshore wind farm**

2

2.7 Solar Power Solutions

Photovoltaic (PV) systems convert sunlight directly into electrical energy without any environmentally harmful emissions, and thus reduce dependence on expensive and ending fossil energy sources. Government stimulation programs and the increase in efficiency are making PV systems more and more attractive for investors as well as power supply companies. Yields can be obtained by feeding solar electricity into the grid.

The three main application areas are:

- Grid-connected photovoltaic systems:
  These photovoltaic systems (from 5 kWp to 50 MWp) are connected to the grid and generate alternating current that is fed into the grid or used directly on the site.
- Stand-alone photovoltaic systems:
  Stand-alone photovoltaic systems equipped with batteries for storing electricity are used to supply power to areas that have no connection to the grid.
- Hybrid systems for back-up supply in regions where the public supply is unreliable.

Components and mode of operation

A grid-connected PV system typically consists of the following components:

- Solar modules
- Cabling
- Inverters and switchgears
- Metering
- Connection to the public grid

Solar cells absorb sunlight and transform it into electrical energy, thereby generating direct current. Several solar cells wired together form a solar module. Solar cells are usually manufactured from either monocrystalline or polycrystalline silicon. The use of thin-layer modules is also becoming increasingly common. The modules are connected in series and combined into arrays. The arrays are connected to the inverter via several connection boxes. Centralized inverter combinations convert the direct current generated by the solar modules into alternating current that than can be fed into the grid. Optimum electrical and structural engineering forms the basis for maximum efficiency and a high degree of reliability.

SINVERTsolar inverter units

The core elements of grid-connected PV systems are the power inverters. With its SINVERTsolar range of inverter units, Siemens offers certified series-manufactured products that comply with all important national and international safety standards. Thanks to their electromagnetic compatibility (EMC) compliant construction, they are even suitable for operation in areas susceptible to electromagnetic interference.

Large subsystems up to 1.6 MVA peak capacity (master/slave combination) can also be implemented with SINVERTsolar inverters. The devices, which are based on IGBT technology, can attain an efficiency of up to 97 %, because they are optimized for extremely low losses. Master/slave operation has the advantage that the inverters can always be operated close to the optimum efficiency range. If, for example, solar irradiation decreases, superfluous inverters can be switched off automatically and the remaining inverters loaded more effectively so that the maximum possible electricity yield can flow into the grid. At night the inverters are switched off, to reduce their time of operation and increase the lifetime.

Requirements for PV systems for buildings

When planning a photovoltaic system, numerous structural engineering requirements must be taken into account, because often no allowance was made for installing photovoltaic systems when a building was first constructed. For many years, Siemens has been developing highly flexible structural and electrical engineering solutions for specific applications for the production of solar electricity. The following factors directly influence efficiency and hence cost-effectiveness when planning and installing a PV system:

- Location of the system (maximum solar irradiation)
- Orientation of the system (due south is optimal)
- Quality of the products (optimally matched)
- Engineering excellence (electrical/mechanical combination)

The following building integrated systems are available:

- Facade-mounted system (fig. 2.7-1a)
- Roof-mounted system (fig. 2.7-1c)
- Flat-roof installation
- Special structural engineering solutions (fig. 2.7-1b)

Planning guidelines

When planning a grid-connected PV system (fig. 2.7-2), the following points must be clarified in advance:

- Choice of the ideal application and orientation (solar irradiation)
- Choice of the ideal system:
  – Deciding on the total capacity of the system, depending on the investment volume and the area available for the installation
  – Drawing up a financing plan
  – Statical calculation of the load-bearing capacity of the roof or facade
  – Electrical and mechanical engineering
  – Determining whether feeding into the grid is possible and making an application to the local distribution network operator

Electricity from roof and facade-mounted systems is usually fed into the low-voltage or medium-voltage system of the local distribution network operator as a 3-phase current. The type of current that is fed into the grid should be clarified with the local distribution network operator in each individual case.

Planning process

Siemens supports the planning process with advice from experts about economical and technical aspects and basic and detailed engineering. Siemens can also help to devise the financing plan. Projects, located in the Netherlands, can offer the following

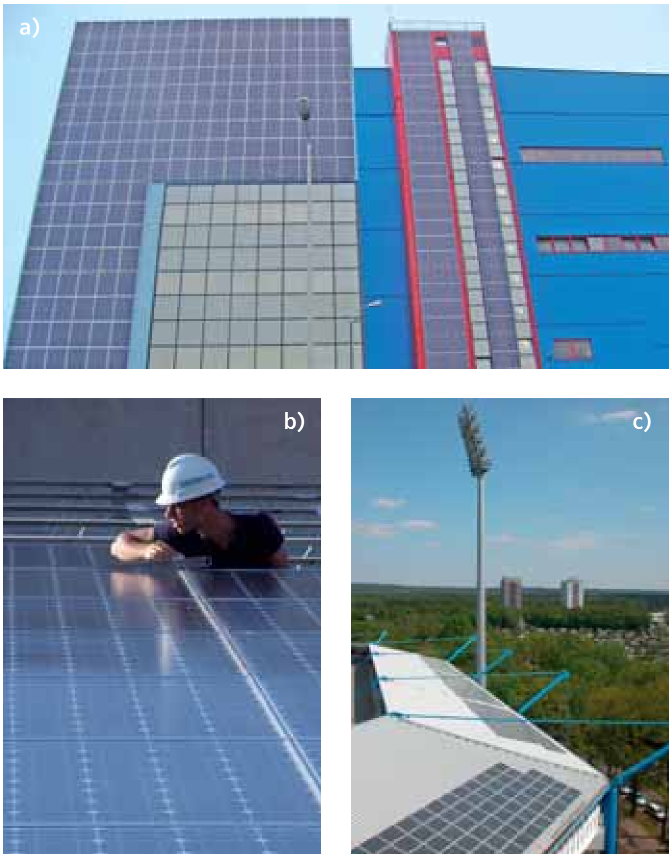

Fig. 2.7-1: **Example of photovoltaic system:**
a) Facade-integrated PV system in Italy
b) Installation of a earth-based PV system of 1 MWp in Italy
c) Example of a 30 m high stadium roof system

system solutions, based on many years of experience in the installation of grid-connected PV systems:

- (Lightweight construction) flat-roof photovoltaic system
- Building-integrated photovoltaic system (BIPV)
- Facade-mounted system (fig. 2.7-1a)
- Special structural engineering solutions (fig. 2.7-1b)
- Roof-mounted system (fig. 2.7-1c)
- Solar roofing SolarPark™

Turnkey solutions

Siemens is a one-stop shop for efficient and reliable system solutions. Its service comprises the turnkey installation of grid-connected PV systems covering everything from planning, procurement and technical realization to site acceptance testing, monitoring and service. The Center of Competence works in close cooperation with local Siemens representatives. Most projects are at this moment implemented in Germany, Italy, Spain, Belgium and France.

For further information, please contact:
www.siemens.com/solar

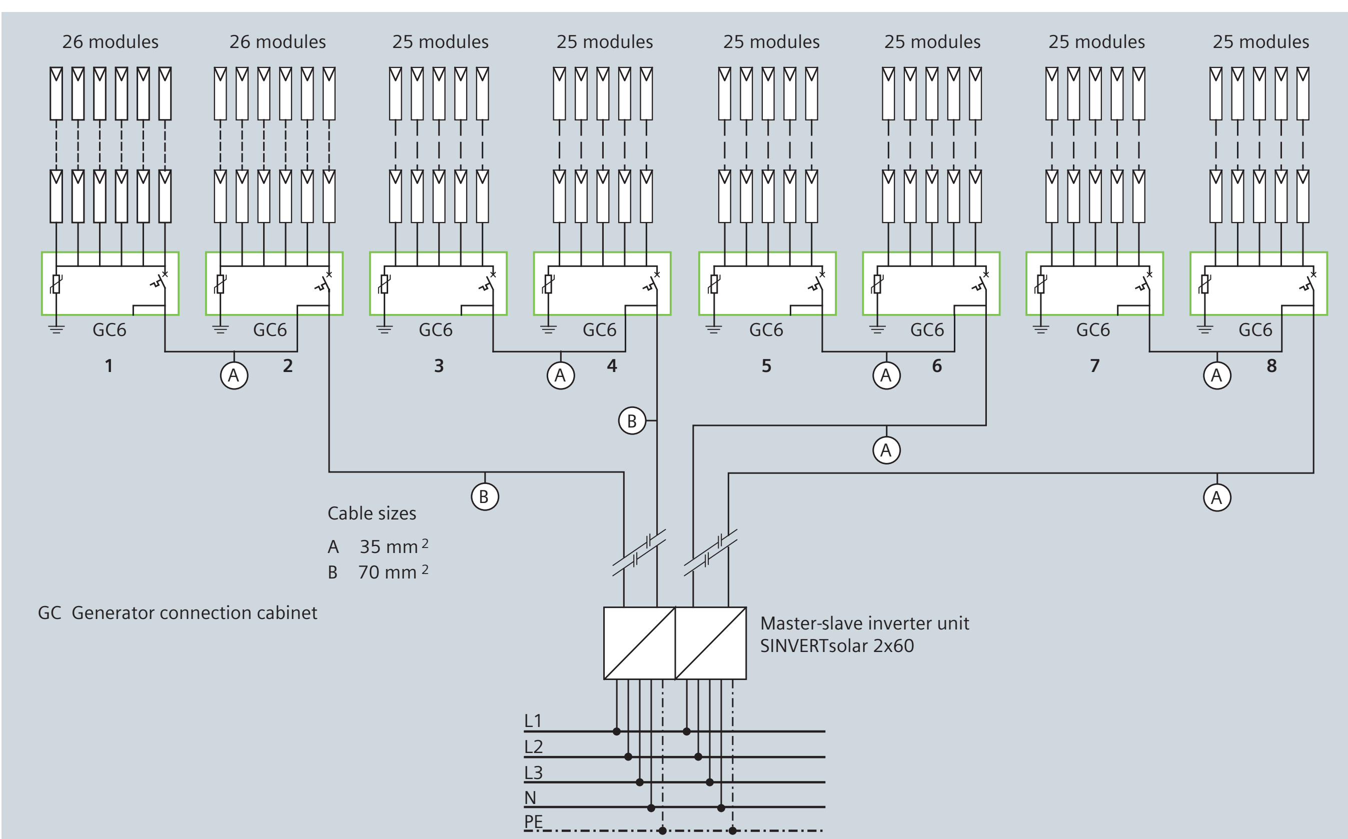

Fig. 2.7- 2: **Schematic diagram of the layout of a grid-linked PV system**

3

Switchgear and Substations

3

3 Switchgear and Substations

3.1 High-Voltage Substations

3.1.1 Turnkey Substations

3

High-voltage substations are normally combined with transformers and other equipment to complete transformer substations in order to:
- Step up from a generator-voltage level to a high-voltage system (MV/HV)
- Transform voltage levels within the high-voltage grid system (HV/HV)
- Step down to a medium-voltage level of a distribution system (HV/MV).

The Siemens Energy Power Transmission division plans and constructs both individual high-voltage substation installations and complete transformer substations, comprising high-voltage switchgear, medium-voltage switchgear, major components such as high-voltage equipment and transformers, as well as all ancillary equipment such as auxiliaries, control systems, protective equipment, and so on, on a turnkey basis or even as general contractor.

The installations supplied worldwide range from basic substations with a single busbar to regional transformer substations with multiple busbars, or a circuit-breaker-and-a-half arrangement for rated voltages up to 800 kV, rated currents up to 8,000 A and short-circuit currents up to 100 kA. The services offered range from system planning to commissioning and after-sales service, including training of customer personnel.

The process of handling such a turnkey installation starts with preparation of a quotation, and proceeds through clarification of the order, design, manufacture, supply and cost-accounting until the project is finally billed. Processing such an order hinges on methodical data processing that in turn contributes to systematic project handling. All these high-voltage installations have in common their high standard of engineering which covers all system aspects such as power systems, steel structures, civil engineering, fire precautions, environmental protection and control systems (fig. 3.1-1).

Every aspect of technology and each work stage is handled by experienced engineers. With the aid of high-performance computer programs, e.g., the finite element method (FEM), installations can be reliably designed even for extreme stresses, such as those encountered in earthquake zones.

All planning documentation is produced on modern CAD/CAE systems; data exchange with other CAD systems is possible via interfaces. By virtue of their active involvement in national and international associations and standardization bodies, our engineers are always fully informed of the state of the art, even before a new standard or specification is published.

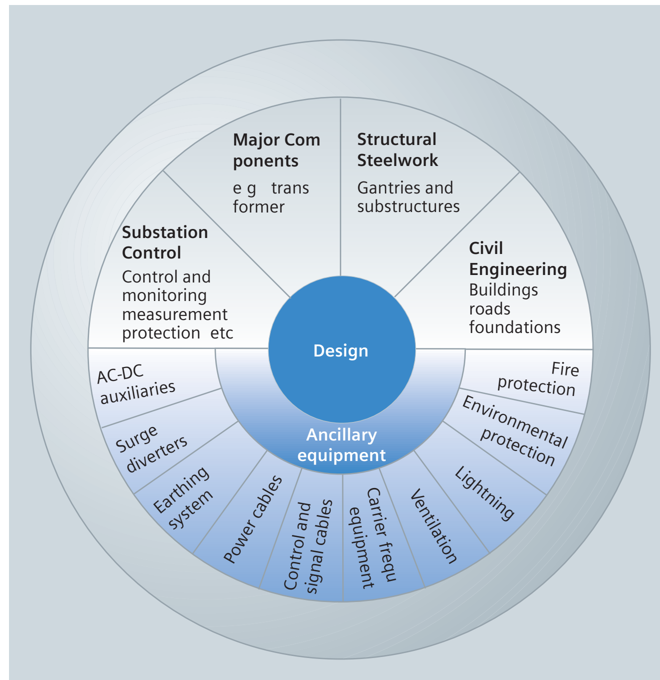

Fig. 3.1-1: **Engineering of high-voltage switchgear**

Quality/environmental management

Our own high-performance, internationally accredited test laboratories and a certified QM system testify to the quality of our products and services. Milestones of the certification were:
- 1983: Introduction of a QM system based on the Canadian standard CSA Z 299 Level 1
- 1989: Certification of the QM system of SWH (Berlin) in accordance with DIN EN ISO 9001 by the German QM certification body Deutsche Gesellschaft zur Zertifizierung von Managementsystemen (DQS)
- 1992: First re-audit and extension of the certification to the Erlangen location
- 1994: Certification of the EM system, following the QM system, as pilot project by DQS
- 1996: Certification of the EM system in accordance with DIN EN ISO 14001 by DQS
- 1997: One QEM certificate for both locations

Further approvals: Accreditation of the PEHLA test bays.

Know-how, experience and worldwide presence

A worldwide network of liaisons and sales offices, along with the specialist departments in Germany, support and advise system operators in all matters of high-voltage substations technology.

3.1.2 High-Voltage Switchgear – Overview

High-voltage substations form an important link in the power transmission chain between generation source and consumer. Two basic designs are possible:

Air-insulated substations (AIS)
AIS are favorably priced high-voltage substations for rated voltages up to 800 kV, which are popular wherever space restrictions and environmental circumstances are not severe. The individual electrical and mechanical components of an AIS installation are assembled on site. Air-insulated outdoor substations of open design are not completely safe to touch, and are directly exposed to the effects of the climate and the environment (fig. 3.1-2).

Gas-insulated indoor or outdoor switchgear (GIS)
The compact design and small dimensions of GIS make it possible to install substations of up to 550 kV right in the middle of load centers of urban or industrial areas. Each switchgear bay is factory-assembled and includes the full complement of disconnecting switches, earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation. The earthed metal enclosures of GIS assure not only insensitivity to contamination but also safety from electric shock (fig. 3.1-3).

Gas-insulated transmission lines (GIL) are special applications of gas-insulated equipment (section 3.1.6). They are used wherever high-voltage overhead-lines are not suitable. GIL have a high power-transmission capability, even when laid underground, low resistive and capacitive losses and low electromagnetic fields.

Mixed technology (compact/hybrid solutions)
Beside the two basic (conventional) designs, there are also compact solutions available that can be realized with air-insulated and/or gas-insulated components.

Fig. 3.1-2: **Air-insulated outdoor switchgear**

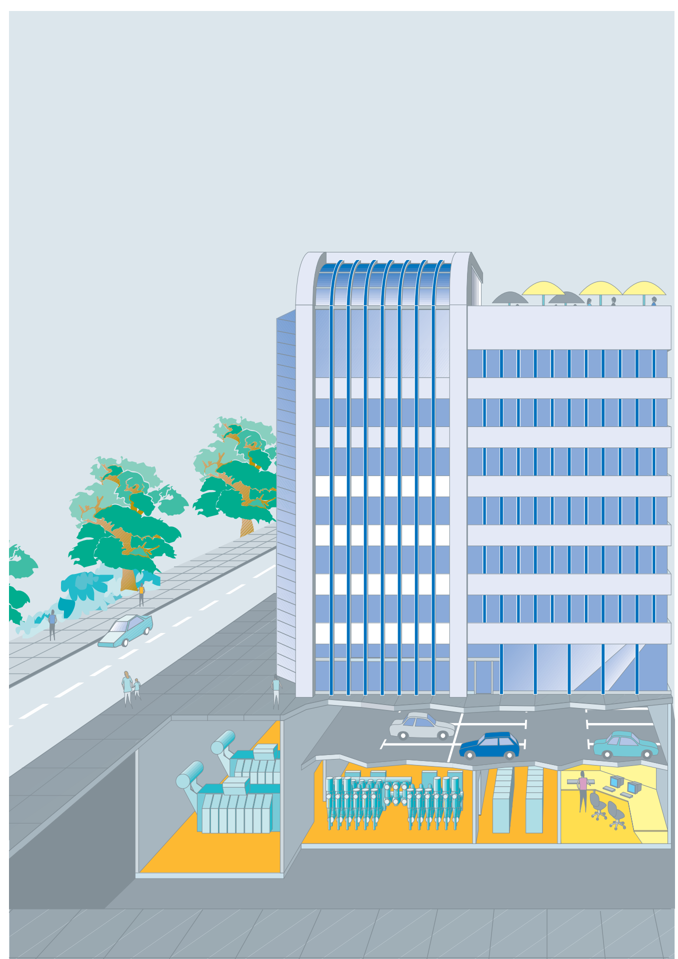

Fig. 3.1-3: **GIS substations in metropolitan areas**

3

3.1.3 Circuit Configuration

High-voltage substations are points in the power network where power can be pooled from generating sources, distributed and transformed and delivered to the load points. Substations in a grid are interconnected with each other so that the power systems become a meshed network. This increases reliability of the network by providing alternate paths for flow of power to take care of any contingency, so that power delivery to the loads is maintained and the generators do not face any outage. The high-voltage substation is a critical component in the power system, and the reliability of the power system depends upon the substation. Therefore, the circuit configuration of the high-voltage substation has to be selected carefully.

Busbars are the part of the substation where all the power is concentrated from the incoming feeders and distributed to the outgoing feeders. That means that the reliability of any high-voltage substation depends on the reliability of the busbars present in the power system. An outage of any busbar can have dramatic effects on the power system. An outage of a busbar leads to the outage of the transmission lines connected to it. As a result, the power flow shifts to the surviving healthy lines that are now carrying more power than they are capable of. This leads to tripping of these lines, and the cascading effect goes on until there is a blackout or similar situation. The importance of busbar reliability should be kept in mind when taking a look at the different busbar systems that are prevalent.

Single-busbar scheme (1 BB)
The applications of this simple scheme are distribution and transformer substations, and feeding industrial areas (fig. 3.1-4). Because it has only one busbar and the minimum amount of equipment, this scheme is a low-cost solution that provides only limited availability. In the event of a busbar failure and during maintenance periods, there will be an outage of the complete substation. To increase the reliability, a second busbar has to be added.

Double-busbar scheme (2 BB)
The more complex scheme of a double-busbar system gives much more flexibility and reliability during operation of the substation (fig. 3.1-5). For this reason, the system is used in network nodes of the power system for distribution and transformer substations. It is possible to control the power flow by using the busbars independently, and by switching a feeder from one busbar to the other. Because the busbar disconnectors are not able to switch the rated current of the feeder, there will be a short disruption in power flow.

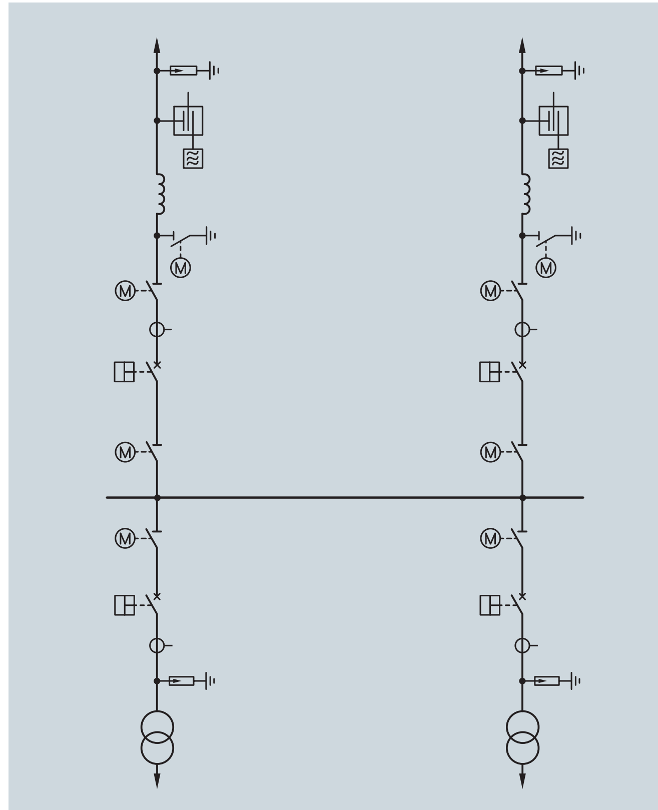

Fig. 3.1-4: **Special single busbar, H-scheme (1 BB)**

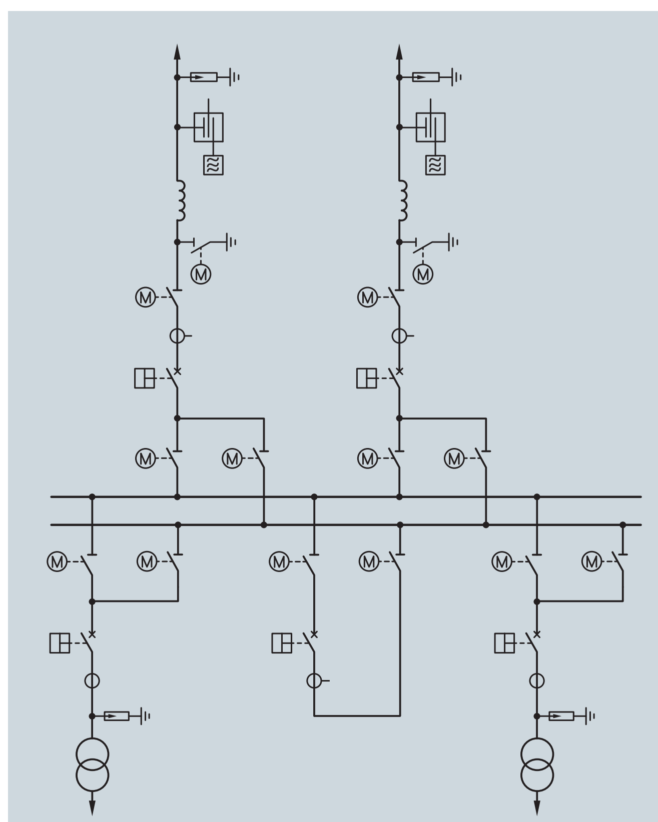

Fig. 3.1-5: **Double-busbar scheme (2 BB)**

Double circuit-breaker scheme (2 CB)
To have a load change without disruption, a second circuit-breaker per feeder has to be used. This is the most expensive way to solve this problem. In very important feeders, the 2 CB solution will be used (fig. 3.1-8).

One circuit-breaker-an-a-half scheme (1.5 CB)
The one circuit-breaker-an-a-half scheme is a compromise between the 2 BB and the 2 CB scheme. This scheme improves the reliability and flexibility because, even in case of loss of a complete busbar, there is no disruption in the power supply of the feeders (fig. 3.1-9).

Fig. 3.1-6: **HIS 145 kV, Austria**

Fig. 3.1-7: **HIS 420 kV, Spain**

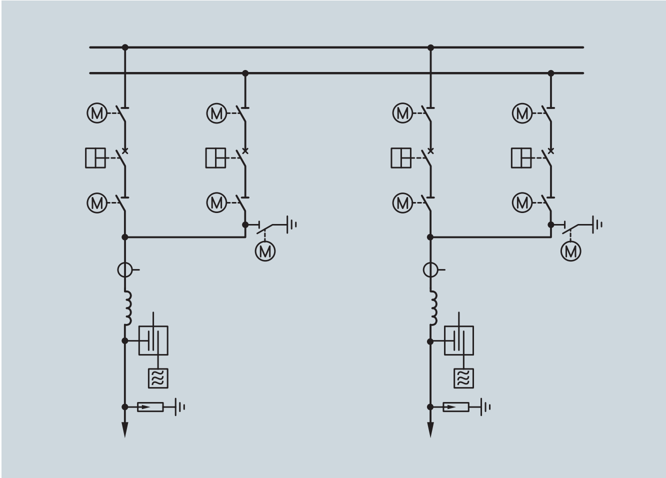

Fig. 3.1-8: **Double circuit-breaker scheme (2 CB)**

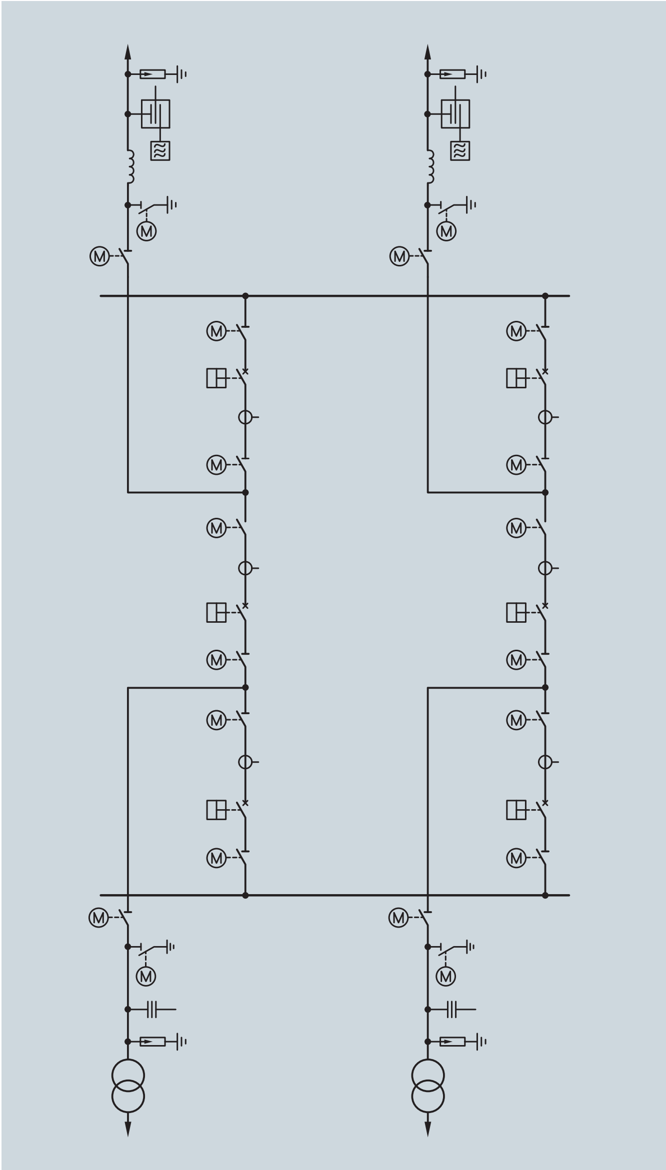

Fig. 3.1-9: **One circuit-breaker-an-a-half scheme (1.5 CB)**

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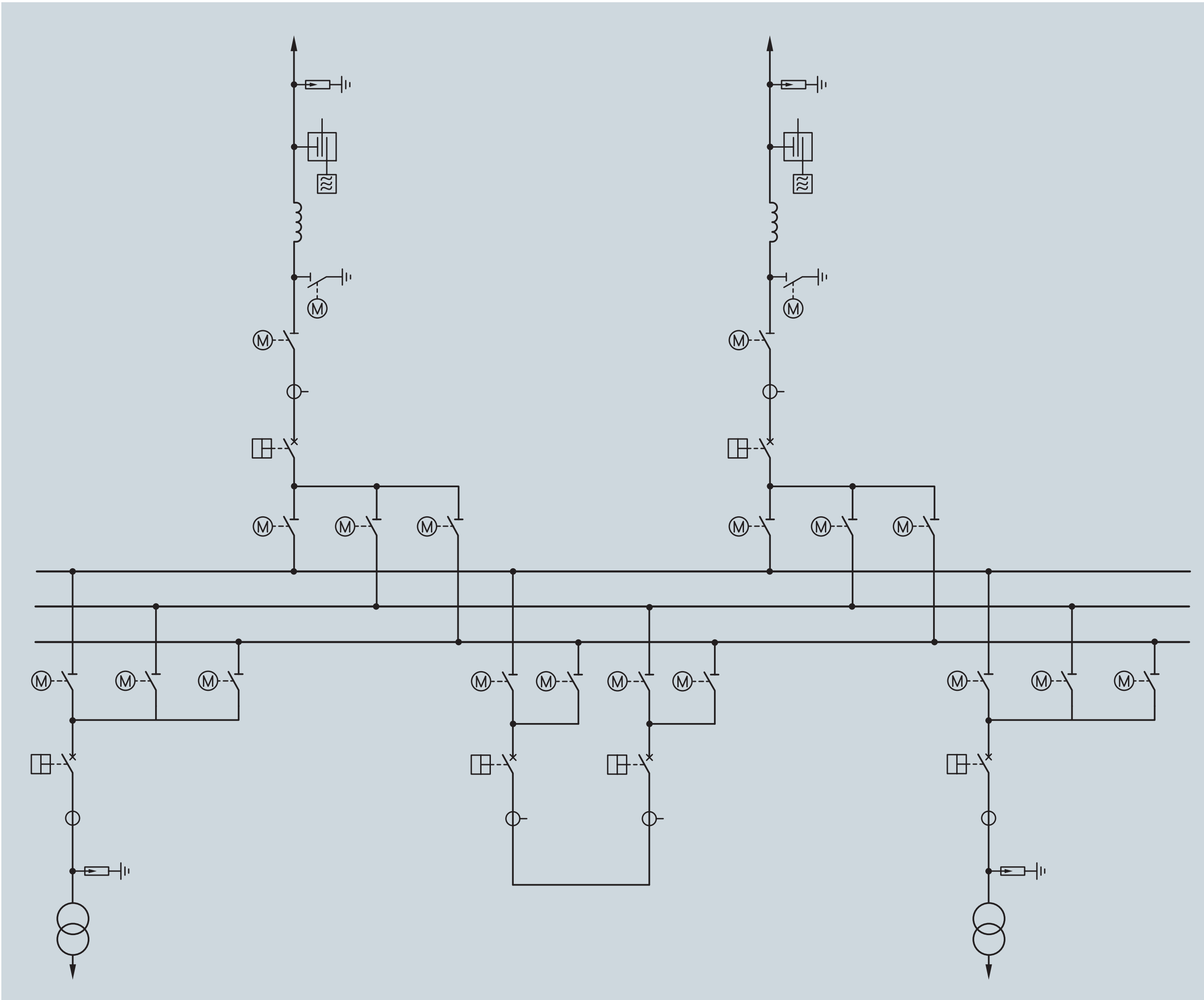

Fig. 3.1-10: **3-phase busbar scheme (3 BB)**

3-phase busbar scheme (3 BB)
For important grid stations at transmission network nodes of higher voltage levels, the 3-phase busbar scheme is used. It is a common scheme in Germany, utilized at the 380 kV level (fig. 3.1-10).

3.1.4 Air-Insulated Substations

In outdoor installations of open design all live parts are insulated by air and are not covered. Therefore, air-insulated substations (AIS) are always set up in a fenced area. Only authorized personnel have access to this operational area. Relevant national and international specifications that apply to outdoor substations and equipment have to be considered. The IEC 61936 standard is valid for European countries. Insulation coordination, including minimum phase-to-phase and phase-to-earth clearances, is effected in accordance with IEC 60071.

Outdoor switchgear are directly exposed to the effects of the environmental conditions. Therefore they have to be designed both for electrical and environmental specifications. There is currently no common international standard covering the setup of air-insulated outdoor substations of open design. Siemens designs AIS in accordance with IEC standards, in addition to national standards or customer specifications. The standard IEC 61936-1, "Erection of power installations with rated voltages above 1 kV," demonstrates the typical protective measures and stresses that have to be taken into consideration for air-insulated switchyards.

Protective measures

The protective measures can be categorized as personal protection and functional protection of substations (S/S).

- Personal protection
  - Protective measures against direct contact, i. e., through appropriate covering, obstruction, through sufficient clearance, appropriately positioned protective devices, and minimum height
  - Protective measures against indirect touching by means of relevant earthing measures in accordance with IEC 61936/ DIN VDE 0101 or other required standards
  - Protective measures during work on equipment, i.e., installation must be planned so that the specifications of DIN EN 50110 (VDE 0105) (e.g., five safety rules) are observed
- Functional protection
  - Protective measures during operation, e.g., use of switchgear interlocking equipment.
  - Protective measures against voltage surges and lightning strikes.
  - Protective measures against fire, water and, if applicable, noise.
- Stresses
  - Electrical stresses, e.g., rated current, short-circuit current, adequate creepage distances and clearances.
  - Mechanical stresses (normal stressing), e.g., weight, static and dynamic loads, ice, wind.
  - Mechanical stresses (exceptional stresses), e.g., weight and constant loads in simultaneous combination with maximum switching forces or short-circuit forces, etc.
  - Special stresses, e.g., caused by installation altitudes of more than 1,000 m above sea level or by earthquakes.

Variables affecting switchgear installation

The switchyard design is significantly influenced by:

- Minimum clearances (depending on rated voltages) between various active parts and between active parts and earth
- Rated and short-circuit currents
- Clarity for operating staff
- Availability during maintenance work; redundancy
- Availability of land and topography
- Type and arrangement of the busbar disconnectors

The design of a substation determines its accessibility, availability and clarity. It must therefore be coordinated in close cooperation with the system operator. The following basic principles apply: accessibility and availability increase with the number of busbars. At the same time, however, clarity decreases. Installations involving single busbars require minimum investment, but they offer only limited flexibility for operation management and maintenance. Designs involving one-circuit-breaker-and-a-half and two-circuit-breaker arrangements ensure a high redundancy, but they also entail the highest costs.

Systems with auxiliary or bypass busbars have proved to be economical. The circuit-breaker of the coupling feeder for the auxiliary bus allows uninterrupted replacement of each feeder circuit-breaker. For busbars and feeder lines, mostly standard aluminum conductors are used. Bundle conductors are required where currents are high. Because of the additional short-circuit forces between the subconductors (the pinch effect), however, bundle conductors cause higher mechanical stresses at the terminal points. When conductors (particularly standard bundle conductors) are used, higher short-circuit currents cause a rise not only in the aforementioned pinch effect, also in further force maxima in the event of swinging and dropping of the conductor bundle (cable pull). This in turn results in higher mechanical stresses on the switchyard components. These effects can be calculated in an FEM (finite element method) simulation (fig. 3.1-11).

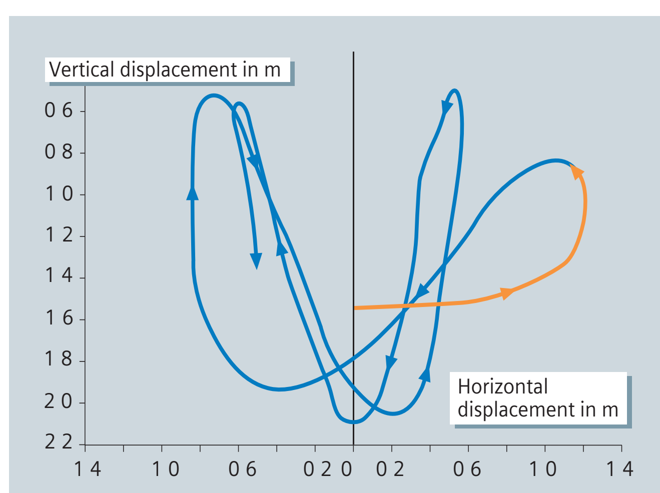

Fig. 3.1-11: **FEM calculation of deflection of wire conductors in the event of short circuit**

Computer-aided engineering/design (CAE/CAD)

A variety of items influence the design of air-insulated substations. In the daily engineering work, database-supported CAE tools are used for the primary and secondary engineering of the substations. The database speeds up all the engineering processes by using predefined solutions and improves the quality (fig. 3.1-12).

Design of air-insulated substations

When rated and short-circuit currents are high, aluminum tubes are increasingly used to replace wire conductors for busbars and feeder lines. They can handle rated currents up to 8,000 A and short-circuit currents up to 80 kA without difficulty. Other influences on the switchyard design are the availability of land, the lie of the land, the accessibility and location of incoming and outgoing overhead-lines, and the number of transformers and voltage levels. A one-line or two-line arrangement, and possibly a U-arrangement, may be the proper solution. Each outdoor switchgear installation, especially for step-up substations in connection with power stations and large transformer substations in the extra-high-voltage transmission system, is therefore unique, depending on the local conditions. HV/MV transformer substations of the distribution system, with repeatedly used equipment and a scheme of one incoming and one outgoing line as well as two transformers together with medium-voltage switchgear and auxiliary equipment, are usually subject to a standardized design.

Preferred designs

Conceivable designs include certain preferred versions that are often dependent on the type and arrangement of the busbar disconnectors.

H-arrangement

The H-arrangement is preferred for use in applications for feeding industrial consumers. Two overhead-lines are connected with two transformers and interlinked by a double-bus sectionalizer. Thus, each feeder of the switchyard can be maintained without disturbance of the other feeders (fig. 3.1-13, fig. 3.1-14).

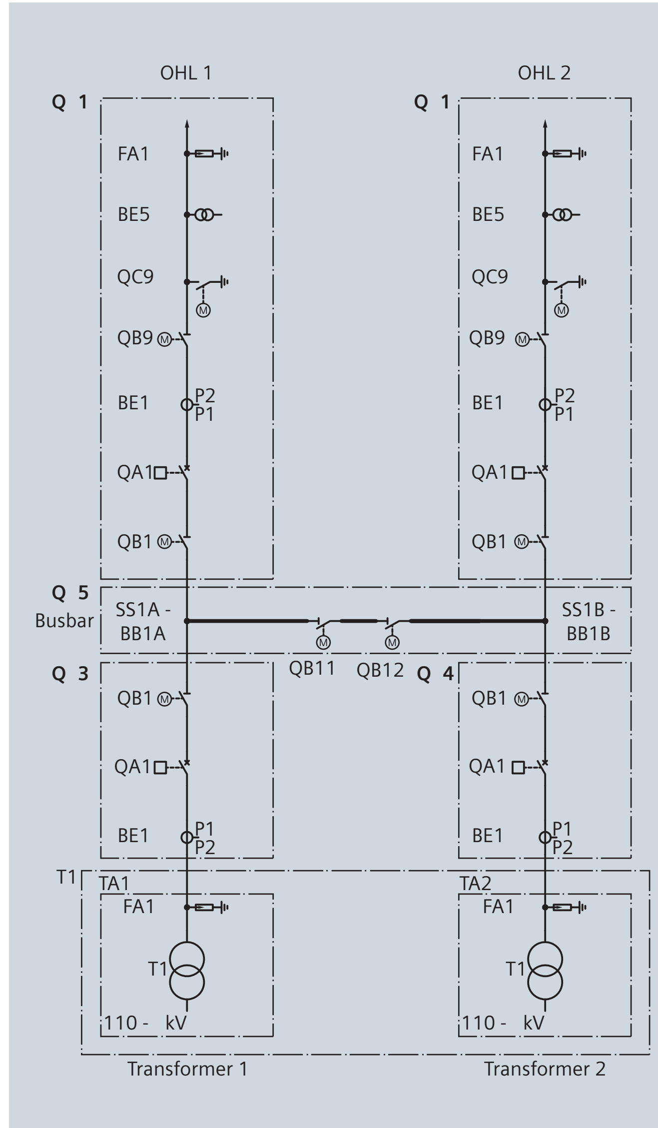

Fig. 3.1-13: **Single-line diagram, H-scheme**

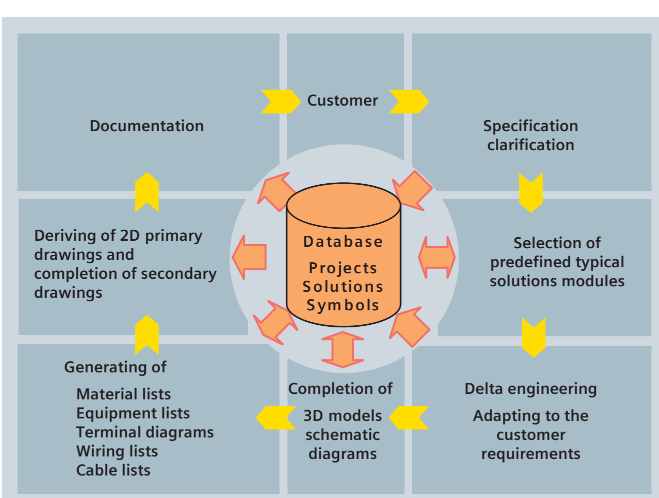

Fig. 3.1-12: **Database supported engineering**

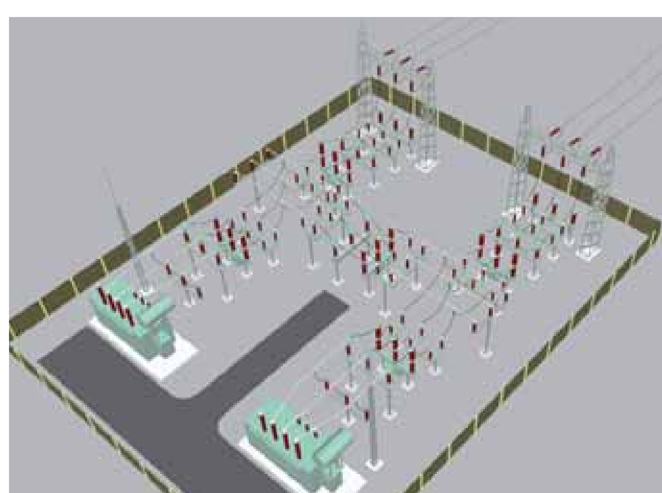

Fig. 3.1-14: **110 kV H-arrangement, conventional AIS**

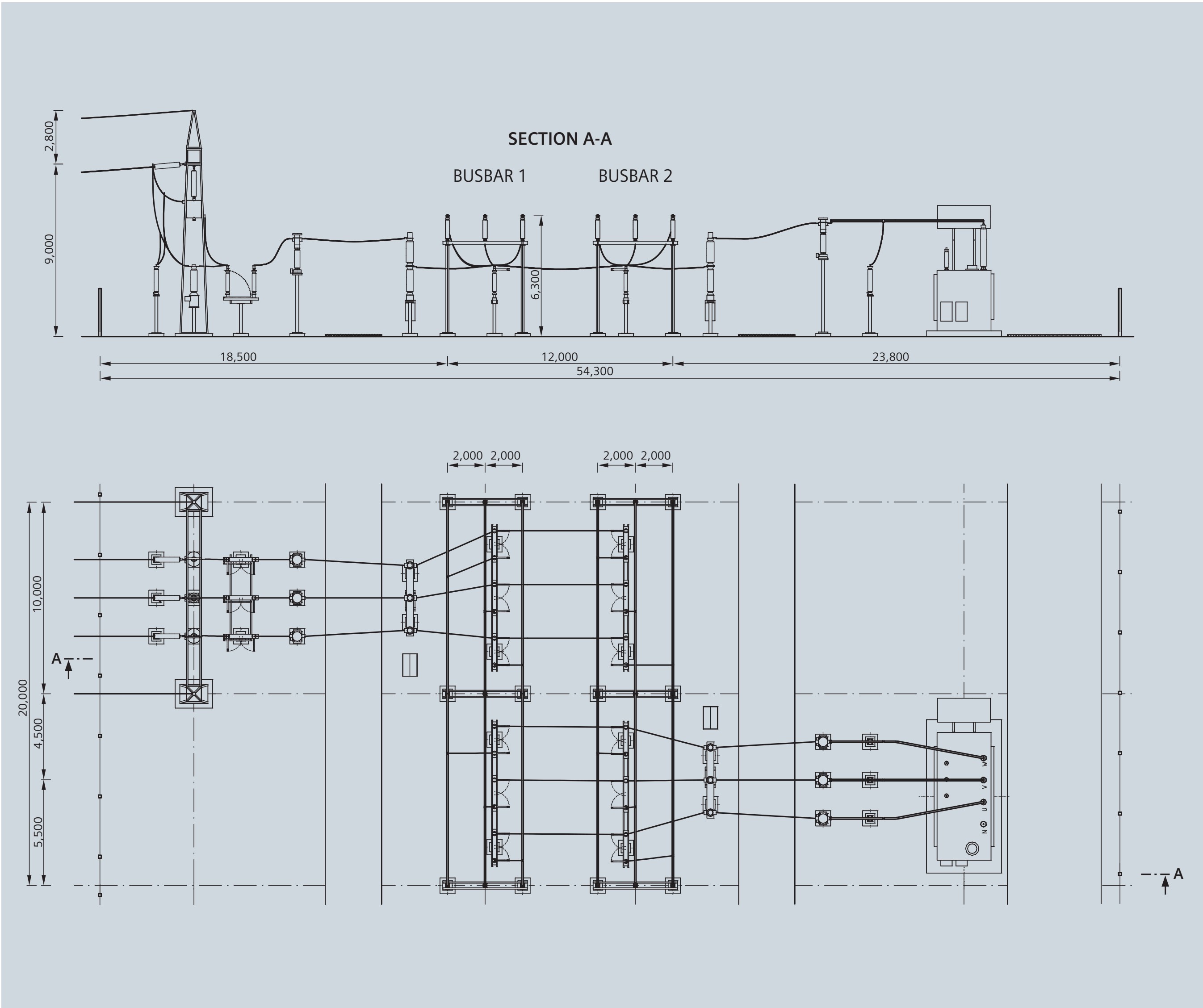

Fig. 3.1-15: **In-line arrangement, 110 kV**

In-line longitudinal arrangement (Kiellinie®), with center breaker disconnectors, preferably 110 to 220 kV

The busbar disconnectors are lined up one behind the other and parallel to the longitudinal axis of the busbar. It is preferable to have either wire-type or tubular busbars. Where tubular busbars are used, gantries are required for the outgoing overhead-lines only. The system design requires only two conductor levels and is therefore clear. The bay width is quite large (in-line arrangement of disconnectors), but the bay length is small (fig. 3.1-15, fig. 3.1-16).

Fig. 3.1-16: **Busbar disconnectors "in line", 110 kV, Germany**

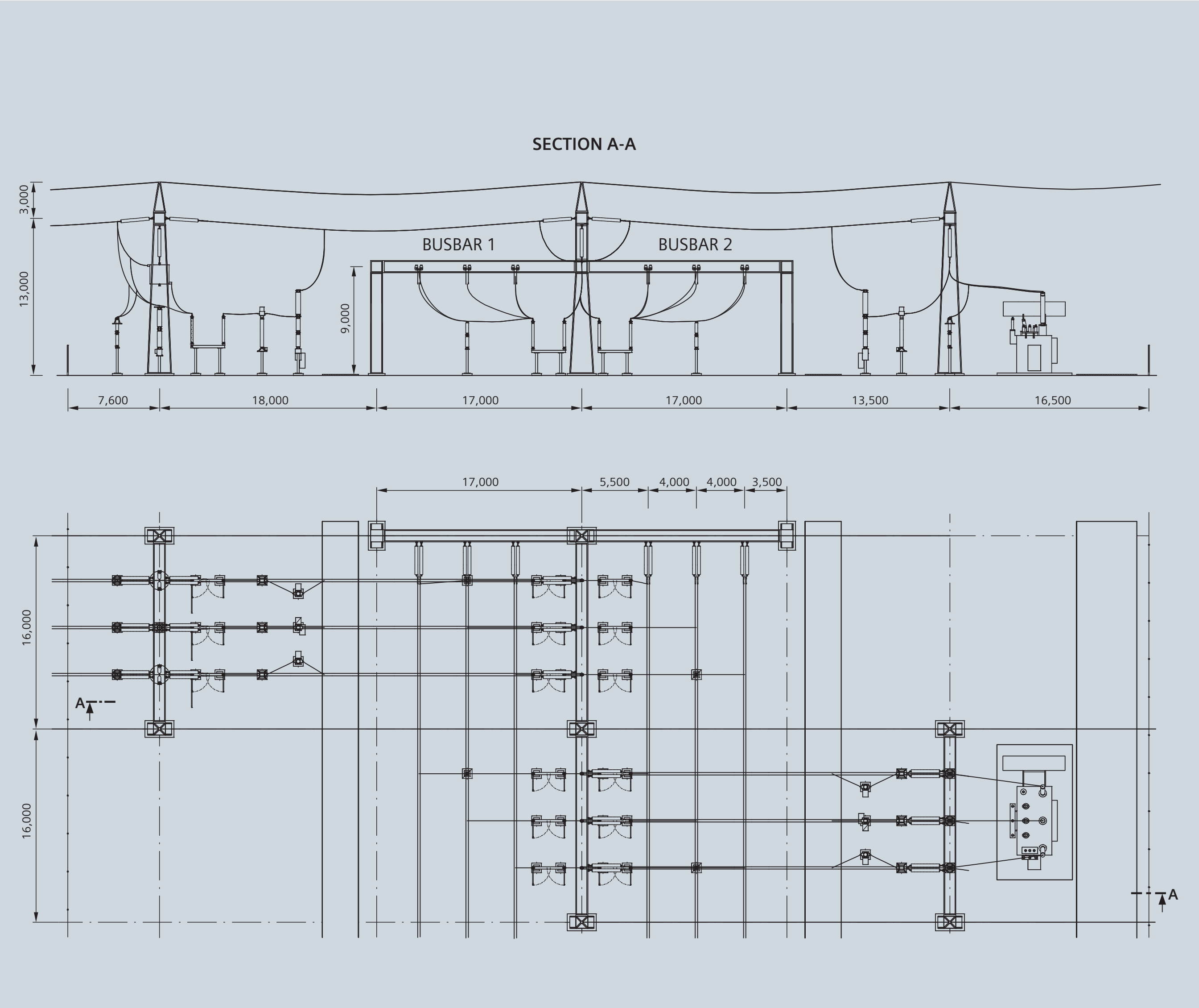

Fig. 3.1-17: **Central/center tower arrangement, 220 kV**

Central/center tower layout with center break disconnectors, normally only for 245 kV
The busbar disconnectors are arranged side by side and parallel to the longitudinal axis of the feeder. Wire-type busbars located at the top are commonly used; tubular busbars are also possible. This arrangement enables the conductors to be easily jumpered over the circuit-breakers, and the bay width to be made smaller than that of in-line designs. With three conductor levels, the system is relatively clear, but the cost of the gantries is high (fig. 3.1-17, fig. 3.1-18).

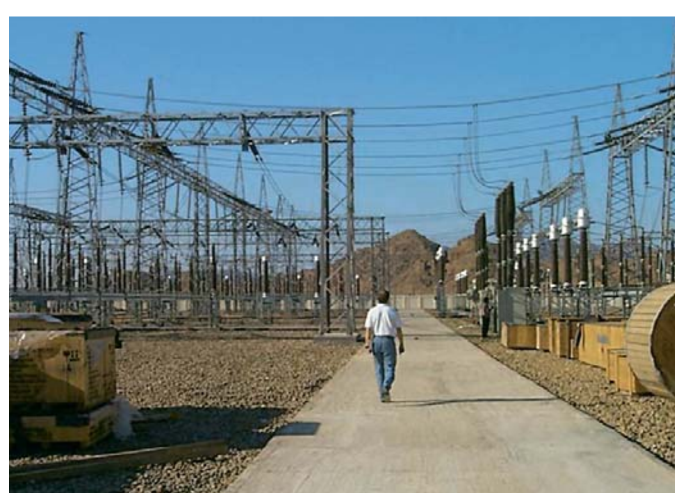

Fig. 3.1-18: **Central/center tower arrangement, 220 kV, Egypt**

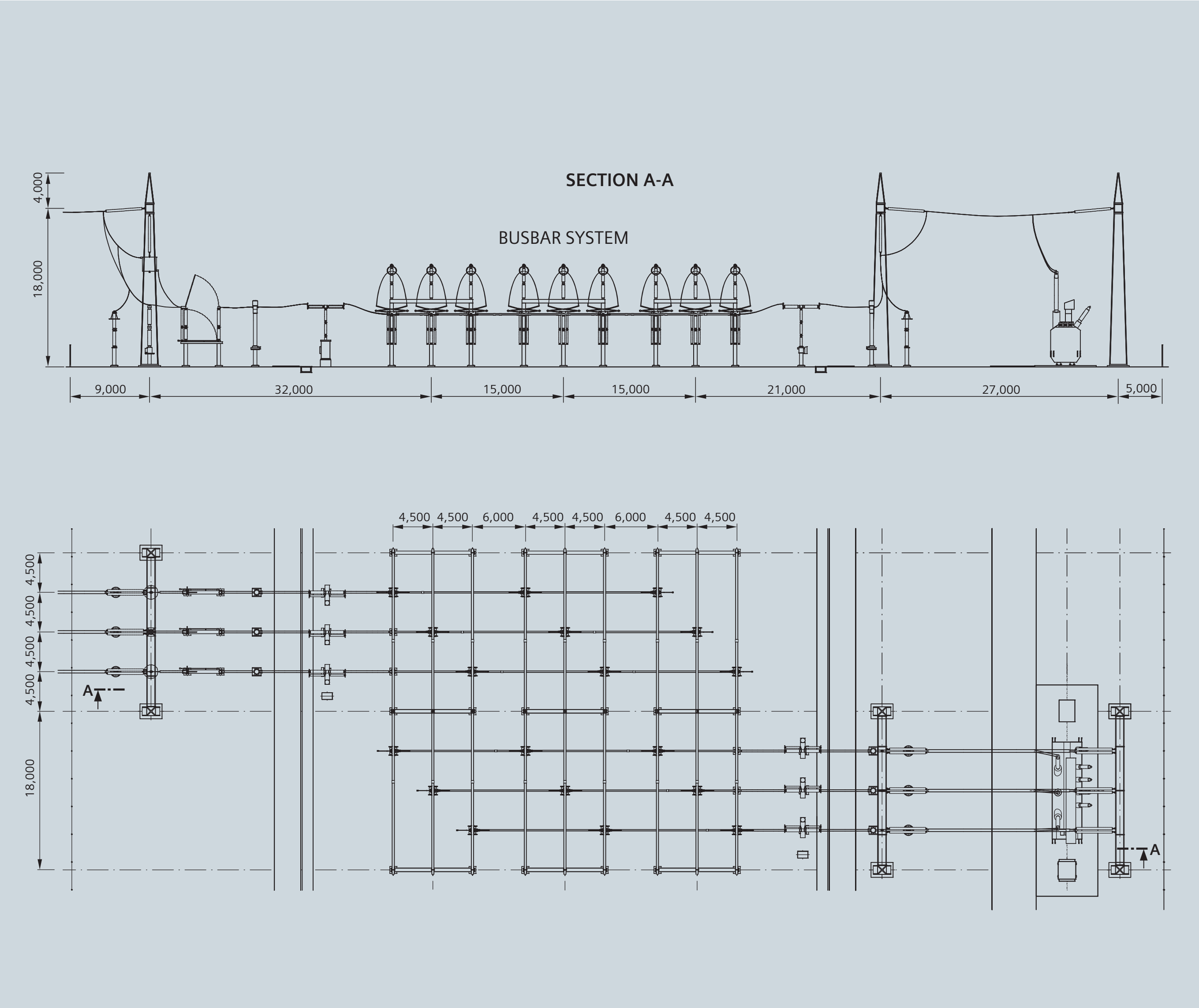

Fig. 3.1-19: **Diagonal arrangement, 380 kV**

Diagonal layout with pantograph disconnectors, preferably 110 to 420 kV

The pantograph disconnectors are placed diagonally to the axis of the busbars and feeder. This results in a very clear and most space-saving arrangement. Wire and tubular conductors are customary. The busbars can be located above or below the feeder conductors (fig. 3.1-19, fig. 3.1-20).

Fig. 3.1-20: **Busbar disconnectors in diagonal arrangement, 380 kV, Germany**

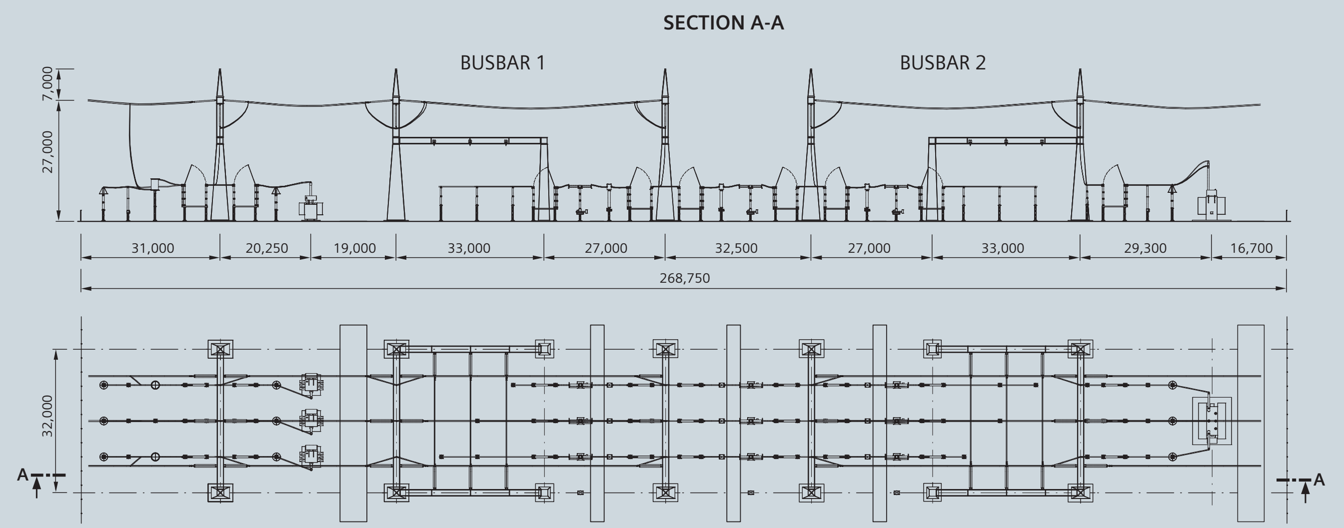

Fig. 3.1-21: **One-circuit-breaker-and-a half arrangement, 500 kV**

One-circuit-breaker-and-a-half layout,
preferably up to 220 to 800 kV

The one-circuit-breaker-and-a-half arrangement ensures high supply reliability; however, the expenditure for equipment is high as well. The busbar disconnectors are of the pantograph, rotary or vertical-break type. Vertical-break disconnectors are preferred for the feeders. The busbars located at the top can be either the wire or tubular type. Two arrangements are customary:

- Internal busbar, feeders in H-arrangement with two conductor levels
- External busbar, feeders in-line with three conductor levels (fig. 3.1-21, fig. 3.1-22, fig. 3.1-23, fig. 3.1-24)

Fig. 3.1-22: **One-circuit-breaker-and-a half arrangement, 500 kV, Pakistan**

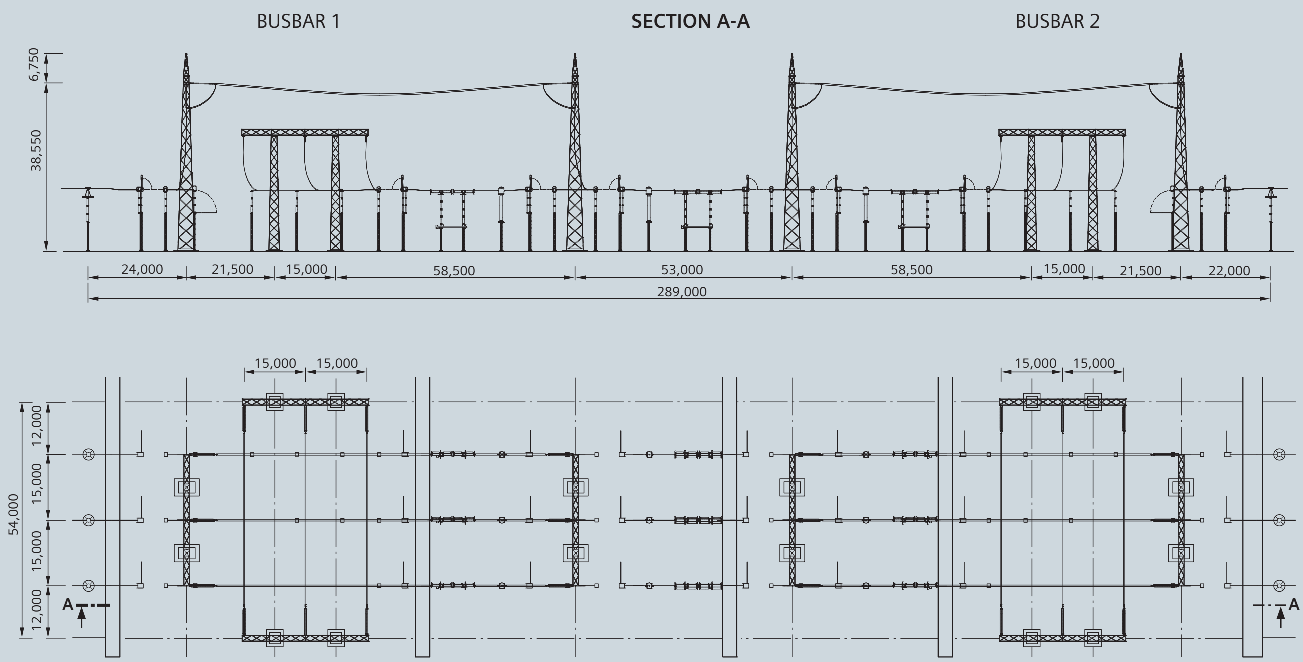

Fig. 3.1-23: **One-circuit-breaker-and-a half arrangement, 800 kV**

Fig. 3.1-24: **One-circuit-breaker-and-a half arrangement, 800 kV, India**

3.1.5 Mixed Technology (Compact/Hybrid Solutions)

Wherever there is a lack of space, system operators have to rely on space-saving outdoor switchgear, especially in regions where smaller-scale transformer substations prevail and in industrial plants. For rated voltages from 72.5 to 170 kV, Siemens Energy offers two different conventional switchgear versions for a reliable and cost-effective power supply:

- SIMOBREAKER, outdoor switchyard featuring a side-break disconnector
- SIMOVER, outdoor switchyard featuring a pivoting circuit-breaker
- HIS, highly-integrated switchgear
- DTC, Dead-Tank Compact

SIMOBREAKER – Substation with rotary disconnector

The design principle of SIMOBREAKER provides for the side-break disconnector blade to be located on the rotating post insulator, which establishes the connection between the circuit-breaker and the transformer. Because the circuit-breaker, the disconnector, the earthing switch and the instrument transformer are integrated into SIMOBREAKER, there is no need for a complex connection with cables and pipes, or for separate foundations, steel, or earthing terminals for each individual device. This means that the system operator gets a cost-effective and standardized overall setup from one source and has no need to provide any items. Coordination work is substantially reduced, and interface problems do not even arise.

SIMOBREAKER can also be used as indoor switchgear. Installation inside a building ensures protection against the elements. This can be an enormous advantage, particularly in regions with extreme climates, but it is also relevant in industrial installations exposed to excessive pollution, e.g., in many industrial plants (fig. 3.1-25, fig. 3.1-26).

SIMOVER – Switchgear with withdrawable circuit-breaker

The compact SIMOVER switchgear, specially conceived for substations with single busbars, features a pivoting circuit-breaker. It is excellent for use in small transformer substations such as windfarms or any plants where space is restricted. It integrates all components of a high-voltage bay. There are no busbar and outgoing disconnectors for the feeders. The cabling is simple, and the switching status is clear. Drive technology is improved and the drive unit is weatherproofed. Pre-assembled components reduce installation times. In SIMOVER, all components of a high-voltage outdoor switchgear bay, including the isolating distances, are integrated in one unit. The instrument transformers and the local control cubicle are part of this substation design.

Cost-effective and reliable

The concept behind SIMOVER is based on customary type-tested standard components. This ensures high reliability. Thanks to economizing on the disconnectors, and integration of the instrument transformers and the local control cubicle, implementation costs are considerably reduced. All the components

Fig. 3.1-25: **SIMOBREAKER module**

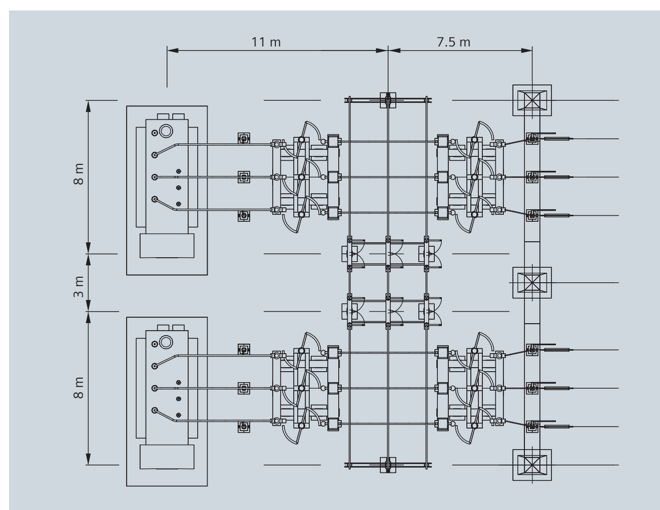

Fig. 3.1-26: **SIMOBREAKER (schematic)**

needed for the full scope of functioning of the movable circuit-breaker can be obtained from a single source, so there is no need for customer-provided items, coordination work is greatly reduced and interface problems do not even arise (fig. 3.1-29, fig. 3.1-30).

Highly integrated switchgear (HIS)

Highly-integrated switchgear (HIS), fig 3.1-27, fig. 3.1-28, fig. 3.1-31 and fig. 3.1-32 combines the advantages of air-insulated installations with those of gas-insulated switchgear technology. HIS switchgear are available up to 550 kV. The compact HIS switchgear is especially suited

- for new substations in a limited space

- where real estate prices are high
- where environmental conditions are extreme
- where the costs of maintenance are high

HIS arrangements are compact solutions used mainly for renewal or expansion of air-insulated outdoor and indoor substations, particularly if the operator wants to carry out modifications while the switchgear is in service. In new construction projects, high site prices and increasingly complex approval procedures mean that the space requirement is the prime factor in costing. With the HIS solution, the circuit-breakers, disconnectors, earthing switches and transformers are accommodated in compressed gastight enclosures, thus rendering the switchgear extremely compact.

Fig 3.1-27: **HIS Substation**

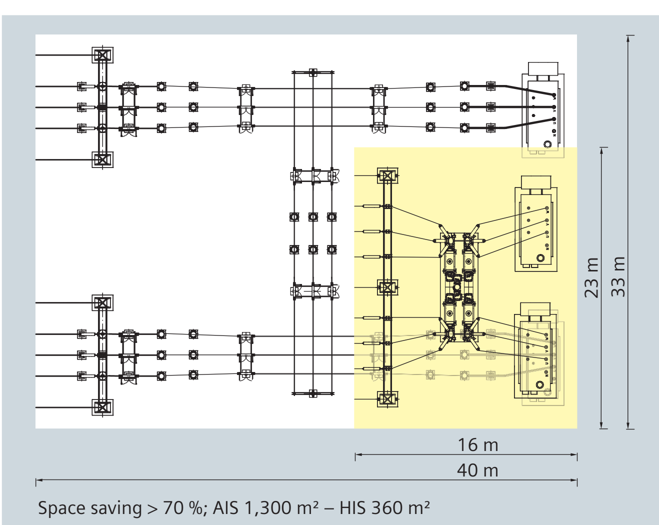

Fig. 3.1-28: **HIS for renewal of AIS space relations**

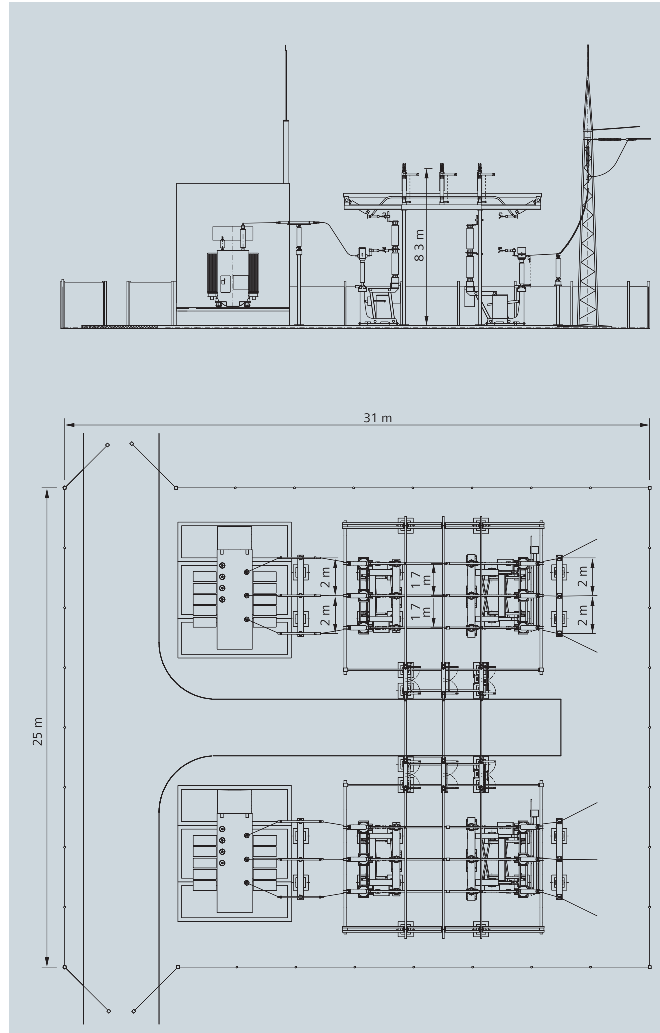

Fig. 3.1-29: **SIMOVER H-arrangement (schematic)**

Fig. 3.1-30: **H-arrangement with SIMOVER, 145 kV, Czech Republic**

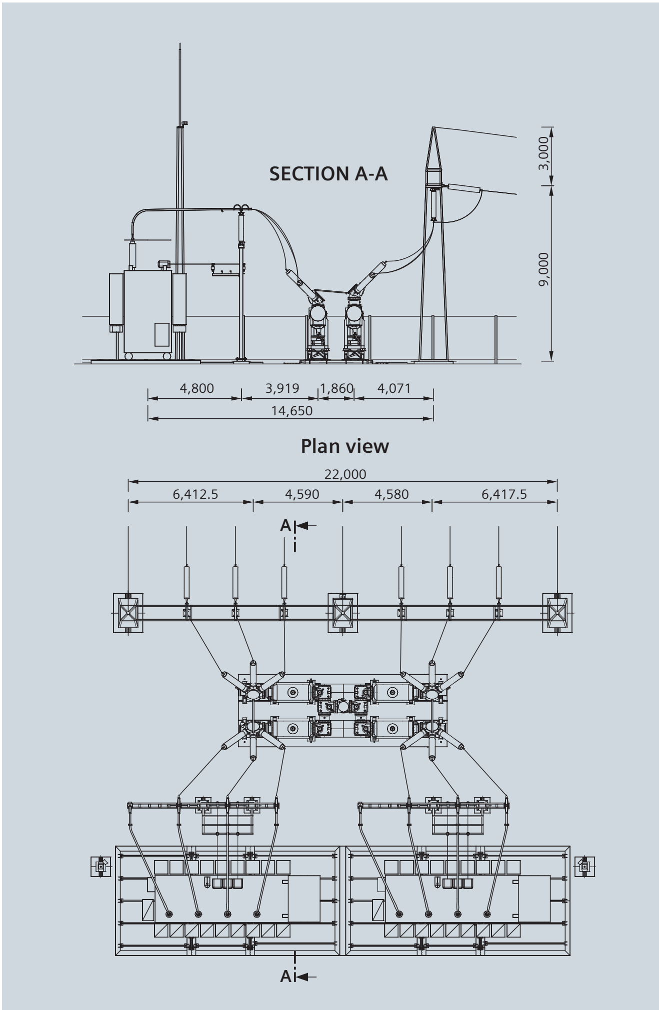

Fig. 3.1-31: **HIS solution (schematic)**

Fig. 3.1-32: **H-arrangement with HIS, 123 kV, Germany**

Dead-Tank Compact (DTC)
The dead-tank compact is another compact solution for the 145 kV voltage level: a dead-tank circuit-breaker together with GIS modules for disconnectors (section 4.1.5).

Planning principles
For air-insulated outdoor substations of open design, the following planning principles must be taken into account:

- High reliability
  - – Reliable mastering of normal and exceptional stresses
  - – Protection against surges and lightning strikes
  - – Protection against surges directly on the equipment concerned (e.g., transformer, HV cable)
- Good clarity and accessibility
  - – Clear conductor routing with few conductor levels
  - – Free accessibility to all areas (no equipment located at inaccessible depth)
  - – Adequate protective clearances for installation, maintenance and transportation work
  - – Adequately dimensioned transport routes
- Positive incorporation into surroundings
  - – As few overhead conductors as possible
  - – Tubular instead of wire-type busbars
  - – Unobtrusive steel structures
  - – Minimal noise and disturbance level
  - – EMC earthing system for modern control and protection
- Fire precautions and environmental protection
  - – Adherence to fire protection specifications and use of flame-retardant and non-flammable materials
  - – Use of environmentally compatible technology and products

3.1.6 Gas-Insulated Switchgear for Substations

Characteristic features of switchgear installations

Since 1968 the concept of Siemens gas-insulated metal-enclosed high-voltage switchgear has proved itself in more than 17,000 bay installations in all regions of the world. Gas-insulated metal-enclosed high-voltage switchgear (GIS) is constantly gaining on other types of switchgear because it offers the following outstanding advantages:

- Minimum space requirements:
  Where the availability of land is low and/or prices are high, e.g., in urban centers, industrial conurbations, mountainous regions with narrow valleys or in underground power stations, gas-insulated switchgear is replacing conventional switchgear because of its very small space requirements.
- Full protection against contact with live parts:
  The surrounding metal enclosure affords maximum safety for personnel under all operating and fault conditions.
- Protection against pollution:
  Its metal enclosure fully protects the switchgear interior against environmental effects such as salt deposits in coastal regions, industrial vapors and precipitates, and sandstorms. The compact switchgear can be installed as an indoor as well as an outdoor solution.
- Free choice of installation site:
  The small site area required for gas-insulated switchgear saves expensive grading and foundation work, e.g., in permafrost zones. Another advantage is the short erection time because of the use of prefabricated and factory tested bay units.
- Protection of the environment:
  The necessity to protect the environment often makes it difficult to erect outdoor switchgear of conventional design. Gas-insulated switchgear, however, can almost always be designed to blend well with the surroundings. Gas-insulated metal-enclosed switchgear is, because of the modular design, very flexible and meets all requirements for configuration that exist in the network design and operating conditions.

Each circuit-breaker bay includes the full complement of disconnecting and earthing switches (regular or make-proof), instrument transformers, control and protection equipment, and interlocking and monitoring facilities commonly used for this type of installation.

Besides the traditional circuit-breaker bay, other circuits, such as single busbar, single-busbar arrangement with bypass busbar, coupler and bay for double and triple busbar, can be supplied.

(Main) product range of GIS for substations

The Siemens product range covers GIS from 66 up to 800 kV rated voltage – the main range covers SF_6 switchgear up to 550 kV (table 3.1-2).

More than 40 years experience with gas-insulated switchgear	
1960	Start of fundamental studies in research and development of SF_6-technology
1964	Delivery of first SF_6 circuit-breaker
1968	Delivery of first GIS
1974	Delivery of first GIL (420 kV)
1997	Introduction of intelligent, bay integrated control, monitoring and diagnostic
1999	Introduction of newest GIS generation: Self-compression interrupter unit and spring operated mechanism
2000	Introduction of the trendsetting switchgear concept HIS (Highly Integrated Switchgear) for extension, retrofit and new compact AIS substations
2005	First GIS with electrical endurance capability (class E2)

Table 3.1-1: **Siemens experience with gas-insulated switchgear**

The development of this switchgear has been based on two overall production concepts: meeting the high technical standards required of high-voltage switchgear and providing maximum customer benefit.

This objective is attained only by incorporating all processes in the quality management system, which has been introduced and certified according to EN 29001/DIN EN ISO 9001.

Siemens GIS switchgear meets all performance, quality and reliability demands, including:

- Compact and low-weight design:
  Small building dimensions and low floor loads, a wide range of options in the utilization of space, and less space taken up by the switchgear.
- Safe encapsulation:
  An outstanding level of safety based on new manufacturing methods and optimized shape of enclosures.
- Environmental compatibility:
  No restrictions on choice of location due to minimum space requirement; extremely low noise and EMC emission as well as effective gas sealing system (leakage < 0.5 % per year per gas compartment). Modern spring mechanisms that are currently available for the whole GIS 8D product spectrum eliminates the need for hydraulic oil.

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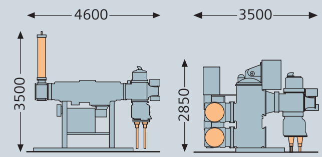
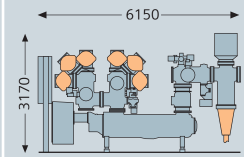
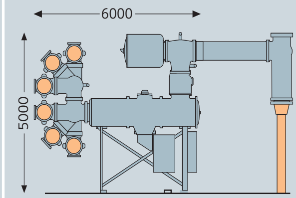
			
Switchgear type	8DN8	8DN9	8DQ1
Rated voltage (kV)	up to 145	up to 300	up to 550
Rated power-frequency withstand voltage (kV)	up to 275	up to 460	up to 740
Rated lightning impulse withstand voltage (kV)	up to 650	up to 1,050	up to 1,800
Rated switching impulse withstand voltage (kV)	–	up to 850	up to 1,250
Rated current, busbar (A)	up to 3,150	up to 4,000	up to 6,300
Rated current, feeder (A)	up to 3,150	up to 4,000	up to 5,000
Rated breaking current (kA)	up to 40	up to 63	up to 63
Rated short-time withstand current (kA)	up to 40	up to 63	up to 63
Rated peak withstand current (kA)	up to 108	up to 170	up to 170
Inspection (years)	> 25	> 25	> 25
Bay width (mm)	650/800	1,500/1,550/2,200	2,550/3,600

Table 3.1-2: **Main product range of GIS**

- Economical transport:
  Simplified fast transport and reduced costs, because shipping units are of the maximum size.
- Low operating costs:
  The switchgear is practically maintenance-free, e.g., contacts of circuit-breakers and disconnectors are designed for extremely long endurance, motor operating mechanisms are lubricated for life, the enclosure is corrosion-free. This ensures that the first inspection is required only after 25 years of operation.
- High reliability:
  The longstanding experience of Siemens in design, production and commissioning – more than 230,000 bay operating years in over 17,000 bay installations worldwide - is testament to the fact that the Siemens products are highly reliable. The mean time between failures (MTBF) amounts to >900 bay years for major faults. A quality management system certified according to ISO 9001, which is supported by highly qualified employees, ensures high quality throughout the whole process chain from the offer/order process to the on-site commissioning of the GIS.
- Smooth and efficient installation and commissioning:
  Transport units are fully assembled, tested at the factory and filled with SF_6 gas at reduced pressure. Coded plug connectors are used to cut installation time and minimize the risk of cabling failures.
- Routine tests:
  All measurements are automatically documented and stored in the electronic information system, which provides quick access to measured data for years.

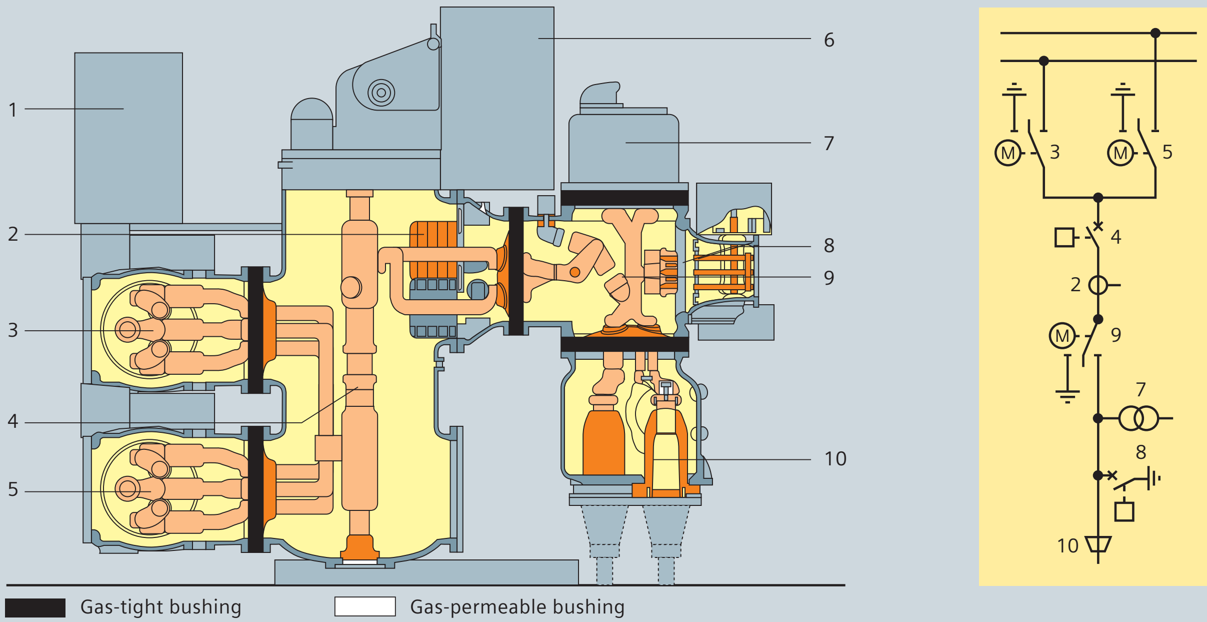
SF_6-insulated switchgear for up to 145 kV, type 8DN8
3-phase enclosures are used for switchgear type 8DN8 in order to achieve small and compact component dimensions. The low bay weight ensures low floor loading, and helps to reduce the cost of civil works and to minimize the footprint. The compact low-weight design allows installing it almost anywhere. Capital cost is reduced by using smaller buildings or existing ones, e.g., when replacing medium-voltage switchyards with the 145 kV GIS.

The bay is based on a circuit-breaker mounted on a supporting frame (fig. 3.1-33). A special multifunctional cross-coupling module combines the functions of the disconnector and earthing switch in a 3-position switching device. It can be used as:

- An active busbar with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-33, pos. 3 and 5)
- An outgoing feeder module with an integrated disconnector and work-in-progress earthing switch (fig. 3.1-32, pos. 9)
- A busbar sectionalizer with busbar earthing

Cable termination modules can be equipped with either conventional sealing ends or the latest plug-in connectors (fig. 3.1-33, pos. 10). Flexible 1-pole modules are used to connect overhead-lines and transformers with a splitting module that links the 3-phase enclosed switchgear to the 1-pole connections.

Thanks to their compact design, the completely assembled and factory-tested bays can be shipped as a single transport unit. Fast erection and commissioning on site ensure the highest possible quality.



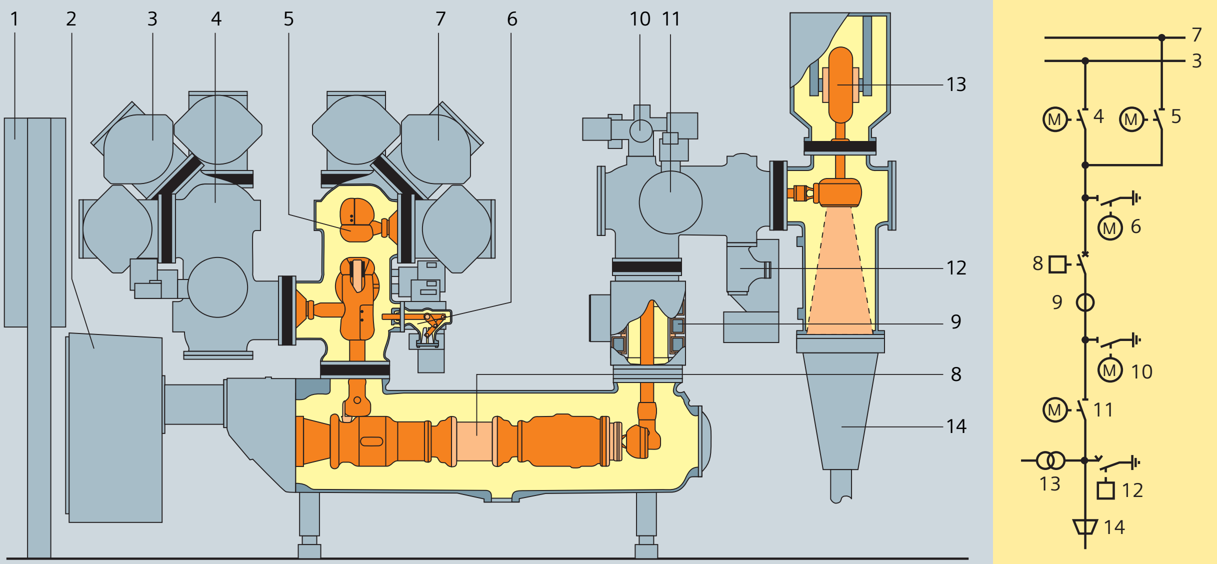
1 Integrated local control cubicle
2 Current transformer
3 Busbar II with disconnector and earthing switch
4 Interrupter unit of the circuit-breaker
5 Busbar I with disconnector and earthing switch
6 Stored-energy spring mechanism with circuit-breaker control unit
7 Voltage transformer
8 High-speed earthing switch
9 Outgoing feeder module with disconnector and earthing switch
10 Cable sealing end

Fig. 3.1-33: **8DN8 switchgear bay for up to 145 kV**

Fig. 3.1-34: **8DN8 GIS for a rated voltage of 145 kV**

Fig. 3.1-35: **8DN8 HIS for a rated voltage of 145 kV**

The feeder control and protection can be installed in a bay-integrated local control cubicle mounted to the front of each bay (fig. 3.1-33, pos. 1). Moreover, state-of-the-art monitoring devices are available at the customer's request, e.g., for partial discharge on-line monitoring.



Gas-tight bushing | Gas-permeable bushing

1 Integrated local control cubicle
2 Stored-energy spring mechanism with circuit-breaker control unit
3 Busbar I
4 Busbar disconnector I
5 Busbar disconnector II
6 Work-in-progress earthing switch
7 Busbar II
8 Circuit-breaker interrupter unit
9 Current transformer
10 Work-in-progress earthing switch
11 Outgoing-feeder disconnector
12 Make-proof earthing switch (high-speed)
13 Voltage transformer
14 Cable sealing end

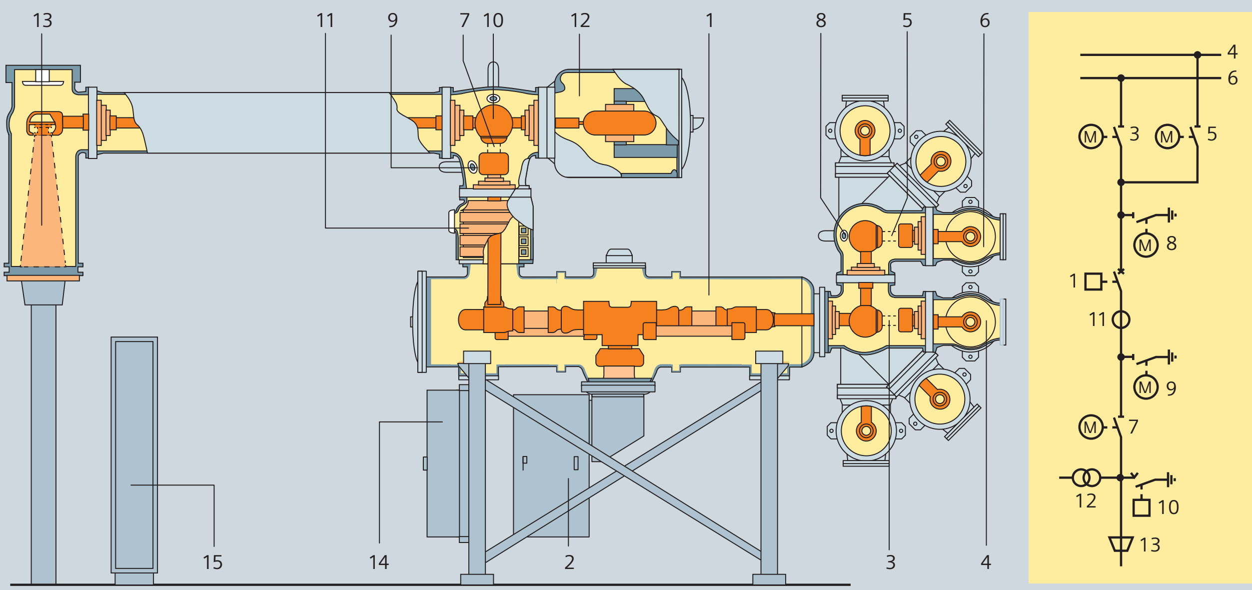
Fig. 3.1-36: **8DN9 switchgear bay for up to 300 kV**

SF_6-insulated switchgear for up to 300 kV, type 8DN9
The clear bay configuration of the lightweight and compact 8DN9 switchgear is evident at first glance. Control and monitoring facilities are easily accessible despite the switchgear's compact design.

The horizontally arranged circuit-breaker forms the basis of every bay configuration. The operating mechanism is easily accessible from the operator area. The other bay modules – of 1-phase enclosed switchgear design, like the circuit-breaker module – are located on top of the circuit-breaker. The 1-phase encapsulated passive busbar is partitioned off from the active equipment (fig. 3.1-36, fig. 3.1-37).

Thanks to "single-function" assemblies (assignment of just one task to each module) and the versatile modular structure, even unconventional arrangements can be set up from a pool of only 20 different modules. The modules are connected to each other with a standard interface that allows implementing an extensive range of bay structures. Switchgear design with standardized modules and the scope of services ensure that all types of bay structures can be set up in a small area. The compact design allows supplying of complete bays that are fully assembled and tested at the factory, which makes for smooth and efficient installation and commissioning.

Fig. 3.1-37: **8DN9 switchgear for a rated voltage of 245 kV**



1 Circuit-breaker interrupter unit
2 Stored-energy spring mechanism
3 Busbar disconnector I
4 Busbar I
5 Busbar disconnector II
6 Busbar II
7 Outgoing feeder disconnector
8 Work-in-progress earthing switch
9 Work-in-progress earthing switch
10 Make-proof earthing switch (high-speed)
11 Current transformer
12 Voltage transformer
13 Cable sealing end
14 Circuit-breaker control cubicle
15 Local control cubicle

Fig. 3.1-38: **8DQ1 switchgear bay for up to 550 kV**

SF_6-insulated switchgear for up to 550 kV, type 8DQ1
GIS type 8DQ1 is a 1-phase enclosed switchgear system for high-power switching stations with individual enclosure of all modules of the 3-phase system.

The base unit for the switchgear is a horizontally arranged circuit-breaker on top of which the housing containing the disconnectors, earthing switches, current transformers, and so on are mounted. The busbar modules are partitioned off from the active equipment (fig. 3.1-38, fig. 3.1-39).

Some other characteristic features of switchgear installation are:
- Circuit-breakers with two interrupter units up to operating voltages of 550 kV and breaking currents of 63 kA
- Horizontal arrangement of the circuit-breakers in the lower section provides low center of gravity for the switchgear
- Utilization of the circuit-breaker transport frame as a supporting device for the entire bay
- Reduced length of sealing surfaces, and thus, decreased risk of leakage through use of only a few modules and equipment combinations in one enclosure.

Fig. 3.1-39: **8DQ1 switchgear for a rated voltage of 420 kV**

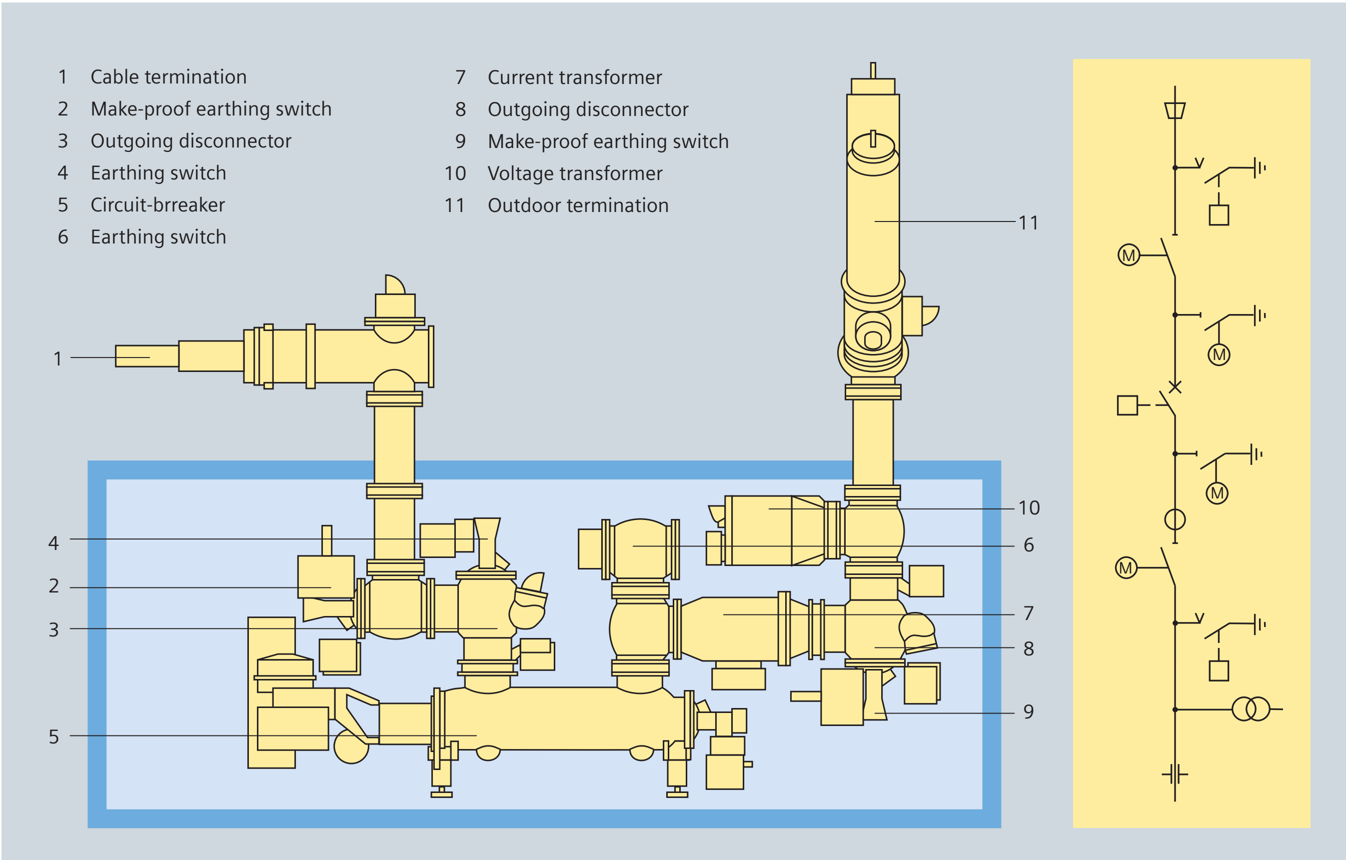


Fig. 3.1-40: **Containerized 8DN9 switchgear (with stub feed)**

Special arrangements

Gas-insulated switchgear – usually accommodated in buildings (such as a tower-type substation) – is expedient wherever land is very expensive or restricted, or where necessitated by ambient conditions. When it comes to smaller switching stations, or in cases of expansion where installation in a building does not provide any advantage, installing the substation in a container is a good solution.

Mobile containerized switchgear

At medium-voltage levels, mobile containerized switchgear is the state of the art. Even high-voltage switching stations can be built this way and are economically operated in many applications. At the core is the metal-enclosed SF_6-insulated switchgear, installed either in a sheet-steel container or in a block house made of prefabricated concrete elements. In contrast to conventional stationary switchgear, there is no need for complicated constructions, as mobile switching stations come with their own "building" (fig. 3.1-40, fig. 3.1-41).

Mobile containerized switching stations can be of single-bay or multi-bay design with a large number of different circuits and arrangements. All of the usual connection components can be employed, among them outdoor bushings, cable adapter boxes and SF_6 tubular connections. If necessary, all control and protection equipment as well as that for local supply can be

Fig. 3.1-41: **Containerized 8DN9 switchgear bay**

accommodated in the container. This allows largely independent operation of the installation on site. Containerized switchgear is pre-assembled at the factory and ready for operation. The only on-site work required is setting up the containers, fitting the exterior system parts and making the external connections. Shifting the switchgear assembly work to the factory enhances quality and operational reliability. Mobile containerized switchgear has a small footprint and usually fits well within the environment. For operators, prompt availability and short commissioning times are a further significant advantage. Considerable cost reductions are achieved in planning, construction work and assembly.

Approvals from building authorities are either not required or required in a simplified form. The installation can also be operated at various locations in succession. Adaptation to local circumstances is not a problem. The following are the possible applications for containerized stations:

- Interim solutions during the modernization of switching stations
- Low-cost transitional solutions where new construction of transformer substations involves tedious formalities, such as the procurement of land or the establishment of cable routes
- Quick erection as an emergency station in the event of malfunctioning of the existing switchgear
- Switching stations for movable geothermal power plants

GIS for up to 245 kV in a standard container

The dimensions of the 8DN9 switchgear make it possible to accommodate all active components of the switchgear (circuit-breaker, disconnector, earthing switch) and the local control cubicle in a standard container. The floor area of 6.1 m x 2.44 m complies with the ISO 668 standard. Although the container exceeds the standard dimension of 2.44 m, this will not cause any problem during transportation, a fact that has already been proven by several equipment deliveries. German Lloyd, an approval authority, already issued a test certificate for an even higher container construction. The standard dimensions and ISO corner fittings facilitate handling during transport in the 6.1 m frame of a container ship and on a low-loader truck. Two doors provide the operating staff with access to the container.

Rent a GIS

Siemens also offers containerized gas-insulated high-voltage substations for rent to fill every gap, instantly and in a remarkably cost-effective manner. The Siemens Instant Power Service offers an economical power supply solution for time periods from a few weeks up to 3 years.

Specification guide for metal-enclosed SF_6-insulated switchgear

Note: The points below are not considered exhaustive, but are a selection of the important. These specifications cover the technical data applicable to metal-enclosed SF_6-insulated switchgear for switching and distributing power in cable and/or overhead-line systems and transformers. Key technical data are contained in the data sheet and the single-line diagram (SLD) attached to the inquiry.

A general SLD and a sketch showing the general arrangement of the substation will be part of a proposal. Any switchgear quoted will be complete and will form a functional, safe and reliable system after installation, even if certain parts required to achieve this have not been specifically been included in the inquiry.

- Applicable standards
  All equipment is designed, built, tested and installed according to the latest issues of the applicable IEC standards, which are:
  – IEC 62271-1 "High-voltage switchgear and controlgear: Common specifications"
  – IEC 62271-203 "High-voltage switchgear and controlgear: Gas-insulated metal-enclosed switchgear for rated voltages above 52 kV"
  – IEC 62271-100 "High-voltage switchgear and controlgear: Alternating-current circuit-breakers"
  – IEC 62271-102 "High-voltage switchgear and controlgear: Alternating current disconnectors and earthing switches"
  – IEC 60044 "Instrument transformers: Current transformers"
- Local conditions
  The equipment described will be installed indoors. To that end, we will quote suitable lightweight, prefabricated buildings, provided that these are available from the supplier.

All the buyer has to provide is a flat concrete floor with the cutouts for cable installation – if this is required. The switchgear comes equipped with adjustable supports (feet). If steel support structures are required for the switchgear, Siemens will provide these as well. For design purposes, the indoor temperatures should be between – 5 °C and + 40 °C, and outdoor temperatures should be between – 30 °C and + 40 °C (+ 50 °C). For parts to be installed outdoors (overhead-line connections), the conditions described in IEC 62271-203 will be observed.
For the enclosures, aluminum or aluminum alloys are preferred.

A minimum of on-site erection work will ensure maximum reliability. Any subassemblies will be erected and tested at the factory if at all possible. Subassembly size is restricted only by transport requirements. Siemens will provide the enclosure in a material and thickness suited to withstand an internal arc and prevent burn-throughs or punctures within the first stage of protection, referred to the rated short-circuit current of the given GIS type.

All assemblies are designed to allow absorption of thermal expansion and contraction caused by varying temperatures. Adjustable metal bellow compensators are installed for this purpose. Density monitors with electrical contacts for at least two pressure levels are installed to allow monitoring the gas in the enclosures. The circuit-breakers can be monitored with density gauges that are fitted in the circuit-breaker control units.

Siemens can assure that the pressure loss for each individual gas compartment – i.e., not just for the complete switchgear installation – will not exceed 0.5 % per year and gas compartment. Each gas-filled compartment comes equipped with static filters that are capable of absorbing any water vapor that penetrates into

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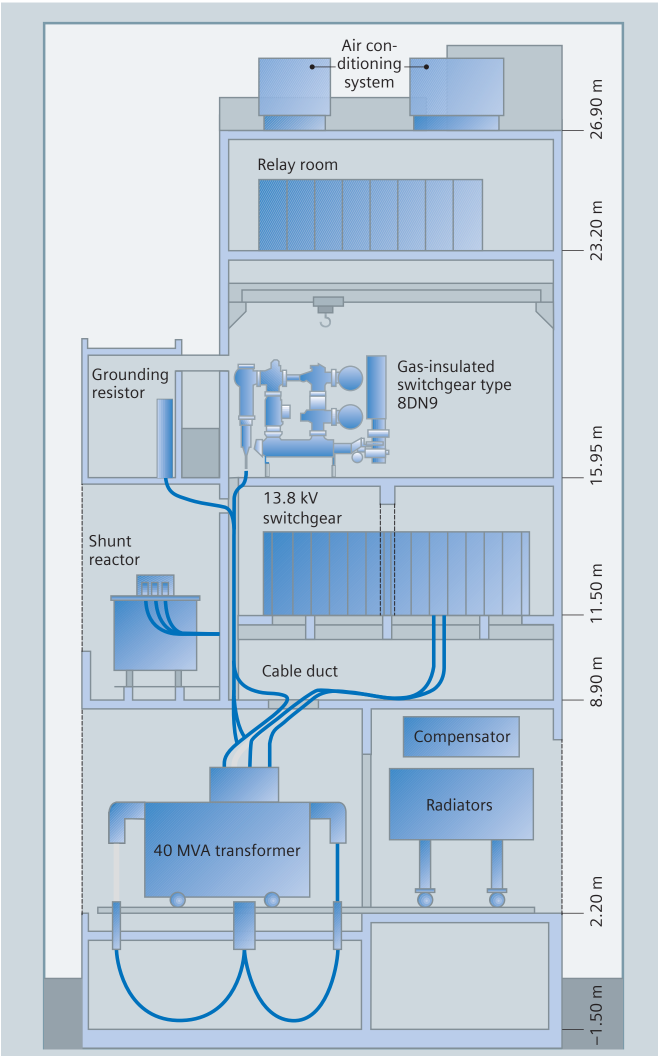


Fig. 3.1-42: **Special arrangement for limited space. Sectional view of a building showing the compact nature of gas-insulated substations.**

the switchgear installation for a period of at least 25 years. Intervals between required inspections are long, which keeps maintenance costs to a minimum. The first minor inspection is due after ten years. The first major inspection is usually required after more than 25 years of operation unless the permissible number of operations is reached before that date.

Arrangement and modules

Arrangement
The system is of the enclosed 1-phase or 3-phase type. The assembly consists of completely separate pressurized sections, and is thus designed to minimize any danger to the operating staff and risk of damage to adjacent sections, even if there should be trouble with the equipment. Rupture diaphragms are provided to prevent the enclosures from bursting discs in an uncontrolled manner. Suitable deflectors provide protection for the operating personnel. For maximum operating reliability, internal relief devices are not installed, because these would affect adjacent compartments. The modular design, complete segregation, arc-proof bushing and plug-in connections allow speedy removal and replacement of any section with only minimal effects on the remaining pressurized switchgear.

Busbars
All busbars of the enclosed 3-phase or the 1-phase type are connected with plugs from one bay to the next.

Circuit-breakers
The circuit-breakers operate according to the dynamic self-compression principle. The number of interrupting units per phase depends on the circuit-breaker's performance. The arcing chambers and circuit-breaker contacts are freely accessible. The circuit-breaker is suitable for out-of-phase switching and designed to minimize overvoltages. The specified arc interruption performance has to be consistent across the entire operating range, from line-charging currents to full short-circuit currents.

The circuit-breaker is designed to withstand at least 10 operations (depending on the voltage level) at full short-circuit rating. Opening the circuit-breaker for service or maintenance is not necessary. The maximum tolerance for phase displacement is 3 ms, that is, the time between the first and the last pole's opening or closing. A standard station battery that is required for control and tripping may also be used for recharging the operating mechanism. The drive and the energy storage system are provided by a stored-energy spring mechanism that holds sufficient energy for all standard IEC close-open duty cycles. The control system provides alarm signals and internal interlocks but inhibits tripping or closing of the circuit-breaker when the energy capacity in the energy storage system is insufficient or the SF_6 density within the circuit-breaker drops below the minimum permissible level.

Disconnectors
All disconnectors (isolators) are of the single-break type. DC motor operation (110, 125, 220 or 250 V), which is fully suited to remote operation, and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary switches in addition to the mechanical indicators. The bearings are lubricated for life.

Earthing switches
Work-in-progress earthing switches are generally provided on either side of the circuit-breaker. Additional earthing switches may be used to earth busbar sections or other groups of the assembly. DC motor operation (110, 125, 220 or 250 V) that is fully suited for remote operation and a manual emergency operating mechanism are provided. Each motor operating mechanism is self-contained and equipped with auxiliary position switches in addition to the mechanical indicators. The bearings are lubricated for life. Make-proof high-speed earthing switches are generally installed at the cable and overhead-line

terminals. Both switch types are equipped with a rapid closing mechanism to provide short-circuit making capacity.

Instrument transformers
Current transformers (CTs) are of the dry-type design. Epoxy resin is not used for insulation purposes. The cores have the accuracies and burdens that are shown on the SLD. Voltage transformers are of the inductive type, with ratings of up to 200 VA. They are foil-gas-insulated.

Cable terminations
1-phase or 3-phase, SF_6 gas-insulated, metal-enclosed cable end housings are provided. The cable manufacturer has to supply the stress cone and suitable sealings to prevent oil or gas from leaking into the SF_6 switchgear. Siemens will supply a mating connection piece to be fitted to the cable end. The cable end housing is suitable for oil-type, gas-pressure-type cables with plastic insulation (PE, PVC, etc.) as specified on the SLD or the data sheets. Additionally, devices for safely isolating a feeder cable and connecting a high-voltage test cable to the switchgear or cable will be provided (fig. 3.1-44, fig. 3.1-45).

Overhead-line terminations
The terminations for connecting overhead-lines come complete with SF_6-to-air bushings but without line clamps (fig. 3.1-46).

Control and monitoring
As a standard, an electromechanical or solid-state interlocking control board is supplied for each switchgear bay. This fault-tolerant interlocking system prevents all operating malfunctions. Mimic diagrams and position indicators provide the operating personnel with clear operating instructions. Provisions for remote control are included. Gas compartments are constantly monitored by density monitors that provide alarm and blocking signals via contacts.

Required tests

Partial discharge tests
All solid insulators fitted in the switchgear are subjected to a routine partial discharge test prior to installation. At 1.2 times the line-to-line voltage (approximately twice the phase-to-earth voltage), no measurable discharge is allowed. This test ensures maximum safety with regard to insulator failure, good long-term performance and thus a very high degree of reliability.

Pressure tests
Each cast-aluminum enclosure of the switchgear is pressure-tested for at least twice the service pressure.

Leakage tests
Leakage tests performed on the subassemblies ensure that the flanges and cover faces are clean, and that the guaranteed leakage rate is not be exceeded.

Power frequency tests
Each assembly is subjected to power-frequency withstand tests, including sensitive partial discharge detection, to verify correct installation of the conductors, and to make sure that the insulator surfaces are clean and the switchgear as a whole is not subject to internal faults.

Additional technical data
Siemens will point out any dimensions, weights or other switchgear data that may affect local conditions and handling of the equipment. Any quotation includes drawings showing the switchgear assembly.

Fig. 3.1-43: **GIS in special building**

Instructions

Detailed instruction manuals on the installation, operation and maintenance of the equipment are supplied with all equipment delivered by Siemens.

Scope of supply

Siemens supplies the following items for all GIS types and interfaces as specified:

- The switchgear bay, including circuit-breakers, disconnectors and earthing switches, instrument transformers and busbar housings, as specified. For the different feeder types, the following limits apply:
  – Overhead-line feeder:
  The connecting stud at the SF_6-to-air bushing is supplied without the line clamp.
  – Cable feeder:
  According to IEC 60859, the termination housing, conductor coupling and connecting plate are part of the GIS delivery, while the cable stress cone with the matching flange is part of the cable supply (fig. 3.1-45).
  – Transformer feeder:
  Siemens supplies the connecting flange at the switchgear bay and the connecting bus ducts to the transformer, including any expansion joints. The SF_6-to-oil bushings plus terminal enclosures are part of the transformer delivery unless otherwise agreed (fig. 3.1-47, fig. 3.1-48).
  Note: This point always requires close coordination between the switchgear manufacturer and the transformer supplier.
- Each feeder bay is equipped with earthing pads. The local earthing network and the connections to the switchgear are included in the installation contractor's scope.
- Initial SF_6 gas filling for the entire switchgear supplied by Siemens is included. Siemens will also supply all gas interconnections from the switchgear bay to the integral gas service and monitoring panel.
- Terminals and circuit protection for auxiliary drives and control power are provided with the equipment. Feeder circuits and cables as well as the pertaining installation material will be supplied by the installation contractor.
- The local control, monitoring and interlocking panels are supplied for each circuit-breaker bay to form completely operational systems. Terminals for remote monitoring and control are also provided.
- Siemens will supply the above-ground mechanical support structures; embedded steel and foundation work are part of the installation contractor's scope.

For further information, please contact:
e-mail: h-gis.ptd@siemens.com

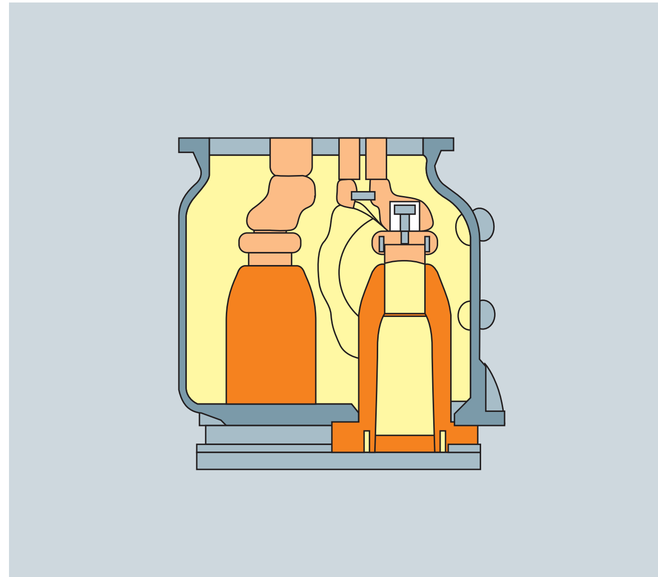


Fig. 3.1-44: **3-phase cable termination module: Example for plug-in cables**

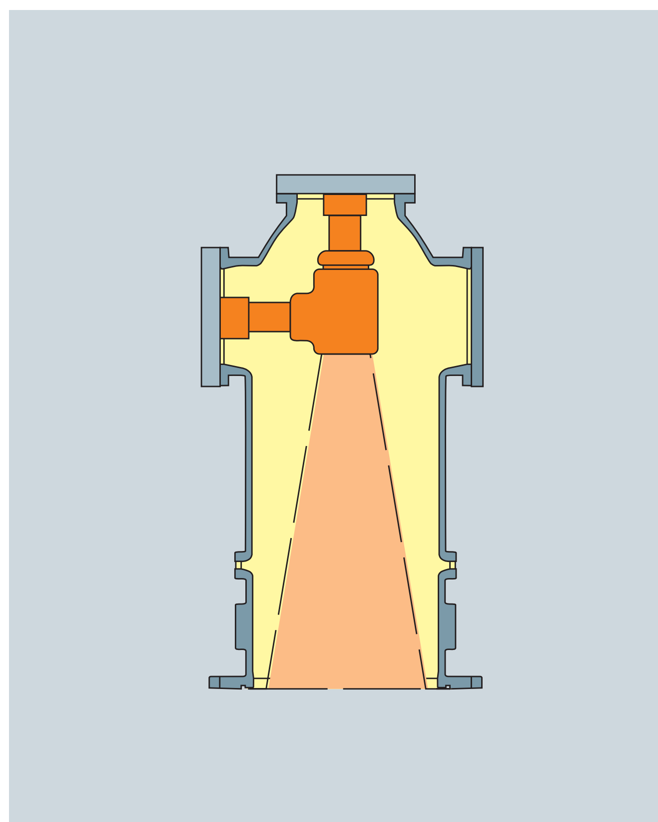


Fig. 3.1-45: **Cable termination module: cable termination modules conforming to IEC are available for connecting the switchgear to high-voltage cables. The standardized construction of these modules allows connection of various cross-sections and insulation types. Parallel cable connections for higher rated currents are also possible with the same module.**

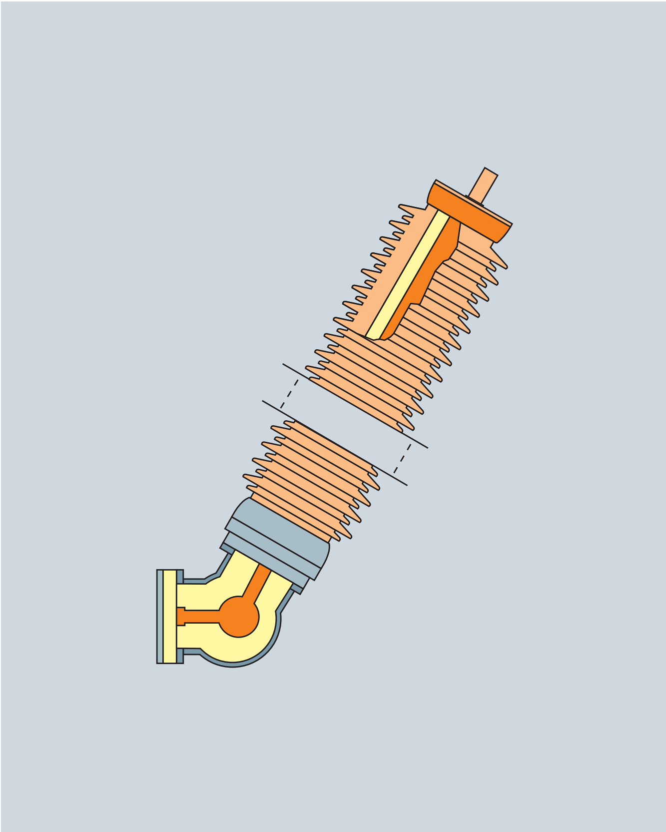


Fig. 3.1-46: **Outdoor termination module: High-voltage bushings are used for the SF_6-to-air transition. The bushings can be matched to your specific requirements with regard to arcing and creepage distances. They are connected to the switchgear by means of angular-type modules of variable design.**

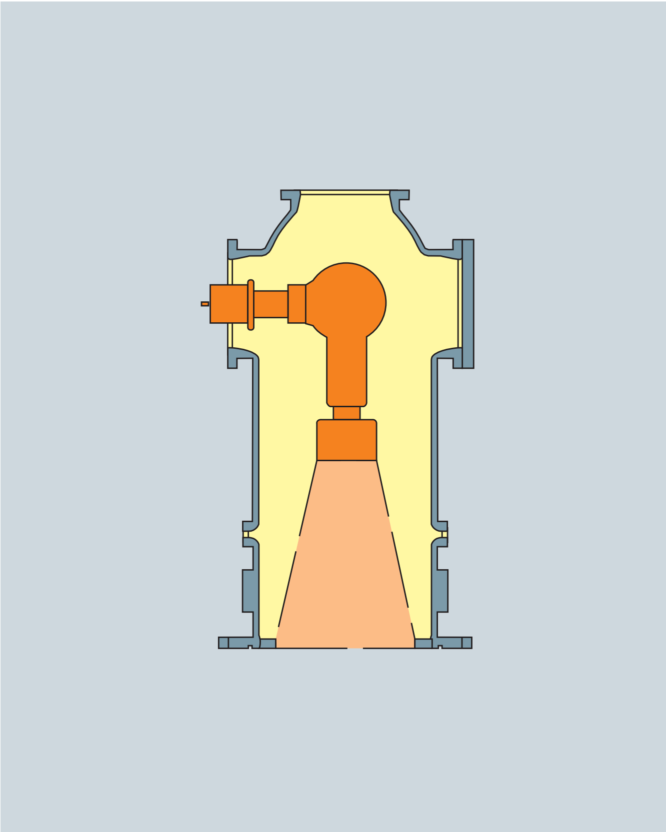


Fig. 3.1-47: **Transformer/reactor termination module: These termination modules form the direct connection between the GIS and oil-insulated transformers or reactance coils. Standardized modules provide an economical way of matching them to various transformer dimensions.**

Fig. 3.1-48: **Transformer termination modules**

Fig. 3.1-49: **The 8DQ1 modular system can meet customer requirements with just a few components.**

3.2 Medium-Voltage Switchgear

3.2.1 Introduction

According to international rules, there are only two voltage levels:

- Low-voltage: up to and including 1 kV AC (or 1,500 V DC)
- High-voltage: above 1 kV AC (or 1,500 V DC)

Most electrical appliances used in household, commercial and industrial applications work with low-voltage. High-voltage is used not only to transmit electrical energy over very large distances, but also for regional distribution to the load centers via fine branches. However, because different high-voltage levels are used for transmission and regional distribution, and because the tasks and requirements of the switchgear and substations are also very different, the term "medium-voltage" has come to be used for the voltages required for regional power distribution that are part of the high-voltage range from 1 kV AC up to and including 52 kV AC (fig. 3.2-1). Most operating voltages in medium-voltage systems are in the 3 kV AC to 40.5 kV AC range.

The electrical transmission and distribution systems not only connect power stations and electricity consumers, but also, with their "meshed systems," form a supraregional backbone with reserves for reliable supply and for the compensation of load differences. High operating voltages (and therefore low currents) are preferred for power transmission in order to minimize losses. The voltage is not transformed to the usual values of the low-voltage system until it reaches the load centers close to the consumer.

In public power supplies, the majority of medium-voltage systems are operated in the 10 kV to 30 kV range (operating voltage). The values vary greatly from country to country, depending on the historical development of technology and the local conditions.

Medium-voltage equipment

Apart from the public supply, there are still other voltages fulfilling the needs of consumers in industrial plants with medium-voltage systems; in most cases, the operating voltages of the motors installed are decisive. Operating voltages between 3 kV and 15 kV are frequently found in industrial supply systems. In power supply and distribution systems, medium-voltage equipment is available in:

- Power stations, for generators and station supply systems
- Transformer substations of the primary distribution level (public supply systems or systems of large industrial companies), in which power supplied from the high-voltage system is transformed to medium-voltage
- Local supply, transformer or customer transfer substations for large consumers (secondary distribution level), in which the power is transformed from medium to low-voltage and distributed to the consumer.

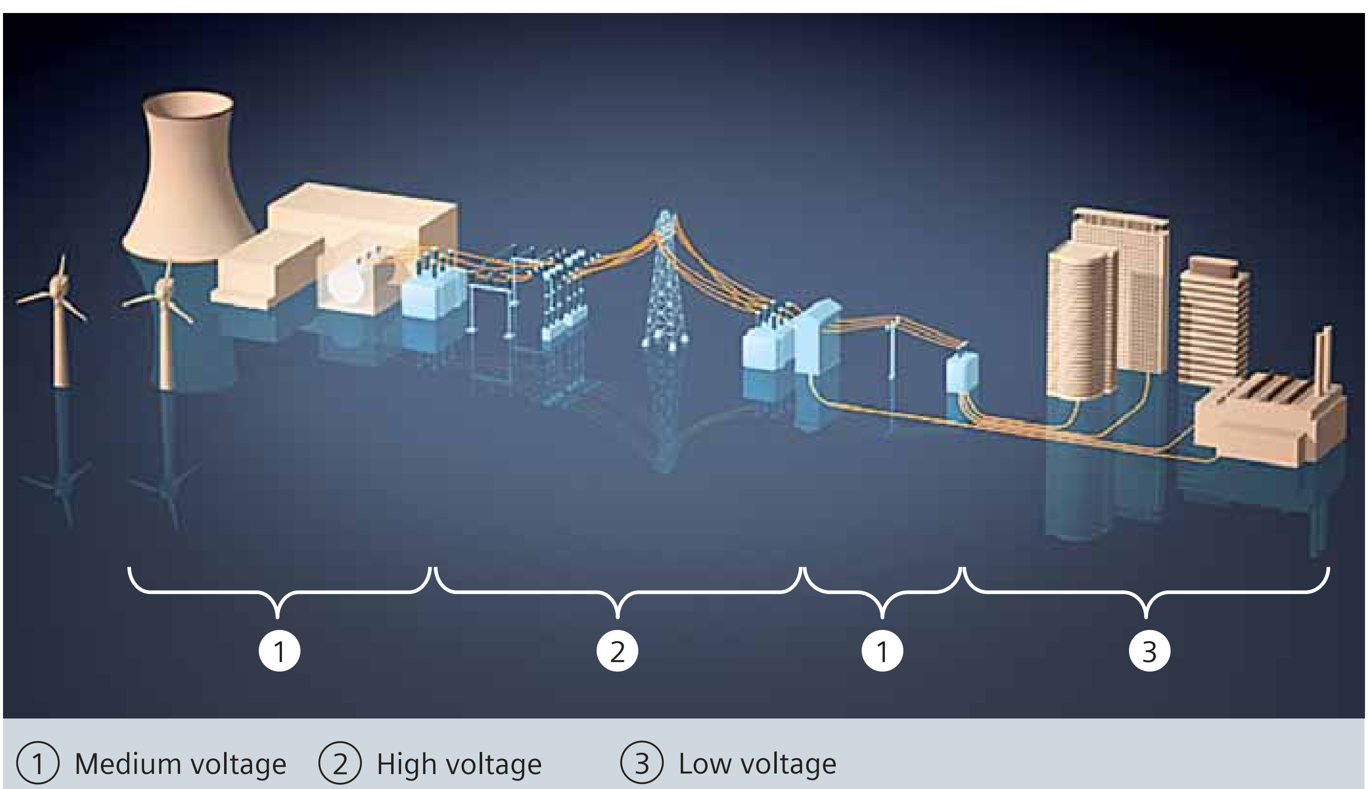


Fig. 3.2-1: **Voltage levels from the power plant to the consumer**

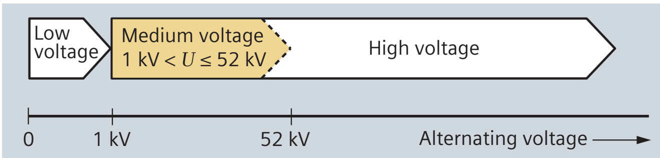


Fig. 3.2-2: **Voltage definitions**

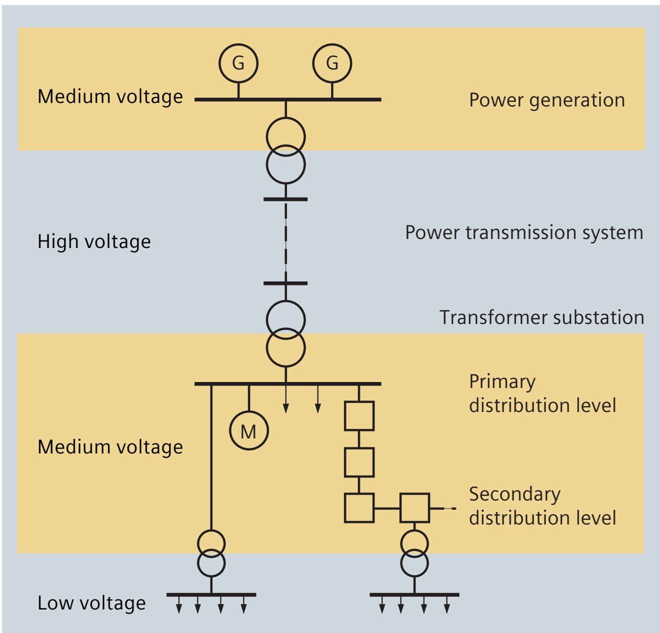


Fig. 3.2-3: **Medium voltage in the power supply and distribution system**

3.2.2 Basics of Switching Devices

What are switching devices?
Switching devices are devices used to close (make) or open (break) electrical circuits. The following stress can occur during making and breaking:

- No-load switching
- Breaking of operating currents
- Breaking of short-circuit currents

What can the different switching devices do?

- Circuit-breakers:
  Make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the full short-circuit current, and this under all fault conditions in the power supply system, such as earth faults, phase opposition, and so on.
- Switches:
  Switch currents up to their rated normal current and make on existing short-circuits (up to their rated short-circuit making current).
- Disconnectors (isolators):
  Used for no-load closing and opening operations. Their function is to "isolate" downstream devices so they can be worked on.
- Switch-disconnectors (load-break switches):
  The combination of a switch and a disconnector, or a switch with isolating distance.
- Contactors:
  Load breaking devices with a limited short-circuit making or breaking capacity. They are used for high switching rates.
- Earthing switches:
  To earth isolated circuits.
- Make-proof earthing switches (earthing switches with making capacity):
  Are used for the safe earthing of circuits, even if voltage is present, that is, also in the event that the circuit to be earthed was accidentally not isolated.
- Fuses:
  Consist of a fuse-base and a fuse-link. With the fuse-base, an isolating distance can be established when the fuse-link is pulled out in de-energized condition (like in a disconnector). The fuse-link is used for one single breaking of a short-circuit current.
- Surge arresters:
  To discharge loads caused by lightning strikes (external overvoltages) or switching operations and earth faults (internal overvoltages) to earth. They protect the connected equipment against impermissibly high-voltages.

Selection of switching devices
Switching devices are selected both according to their ratings and according to the switching duties to be performed, which also includes the switching rates. The following tables illustrate these selection criteria: table 3.2-1, next page shows the selection according to ratings. Table 3.2-2 through table 3.2-5 show the endurance classes for the devices.

Selection according to ratings
The system conditions, that is, the properties of the primary circuit, determine the required parameters. The most important of these are:

- Rated voltage:
  The upper limit of the system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.
- Rated insulation level:
  The dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance. The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).

3

Device	Withstand capability, rated …				Switching capacity, rated …		
	insulation level	voltage	normal current	peak withstand current	breaking current	short-circuit breaking current	short-circuit making current
Circuit-breaker	x	x	x			x	x
Switch(-disconnector)	x	x	x		x		x
Disconnector	x		x	x			
Earthing switch	x			x			
Make-proof earthing switch	x	x					x
Contactor	x	x	x	x		x [1)]	x [1)]
Fuse-link		x	x			x	
Fuse-base	x		x				
Surge arrester*	x [2)]	x [3)]		x [4)]		x [5)]	
Current limiting reactor	x		x	x			
Bushing	x		x	x [6)]			
Post insulator (insulator)	x			x [6)]			

x Selection parameter
1) Limited short-circuit breaking capacity
2) Applicable as selection parameter in special cases only, e.g., for exceptional pollution layer
3) For surge arresters with spark gap: rated voltage
4) Rated discharge current for surge arresters
5) For surge arresters: short-circuit strength in case of overload
6) For bushings and insulators: Minimum failing loads for tension, bending and torsion
* See also section 3.3

(Parameters of the secondary equipment for operating mechanisms, control and monitoring are not taken into consideration in this table.)

Table 3.2-1: **Device selection according to data of the primary circuit**

Class		*Operating cycles*	*Description*	
M	M1	1,000	Mechanical endurance	
	M2	5,000	Increased mechanical endurance	
E	E1	10 × I_1 10 × I_{2a} 2 × I_{ma}	20 × 0.05 × I_1 10 × I_{4a} 10 × 0.2 … 0.4 × I_{4a} 10 × I_{4b} 10 × I_{6a} 10 × I_{6b}	I_1 mainly active load-breaking current I_{2a} closed-loop breaking current I_{4a} cable-charging breaking current I_{4b} line-charging breaking current I_{6a} earth-fault breaking current I_{6b} cable-charging and line-charging breaking current under earth-fault conditions I_{ma} short-circuit making current
	E2	30 × I_1 20 × I_{2a} 3 × I_{ma}		
	E3	100 × I_1 20 × I_{2a} 5 × I_{ma}		

Table 3.2-2: **Endurance classes for switches**

<table>
<tr><th colspan="2">Class</th><th colspan="3">Description</th></tr>
<tr><td rowspan="2">M</td><td>M1</td><td>2,000 operating cycles</td><td colspan="2">Normal mechanical endurance</td></tr>
<tr><td>M2</td><td>10,000 operating cycles</td><td colspan="2">Extended mechanical endurance, low maintenance</td></tr>
<tr><td rowspan="3">E</td><td>E1</td><td>2 x C and 3 x O with 10 %, 30 %, 60 % and 100 % I_{sc}</td><td colspan="2">Normal electrical endurance (not covered by E2)</td></tr>
<tr><td rowspan="2">E2</td><td>2 x C and 3 x O with 10 %, 30 %, 60 % and 100 % I_{sc}</td><td>Without AR* operation</td><td rowspan="2">Extended electrical endurance without maintenance of the arcing chamber</td></tr>
<tr><td>26 x C 130 x O 10 % I_{sc}
26 x C 130 x O 30 % I_{sc}
4 x C 8 x O 6 % I_{sc}
4 x C 6 x O 100 % I_{sc}</td><td>Without AR* operation</td></tr>
<tr><td colspan="5">* AR = Automatic Reclosing</td></tr>
</table>

Table 3.2-3: **Endurance classes for circuit-breakers**

Class		*Operating cycles*	*Description*
	M0	1,000	For general requirements
M	M1	2,000	Extended mechanical endurance
	M2	10,000	

Table 3.2-4: **Endurance classes for disconnectors**

<table>
<tr><th colspan="2">Class</th><th>Operating cycles</th><th colspan="2">Description</th></tr>
<tr><td rowspan="3">E</td><td>E0</td><td>0 × I_{ma}</td><td>No short-circuit making capacity</td><td rowspan="2">For general requirements</td></tr>
<tr><td>E1</td><td>2 × I_{ma}</td><td rowspan="2">Short-circuit making capacity</td></tr>
<tr><td>E2</td><td>5 × I_{ma}</td><td>Reduced maintenance required</td></tr>
</table>

Table 3.2-5: **Endurance classes for earthing switches**

- Rated normal current:
  The current that the main circuit of a device can continuously carry under defined conditions. The temperature increase of components – especially contacts – must not exceed defined values. Permissible temperature increases always refer to the ambient air temperature. If a device is mounted in an enclosure, it may be advisable to load it below its full rated current, depending on the quality of heat dissipation.
- Rated peak withstand current:
  The peak value of the major loop of the short-circuit current during a compensation process after the beginning of the current flow, which the device can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the next item in this list).
- Rated short-circuit making current:
  The peak value of the making current in case of short-circuit at the terminals of the switching device. This stress is greater than that of the rated peak withstand current, because dynamic forces may work against the contact movement.
- Rated breaking current:
  The load breaking current in normal operation. For devices with full breaking capacity and without a critical current range, this value is not relevant (see the previous item in this list).
- Rated short-circuit breaking current:
  The root-mean-square value of the breaking current in case of short-circuit at the terminals of the switching device.

Selection according to endurance and switching rates
If several devices satisfy the electrical requirements and no additional criteria have to be taken into account, the required switching rate can be used as an additional selection criterion. Table 3.2-1 through table 3.2-5 show the endurance of the switching devices, providing a recommendation for their appropriate use. The respective device standards distinguish between classes of mechanical (M) and electrical (E) endurance, whereby they can also be used together on the same switching device; for example, a switching device can have both mechanical class M1 and electrical class E3.

- Switches:
  Standard IEC 60265-1/VDE 0670-301 only specifies classes for the so-called general-purpose switches. There are also "special switches" and "switches for limited applications."*
  – General-purpose switches
    General-purpose switches must be able to break different types of operating currents (load currents, ring currents, currents of unloaded transformers, charging currents of unloaded cables and overhead-lines), as well as to make on short-circuit currents.
    General-purpose switches that are intended for use in systems with isolated neutral or with earth earth-fault compensation, must also be able to switch under earth-fault conditions. The versatility is mirrored in the very exact specifications for the E classes.
  – SF_6 switches
    SF_6 switches are appropriate when the switching rate is not more than once a month. These switches are usually classified as E3 with regard to their electrical endurance.
  – Air-break or hard-gas switches:
    Air-break or hard-gas switches are appropriate when the switching rate is not more than once a year. These switches are simpler and usually belong to the E1 class. There are also E2 versions available.
  – Vacuum switches:
    The switching capacity of vacuum switches is significantly higher than that of the M2/E3 classes. They are used for special tasks – mostly in industrial power supply systems – or when the switching rate is at least once a week.
- Circuit-breakers:
  Whereas the number of mechanical operating cycles is specifically stated in the M classes, the circuit-breaker standard IEC 62271-100/VDE 0671-100 does not define the electrical endurance of the E classes by specific numbers of operating cycles; the standard remains very vague on this.
  The test duties of the short-circuit type tests provide an orientation as to what is meant by "normal electrical endurance" and "extended electrical endurance." The number of make and break operations (**C**lose, **O**pen) is specified in table 3.2-3.
  Modern vacuum circuit-breakers can generally make and break the rated normal current up to the number of mechanical operating cycles.
  The switching rate is not a determining selection criterion, because circuit-breakers are always used where short-circuit breaking capacity is required to protect equipment.
- Disconnectors:
  Disconnectors do not have any switching capacity (switches for limited applications must only control some of the switching duties of a general-purpose switch). Switches for special applications are provided for switching duties such as switching of single capacitor banks, paralleling of capacitor banks, switching of ring circuits formed by transformers connected in parallel, or switching of motors in normal and locked condition. Therefore, classes are only specified for the number of mechanical operating cycles.
- Earthing switches:
  With earthing switches, the E classes designate the short-circuit making capacity (earthing on applied voltage). E0 corresponds to a normal earthing switch; switches of the E1 and E2 classes are also-called make-proof or high-speed earthing switches.
  The standard does not specify how often an earthing switch can be actuated purely mechanically; there are no M classes for these switches.
- Contactors:
  The standard has not specified any endurance classes for contactors yet. Commonly used contactors today have a mechanical and electrical endurance in the range of 250,000 to 1,000,000 operating cycles. They are used wherever switching operations are performed very frequently, e.g., more than once per hour.

* *Disconnectors up to 52 kV may only switch negligible currents up to 500 mA (e.g., voltage transformer), or larger currents only when there is an insignificant voltage difference (e.g., during busbar transfer when the bus coupler is closed).*

3.2.3 Requirements of Medium-Voltage Switchgear

The major influences and stress values that a switchgear assembly is subjected to result from the task and its rank in the distribution system. These influencing factors and stresses determine the selection parameters and ratings of the switchgear (fig. 3.2-4).

Influences and stress values

System voltage
The system voltage determines the rated voltage of the switchgear, switching devices and other installed components. The maximum system voltage at the upper tolerance limit is the deciding factor.

Assigned configuration criteria for switchgear
- Rated voltage U_r
- Rated insulation level U_d; U_p
- Rated primary voltage of voltage transformers U_{pr}

Short-circuit current
The short-circuit current is characterized by the electrical values of peak withstand current I_p (peak value of the initial symmetrical short-circuit current) and sustained short-circuit current I_k. The required short-circuit current level in the system is predetermined by the dynamic response of the loads and the power quality to be maintained, and determines the making and breaking capacity and the withstand capability of the switching devices and the switchgear (table. 3.2-6).

Important note: The ratio of peak current to sustained short-circuit current in the system can be significantly larger than the standardized factor I_p/I_k = 2.5 (50 Hz) used for the construction of the switching devices and the switchgear. A possible cause, for example, are motors that feed power back to the system when a short circuit occurs, thus increasing the peak current significantly.

Normal current and load flow
The normal current refers to current paths of the incoming feeders, busbar(s) and outgoing consumer feeders. Because of the spatial arrangement of the panels, the current is also distributed, and therefore there may be different rated current values next to one another along a conducting path; different values for busbars and feeders are typical.

Reserves must be planned when dimensioning the switchgear:
- In accordance with the ambient air temperature
- For planned overload
- For temporary overload during faults

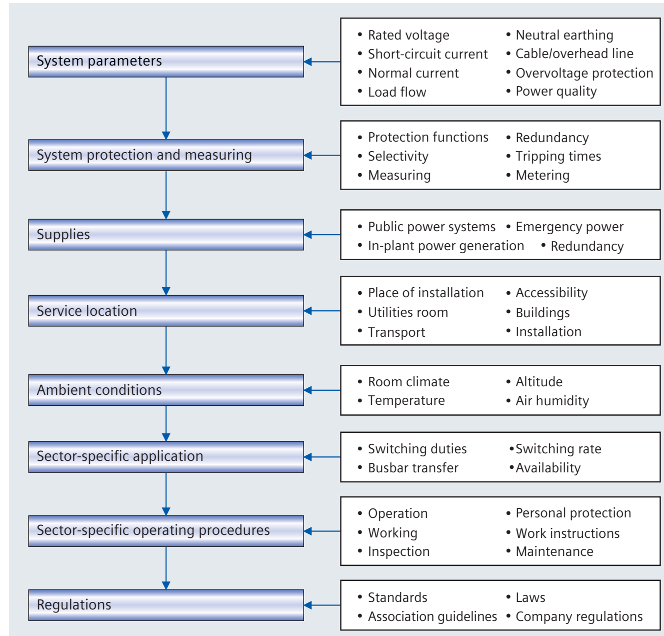


Fig. 3.2-4: **Influencing factors and stresses on the switchgear**

Assigned configuration criteria for switchgear	
Main and earthing circuits	– Rated peak withstand current I_p – Rated short-time withstand current I_k
Switching devices	– Rated short-circuit making current I_{ma} – Rated short-circuit breaking current I_{sc}
Current transformers	– Rated peak withstand current $I_{k\text{-}dyn}$ – Rated short-time thermal current I_{th}

Table 3.2-6: **Configuration criteria for short-circuit current**

Large cable cross sections or several parallel cables must be connected for high normal currents; the panel connection must be designed accordingly.

Assigned configuration criteria for switchgear
- Rated current of busbar(s) and feeders
- Number of cables per phase in the panel (parallel cables)
- Current transformer ratings

Loss of service continuity category		When an accessible compartment of the switchgear is opened ...	Type of construction
LSC 1		the busbar and therefore the complete switchgear must be isolated.	No partitions within the panel; no panel separation walls to adjacent panels.
LSC 2	LSC 2A	the incoming cable must be isolated. The busbar and the adjacent switchgear panels can remain in operation.	Panel separation walls and isolating distance with partition to the busbar.
	LSC 2B	the incoming cable, the busbar and the adjacent switchgear panels can remain in operation.	Panel separation walls and isolating distance with partition to the busbar and to the cable.

Table 3.2-7: **Loss of service continuity categories**

Type of accessibility to a compartment	Access features	Type of construction
Interlock-controlled	Opening for normal operation and maintenance, e.g., fuse replacement.	Access is controlled by the construction of the switchgear, i.e., integrated interlocks prevent impermissible opening.
Procedure-based	Opening for normal operation or maintenance, e.g., fuse replacement.	Access control via a suitable procedure (work instruction of the operator) combined with a locking device (lock).
Tool-based	Opening not for normal operation and maintenance, e.g., cable testing.	Access only with tool for opening; special access procedure (instruction of the operator).
Not accessible	Opening not possible not intended for operator; opening can destroy the compartment. This applies generally to the gas-filled compartments of gas-insulated switchgear. Because the switchgear is maintenance-free and climate-independent, access is neither required nor possible.	

Table 3.2-8: **Accessibility of compartments**

The notation IAC A FLR, I and t contains the abbreviations for the following values:	
IAC	Internal Arc Classification
A	Distance between the indicators 300 mm, i.e., installation in rooms with access for authorized personnel; closed electrical service location.
FLR	Access from the front (F), from the sides (L = Lateral) and from the rear (R).
I	Test current = Rated short-circuit breaking current (in kA)
t	Arc duration (in s)

Table 3.2-9: **Internal arc classification according to IEC 62271-200**

3.2.4 Medium-Voltage Switchgear

3

Distribution level	Insulation	Type of construction	Loss of service continuity	Partition class	Internal arc classification*
Primary	Gas-insulated	Extendable	LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FLR 31.5 kA, 1 s
			LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FLR 25 kA, 1 s
			LSC 2B	PM	IAC A FLR 31.5 kA, 1 s
			LSC 2B	PM	IAC A FLR 31.5 kA, 1 s
			LSC 2B	PM	IAC A FL 40 kA, 1 s
			LSC 2B	PM	IAC A FL 40 kA, 1 s
	Air-insulated	Extendable	LSC 2B	PM	IAC A FLR 31.5 kA, 1 s
			LSC 2B	PM	IAC A FLR 25 kA, 1 s
			LSC 2B	PM	IAC A FLR 50 kA, 1 s
			LSC 2B	PM	IAC A FLR 50 kA, 1 s
			LSC 2B	PM	IAC A FLR 40 kA, 1 s
			LSC 2A	PM	IAC A FLR 25 kA, 1 s
			LSC 2B	PM	IAC A FLR 31.5 kA, 1 s
			LSC 1	PM	IAC A FL 16 kA, 1 s
Secondary	Gas-insulated	Non-extendable	LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FL 21 kA, 1 s
			LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FL 21 kA, 1 s
		Extendable	LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FLR 21 kA, 1 s
	Air-insulated	Extendable	LSC 2B (panels without HV HRC fuses) LSC 2A (panels with HV HRC fuses)	PM	IAC A FLR 20 kA, 1 s

* Maximum possible IAC classification

Table 3.2-10: **Overview of Siemens medium-voltage switchgear**

3

Switchgear type	Busbar system	Rated voltage (kV)	Rated short-time withstand current (kA)		Rated current, busbar (A)	Rated current, feeder (A)
			1 s	3 s		
NXPLUS C	Single	15	31.5	31.5	2,500	2,500
		24.0	25	25	2,500	2,000
NXPLUS C	Double	24	25	25	2,500	1,250
NXPLUS	Single	40.5	31.5	31.5	2,500	2,500
NXPLUS	Double	36	31.5	31.5	2,500	2,500
8DA10	Single	40.5	40	40	5,000	2,500
8DB10	Double	40.5	40	40	5,000	2,500
NXAIR	Single	12	31.5	31.5	2,500	2,500
NXAIR M	Single	24	25	25	2,500	2,500
NXAIR P	Single	15	50	50	4,000	4,000
NXAIR P	Double	15	50	50	4,000	4,000
SIMOPRIME	Single	17.5	40	40	3,600	3,600
8BT1	Single	24	25	25	2,000	2,000
8BT2	Single	36	31.5	31.5	2,500	2,500
8BT3	Single	36	16	16	1,250	1,250
8DJ10	Single	17.5	25	20	630	630
		24	20	20	630	630
8DJ20	Single	17.5	25	20	630	630
		24	20	20	630	630
8DH10	Single	17.5	25	20	1,250	1,250
		24	20	20	1,250	1,250
SIMOSEC	Single	17.5	25	20	1,250	1,250
		24	20	20	1,250	1,250

NXAIR

Fig. 3.2-5: **NXAIR panel**

Performance features

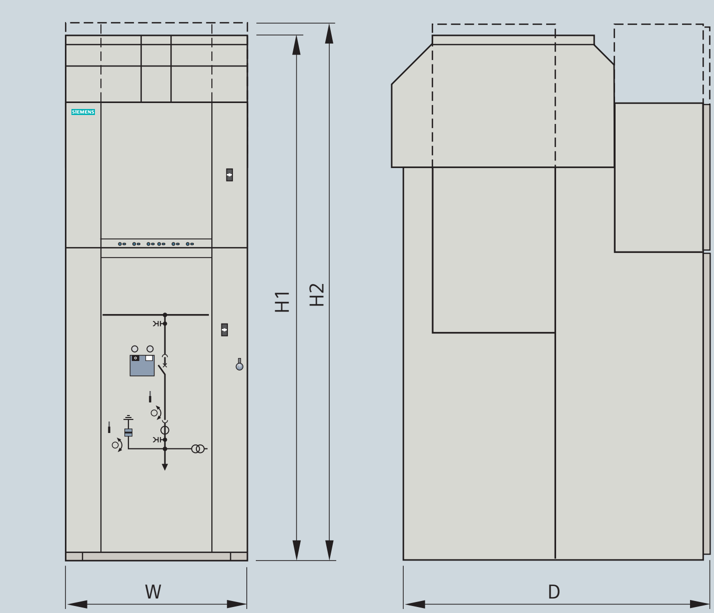
The air-insulated, metal-clad switchgear type NXAIR is an innovation in the switchgear field for the distribution and process level up to 12 kV, 31.5 kA, 2,500 A.

- Metal-enclosed, metal-clad LSC 2B PM switchgear
- Resistance to internal faults: IAC A FLR 31.5 kA, 1 s
- Type tests of the circuit-breaker and make-proof earthing switch in the panel
- Cable connection from the front or from the rear
- Bushing-type transformers enable selective shutdown of feeders
- Confinement of internal fault to respective compartment
- Replacement of module and connection compartment possible
- Modular contactor panels

Rated			
Voltage	kV	7.2	12
Frequency	Hz	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*
Lightning impulse withstand voltage	kV	60	75
Short-circuit breaking current	max. kA	31.5	31.5
Short-time withstand current, 3 s	max. kA	31.5	31.5
Short-circuit making current**	max. kA	80	80
Peak withstand current**	max. kA	80	80
Normal current of the busbar	max. A	2,500	2,500
Normal current of the feeders			
with circuit-breaker	max. A	2,500	2,500
with switch-disconnector	max. A	200***	200***
with vacuum contactor	max. A	400***	400***

* 42 kV optional
** Values for 50 Hz
*** Depending on the rated current of the HV HRC fuses used

Table 3.2-11: **Technical data of NXAIR**



All panel types			Dimensions in mm
Width	W		405/650/800/1,000
Height	H1	With standard low-voltage compartment, natural ventilation	2,300
	H2	With high low-voltage compartment or with additional compartment for busbar components	2,350
Depth	D	Single busbar ≤ 31.5 kA; ≤ 2,500 A	1,350

Fig. 3.2-6: **Dimensions of NXAIR**

NXAIR M

Fig. 3.2-7: **NXAIR M panel**

Performance features

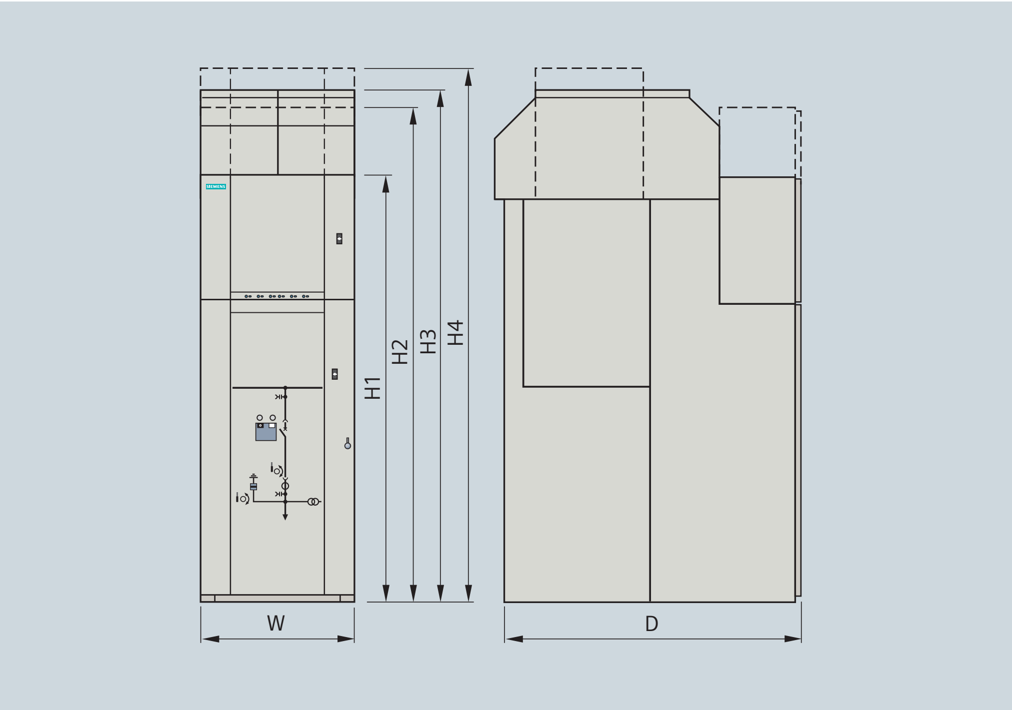
The air-insulated, metal-clad switchgear type NXAIR M is the resulting further development of the NXAIR family for use in the distribution and process level up to 24 kV, 25 kA, 2,500 A.

- Metal-enclosed, metal-clad LSC 2B PM switchgear
- Resistance to internal faults: IAC A FLR 25 kA, 1 s
- Type tests of the circuit-breaker and make-proof earthing switch in the panel
- Cable connection from the front or from the rear
- Bushing-type transformers enable selective shutdown of feeders
- Confinement of internal fault to respective compartment
- Replacement of module and connection compartment possible

Rated		
Voltage	kV	24
Frequency	Hz	50
Short-duration power-frequency withstand voltage	kV	50
Lightning impulse withstand voltage	kV	125
Short-circuit breaking current	max. kA	25
Short-time withstand current, 3 s	max. kA	25
Short-circuit making current	max. kA	63
Peak withstand current	max. kA	63
Normal current of the busbar	max. A	2,500
Normal current of the feeders with circuit-breaker with switch-disconnector	 max. A max. A	 2,500 200*

* Depending on the rated current of the HV HRC fuses used

Table 3.2-12: **Technical data of NXAIR M**



All panel types				Dimensions in mm
Width	W	Circuit-breaker panel	≤ 2,000 A 2,500 A	800 1,000
		Disconnecting panel	≤ 2,000 A 2,500 A	800 1,000
		Bus sectionalizer	≤ 1,250 A 1,600 A/2,000 A/2,500 A	2 x 800 2 x 1,000
		Metering panel		800
Height	H1 H2 H3 H4	With standard low-voltage compartment With high low-voltage compartment Standard panel or standard panel with natural ventilation With additional compartment for busbar components		2,200 2,550 2,655 2,770
Depth	D	Single busbar		1,554

Fig. 3.2-8: **Dimensions of NXAIR M**

NXAIR P

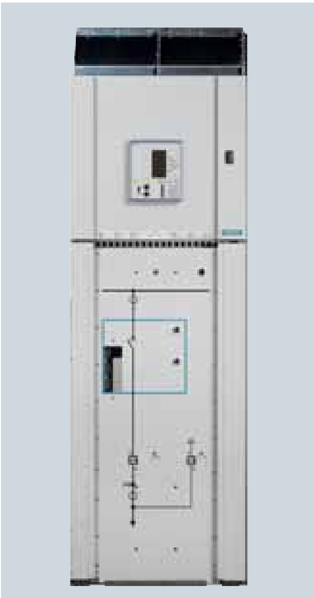


Fig. 3.2-9: **NXAIR P panel**

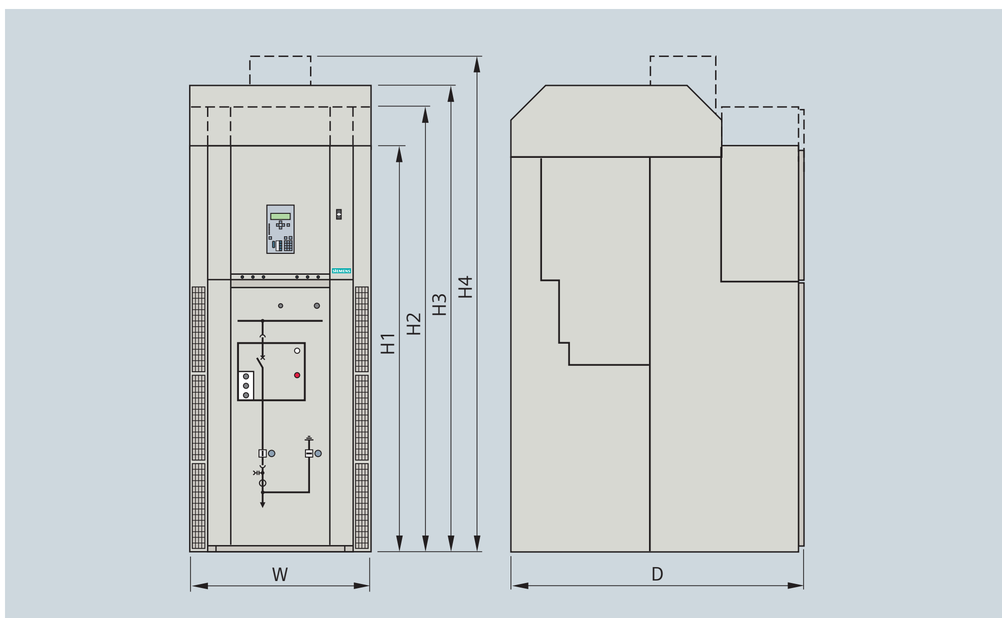
Performance features
The air-insulated, metal-clad switchgear type NXAIR P is based on the construction principles of the NXAIR family and designed for use in the distribution and process level up to 15 kV, 50 kA, 4,000 A.

- Metal-enclosed, metal-clad LSC 2B PM switchgear
- Resistance to internal faults: IAC A FLR 50 kA, 1 s
- Type tests of the circuit-breaker and make-proof earthing switch in the panel
- Cable connection from the front or from the rear
- Can be delivered as withdrawable or truck-type switchgear
- Bushing-type transformers enable selective shutdown of feeders up to 31.5 kA
- Confinement of internal fault to respective compartment up to 31.5 kA
- Replacement of module and connection compartment is possible
- Modular contactor panels

Rated				
Voltage	kV	7.2	12	15
Frequency	Hz	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28	35
Lightning impulse withstand voltage	kV	60	75	95
Short-circuit breaking current	max. kA	50	50	50
Short-time withstand current, 3 s	max. kA	50	50	50
Short-circuit making current*	max. kA	125	125	125
Peak withstand current*	max. kA	125	125	125
Normal current of the busbar	max. A	4,000	4,000	4,000
Normal current of the feeders with circuit-breaker with vacuum contactor	max. A	4,000 400**	4,000 400**	4,000 –

* Values for 50 Hz
** Depending on the rated current of the HV HRC fuses used

Table 3.2-13: **Technical data of NXAIR P**



All panel types (except vacuum contactor panel)			Dimensions in mm
Width	W	≤ 2,000 A > 2,000 A (for panel ventilation)	800 1,000
Height	H1 H2 H3 H4	Front for standard low-voltage compartment (≤ 3150 A) With higher low-voltage compartment With standard, top-mounted pressure relief duct For forced ventilation	2,225 2,485 2,550 2,710
Depth	D	Single busbar Double-busbar for back-to-back arrangement	1,635 3,320
Vacuum contactor panel			
Width	W		400
Height	H1 H2 H3 H4	Front for standard low-voltage compartment (≤ 3150 A) With higher low-voltage compartment With standard, top-mounted pressure relief duct For forced ventilation (400 A)	2,225 2,485 2,550 2,710
Depth	D	Single busbar	1,650

Fig. 3.2-10: **Dimensions of NXAIR P**

SIMOPRIME

Fig. 3.2-11: **SIMOPRIME panel**

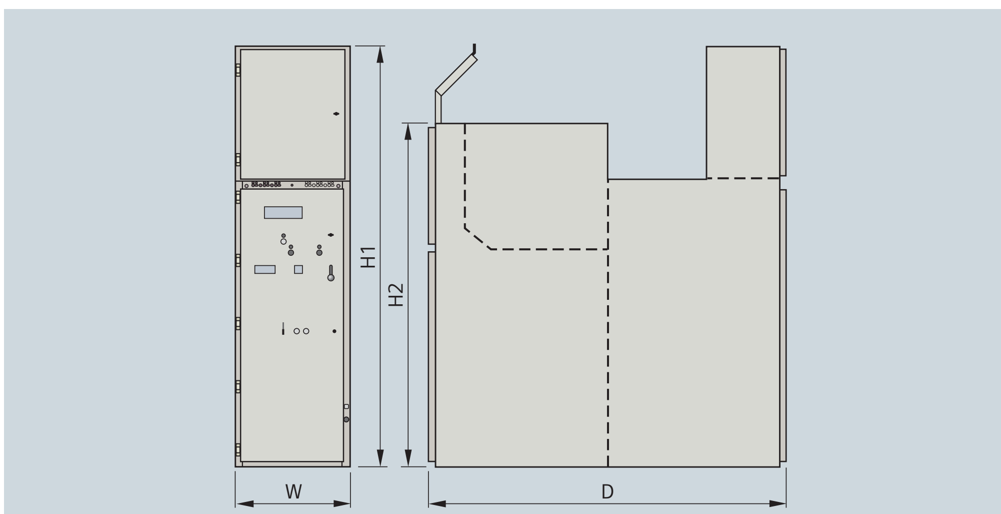
Performance features
The air-insulated, metal-clad switchgear type SIMOPRIME is a factory-assembled, type-tested indoor switchgear for use in the distribution and process level up to 17.5 kV, 40 kA, 3,600 A.

- Metal-enclosed, metal-clad LSC 2B PM switchgear
- Resistance to internal faults: IAC A FLR 40 kA, 1 s
- Type tests of the circuit-breaker and make-proof earthing switch in the panel
- Cable connection from the front or from the rear
- Truck-type design
- Use of block-type or ring-core current transformers
- All switching operations with closed door
- Logical mechanical interlocks

Rated					
Voltage	kV	**7.2**	**12**	**15**	**17.5**
Frequency	Hz	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	35	38
Lightning impulse withstand voltage	kV	60	75	95	95
Short-circuit breaking current	max. kA	40	40	40	40
Short-time withstand current, 3 s	max. kA	40	40	40	40
Short-circuit making current**	max. kA	100	100	100	100
Peak withstand current**	max. kA	100	100	100	100
Normal current of the busbar	max. A	3,600	3,600	3,600	3,600
Normal current of the feeders					
with circuit-breaker	max. A	3,600	3,600	3,600	3,600
with switch-disconnector	max. A	200***	200***	200***	200***
with vacuum contactor	max. A	400***	400***	–	–

* 42 kV optional
** Values for 50 Hz
*** Depending on the rated current of the HV HRC fuses used

Table 3.2-14: **Technical data of SIMOPRIME**



All panel types				**Dimensions in mm ≤ 31.5 kA**	**40 kA**
Width	W	Circuit-breaker panel	≤ 1,250 A	600	800
			2,500 A/3,150 A/3,600 A	800	
		Vacuum contactor panel		400	
		Disconnector panel	≤ 1,250 A	600	800
			2,500 A/3,150 A/3,600 A	800	
		Switch-disconnector/fuse panel	12 kV	600	800
			17.5 kV	600	800
		Bus sectionalizer/circuit-breaker panel	1,250 A	600	800
			≤ 2,500 A/3,150 A/3,600 A	800	
		Bus sectionalizer/bus riser panel	≤ 2,500 A	600	800
			3,150 A/3,600 A	800	
		Metering panel		600	800
Height	H1	With standard low-voltage compartment and IAC 0.1 s		2,200	
		With standard low-voltage compartment and IAC 1.0 s		2,437	
	H2	–		1,780	
Depth	D	Standard		1,860	

Fig. 3.2-12: **Dimensions of SIMOPRIME**

3

8BT1

Fig. 3.2-13: **8BT1 panel**

Performance features

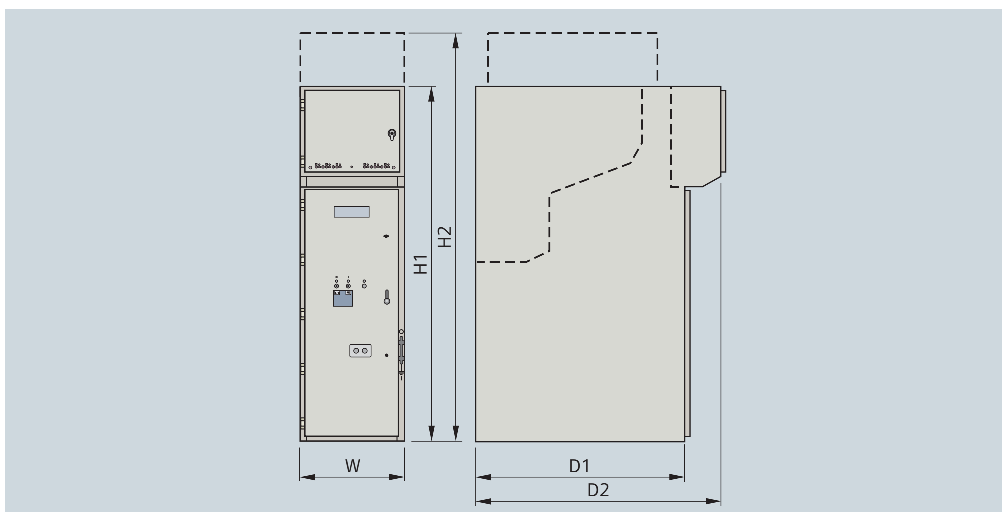
The air-insulated, cubicle-type switchgear type 8BT1 is a factory-assembled, type-tested indoor switchgear for lower ratings in the distribution and process level up to 24 kV, 25 kA, 2,000 A.

- Metal-enclosed, LSC 2A PM cubicle-type switchgear
- Type tests of the circuit-breaker and make-proof earthing switch in the panel
- Tested for resistance to internal faults: IAC A FLR 25 kA, 1 s
- Circuit-breaker panel, fixed-mounted switch-disconnector panel, modular
- Cable connection from the front
- Truck-type design
- Use of block-type current transformers
- All switching operations with closed door
- Logical mechanical interlocks
- Use of SION vacuum circuit-breakers

Rated			
Voltage	kV	**12**	**24**
Frequency	Hz	50	50
Short-duration power-frequency withstand voltage	kV	28	50
Lightning impulse withstand voltage	kV	75	125
Short-circuit breaking current	max. kA	25	25
Short-time withstand current, 3 s	max. kA	25	25
Short-circuit making current	max. kA	63	63
Peak withstand current	max. kA	63	63
Normal current of the busbar	max. A	2,000	2,000
Normal current of the feeders			
with circuit-breaker or disconnector truck	max. A	2,000	2,000
with switch-disconnector	max. A	630 A/200 A*	630 A/200 A*

* Depending on the rated current of the HV HRC fuses used

Table 3.2-15: **Technical data of 8BT1**



All panel types			**Dimensions in mm**
7.2/12 kV			
Width	W	For circuit-breaker max. 1,250 A For circuit-breaker 2,000 A For switch-disconnector	600 800 600
Height	H1 H2 H2	With standard low-voltage compartment With pressure relief system* With lead-off duct*	2,050 2,300 2,350
Depth	D1 D2	Without low-voltage compartment With low-voltage compartment	1,200 1,410
24 kV			
Width	W	For circuit-breaker max. 1,250 A For circuit-breaker 2,000 A For switch-disconnector	800 1,000 800
Height	H1 H2 H2	With standard low-voltage compartment With pressure relief system* With lead-off duct*	2,050 2,300 2,350
Depth	D1 D2	Without low-voltage compartment With low-voltage compartment	1,200 1,410

* For 1 s arc duration

Fig. 3.2-14: **Dimensions of 8BT1**

8BT2

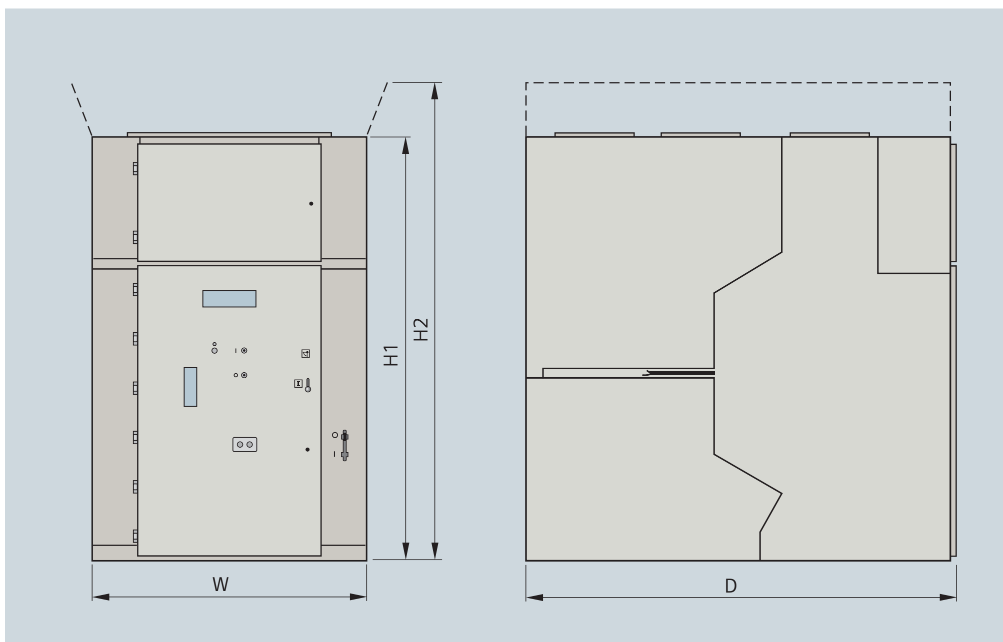
Fig. 3.2-15: **8BT2 switchgear**

Performance features
The air-insulated, metal-clad switchgear type 8BT2 is a factory-assembled, type-tested indoor switchgear for use in the distribution and process level up to 36 kV, 25 kA, 2,500 A.

- LSC 2B PM switchgear
- Tested for resistance to internal faults: IAC A FLR 31.5 kA, 1 s
- Cable connection from the front
- Truck-type design
- Use of block-type current transformers
- All switching operations with closed door
- Logical mechanical interlocks

Rated		
Voltage	kV	**36**
Frequency	Hz	50/60
Short-duration power-frequency withstand voltage	kV	70
Lightning impulse withstand voltage	kV	170
Short-circuit breaking current	max. kA	31.5
Short-time withstand current, 3 s	max. kA	31.5
Short-circuit making current	max. kA	80/82
Peak withstand current	max. kA	80/82
Normal current of the busbar	max. A	2,500
Normal current of the feeders with circuit-breaker with contactor with switch-disconnector	 max. A max. A max. A	 2,500 – –

Table 3.2-16: **Technical data of 8BT2**



Dimensions			**Dimensions in mm**
Width	W		1,550
Height	H1 H2	≤ 25 kA 31.5 kA	2,400 2,775
Depth	D		2,450/2,700* * tested for rear access

Fig. 3.2-16: **Dimensions of 8BT2**

8BT3

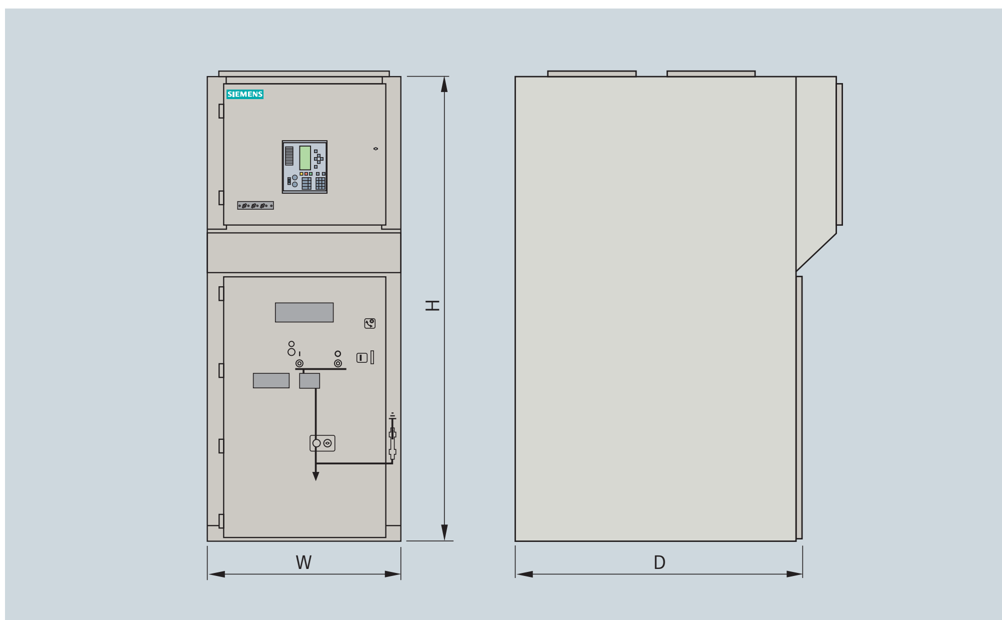
Fig. 3.2-17: **8BT3 switchgear**

Performance features
The air-insulated, cubicle-type switchgear type 8BT3 is a factory-assembled, type-tested indoor switchgear for lower ratings in the distribution and process level up to 36 kV, 16 kA, 1,250 A.

- LSC 1 switchgear
- Tested for resistance to internal faults: IAC FL 16 kA, 1 s
- Circuit-breaker panel, fixed-mounted switch-disconnector panel, modular
- Cable connection from the front
- Truck-type design
- Use of block-type current transformers
- All switching operations with closed door
- Logical mechanical interlocks

Rated		
Voltage	kV	36
Frequency	Hz	50/60
Short-duration power-frequency withstand voltage	kV	70
Lightning impulse withstand voltage	kV	170
Short-circuit breaking current	max. kA	16
Short-time withstand current, 3 s	max. kA	16
Short-circuit making current	max. kA	40/42
Peak withstand current	max. kA	40/42
Normal current of the busbar	max. A	1,250
Normal current of the feeders		
with circuit-breaker	max. A	1,250
with contactor	max. A	–
with switch-disconnector	max. A	400*
* Depending on the rated current of the HV HRC fuses used		

Table 3.2-17: **Technical data of 8BT3**



Dimensions		Dimensions in mm
Width	W	1,000
Height	H	2,400
Depth	D	1,450

Fig. 3.2-18: **Dimensions of 8BT3**

8DJ10

Fig. 3.2-19: **8DJ10 switchgear**

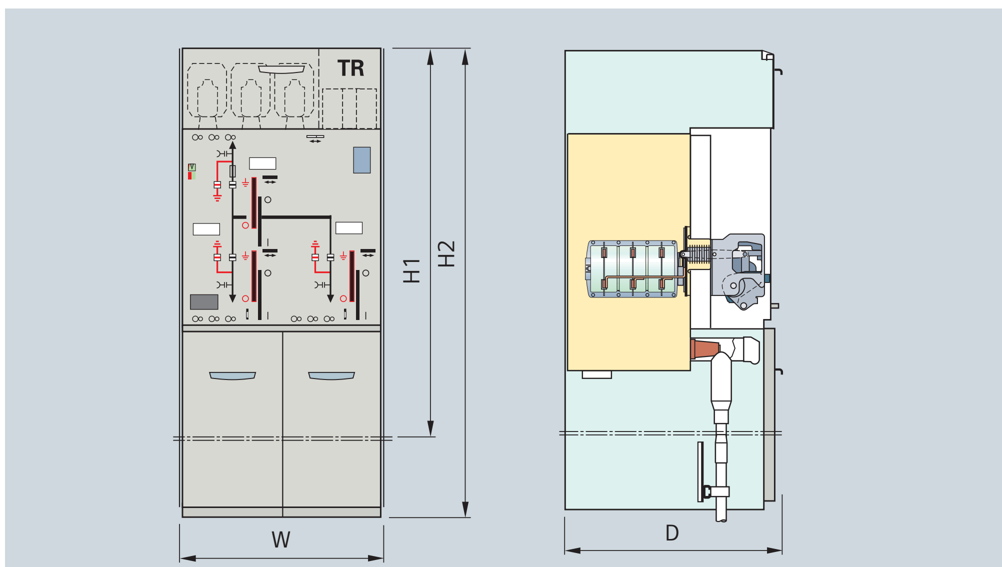
The gas-insulated switchgear type 8DJ10 with switch-disconnectors is used for power distribution in secondary distribution systems up to 24 kV. With its extremely narrow design, block versions with up to six feeders can be used in all types of substations.

Performance features:
- Type-tested according to IEC 62271-200
- Sealed pressure system with SF_6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Block-type construction, non-extendable
- 3-pole, gas-insulated switchgear vessel with three-position switch, for connection of cable plugs
- Operating mechanisms are located outside the switchgear vessel and are easily accessible
- Metal-enclosed, partition class PM

Rated						
Voltage	kV	**7.2**	**12**	**15**	**17.5**	**24**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	36	38	50
Lightning impulse withstand voltage	kV	60	75	95	95	125
Short-time withstand current, 1 s	max. kA	25	25	25	25	20
Short-time withstand current, 3 s	max. kA	–	20	20	20	20
Short-circuit making current	max. kA	25	25	25	25	20
Peak withstand current	max. kA	63	63	63	63	50
Normal current of the ring-main feeders	A	630				
Normal current of the transformer feeders (depending on the HV HRC fuse-link)	A	200				

* 42 kV/75 kV, according to some national requirements

Table 3.2-18: **Technical data of 8DJ10**



Dimensions			Dimensions in mm
Width (module)	W	Connection method: 2RC + 1T (scheme 10) 3RC + 1T (scheme 71) 4RC + 2T (scheme 62)	 710 1,060 1,410
Height	H1 H2	Low structure High structure	1,360 1,650
Depth	D	Standard switchgear Switchgear with pressure absorber	775 880

Fig. 3.2-20: **Internal arc classification according to IEC 62271-200**

- Loss of service continuity category for switchgear:
  – Without HV HRC fuses: LSC 2B
  – With HV HRC fuses: LSC 2A
- Internal arc classification (option): IAC A FL 21 kA, 1 s
- No gas work during installation

Advantages:
- Independent of the environment and climate
- Compact
- Maintenance-free
- High operating and personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

8DJ20

Fig. 3.2-21: **8DJ20 switchgear**

The gas-insulated medium-voltage switchgear type 8DJ20 is used for power distribution in secondary distribution systems up to 24 kV. Ring-main feeders, circuit-breaker feeders and transformer feeders are all part of a comprehensive product range in compact block-type construction to satisfy all requirements – also for extreme ambient conditions.

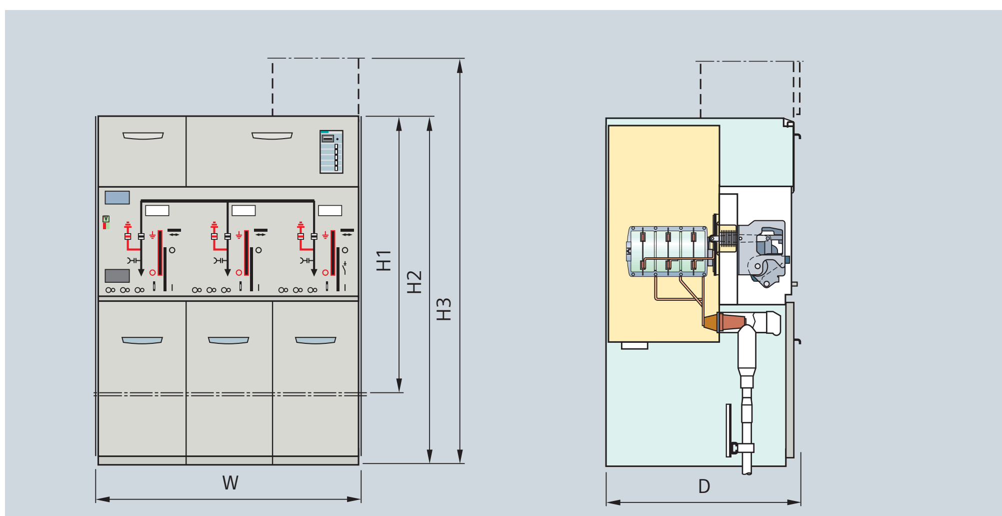
Performance features:

- Type-tested according to IEC 62271-200
- Sealed pressure system with SF_6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Block-type construction, non-extendable
- 3-pole, gas-insulated switchgear vessel with three-position switch, for connection of cable plugs
- Operating mechanisms are located outside the switchgear vessel and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear:
  – Without HV HRC fuses: LSC 2B
  – With HV HRC fuses: LSC 2A
- Internal arc classification (option): IAC A FL 21 kA, 1 s
- No gas work during installation

Rated						
Voltage	kV	**7.2**	**12**	**15**	**17.5**	**24**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	36	38	50
Lightning impulse withstand voltage	kV	60	75	95	95	125
Short-circuit breaking current for switchgear with circuit-breakers	max. kA	20	20	16	16	16
Short-time withstand current, 1 s	max. kA	25	25	25	25	20
Short-time withstand current, 3 s	max. kA	–	20	20	20	20
Short-circuit making current	max. kA	25	25	25	25	20
Peak withstand current	max. kA	63	63	63	63	50
Normal current of the ring-main feeders	A	630				
Normal current of the circuit-breaker feeders	A	250 or 630				
Normal current of the transformer feeders (depending on the HV HRC fuse-link)	A	200				

* 42 kV/75 kV, according to some national requirements

Table 3.2-19: **Technical data of 8DJ20**



Dimensions			Dimensions in mm
Width	W	Number of feeders (in extracts) 2 feeders (e.g., 2RC) 3 feeders (e.g., 2RC + 1T) 4 feeders (e.g., 3RC + 1T, 4RC) 5 feeders (e.g., 4RC + 1T, 5RC)	 710 1,060 1,410 1,760
Height	H1 H2 H3	Low overall height Standard overall height High structure (higher frame)	1,200 1,400 1,760
		Option: Low-voltage compartment, compartment height:	400 or 600
Depth	D	Standard switchgear Switchgear with pressure absorber (option)	775 880

Fig. 3.2-22: **Dimensions of 8DJ20**

Advantages:

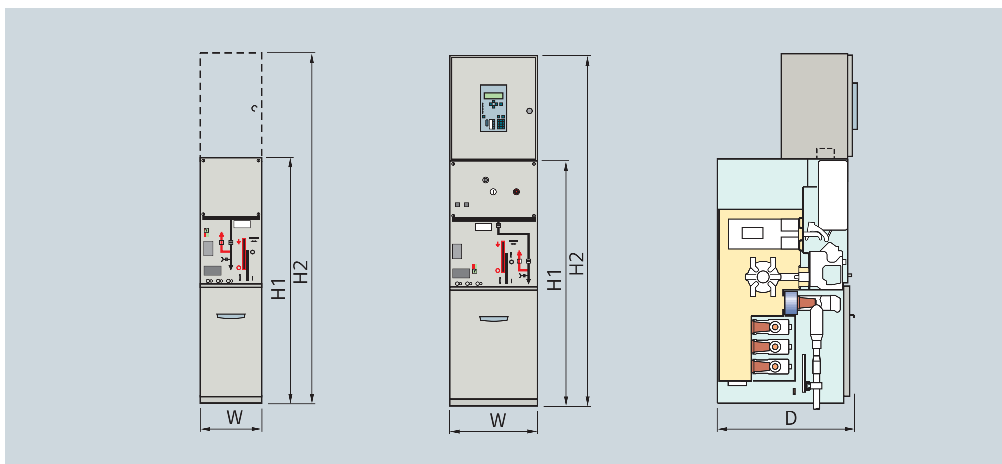
- Independent of the environment and climate
- Compact
- Maintenance-free
- High operating and personal safety
- Environmentally compatible
- Cost-efficient

8DH10

Fig. 3.2-23: **8DH10 switchgear**

Rated						
Voltage	kV	**7.2**	**12**	**15**	**17.5**	**24**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	36	38	50
Lightning impulse withstand voltage	kV	60	75	95	95	125
Short-circuit breaking current	max. kA	25	25	25	25	20
Short-time withstand current, 1 s	max. kA	25	25	25	25	20
Short-time withstand current, 3 s	max. kA	–	20	20	20	20
Short-circuit making current	max. kA	25	25	25	25	20
Peak withstand current	max. kA	63	63	63	63	50
Normal current of the busbar	A	630 or 1,250				
Normal current of the feeders	A	630	630	630	630	630
* 42 kV/75 kV, according to some national requirements						

Table 3.2-20: **Technical data of 8DH10**



Dimensions			Dimensions in mm
Width	W	Ring-main feeders Transformer feeders, circuit-breaker feeders, bus sectionalizer panels	350/500 500 500
		Metering panels	600/850
		Panel blocks	700/1,050/1,400
Height	H1 H2 H3	Panels without low-voltage compartment Panels with low-voltage compartment Switchgear with pressure absorber (option)	1,400 2,000 or 2,300 1,700/2,300 or 2,600
Depth	D	Standard switchgear Switchgear with pressure absorber (option)	775 890

Fig. 3.2-24: **Dimensions of 8DH10**

The gas-insulated medium-voltage switchgear type 8DH10 is used for power distribution in secondary and primary distribution systems up to 24 kV. The product range includes individual panels such as ring-main, transformer and circuit-breaker panels or metering panels, as well as panel blocks, to satisfy all requirements with the highest level of operational reliability.

Performance features:
- Type-tested according to IEC 62271-200
- Sealed pressure system with SF_6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 1-pole insulated busbar
- 3-pole gas-insulated switchgear vessels with three-position switch, circuit-breaker and earthing switch for connection of cable plugs
- Operating mechanisms and transformers are located outside the switchgear vessel and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear:
  – Without HV HRC fuses: LSC 2B
  – With HV HRC fuses: LSC 2A
- Internal arc classification (option) for:
  – Wall-standing arrangement:
  IAC A FL 21 kA, 1 s
  – Free-standing arrangement:
  IAC A FLR 21 kA, 1 s
- No gas work during installation or extension

Advantages:
- Independent of the environment and climate
- Compact
- Maintenance-free
- High operating and personal safety
- Operational reliability and security of investment
- Environmentally compatible
- Cost-efficient

3

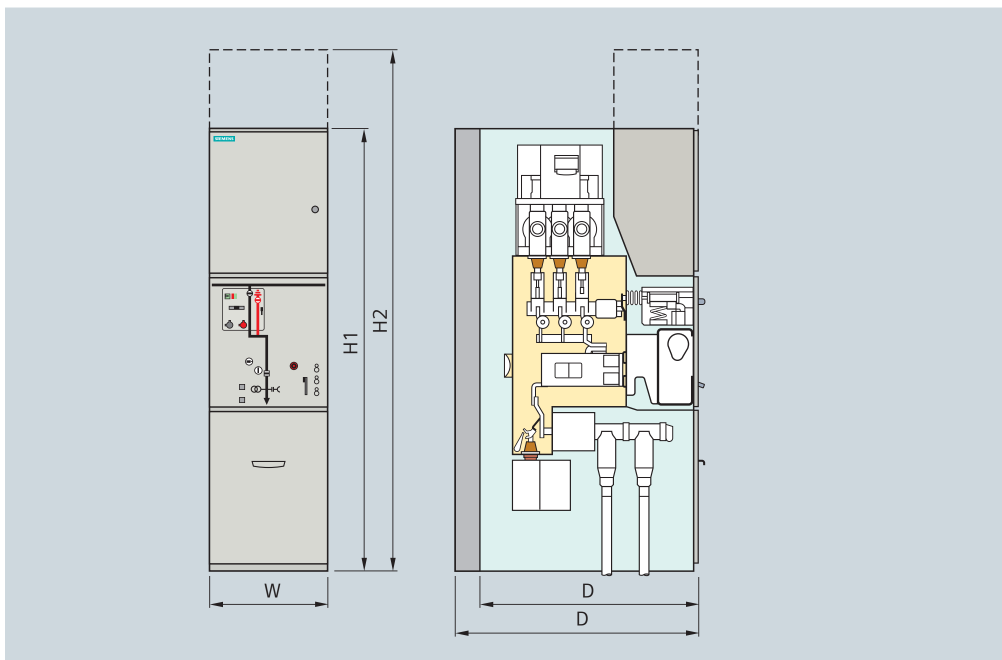
NXPLUS C

Fig. 3.2-25: **NXPLUS C panel**

Rated						
Voltage	kV	**7.2**	**12**	**15**	**17.5**	**24**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	36	38	50
Lightning impulse withstand voltage	kV	60	75	95	95	125
Short-circuit breaking current	max. kA	31.5	31.5	31.5	25	25
Short-time withstand current, 3 s	max. kA	31.5	31.5	31.5	25	25
Short-circuit making current	max. kA	80	80	80	63	63
Peak withstand current	max. kA	80	80	80	63	63
Normal current of the busbar	max. A	2,500	2,500	2,500	2,500	2,500
Normal current of the feeders	max. A	2,500	2,500	2,500	2,000	2,000

* 42 kV/75 kV, according to some national requirements

Table 3.2-21: **Technical data of NXPLUS C**



Dimensions			Dimensions in mm
Width	W	630 A/1,000 A/1,250 A	600
		2,000 A/2,500 A	900
Height	H1 H2	Standard design For higher low-voltage compartment	2,250 2,650
Depth	D	Wall-standing arrangement Free-standing arrangement	1,100 1,250

Fig. 3.2-26: **Dimensions of NXPLUS C**

The compact NXPLUS C is the medium-voltage circuit-breaker switchgear that made gas insulation with the proven vacuum switching technology economical in its class. The NXPLUS C is used for secondary and primary distribution systems up to 24 kV, up to 31.5 kA and up to 2,500 A. It can also be supplied as double-busbar switchgear in a back-to-back arrangement (see Catalog HA35.41).

Performance features:

- Type-tested according to IEC 62271-200
- Sealed pressure system with SF_6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- 1-pole insulated and screened busbar
- 3-pole gas-insulated switchgear vessels with three-position switch and circuit-breaker, for connection of cable plugs
- Operating mechanisms and transformers are located outside the switchgear vessel and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear:
  – Without HV HRC fuses: LSC 2B
  – With HV HRC fuses: LSC 2A
- Internal arc classification for:
  – Wall-standing arrangement: IAC A FL 31.5 kA, 1 s
  – Free-standing arrangement: IAC A FLR 31.5 kA, 1 s

Advantages:

- No gas work during installation or extension
- Compact
- Independent of the environment and climate
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

8DA/8DB

Fig. 3.2-27: **8DA (on the left) for single-busbar and 8DB for double-busbar applications**

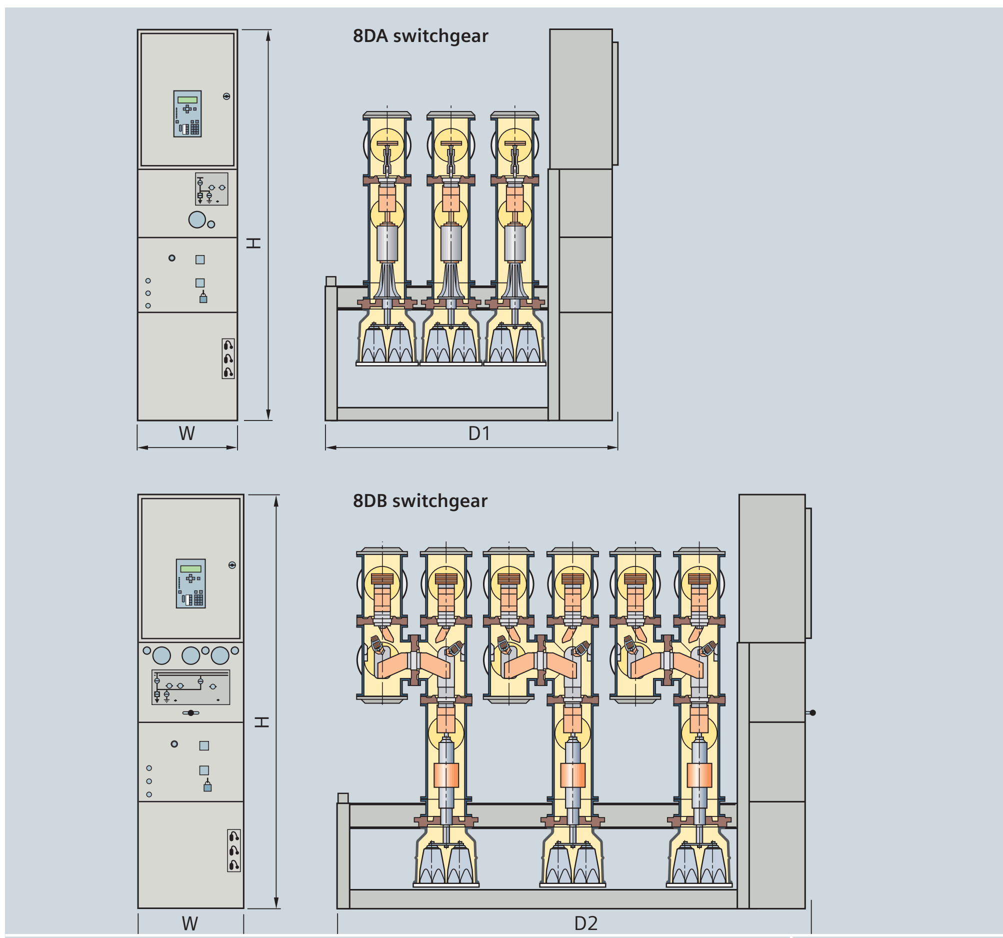
8DA/8DB are gas-insulated medium-voltage circuit-breaker switchgear assemblies up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. 8DA/8DB is suitable for primary distribution systems up to 40.5 kV, 40 kA, up to 4000 A.

Performance features:

- Type-tested according to IEC 62271-200
- Enclosure with modular standardized housings made from corrosion-resistant aluminum alloy
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Operating mechanisms and transformers are easily accessible outside the enclosure
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2B
- Internal arc classification: IAC A FLR 40 kA 1 s

Rated					
Voltage	kV	**12**	**24**	**36**	**40.5**
Frequency	Hz	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	28	50	70	50
Lightning impulse withstand voltage	kV	75	125	170	185
Short-circuit breaking current	max. kA	40	40	40	40
Short-time withstand current, 3 s	max. kA	40	40	40	40
Short-circuit making current	max. kA	100	100	100	100
Peak withstand current	max. kA	100	100	100	100
Normal current of the busbar	max. A	5,000	5,000	5,000	5,000
Normal current of the feeders	max. A	2,500	2,500	2,500	2,500

Table 3.2-22: **Technical data of 8DA/8DB**



Dimensions			**Dimensions in mm**
Width (spacing)	W		600
Height	H	Standard design Design with higher low-voltage compartment	2,350 2,700
Depth	D1 D2	Single-busbar switchgear Double-busbar switchgear	1,625 2,660

Fig. 3.2-28: **Dimensions of 8DA/8DB**

Advantages:

- Independent of the environment and climate
- Compact
- Low maintenance
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

NXPLUS

Fig. 3.2-29: **NXPLUS switchgear for single-busbar applications (on the left), NXPLUS switchgear for double-busbar applications (on the right)**

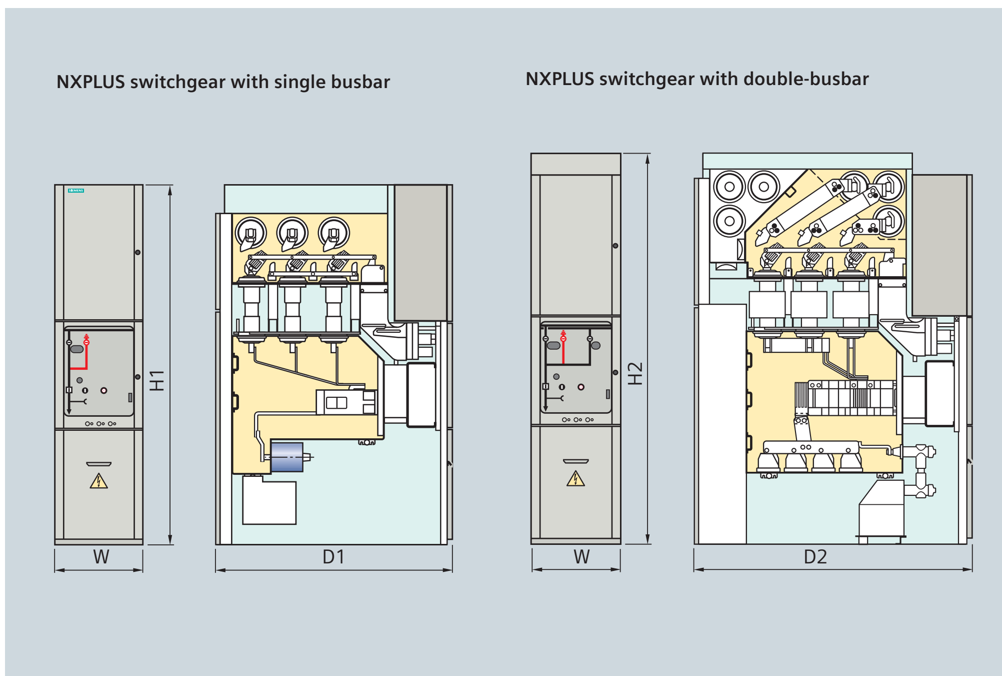
NXPLUS is a gas-insulated medium-voltage circuit-breaker switchgear up to 40.5 kV with the advantages of the vacuum switching technology – for a high degree of independence in all applications. NXPLUS can be used for primary distribution systems up to 40.5 kV, up to 31.5 kA, up to 2,000 A (for double-busbar switchgear up to 2,500 A).

Performance features:
- Type-tested according to IEC 62271-200
- Sealed pressure system with SF_6 filling for the entire service life
- Safe-to-touch enclosure and standardized connections for plug-in cable terminations
- Separate 3-pole gas-insulated modules for busbar with three-position disconnector, and for circuit-breaker, for connection of cable plugs
- Interconnection of modules with 1-pole insulated and screened module couplings
- Operating mechanisms and transformers are arranged outside the switchgear vessels and are easily accessible
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: LSC 2B
- Internal arc classification: IAC A FLR 31,5 kA, 1 s
- No gas work during installation or extension

Advantages:
- Independent of the environment and climate
- Compact
- Maintenance-free
- Personal safety
- Operational reliability
- Environmentally compatible
- Cost-efficient

Rated						
Voltage	kV	**7.2**	**12**	**24**	**36**	**40.5**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28	50	70	85
Lightning impulse withstand voltage	kV	60	75	125	170	185
Short-circuit breaking current	max. kA	31.5	31.5	31.5	31.5	31.5
Short-time withstand current, 3 s	max. kA	31.5	31.5	31.5	31.5	31.5
Short-circuit making current	max. kA	80	80	80	80	80
Peak withstand current	max. kA	80	80	80	80	80
Normal current of the busbar	max. A	2,500	2,500	2,500	2,500	2,000
Normal current of the feeders	max. A	2,500	2,500	2,500	2,500	2,000

Table 3.2-23: **Technical data of NXPLUS**



Dimensions			**Dimensions in mm**
Width (spacing)	W	Feeders up to 1,250 A	600
Height	H H1 H2	Switchgear design Single-busbar switchgear Double-busbar switchgear	 2,450 2,600
Depth	D1 D2	Single-busbar switchgear Double-busbar switchgear	1,600 1,840

Fig. 3.2-30: **Dimensions of NXPLUS**

SIMOSEC

Fig. 3.2-31: **SIMOSEC switchgear**

The air-insulated medium-voltage switchgear type SIMOSEC is used for power distribution in secondary and primary distribution systems up to 24 kV and up to 1,250 A. The modular product range includes individual panels such as ring-main, transformer and circuit-breaker panels or metering panels to fully satisfy all requirements for power supply companies and industrial applications.

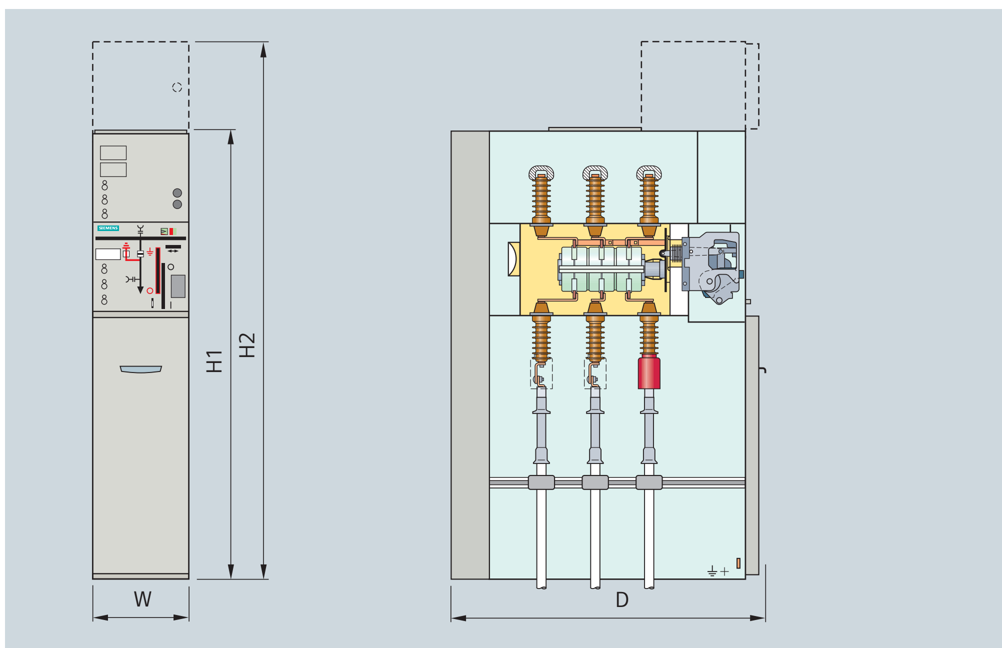
Performance features:

- Type-tested according to IEC 62271-200
- Phases for busbar and cable connection are arranged one behind the other
- 3-pole gas-insulated switchgear vessel with three-position disconnector, circuit-breaker and earthing switch as a sealed pressure system with SF_6 filling for the entire service life
- Air-insulated busbar system
- Air-insulated cable connection system, for conventional cable sealing ends
- Metal-enclosed, partition class PM
- Loss of service continuity category for switchgear: Without HV HRC fuses: LSC 2B With HV HRC fuses: LSC 2A

Rated						
Voltage	kV	**7.2**	**12**	**15**	**17.5**	**24**
Frequency	Hz	50/60	50/60	50/60	50/60	50/60
Short-duration power-frequency withstand voltage	kV	20	28*	36	38	50
Lightning impulse withstand voltage	kV	60	75	95	95	125
Short-circuit breaking current	max. kA	25	25	25	25	20
Short-time withstand current, 1 s	max. kA	25	25	25	25	20
Short-time withstand current, 3 s	max. kA	–	20	20	20	20
Short-circuit making current	max. kA	25	25	25	25	20
Peak withstand current	max. kA	63	63	63	63	50
Normal current of the busbar	A	630 or 1,250				
Normal current of the feeders	max. A	1,250	1,250	1,250	1,250	1,250

* 42 kV/75 kV, according to some national requirements

Table 3.2-24: **Technical data of SIMOSEC**



Dimensions			**Dimensions in mm**
Width (spacing)	W	Ring-main feeders, transformer feeders	375 or 500
		Circuit-breaker feeders, bus sectionalizer	750 or 875
		Metering panels	750
Height	H1 H2	Panels without low-voltage compartment Panels without low-voltage compartment	1,760 2,100 or 2,300
Depth	D	Standard	1,230

Fig. 3.2-32: **Dimensions of SIMOSEC**

- Internal arc classification for:
  - Wall-standing arrangement: IAC A FL 20 kA, 1 s
  - Free-standing arrangement: IAC A FLR 20 kA, 1 s
- Can be mounted side by side and extended as desired

Advantages:

- Compact modular design
- High operating and personal safety
- Environmentally compatible
- Cost-efficient

3.2.5 High-Current and Generator Switchgear

As central components, high-current and generator switchgear provides the link between the generator and the transformer (feeding into the transmission and distribution networks). Siemens offers various generator switchgear types with rated voltages up to 17.5 kV, rated currents up to 10,000 A and rated short-circuit breaking currents up to 72 kA for indoor and outdoor installations.

The heart of the generator switchgear is the circuit-breaker. Its primary function is to withstand very high currents and to switch off extremely high short-circuit currents. Siemens generator circuit-breakers, designed using environmentally friendly vacuum switching technology, are designed to withstand maximum normal currents and meet the demanding requirements of the generator circuit-breaker standard IEEE C37.013-1997.

Performance features:
- High mechanical stability
- Low fire load
- High operational safety

HIGS (highly integrated generator switchgear)
HIGS is an air-insulated, metal-enclosed generator switchgear for voltages and currents up to 13.8 kV, 63 kA, 3,150 A for indoor and outdoor installation. For the first time, the neutral treatment of the generator as well as the auxiliary feeder are integrated in a single generator switchgear (fig. 3.2-33).

Performance features:
- Generator circuit-breaker according to IEEE C37.013 in the main transformer feeder
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Integrated auxiliary feeder with disconnector and generator circuit-breaker or with switch-disconnector and fuses

The technical data of HIGS and generator switchgear is shown in the table 3.2-25.

Fig. 3.2-33: **HIGS**

Type		HIGS	8BK40	HB1	HB1 Outdoor	HB3
Installation		IR, FL	IR	IR	FL	IR, FL
Dimensions L x W x H	mm	3,430 x 1,200 x 2,500	2,300 x 1,100 x 2,500	4,000 x 1,900 x 2,500*	6,300 x 1,900 x 2,600*	2,900 x 4,040 x 2,400*
Rated voltage	kV	13.8	max. 17.5	17.5	17.5	17.5
Rated lightning impulse withstand voltage	kV	110	95	110	110	110
Rated short-duration power-frequency withstand voltage	kV	50	38	50	50	50
Rated short-circuit-breaking current	kA	31.5 – 63	50/63	50/63/72	50/63/72	50/63/72
Rated normal current:	A	2,000 – 3,150		max. 6,100	max. 5,400	max 10,000
of the busbar			5,000			
of the feeder			5,000			

* Measurements may vary according to type

Table 3.2-25: **Technical data of HIGS and generator switchgear**

8BK40

8BK40 is an air-insulated, metal-enclosed generator switchgear with truck-type circuit-breaker for indoor installation up to 17.5 kV; 63 kA; 5,000 A (fig. 3.2-34).

Performance features:

- Generator circuit-breaker according to IEEE C37.013, or circuit-breaker according to IEC 62271-100
- Disconnecting function by means of truck-type circuit-breaker
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors

HB1, HB1 Outdoor and HB3

This is an air-insulated, metal-enclosed horizontal busbar switchgear, not phase-segregated (HB1, HB1 Outdoor, fig. 3.2-35, fig. 3.2-36) or phase-segregated (HB3, fig. 3.2-37).

Performance features:

- Generator circuit-breaker according to IEEE C37.013
- Disconnector
- Earthing switch on generator and transformer side
- Current and voltage transformers
- Surge arresters
- Surge capacitors
- Further options
  - Integrated SFC starter
  - Integrated auxiliary feeder, with generator circuit-breaker or with switch-disconnector and fuses
  - Integrated excitation feeder
  - Brake switch

Fig. 3.2-34: **8BK40**

Fig. 3.2-35: **HB1**

Fig. 3.2-36: **HB1 Outdoor**

Fig. 3.2-37: **HB3**

3

3.2.6 Industrial Load Center Substation

Introduction
Industrial power supply systems call for a maximum level of personal safety, operational reliability, economic efficiency and flexibility. And they likewise necessitate an integral approach that includes "before" and "after" customer service, that can cope with the specific load requirements and, above all, that is tailored to each individually occurring situation. With SITRABLOC® (fig. 3.2-38), such an approach can be easily turned into reality.

General
SITRABLOC is an acronym for Siemens TRAnsformer BLOC-type. SITRABLOC is supplied with power from a medium-voltage substation via a fuse/switch-disconnector combination and a radial cable. In the load center, where SITRABLOC is installed, several SITRABLOCs are connected together by means of cables or bars (fig. 3.2-39).

Features
- Due to the fuse/switch-disconnector combination, the short-circuit current is limited, which means that the radial cable can be dimensioned according to the size of the transformer.
- In the event of cable faults, only one SITRABLOC fails.
- The short-circuit strength is increased due to the connection of several stations in the load center. The effect of this is that, in the event of a fault, large loads are selectively disconnected in a very short time.
- The transmission losses are optimized because only short connections to the loads are necessary.
- SITRABLOC has, in principle, two transformer outputs:
  - 1,250 kVA during AN operation (ambient air temperature up to 40 °C)
  - 1,750 kVA during AF operation (140 % with forced cooling)

These features ensure that, if one station fails, for whatever reason, supply of the loads is maintained without interruption.

The SITRABLOC components are:
- Transformer housing with roof-mounted ventilation for AN/AF operating mode
- GEAFOL transformer
  - (Cast-resin insulated) with make-proof earthing switch
  - AN operating mode: 100 % load up to an ambient air temperature of 40 °C
  - AF operating mode: 140 % load
- LV circuit-breaker as per transformer AF load
- Automatic power factor correction equipment (tuned/detuned)
- Control and metering panel as well as central monitoring interface
- Universal connection to the LV distribution busway system (fig. 3.2-40)

Whether in the automobile or food industry, in paint shops or bottling lines, putting SITRABLOC to work in the right place considerably reduces transmission losses. The energy is transformed in the production area itself, as close as possible to the loads. For installation of the system itself, no special building or fire-protection measures are necessary.

Available with any level of output
SITRABLOC can be supplied with any level of power output, the latter being controlled and protected by a fuse/switch-disconnector combination.

A high-current busbar system into which up to four transformers can feed power ensures that even large loads can be brought onto load without any loss of energy. Due to the interconnection of units, it is also ensured that large loads are switched off selectively in the event of a fault.

Fig. 3.2-38: **SITRABLOC system**

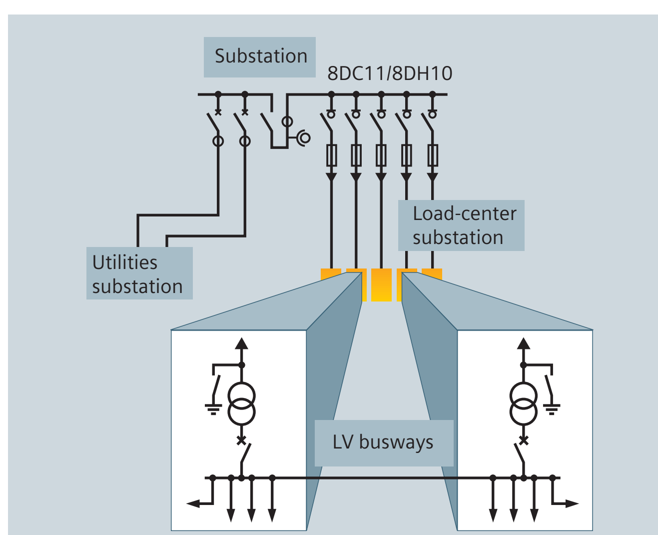


Fig. 3.2-39: **Example of a schematic diagram**

Integrated automatic power factor correction
With SITRABLOC, power factor correction is integrated from the very beginning. Unavoidable energy losses – e.g., due to magnetization in the case of motors and transformers – are balanced out with power capacitors directly in the low-voltage network. The advantages are that the level of active power transmitted increases and energy costs are reduced (fig. 3.2-41).

Reliability of supply
With the correctly designed transformer output, the n-1 criterion is no longer a problem. Even if one module fails (e.g., a medium-voltage switching device or a cable or transformer), power continues to be supplied without the slightest interruption. None of the drives comes to a standstill, and the whole manufacturing plant continues to run reliably. With SITRABLOC, the power is where it is needed – and it is safe, reliable and economical.

n-1 operating mode
n-1 criteria
With the respective design of a factory grid on the MV side as well as on the LV side, the so-called n-1 criteria is fulfilled. In case one component fails on the line side of the transformer (e.g., circuit-breaker or transformer or cable to transformer) no interruption of the supply on the LV side will occur (fig. 3.2-42).

Load required 5,000 kVA = 4 x 1,250 kVA. In case one load center (SITRABLOC) is disconnected from the MV network, the missing load will be supplied via the remaining three (n-1) load centers. SITRABLOC is a combination of everything that present-day technology has to offer. The GEAFOL® cast-resin transformers are just one example of this.

Their output is 100 % load without fans plus reserves of up to 140 % with fans. The safety of operational staff is ensured – even in the direct vicinity of the installation.

Another example is the SENTRON high-current busbar system. It can be laid out in any arrangement, is easy to install and conducts the current wherever you like – With almost no losses. The most important thing, however, is the uniformity of SITRABLOC throughout, regardless of the layout of the modules.

The technology at a glance
(table 3.2-26, fig. 3.2-44, next page)
SITRABLOC can cope with any requirements. Its features include:

- A transformer cubicle with or without fans (AN/AF operation)
- GEAFOL cast-resin transformers with make-proof earthing switch – AN operation 1,250 kVA, AF operation 1,750 kVA (fig. 3.2-43, next page)
- External medium-voltage switchgear with fuse/switch-disconnectors
- Low-voltage circuit-breakers
- Automatic reactive-power compensation: up to 500 kVAr unrestricted, up to 300 kVAr restricted
- The SENTRON high-current busbar system: connection to high-current busbar systems from all directions
- SIMATIC ET 200/PROFIBUS interface for central monitoring system (if required).

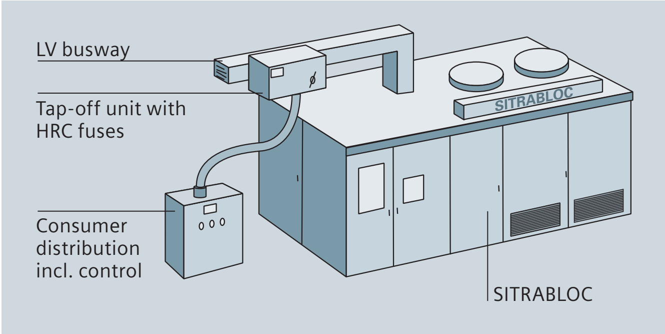


Fig. 3.2-40: **Location sketch**

Rated voltage	12 kV and 24 kV
Transformer rating AN/AF	1,250 kV A/1,750 kVA
Transformer operating mode	100 % AN up to 40 °C 140 % AF
Power factor correction	up to 500 kVAr without reactors up to 300 kVAr with reactors
Busway system	1,250 A; 1,600 A; 2,500 A
Degree of protection	IP23 for transformer housing IP43 for LV cubicles
Dimensions (min) (LxHxD)	3,600 mm x 2,560 mm x 1,400 mm
Weight approx.	6,000 kg

Table 3.2-26: **Technical data of SITRABLOC**

Fig. 3.2-41: **Capacitor Banks**

3

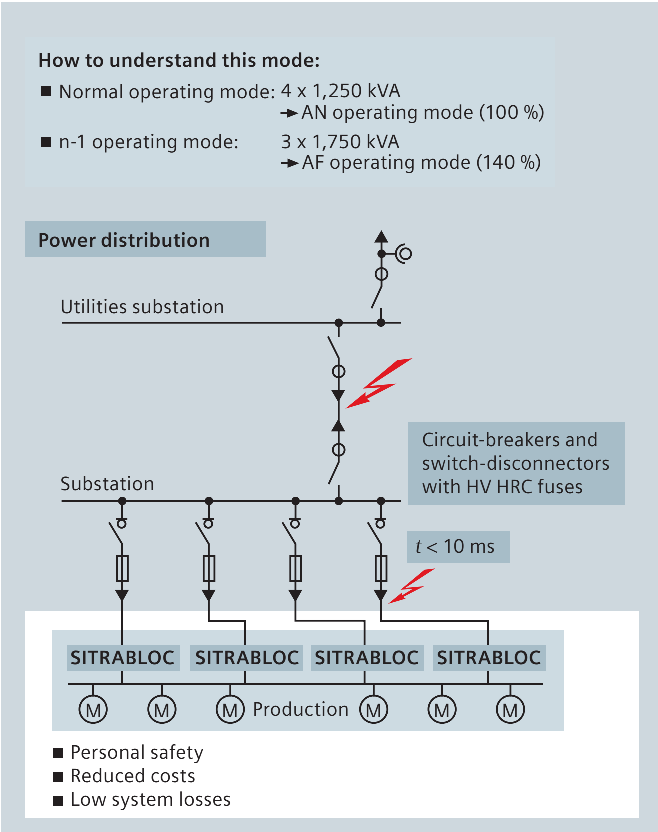


Fig. 3.2-42: **n-1 operating mode**

Fig. 3.2-43: **Transformer and earthing switch, LV bloc**

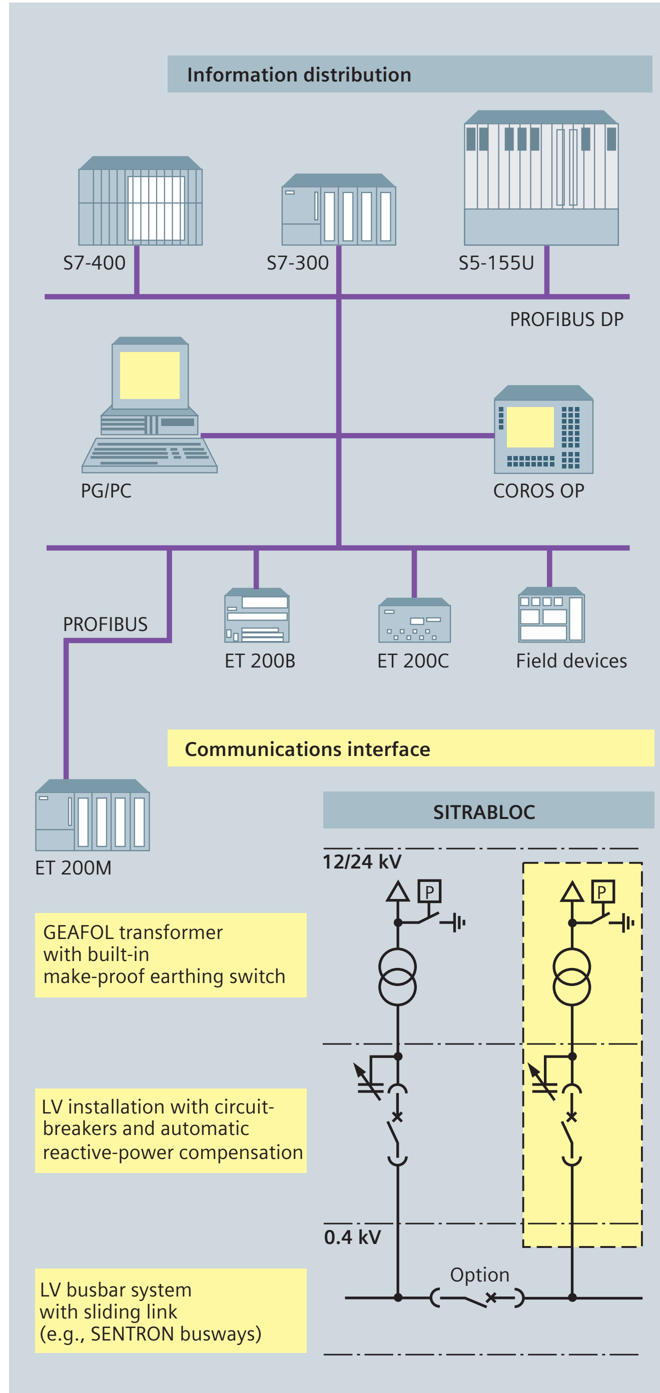


Fig. 3.2-44: **SIMATIC ET 200/PROFIBUS interface for control monitoring system**

For further information please contact:
Fax: ++ 49 91 31 7-3 15 73

3.3 Low-Voltage Switchgear

3.3.1 Requirements for Electrical Power Systems in Buildings

The efficiency of a power supply system depends on the quality for system planning (fig. 3.3-1). For this reason, power supply concepts must always be assessed in the context of their framework parameters and project goals. When focusing on power supply in the field of building infrastructure, the spectrum of reasonable options can be narrowed down.

When designing a power distribution system, the focus should be on the following aspects:

- Simplification of operational management by transparent, simple power system structures
- Low power-loss costs, e.g., by medium-voltage side power transmission to the load centers
- High supply and operational safety of the installations, even in the event of individual equipment failures (redundant supply, selectivity of the power system protection and high availability)
- Easy adaptation to changing load and operational conditions
- Low operating cost due to equipment that is easy to maintain
- Sufficient transmission capacity of the equipment under normal operating conditions as well as in fault conditions that arise
- Good quality of the power supply, i.e., few voltage changes due to load fluctuations, with sufficient voltage symmetry and few harmonic distortions in the voltage
- Compliance with IEC/EN/VDE specifications and project-related stipulations for special installations

Standards

To minimize technical risks and/or to protect persons involved in handling electric equipment or components, major planning rules have been compiled in standards. Standards represent the state of the art; they are the basis for evaluation and legal decisions.

Technical standards are desired conditions stipulated by professional associations that are made binding by various legal standards, for example, requiring safety in the workplace. Furthermore, compliance with technical standards is crucial for any approval of operation granted by authorities, and for obtaining insurance coverage.

While in the past standards were mainly drafted at a national level and debated in regional (e.g., European, American) committees, it has now been agreed upon that drafts will be submitted at the central (IEC) level and then adopted as regional or national standards. Today, a standard will be drafted regionally only if the IEC is not interested in dealing with the matter or if there are time constraints for establishing a new standard.

The interrelations of the different standardization levels is illustrated in table 3.3-1.

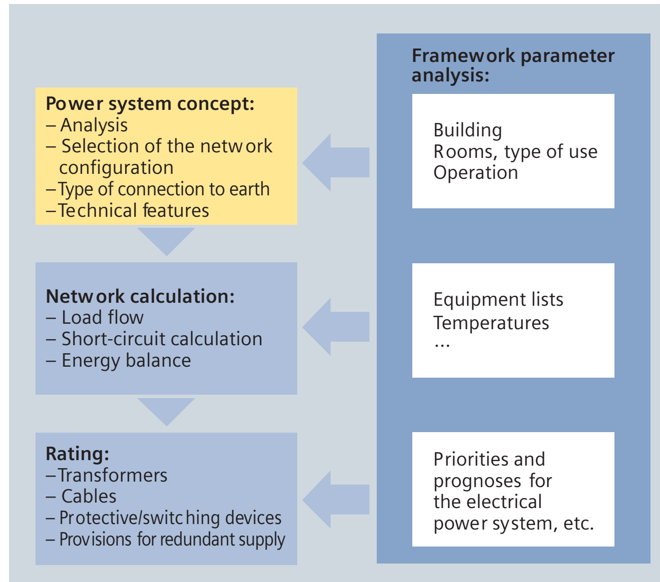


Fig. 3.3-1: **Power system planning tasks**

Regional	America PAS	Europe CENELEC	Australia	Asia	Africa
National	USA: ANSI	D: DIN VDE	AUS: SA	CN: SAC	SA: SABS
	CA: SCC	I: CEI	NZ: SNZ	J: JISC	
	BR: COBEI	F: UTE		...	
	...	GB: BS			

ANSI	American National Standards Institute
BS	British Standards
CENELEC	European Committee for Electrotechnical Standardization (Comité Européen de Normalisation Electrotechnique)
CEI	Italian Electrical Engineering Committee (Comitato Elettrotecnico Italiano)
COBEI	Comitê Brasileiro de Eletricidade, Eletrônica, Iluminação e Telecomunicações
SAC	Standardisation Administration of China
DIN VDE	German Industrial Standard, Association of German Electrical Engineers
IEC	International Electrical Engineering Commission
JISC	Japanese Industrial Standards Committee
PAS	Pacific Area Standards
SABS	South African Bureau of Standards
SA	Standards Australia
SCC	Standards Council of Canada
SNZ	Standards New Zealand
UTE	Technical Association of Electrical Engineering & Communications (Union Technique de L'electricite et de la Comunication)

Table 3.3-1: **Interdependencies of national, regional and international standards for electrical engineering**

Network configurations

The supply task determines the configuration of a power system. Buildings featuring different power densities can therefore be distinguished according to their type of configuration.

An optimum configuration should meet the following requirements in particular:

- Simple structure
- High reliability of supply
- Low losses
- Favorable and flexible expansion options

The following characteristics should be selected accordingly:

- Type of meshing
- Number of feeder points
- Type of supply

Radial networks

Low-voltage side power distribution is best designed in a radial topology (fig. 3.3-2).

The clearly hierarchical structuring of a radial network offers the following advantages:

- Easy monitoring of the power system
- Fast fault location
- Simple power system protection
- Easy operation

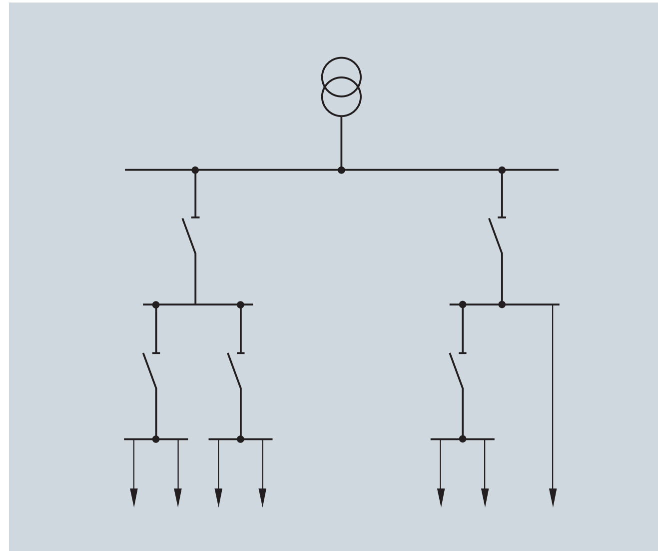
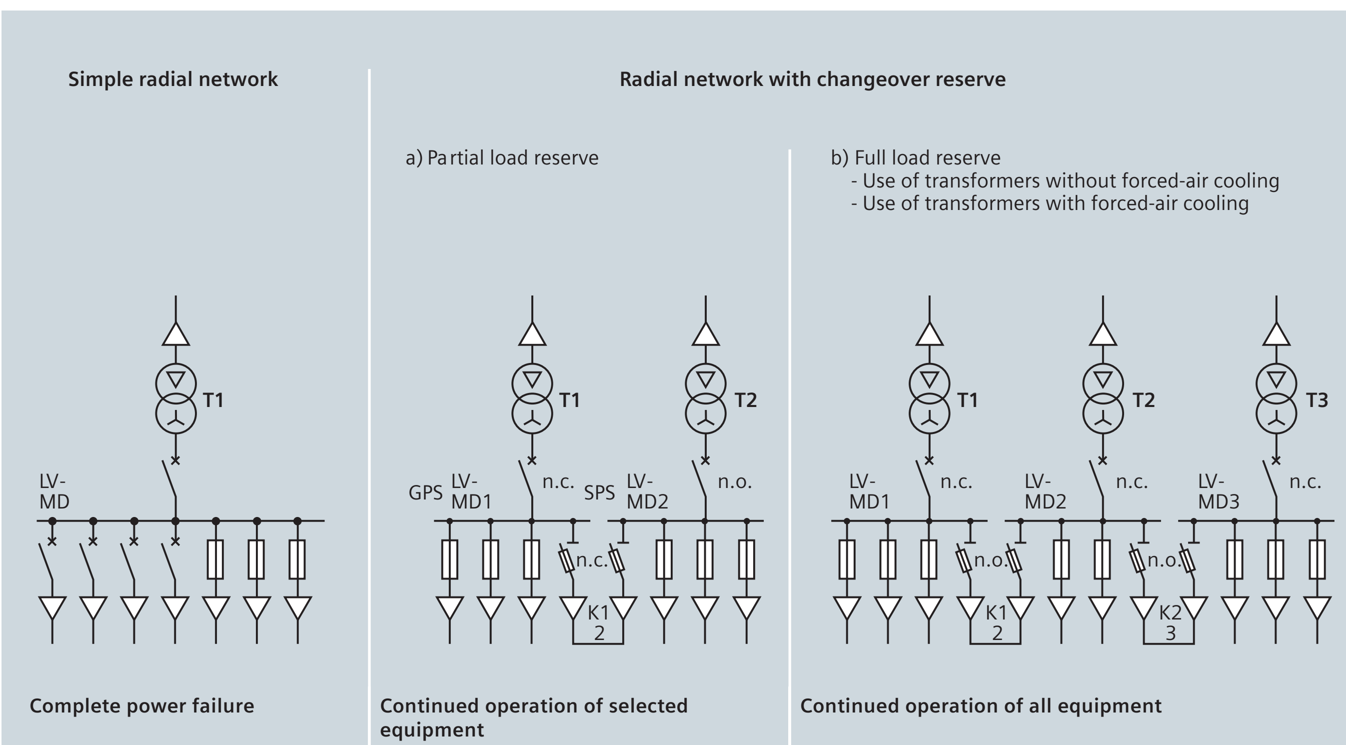


Fig. 3.3-2: **Radial network**



$S_{N,T1} \geq P_{total}/\cos\varphi$	$(n\text{-}1)\ 8\ S_{N,i} < P_{total}/\cos\varphi < n \cdot S_{N,i}$	$(n\text{-}1) \cdot a_i \cdot S_{N,i} \geq P_{total}/\cos\varphi$

n.c. = Normally closed; n.o. = Normally open; K1, K2 = Cable route with current-limiting fuse; n = Number of transformers; $_i$ = Index for transformers T1, T2, T3; a_i = Utilization factor; in the example a_i = 0.66 for unvented transformers and a_i = 0.9 for vented transformers

Fig. 3.3-3: **Radial topology variants**

Because the operation of a meshed system places high demands on plant management, the radial system is generally preferred at the infrastructure level, for economical reasons. Ring-type systems are mainly used in highly consumptive industrial processes in combination with high-current busbar trunking systems, because these systems have the advantage of reliable and flexible supply for the equipment. They are also used for public grids at a level > 1 kV.

Number of feeder points
The availability of the radial power system can be optimized by means of its supply configuration. Fig. 3.3-3 shows the optimization of a radial network, assuming a transformer failure.

Type of supply
Electrical energy can be fed into the power system in different ways depending on its primary function (table 3.3-2).

For general power supply (GPS):
- Direct connection to the public grid: normally up to 300 kW at 400 V
- Supply from the medium-voltage system (up to 52 kV) via distribution transformers up to 2 MVA

For redundant power supply (RPS), power sources are selected depending on the permissible interruption time as follows (table 3.3-2):
- Generators, for safety power supply
- Second independent system supply with automatic changeover, for safety supply equipment
- Static uninterruptible power supply (UPS) from a rectifier/inverter unit or storage battery
- Rotating UPS consisting of motor and generator set

Type	Example
General power supply (GPS)	Supply of all installations and consumer devices available in the building
Safety power supply (SPS)	Supply of life-protecting facilities in cases of emergency: ▪ Safety lighting ▪ Elevators for firefighters ▪ Fire-extinguishing equipment
Uninterruptible power supply (UPS)	Supply of sensitive consumer devices that must be operated without interruption in the event of a GPS failure: ▪ Emergency lighting ▪ Servers/computers ▪ Communications equipment

Table 3.3-2: **Supply types**

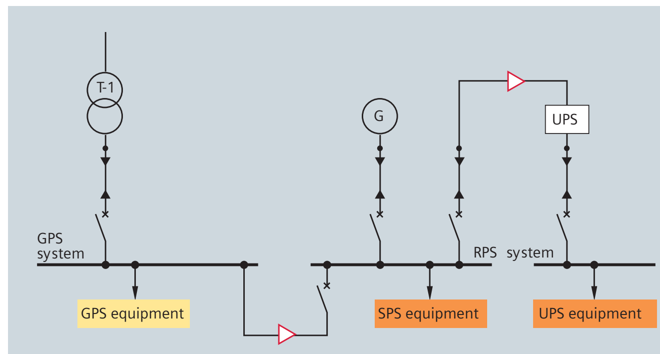


Fig. 3.3-4: **Supply type depending on primary system function**

A constellation as described in fig. 3.3-4 has proven itself suitable for the building infrastructure level.

Power supply systems
Electric power systems (fig. 3.3-5) are distinguished as follows:
- Type of current used: DC; AC ~ 50 Hz
- Type and number of live conductors within the system: L1, L2, L3, N, PE
- Type of connection to earth:
  Low-voltage systems: IT, TT, TN
  Medium-voltage systems: isolated, low-resistance, compensated

The type of connection to earth must be selected carefully for the MV or LV system because it has a major impact on the expense required for protective measures. It also determines electromagnetic compatibility with regard to the low-voltage system.

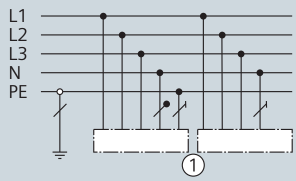
From experience, the best cost-benefit ratio for electric systems within the general power supply is achieved with the TN-S system at the low-voltage level.

In a TN-S system, the short-circuit current generated in the event of a fault is not fed back to the voltage source via a connection to earth but via a line or cable. The comparatively high 1-pole earth-fault current allows rather simple protective devices to be used, such as fuses or circuit-breakers, tripping in the event of a fault.

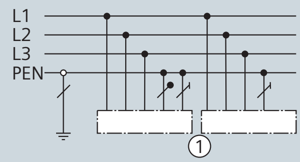
When TN-S systems are used, residual currents in the building can be avoided, because current flows back via a separate N conductor. Magnetic fields depend on the geometrical arrangement of the connections.

Because a TN-S system is only permissible in a central arrangement of the supply system (according to IEC 60364-5-54), Siemens recommends always using the TN-C-S system that is shown in fig. 3.3-6.

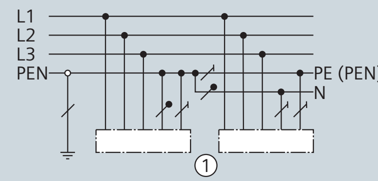
In case of distributed supply, 4-pole switching/protective devices must be provided at the feeder points and changeover equipment (parallel operation inhibited).



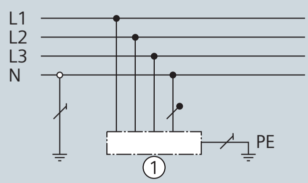
TN-S system
Neutral-conductor and protective-earth-conductor functions are separated throughout the system.



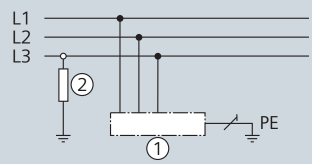
TN-C system
Neutral-conductor and protective-earth-conductor functions have been combined throughout the system.



TN-C-S system
Combination of neutral-conductor and protective-earth conductor functions. In one part of the system, these functions have been combined into one conductor, in another part, they are separate.



TT system
In the TT system, one point is directly earthing, and all exposed conductive parts in the electric installation are connected to earthing electrodes, which are separated from the system earthing. The protective measures applied in the TT system today are: protective earthing and current-operated as well as voltage-operated earth-fault circuit interrupter protection.



IT system
The IT system does not provide a direct connection between live conductors and earthed parts; exposed conductive parts in the electric installation are earthed. The protective measure now applied in the IT system is the protective-conductor system.

First letter = earthing conditions of the supplying source of electricity:
T = Direct **earthing** of one point
I = Either an **insulation** of all live parts against earth, or connection of one point to earth by means of impedance

Second letter = earthing conditions of exposed conductive parts in the electric installation:
T = Exposed conductive part is **directly earthed**, independent of a possibly existing earthing of another point in the power supply system
p = Exposed conductive part is directly connected to the **system earthing**; in AC networks, this earthed point is usually the star point

Further letters = arrangement of the neutral conductor and PE conductor:
S = Neutral-conductor and protective-earth conductor functions are implemented by **separate** conductors
C = Neutral-conductor and protective-earth conductor functions are **combined** in one conductor (PEN)

① Exposed conductive part
② Impedance

Fig. 3.3-5: **TN systems: Power distribution systems (according to their connection to earth) in compliance with ICE 60364-3 (DIN VDE 0100-300) – Determining the protective measure and selection of electrical equipment corresponding to the distribution system**

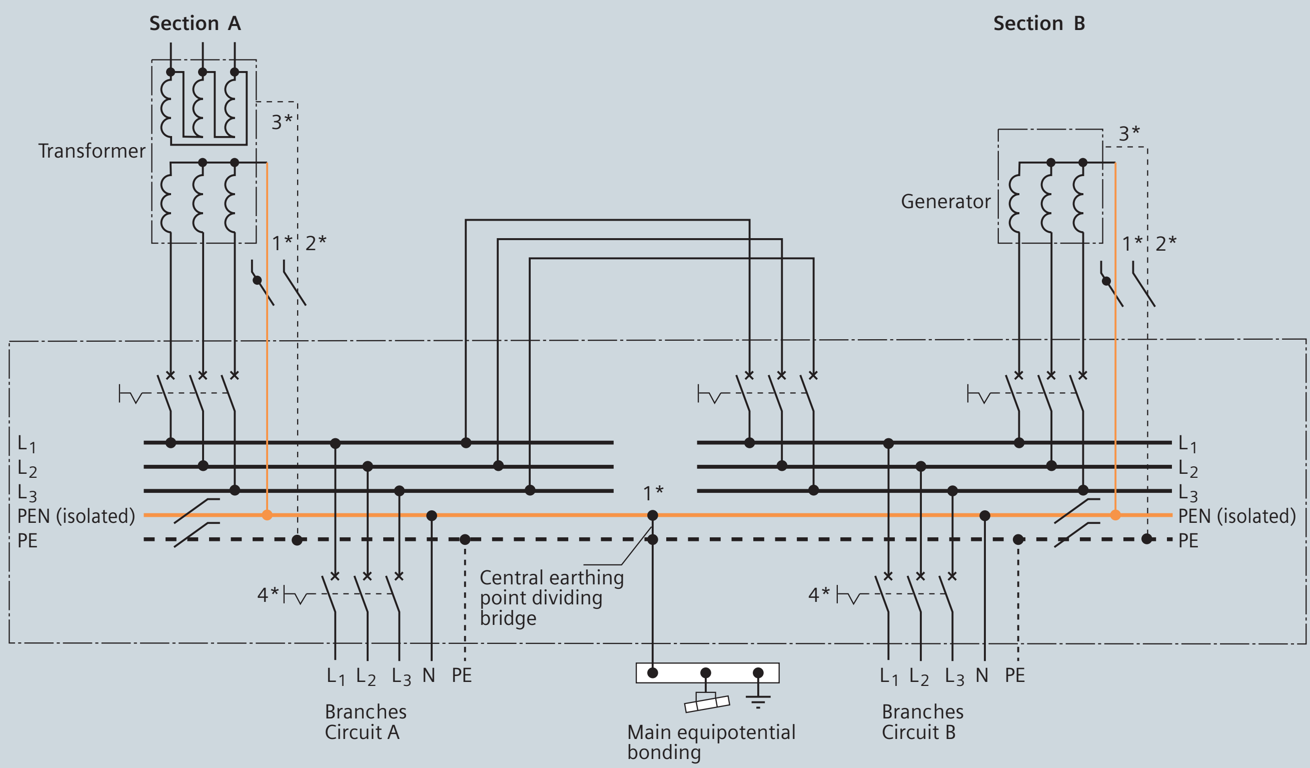
Routing/Wiring
Nowadays, the operator can choose between cables and busbars for power distribution. Some features of these different options are as follows:

- Cable laying
  - \+ Lower material costs
  - \+ When a fault occurs along the line, only one distribution board, including its downstream subsystem, will be affected
  - – High installation expense
  - – Increased fire load
  - – Each cable must be separately fused in the LVMD
- Busbar distribution
  - \+ Rapid installation
  - \+ Flexible in case of changes or expansions
  - \+ Low space requirements
  - \+ Reduced fire load
  - – Rigid coupling to the building geometry
  - \+ Halogen-free

These aspects have to be evaluated with regard to the building use and specific area loads when configuring a specific distribution.

Connection layout comprises the following specifications for wiring between output and target distribution board:

- Overload protection $I_b \leq I_r \leq I_z$ and $I_z > I_2/1.45$
- Short-circuit protection $S^2K^2 \geq I^2t$
- Protection against electric shock in the event of indirect contact
- Permissible voltage drop



1* The PEN conductor must be wired isolated along the entire route; this also applies to its wiring in the low-voltage main distribution (LVMD).

2* The PE conductor connection between LVMD and transformer chamber must be configured for the max. short-circuit current that might occur ($K^2S^2 \geq I_k^2 t_k$).

3* There must be no connection between the transformer neutral to earth or to the PE conductor in the transformer chamber.

4* All branch circuits must be designed as TN-S systems, i.e., in the case of a distributed N conductor function with a separately wired N conductor and PE conductor, both 3-pole and 4-pole switching devices may be used. If N conductors with reduced cross-sections are used (not recommended), a protective device with integrated overload protection should be used at the N conductor (e.g., LSIN).

Fig. 3.3-6: **EMC-friendly power system, centrally installed (short distances)**

Switching and protective devices

As soon as the initial plans are drafted, it is useful to determine which technology will be used to protect electric equipment. The technology that has been selected affects the behavior and properties of the power system, and thus also influences certain aspects of use, such as:

- Supply reliability
- Installation expenses
- Maintenance and downtimes

Types of protective equipment

Protective equipment can be divided into two categories, which can, however, be combined:

- Fuse-protected technology
  - \+ Good current-limiting properties
  - \+ High switching capacity up to 120 kA
  - \+ Low investment cost
  - \+ Easy installation
  - \+ Safe tripping, with no auxiliary power required
  - \+ Easy grading between fuses
  - – Downtime after fault
  - – Reduces selective tripping in connection with circuit-breakers
  - – Fuse ageing
  - – Separate protection of personnel required for switching high currents
- Circuit-breaker protected technology
  - \+ Clear tripping times for overload and short-circuit
  - \+ Safe switching of operating and fault currents
  - \+ Fast resumption of normal operation after fault trip
  - \+ Various tripping methods adapted to the protective task
  - \+ Communication ability: signaling of system states
  - – Coordination of the protection concept requires a calculation of short-circuits
  - – Higher investment costs

Protective tripping

When circuit-breaker protected technology is employed, the selection of the tripping unit is crucial for meeting the defined objectives for protection, because tripping units can be individually set.

In power systems for buildings, selective tripping is gaining more and more importance, because it results in greater supply safety and higher quality. While standards such as DIN VDE 0100 Part 710 or Part 718 demand a selective behavior of the protective equipment for safety power supply or certain areas of indoor installations, the number of buildings where selective tripping is also desired for the general power supply is increasing.

Generally speaking, a combined solution using selective and partially selective network sections should be applied in power systems for buildings when economic aspects are important to consider.

In this context, the following device properties must be taken into account:

Current limiting (fig. 3.3-7):
A protective device has a current-limiting effect if it shows a lower let-through current in the event of a fault than the prospective short-circuit current at the fault location.

Selectivity (fig. 3.3-8):
When series-connected protective devices work together for graded tripping, the upstream protective device that is closest to the fault location must trip first. The other upstream devices remain in operation. The temporal and spatial effects of a fault will be kept to a minimum.

Back-up protection (fig. 3.3-9):
Q1 be a current-limiting device. If the fault current is higher than the rated breaking capacity of the downstream device in the event of a line shorting, it will be protected by the upstream protective device. Q2 can be selected with $I_{cu} < I_{kmax,\,Q2}$. This results in partial selectivity.

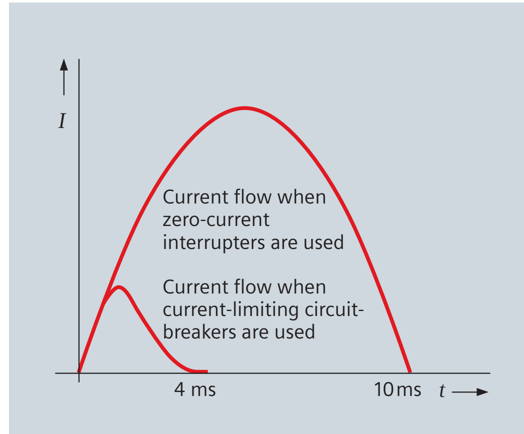


Fig. 3.3-7: **Current limiting**

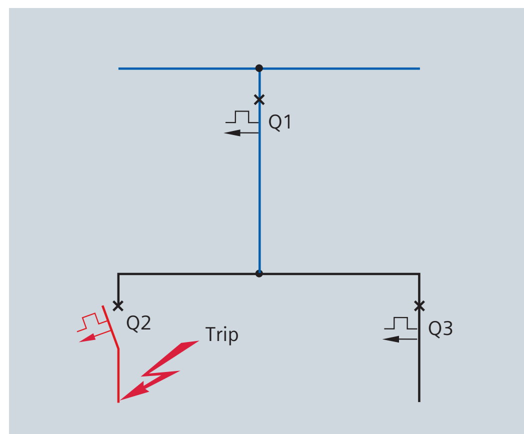


Fig. 3.3-8: **Selective tripping**

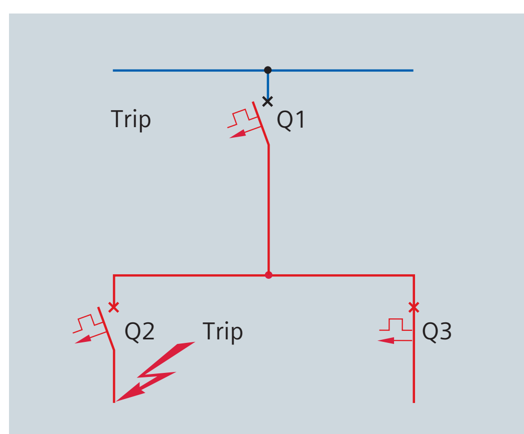


Fig. 3.3-9: **Back-up-conditioned fault tripping**

3.3.2 Dimensioning of Power Distribution Systems

When the basic supply concept for the electricity supply system has been established, it is necessary to dimension the electrical power system.

Dimensioning means the sizing rating of all equipment and components to be used in the power system.

The dimensioning target is to obtain a technically permissible combination of switching protective devices and connecting lines for each circuit in the power system.

Basic rules
In principle, circuit dimensioning should be performed in compliance with the technical rules standards listed in fig. 3.3-10.

Cross-circuit dimensioning
When selected network components and systems are matched, an economically efficient overall system can be designed. This cross-circuit matching of network components may bear any degree of complexity, because subsequent modifications to certain components, e.g., a switch or protective device, may have effects on the neighboring higher-level or all lower-level network sections (high testing expense, high planning risk).

Dimensioning principles
For each circuit, the dimensioning process comprises the selection of one or more switching protective devices to be used at the beginning or end of a connecting line, and the selection of the connecting line itself (cable/line or busbar connection) after considering the technical features of the corresponding switching protective devices. For supply circuits in particular, dimensioning also includes rating the power sources.

The objectives of dimensioning may vary depending on the circuit type. The dimensioning target of overload and short-circuit protection can be attained in correlation to the mounting location of the protective equipment. Devices applied at the end of a connecting line can ensure overload protection for this line at best, not, however, short-circuit protection.

Circuit types
The basic dimensioning rules and standards listed in fig. 3.3-10 principally apply to all circuit types. In addition, there are specific requirements for these circuit types that are explained in detail below.

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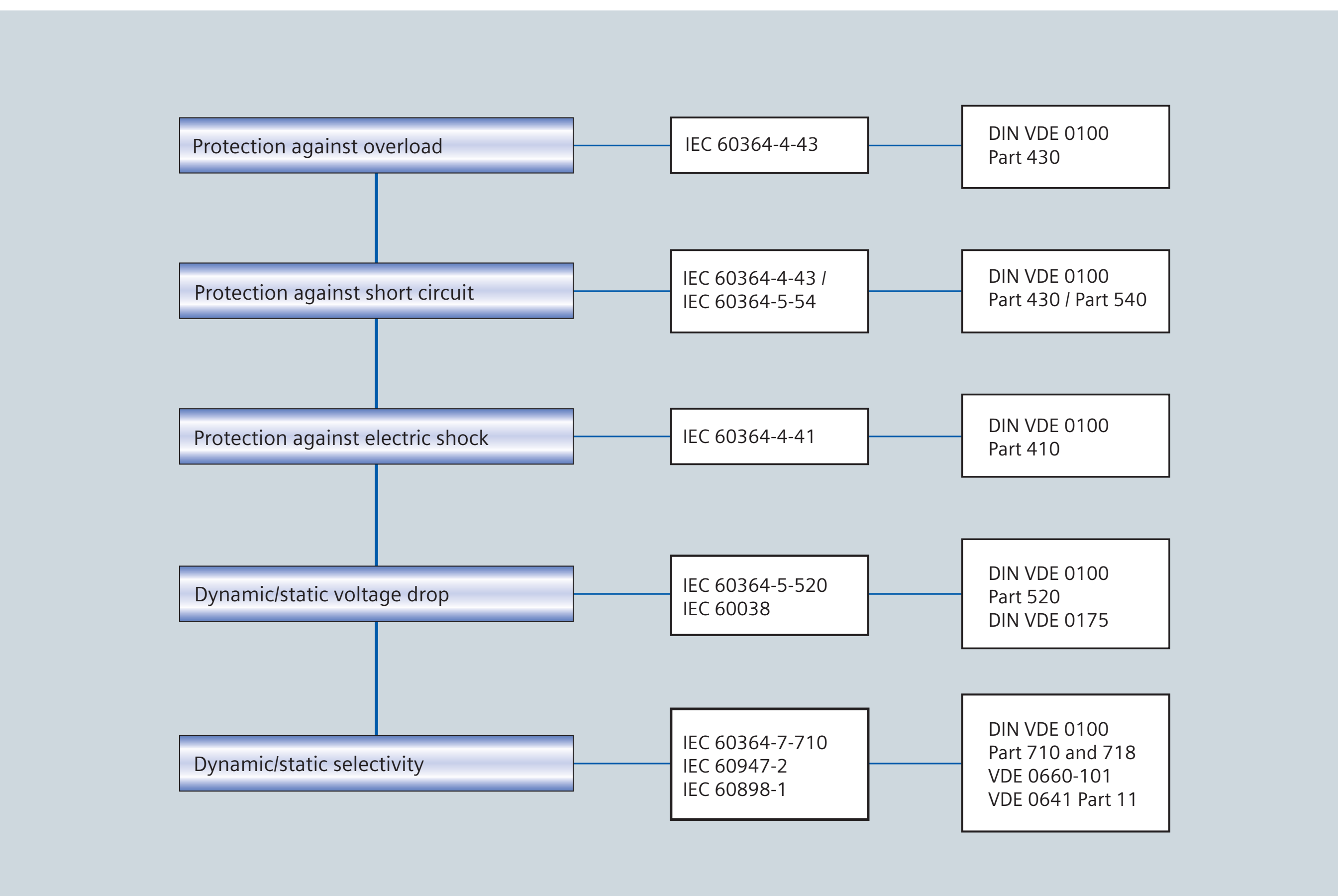


Fig. 3.3-10: **Relevant standards for circuit dimensioning**

Supply circuits

Particularly stringent requirements apply to the dimensioning of supply circuits. This starts with the rating of the power sources. Power sources are rated according to the maximum load current to be expected for the power system, the desired amount of reserve power, and the degree of supply reliability required in case of a fault (overload short-circuit).

Load conditions in the entire power system are established by taking the energy balance (in an “energy report”). Reserve power and operational safety in the vicinity of the supply system are usually established by building up appropriate redundancies, for example, by doing the following:

- Providing additional power sources (transformer, generator, UPS).
- Rating the power sources according to the failure principle; n- or (n–1) principle: Applying the (n–1) principle means that two out of three supply units are principally capable of continually supplying the total load for the power system without any trouble if the smallest power source fails.
- Rating those power sources that can temporarily be operated under overload (e.g., using vented transformers).

Independent of the load currents established, dimensioning of any further component in a supply circuit is oriented to the ratings of the power sources, the system operating modes configured and all the related switching states in the vicinity of the supply system.

As a rule, switching protective devices must be selected in such a way that the planned performance maximum can be transferred. In addition, the different minimum/maximum short-circuit current conditions in the vicinity of the supply system, which are dependent on the switching status, must be determined.

When connecting lines are rated (cable or busbar), appropriate reduction factors must be taken into account; these factors depend on the number of systems laid in parallel and the installation type.

When devices are rated, special attention should be paid to their rated short-circuit breaking capacity. In addition, a high-quality tripping unit with variable settings is preferred, because this component is an important foundation for attaining the best possible selectivity toward all upstream and downstream devices.

Distribution circuit

Dimensioning of cable routes and devices follows the maximum load currents to be expected at this distribution level.

As a rule

$I_{b\,max} = \sum$ installed capacity x simultaneity factor

Switching/protective device and connecting line are to be matched with regard to overload and short-circuit protection.

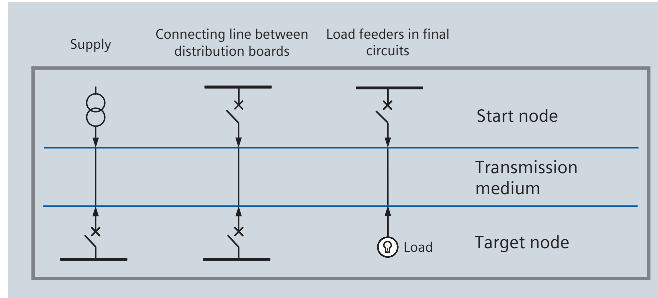


Fig. 3.3-11: **Schematic representation of the different circuit types**

In order to ensure overload protection, the standardized conventional (non-)tripping currents referring to the devices in application have to be observed. A verification based merely on the rated device current or the setting value I_r would be insufficient.

Basic rules for ensuring overload protection:

Rated current rule

- Non-adjustable protective equipment
  $I_b \leq I_n \leq I_z$
  The rated current I_n of the selected device must be between the calculated maximum load current I_b and the maximum permissible load current I_z of the selected transmission medium (cable or busbar).
- Adjustable protective equipment
  $I_b \leq I_r \leq I_z$
  The rated current I_r of the overload release must be between the calculated maximum load current I_b and the maximum permissible load current I_z of the selected transmission medium (cable or busbar).

Tripping current rule

$I_2 \leq 1.45 \text{ x } I_z$

The maximum permissible load current I_z of the selected transmission medium (cable or busbar) must be above the conventional tripping current I_2-/1.45 of the selected device.

The test value I_2 is standardized and varies according to the type and characteristics of the protective equipment applied.

Basic rules for ensuring short-circuit protection:

Short-circuit energy

$K^2S^2 \geq I^2t$

(K = Material coefficient; S = Cross-section)

The amount of energy that is set free when a short-circuit occurs – and up to the moment it is cleared automatically – must be less than the energy that the transmission medium can carry as a maximum or there will be irreparable damage. As a standard, this basic rule applies in the time range up to max. 5 s.

Below 100 ms of short-circuit breaking time, the let-through energy of the protective device (according to the equipment manufacturer’s specification) must be taken into account.

When devices with a tripping unit are used, observance of this rule across the entire characteristic device curve must be verified.

A mere verification in the range of the maximum short-circuit current applied ($I_{k\,max}$) is not always sufficient, in particular when time-delayed releases are used.
Short-circuit time
$t_a\ (I_{k\,min}) \leq 5\ s$

The resulting current-breaking time of the selected protective equipment must ensure that the calculated minimum short-circuit current $I_{k\,min}$ at the end of the transmission line or protected line is automatically cleared within 5 s at the most.

Overload and short-circuit protection need not necessarily be provided by one and the same device. If required, these two protection targets may be realized by a device combination. The use of separate switching protective devices could also be considered, i.e., at the start and end of a cable route. As a rule, devices applied at the end of a cable route can ensure overload protection for that line only.

Final circuits
The method for coordinating overload and short-circuit protection is practically identical for distribution and final circuits. Besides overload and short-circuit protection, the protection of human life is also important for all circuits.

Protection against electric shock
$t_a\ (I_{k1\,min}) \leq t_{a\,perm}$

If a 1-phase fault to earth ($I_{k1\,min}$) occurs, the resulting current breaking time t_a for the selected protective equipment must be shorter than the maximum permissible breaking time $t_{a\,perm}$ that is required for this circuit according to IEC 60364-4-41/ DIN VDE 0100-410 to ensure the protection of persons.

Because the required maximum current breaking time varies according to the rated system voltage and the type of load connected (stationary and non-stationary loads), protection requirements regarding minimum breaking times $t_{a\,perm}$ may be transferred from one load circuit to other circuits. Alternatively, this protection target may also be achieved by observing a maximum touch voltage.

Because final circuits are often characterized by long supply lines, their dimensioning is often affected by the maximum permissible voltage drop.

As far as the choice of switching protective devices is concerned, it is important to bear in mind that long connecting lines are characterized by high impedances, and thus strong attenuation of the calculated short-circuit currents.

Depending on the system operating mode (coupling open, coupling closed) and the medium of supply (transformer or generator), the protective equipment and its settings must be configured for the worst-case scenario for short-circuit currents.

In contrast to supply or distribution circuits, where the choice of a high-quality tripping unit is considered very important, there are no special requirements on the protective equipment of final circuits regarding the degree of selectivity to be achieved. The use of a tripping unit with LI characteristics is normally sufficient.

Summary
Basically, the dimensioning process itself is easy to understand and can be performed using simple means.

Its complexity lies in the procurement of the technical data on products and systems required. This data can be found in various technical standards and regulations as well as in numerous product catalogs.

An important aspect in this context is the cross-circuit manipulation of dimensioned components owing to their technical data. One such aspect is the above mentioned inheritance of minimum current breaking times of the non-stationary load circuit to other stationary load or distribution circuits.

Another aspect is the mutual impact of dimensioning and network calculation (short-circuit), e.g., for the use of short-circuit current-limiting devices.

In addition, the complexity of the matter increases, when different national standards or installation practices are to be taken into account for dimensioning.

For reasons of risk minimization and time efficiency, a number of engineering companies generally use advanced calculation software, such as SIMARIS design, to perform dimensioning and verification processes in electrical power systems.

3.3.3 Low-Voltage Switchgear

When developing a power distribution concept including dimensioning of the systems and devices, its requirements and feasibility have to be matched by the end user and the manufacturer.

When selecting a low-voltage main distribution board (LVMD), the prerequisite for its efficient sizing is knowledge of its use, availability and future options for extension. The demands on power distribution are extremely diverse. They start with buildings that do not place such high demands on the power supply, such as office buildings, and continue through to the high demands, for example, made by data centers, in which smooth operation is of prime importance.

Because no major switching functions in the LVMD have to be considered in the planning of power distribution systems in commercial buildings and no further extensions are to be expected, a performance-optimized technology with high component density can be used. In these cases, mainly fuse-protected equipment in fixed-mounted design is used. When planning a power distribution system for a production plant, however, system availability, extendibility, control and the visualization are important functions to keep plant downtimes as short as possible. The use of circuit-breaker protected and fuse-protected withdrawable design is an important principle. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that is to be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in all cases. When selecting appropriate switchgear, it must be ensured that it is a type-tested switchgear assembly (TTA, in compliance with IEC 60439-1 and DIN VDE 0660-500) with extended testing of behavior in the event of an accidental arc (IEC 61641, VDE 0660-500, Addendum 2), and that the selection is always made in light of the regulations governing the entire supply system (full selectivity, partial selectivity).

Further information:
Dimensioning of the low-voltage main distribution system:
Siemens AG (ed.): Totally Integrated Power, Application Manual, Establishment of Basic Data and Preliminary Planning, 2006, chapter 5, p. 5/17 ff.
For detailed planning:
Siemens AG: SIVACON planning manuals. The planning manuals are also available for download at www.siemens.com/sivacon –> Support –> Infomaterial.

Fig. 3.3-12: **SIVACON S8 switchgear**

Overview

The SIVACON S8 low-voltage switchgear (fig. 3.3-12) is a variable, multi-purpose and type-tested low-voltage switchgear assembly (TTA) that can be used for the infrastructure supply not only in administrative and institutional buildings, but also in industry and commerce. SIVACON S8 consists of standardized, modular components that can be flexibly combined to form an economical, overall solution, depending on the specific requirements. SIVACON S8 has a high level of functionality, flexibility and quality, and has compact dimensions and a high degree of safety for persons and equipment. Siemens or its authorized contracting party will perform the following:

- The customer-specific configuration
- The mechanical and electrical installation
- The testing, for which type-tested function modules are used

The authorized contracting party will use the specified documentation. SIVACON S8 can be used as a type-tested power distribution board up to 4,000 A. Further information is available on the Internet at ***www.siemens.com/sivacon.***

Standards and regulations

SIVACON S8 is a type-tested low-voltage switchgear assembly (TTA) in compliance with IEC 60439-1/DIN EN 60439-1/VDE 0660-500. SIVACON S8 is resistant to accidental arcs, in compliance with IEC 61641, DIN EN 60439/VDE 0660-500, Addendum 2. SIVACON S8 is available in several mounting designs (fig. 3.3-13).

Circuit-breaker design

The panels for installation of 3WL and 3VL circuit-breakers are used for the supply of the switchgear and for outgoing feeders and bus ties (bus sectionalizer and bus coupler). The rule that only one circuit-breaker is used for each panel applies to the entire circuit-breaker design (fig. 3.3-14).

The device mounting space is intended for the following functions:

- Incoming/outgoing feeders with 3WL circuit-breakers in fixed-mounted and withdrawable designs up to 4,000 A
- Bus sectionalizer and bus coupler with 3WL circuit-breakers in fixed-mounted and withdrawable designs up to 4,000 A
- Incoming/outgoing feeders with 3VL circuit-breakers in fixed-mounted design up to 1,600 A

Universal installation design

The panels for cable feeders in fixed-mounted and plug-in designs up to 630 A are intended for the installation of the following switchgear (fig. 3.3-15):

- SIRIUS 3RV/3VL circuit-breaker
- SENTRON 3K switch-disconnector
- SENTRON 3NP switch-disconnector
- SENTRON 3NJ6 switch-disconnector in plug-in design

The switching devices are mounted on mounting plates and connected to the vertical current distribution bars on the supply side. Plug-in 3NJ6 in-line switch-disconnectors can be installed using an adapter. The front is covered by panel doors or compartment doors.

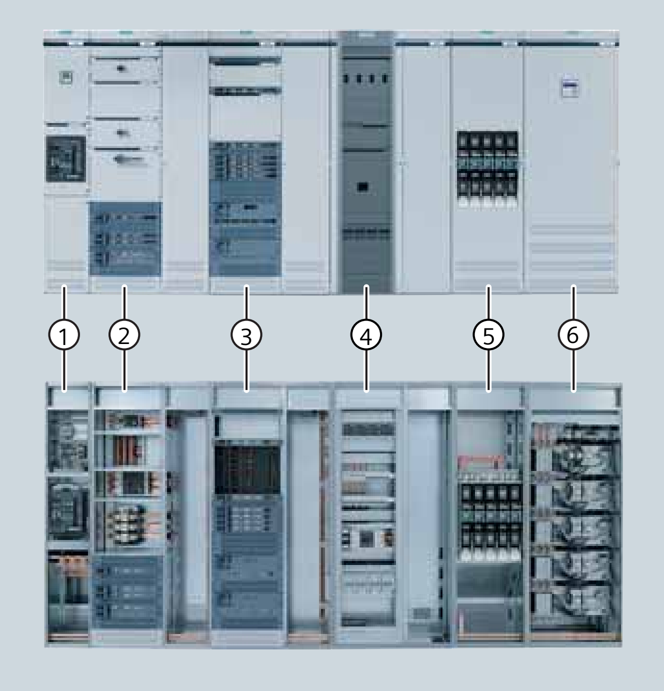


Fig. 3.3-13: **The following mounting designs are available:**
(1) Circuit-breaker design with SENTRON 3WL up to 4,000 A or 3VL up to 1,600 A
(2) Universal installation design for cable feeders up to 630 A in fixed-mounted and plug-in designs (3NJ6)
(3) 3NJ6 in-line switch-disconnector design (plugged in) for cable feeders up to 630 A in plug-in design
(4) Fixed-mounted panel (front cover) for cable feeders up to 630 A and modular devices
(5) 3NJ4 in-line switch-disconnector design (fixed-mounted) for cable feeders up to 630 A
(6) Reactive-power compensation up to 600 kVAr

Plug-in 3NJ6 in-line switch-disconnector design

The panels for cable feeders in the plug-in design up to 630 A are intended for the installation of in-line switch-disconnectors. The plug-in contact on the supply side is a cost-effective alternative to the withdrawable design. The modular design of the plug-ins enables an easy and quick retrofit or replacement under operating conditions. The device mounting space is intended for plug-in, in-line switch-disconnectors with a distance between pole centers of 185 mm. The vertical plug-on bus system is arranged at the back of the panel and is covered by an optional touch protection with pick-off openings in the IP20 degree of protection. This enables the in-line switch-disconnectors to be replaced without shutting down the switchgear (fig. 3.3-16).

Fixed-mounted design with front covers

The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of the following switchgear (fig. 3.3-17):

- SIRIUS 3RV/3VL circuit-breaker
- SENTRON 3K switch-disconnector
- SENTRON 3NP switch-disconnector
- Modular devices

The switching devices are mounted on infinitely adjustable device holders and connected to the vertical current distribution bars on the supply side. The front of the panel has either covers (with or without hinges) or additional doors (with or without a window).

Fixed-mounted 3NJ4 in-line switch-disconnector design
The panels for cable feeders in fixed-mounted design up to 630 A are intended for the installation of 3NJ4 in-line fuse switch-disconnectors. With their compact design and modular structure, in-line fuse switch-disconnectors offer optimal installation conditions with regard to the achievable packing density. The busbar system is arranged horizontally at the back of the panel. This busbar system is connected to the main busbar system via cross-members. The in-line fuse switch-disconnectors are screwed directly onto the busbar system (fig. 3.3-18).

Low-voltage main distribution
When selecting a low-voltage main distribution system, the prerequisite for its efficient sizing is knowing about its use, availability and future options for extension. The requirements for power distribution are extremely diverse.

Normally, frequent switching operations need not be considered in the planning of power distribution for commercial, institutional and industrial building projects, and extensions are generally not to be expected. For these reasons, a performance-optimized technology with high component density can be used. In these cases, Siemens mainly uses circuit-breaker protected equipment in fixed-mounted design. When planning a power distribution system for a production plant, however, system availability, extendibility, control and the visualization of status information and control functions are important issues related to keeping plant downtimes as short as possible. The use of circuit-breaker protected technology in withdrawable design is important. Selectivity is also of great importance for reliable power supply. Between these two extremes there is a great design variety that should be optimally matched to customer requirements. The prevention of personal injury and damage to equipment must, however, be the first priority in any case. When selecting appropriate switchgear, it must be ensured that it is a type-tested switchgear assembly (TTA, in compliance with DIN VDE 0660 Part 500, IEC 439-1 and EN 60439-1), with extended testing of behavior in the event of an internal arc fault (IEC 61641, VDE 0660 Part 500, Addendum 2).

Low-voltage main distribution systems should be chosen among those featuring a total supply power up to 3 MVA. Up to this rating, the equipment and distribution systems are relatively inexpensive due to the maximum short-circuit currents to be encountered.

For rated currents up to 3,200 A, power distribution via busbars is usually sufficient if the arrangement of the incoming/outgoing feeder panels and coupler panels has been selected in a performance-related way. Ambient air temperatures, load on individual feeders and the maximum power loss per panel have a decisive impact on the devices to be integrated and the number of panels required, as well as their component density (number of devices per panel).

Fig. 3.3-14: **Circuit-breaker design**

Fig. 3.3-15: **Universal installation design**

Fig. 3.3-16: **Plug-in 3NJ6 in-line switch-disconnector design**

Fig. 3.3-17: **Fixed-mounted design with front covers**

Fig. 3.3-18: **Fixed-mounted 3NJ4 in-line switch-disconnector design**

Planning notes for switchgear up to 3,200 A
Dimensions should be defined for the entire switchgear assembly (table 3.3-3, fig. 3.3-19, fig. 3.3-20, fig. 3.3-21). Siemens recommends transport units no larger than the following:
Length: 2,400 mm
Depth: 1,050 mm
Width: Segment width + 200 mm

Packaging for export: For ocean shipment, 30 mm must be added to each dimension.

Power losses
The power losses listed in table 3.3-6, page 113 are guiding values for determining the power loss to be discharged from the switchgear room; they refer to one panel plus the main circuit of functional units. If applicable, the power losses of additional auxiliary appliances must also be taken into account.

Space requirements
Height: 2,000 mm + 200 mm base
Depth: 600 mm
Width: For data required for the addition of panels, please refer to the panel descriptions
Type of installation: At the wall or stand-alone
The following minimum clearances between switchgear and obstacle must be observed:
Rear side of switchgear: 75 mm
Side walls: 100 mm
Vertical clearance above switchgear: 400 mm
(Take possible additional clearance required for incoming/outgoing feeders (branches) of busbar systems into account)
Switchgear front:
700 mm for control aisles (observe direction of escape route)
1,500 mm if manual lift trucks are to be used

Table 3.3-3: **Space requirements of low-voltage switchgear**

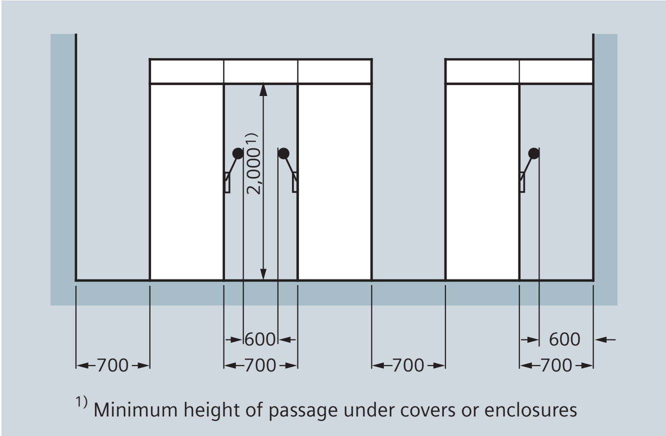


Fig. 3.3-19: **Operation and control aisles (acc. to DIN VDE 0100 Part 729/IEC 60364-7-729)**

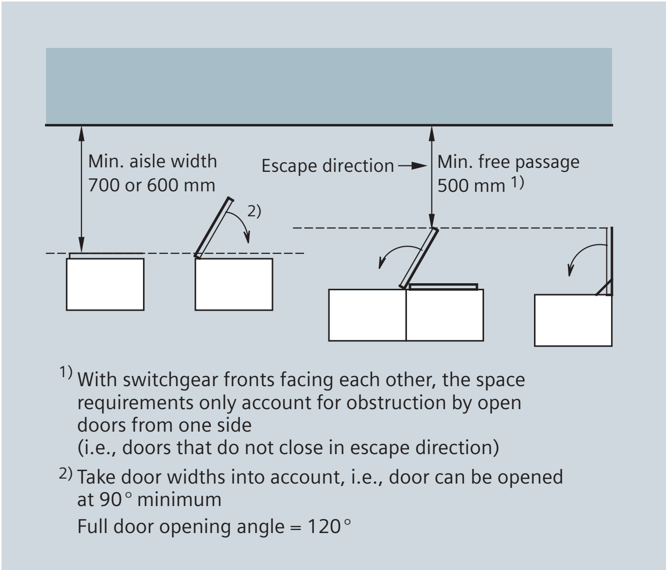


Fig. 3.3-20: **Reduced aisle widths within the range of open doors**

Environmental conditions for power distribution boards
The outside climate and the external environmental conditions (natural foreign matter, chemically active harmful substances, small animals) have varyingly strong influences on power distribution boards (table 3.3-4, table 3.3-5).

With high concentrations of influences, measures to reduce the content of harmful substances must be taken, such as the following:

- Suction of the air for the operating area from a point with low exposure
- Application of slight overpressure to the operating area (e.g., supply of clean air to the power distribution board)
- Control room air-conditioning (temperature reduction, relative humidity < 60 % and use of pollutant filter, if required)
- Reduction of temperature rise (overdimensioning of switching devices or components such as busbars and distribution busbars).

Ambient conditions in the switchgear room				Measure at the switchgear				
Room climate acc. to IEC 60721-3-3 with direct impact on switchgear	Ambient air temperature Relative humidity	Condensation	Natural foreign substances, chemically active pollutants, small animals	Heating	Degree of protection to the operating room	Degree of protection to the cable basement	Contact treatment	
							Screw points	Movable
Environment cat. IR1 [3K3]	+5 to +40 °C 5 % to 85 % 24-h-mean max. 3 °C	None	None	–	IP20/40	–	–	–
Environment cat. IR2 [3K3]	−25 to +55 °C 10 % to 98 % 24-h-mean max. 50 °C	Occasionally, about 1 x per month for 2 h	None	–	IP20/40	–	–	–
			Drifting sand, dust	–	IP54	–	–	–
			Small animals	–	IP40	IP40	–	–
Environment cat. IR3 [3K3]	−25 to +55 °C 10 % to 98 % 24-h-mean max. 50 °C	Often, about 1 x per day for 2 h	None	●	IP20/40	–	–	–
			Drifting sand, dust	●	IP54	–	–	–
			Dripping water acc. to IEC 60529	●	IP41	–	–	–
			Drifting sand, dust and splash water acc. to IEC 60529	●	IP54	–	–	–
			Small animals	●	IP40	IP40	–	–

Table 3.3-4: **Ambient conditions and degrees of protection**

Areas with chemical emission		
Constantly permissible concentration		Measures if higher concentrations are present:
Sulphur dioxide (SO_2)	<-2 ppm	If higher concentrations are present, pollutant-reducing measures are required, such as the following: ▪ Air intake for operating room from a less contaminated point ▪ Slightly pressurizing the operating room (e.g., by blowing uncontaminated air into the switchgear) ▪ Air-conditioning of switchgear room (reduce temperature, relative air humidity < 60 %, use pollutant filters, if necessary) ▪ Air-conditioning of switchgear room (reduce temperature, oversizing of switching devices or other components such as busbars and distribution bars)
Hydrosulphide (H_2S)	<-1 ppm	
Hydrogen chloride (HCl)	<-3 ppm	
Ammonia (NH_3)	<-15 ppm	
Nitrogen dioxide (NO_2)	<-2 ppm	
Chloride precipitation (salty fog)	<-2 mg/dm²	

Table 3.3-5: **Typical chemical emissions and countermeasures**

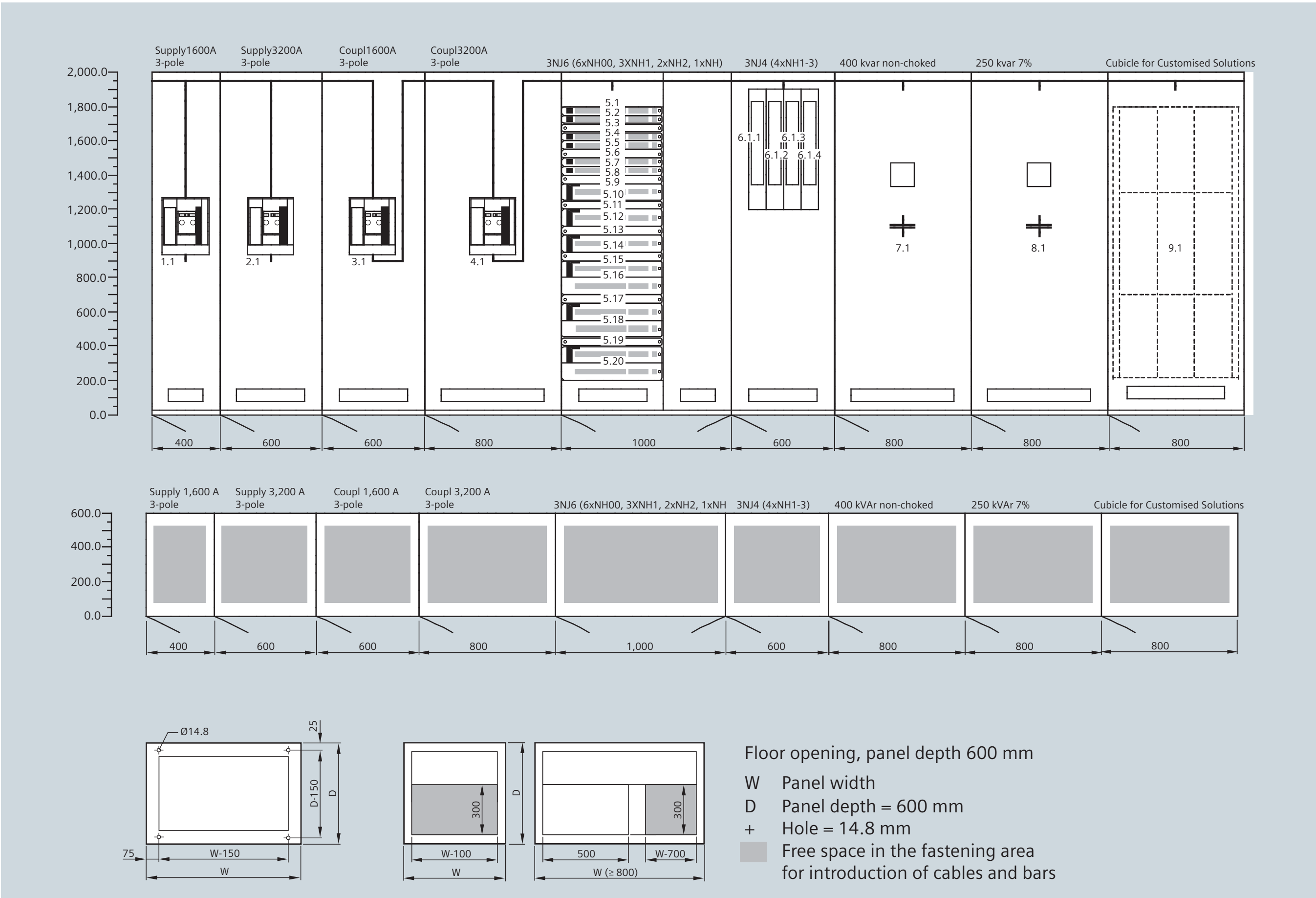


Fig. 3.3-21: **SIVACON S8 typicals; system depth 600 mm, system width 6,400 mm**

Panel type	Supply	Supply	Coupler	Coupler	Plug-in NH feeders 1)	Fixed-mounted NH feeders 1)	Compen-sation	Compen-sation	CCS panel
Height	2,000 mm	2,000 mm	2,000 mm	2,000 mm	2,000 mm	2,000 mm	2,000 mm	2,000 mm	2,000 mm
Width	400 mm	600 mm	600 mm	800 mm	1,000 mm	600 mm	800 mm	800 mm	800 mm
Depth	600 mm	600 mm	600 mm	600 mm	600 mm	600 mm	600 mm	600 mm	600 mm
Degree of protection	IP40, vented	IP40, vented	IP40, vented	IP40, vented	IP40, vented	IP40, vented	IP40, vented	IP40, vented	IP40, vented
Weights	390 kg	510 kg	390 kg	510 kg	440 kg	360 kg	930 kg	930 kg	300 kg
Currents (A)	630–1,600 A	2,000–3,200 A	1,600 A	3,200 A	NH 00 to NH 3	NH 00 to NH 3	4 x 100 kVAr non-choked	5 x 50 kVAr 7 % choked	automats
1) Continuous operating current of outgoing feeders depends on the number and arrangement of devices per panel. For data on combinations arrangement and max. number, consult the manufacturer.									
Switching device	**3WL11**	**3WL12**	**3WL11**	**3WL12**	**3NJ6**	**3NJ4**	**4RF**	**4RF**	**5SY6**
Approx. *Pv* (at 80 % load)	140–640 W	740–2,500 W	640 W	2,500 W	1,500 W	600 W	approx. 1,4 W/kVAr	approx. 6 W/kVAr	500 W
Internal subdivision	Form 2b	Form 2b	Form 2b	Form 2b	Form 2b	Form 2b	Form 2b	Form 2b	Form 2b
Number of devices	1	1	1	1	31 x NH 00 15 x NH 1 7 x NH 2 7 x NH 3	8 x NH 00 4 x NH 1 4 x NH 2 4 x NH 3			288 modular widths

Table 3.3-6: **Technical data of the panel examples**

3

Panel Descriptions

Circuit-breaker design for incoming/outgoing feeders and couplers

Description:
- Circuit-breaker (fixed-mounted or withdrawable design)
- Motor/manual operating stored-energy mechanism with stored energy
- Current measuring with current transformers (3-fold)
- Voltage measuring with changeover switch (ensure fusing)

Panel width:
For rated circuit-breaker current up to 1,600 A: 400 mm
For rated circuit-breaker current up to 3,200 A: 600 mm
Cable/busbar connection: top or bottom

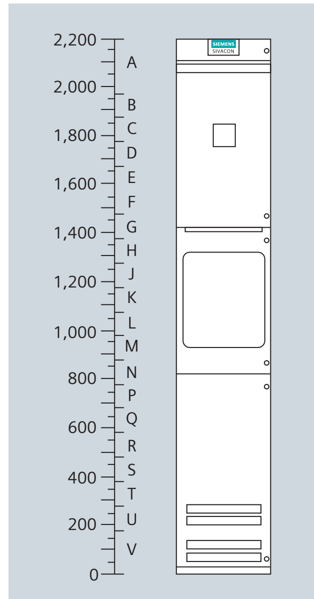


Fig. 3.3-22: **Circuit-breaker panel**

Derating factors I_e/I_n at an average ambient air temperature of 35 °C					
		Function: Bus sectionalizer		Function: Bus coupler	
Rated circuit-breaker current (A)	Unvented (e.g., IP40)	Unvented (e.g., IP54)	Vented (e.g., IP40)	Unvented (e.g., IP54)	Vented (e.g., IP40)
630 – 800	1	1	1	1	1
1,000	1	1	1	1	1
1,250	1	1	0.91	0.94	1
1,600	1	0.85	1	0.88	1
2,000	0.91	0.73	0.91	0.73	0.91
2,500	0.93	0.77	0.98	0.78	0.93
3,200	0.91	0.70	0.88	0.77	0.91
These derating factors are rounded values that may be used for rough planning. The precise rated currents for circuit-breaker panels as well as factors for deviating ambient tolerances must be obtained.					

Table 3.3-7: **Derating factors for circuit-breaker technology**

Plug-in 3NJ6 design for cable feeders

Suitable for:

- All switch-disconnectors with fuses, double interruptions and auxiliary switches
- All feeders with 1-phase current measurement

Panel width: 1,000 mm

Panel design:

- Height of device mounting space: 1,750 mm
- Width of device mounting space: 600 mm
- Width of cable connection space: 400 mm
- Compartment for auxiliary devices and instruments: 200 mm to 400 mm high

Cable connection: top or bottom

Component mounting rules for vented panels with 3-pole in-line switch-disconnectors:

- Component mounting in the panel from bottom to top, decreasing in component size from size 3 to size 00
- Recommended maximum component density per panel inclusive reserve 1,100 mm (approx. 2/3)
- Distribute in-line switch-disconnectors of size 2 and 3 to different panels, if possible
- Total operating current per panel max. 2,000 A
- Rated currents of component sizes = $0.8 \times I_n$ of the largest fuse-link
- Rated currents of smaller fuse-link sizes = $0.8 \times I_n$ of the fuse-link

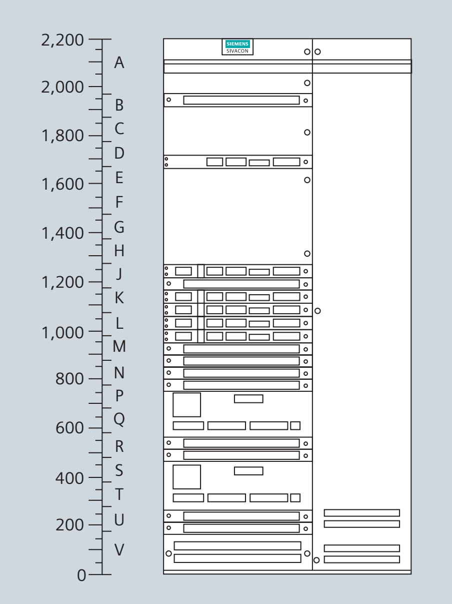


Fig. 3.3-23: **In-line switch-disconnector panel, plugged**

Component mounting data for vented panels with 3-pole in-line switch-disconnectors				
Rated current [A]	Size	Derating factors I_e/I_n vented at 35 °C	Max. number of components per panel	Vertical space requirements of in-line switch-disconnectors (mm)
160	00	0.78	35	50
250	1	0.8	17	100
400	2	0.8	8	200
630	3	0.79	8	200

Table 3.3-8: **Selection table for in-line switch-disconnector design**

Universal installation design for cable feeders in fixed-mounted and plug-in designs (3NJ6)

Suitable for:
- Circuit-breaker protected cable feeders up to 630 A
- Fuse-protected cable feeders up to 630 A

Design options:
- Molded-case circuit-breakers
- Fuse switch-disconnectors
- In-line switch-disconnectors 3NJ6

Panel width: 1,000 mm

Panel design:
- Height of device mounting space: 1,800 mm
- Width of device mounting space: 600 mm
- Width of cable connection space: 400 mm

Cable connection: top or bottom

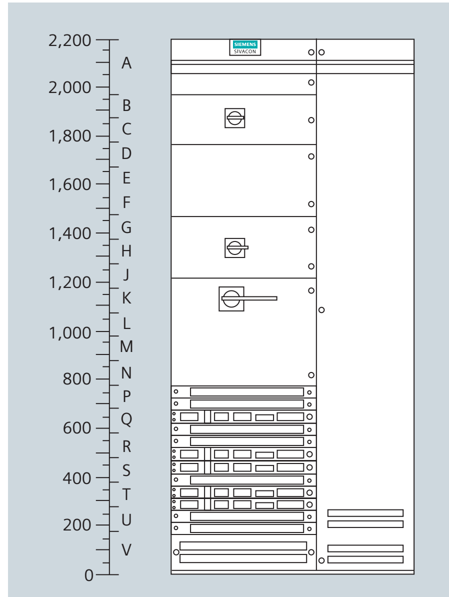


Fig. 3.3-24: **Universal installation panel, fixed-mounted and plug-in 3NJ6 designs**

Cable feeders, 3-pole

Type	Rated size	Derating factors I_e/I_n		Module height [mm]
		Vented	Unvented	
Fuse switch-disconnector	NH 00/160 A	0.94	0.72	150
	NH 1/250 A	1	0.95	250
	NH 2/400 A	0.90	0.85	300
	NH 3/630 A	0.79	0.73	350
Circuit-breaker	160 A	0.98	0.78	150
	250 A	1	0.99	200
	400 A	1	1	250
	630 A	0.86	0.79	250

Table 3.3-9: **Selection table for fixed-mounted design**

Universal installation design for motor loads, cable feeders and supplies, in withdrawable, fixed-mounted and plug-in designs (3NJ6)

Suitable for:
- Circuit-breaker protected load circuits up to 250 kW
- Fuse-protected load circuits up to 250 kW
- Motor feeders with or without overload relay
- Withdrawable units with or without communication link

Vertical current distribution bar in panel:
- Arcing-proof embedding
- Probe-proof (IP20)
- Interphase insulation
- Tap openings in modular widths of 50 mm

Panel width: 1,000 mm

Size of withdrawable unit:
- 4x KE ¼ = Height 150/200 mm (up to 18.5 kW)
- 2x KE ½ = Height 150/200 mm (up to 18.5 kW)
- 1x NE = Height 100 mm (up to 11 kW)
- 1x NE = Height 150 mm (up to 22 kW)
- 1x NE = Height 200 mm (up to 45 kW)
- 1x NE = Height 400 mm (up to 132 kW)
- 1x NE = Height 600 mm (up to 250 kW)

- Height of device mounting space: 1,800 mm
- Width of device mounting space: 600 mm
- Width of cable connection space: 400 mm

Cable connection: top or bottom

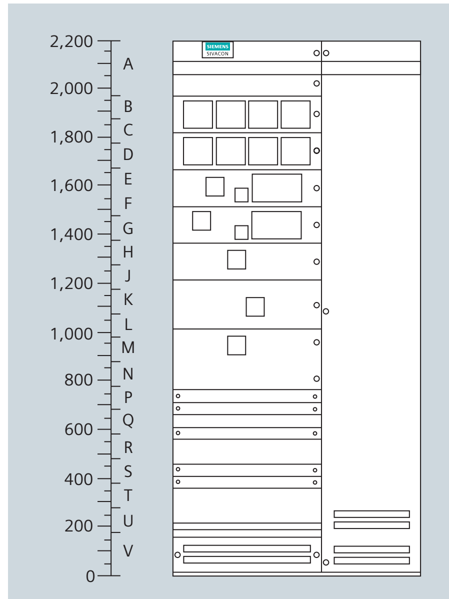


Fig. 3.3-25: **Panel in withdrawable design**

The total current of all branch circuits must not exceed the rated current of the vertical current distribution bar in the panel.

Rated current of the vertical current distribution bar:
- 1,100 A (vented 35 °C, e.g., IP40);
- 1,000 A (unvented 35 °C, e.g., IP54)

Reactive-power compensation

Closed-loop controlled reactive-power compensation unit connected to the main busbar or separate installation:

- Without choking, up to 600 kVAr per panel
- With choking, up to 500 kVAr per panel
- Up to 3 modules with 200 kVAr each

Panel width: 800 mm

Reactive power compensation panels, non-choked
- Up to 5 modules with 100 kVAr each
- 1 controller module with fan

Reactive-power compensation panels, choked
- Up to 5 modules with 100 kVAr each
- Choking rate 5.67 %/7 %/14 %
- 1 controller module with fan

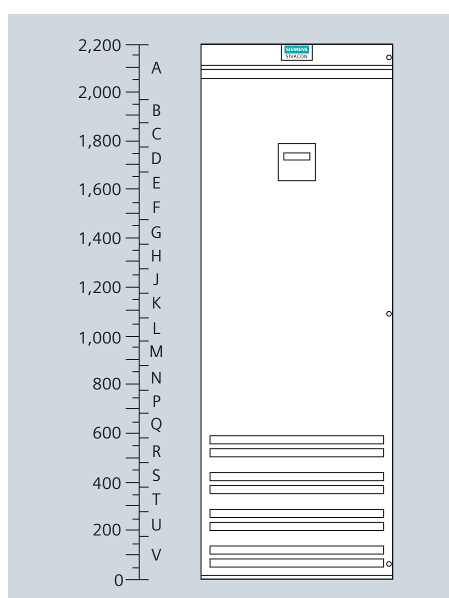


Fig. 3.3-26: **Compensation panel**

Calculation and determination of required capacitor power

1. The electricity bill of the power supply company shows the consumption of active energy in kWh and reactive energy in kVArh; the company demands $\cos\varphi$ of 0.9 ... 0.95; in order to cut costs, reactive energy should be compensated to a value approximating $\cos\varphi = 1$.

   Establishment of $\tan\varphi_1 = \frac{\text{Reactive energy}}{\text{Active energy}} = \frac{\text{kVArh}}{\text{kWh}}$

2. Refer to table 3.3-11 for the conversion factor *"f"* and multiply it by the mean power consumption P_m.

   With $\tan\varphi_1$, $\cos\varphi_1$ shows the power factor prior to compensation; $\cos\varphi_2$ shows in factor *"f"* the desired power factor for compensation.

3. Required compensation power is indicated in kVAr.

Example:

Reactive energy W_b = 19,000 kVArh per month

Active energy W_w = 16,660 kWh per month

Mean power consumption

$$\frac{\text{Active energy}}{\text{Working hours}} = \frac{16{,}660\ \text{kWh}}{180\ \text{h}} = 92.6\ \text{kW}$$

$$\tan\varphi_1 = \frac{\text{Reactive energy}}{\text{Active energy}} = \frac{19{,}000\ \text{kWh}}{16{,}660\ \text{kWh}} = 1.14$$

Power factor $\cos\varphi_1$ = 0.66 (for $\tan\varphi_1 = 1.14$)

Power factor $\cos\varphi_2$ = 0.95 (desired)

Conversion factor *"f"* = 0.81 (from $\tan\varphi_1$ and $\cos\varphi_2$)

Compensation power = Mean power x factor *"f"*
= 92.6 kW x 0.81

Required compensation power: 75 kVAr

Selection table for direct connection to main busbar			
Reactive power per level	Choking	Modules	Switch-disconnector
[kVAr]		[kVAr]	
100	•	4 x 25	•
150	•	6 x 25	•
200	•	4 x 50	•
250	•	5 x 50	•
300	•	6 x 50	•
400	•	8 x 50	•
500	•	10 x 50	•
600	•	12 x 50	•
Further module variants on requests			
Selection table for back-up fuse and connecting cable for separate installation			
Reactive power per panel	Choking	Back-up fuse (for separate installation)	Cable cross-section
[kVAr]		[A]	(for separate installation) [mm²]
100	•	250	120
125	•	300	150
150	•	355	2 x 70
175	•	400	2 x 95
200	•	500	2 x 120
250	•	630	2 x 150
300	•	2 x 355	2 x 185
400	•	2 x 500	4 x 120
500	•	2 x 630	4 x 150
600	•	2 x 630	4 x 185

Table 3.3-10: **Selection tables for reactive-power compensation**

Actual value (versus) conversion factor "*f*"

$\tan \varphi_1$	$\cos \varphi_1$	$\cos \varphi_2$ = 0.70	$\cos \varphi_2$ = 0.75	$\cos \varphi_2$ = 0.80	$\cos \varphi_2$ = 0.82	$\cos \varphi_2$ = 0.85	$\cos \varphi_2$ = 0.87	$\cos \varphi_2$ = 0.90	$\cos \varphi_2$ = 0.92	$\cos \varphi_2$ = 0.95	$\cos \varphi_2$ = 0.97	$\cos \varphi_2$ = 1.00
4.90	0.20	3.88	4.02	4.15	4.20	4.28	4,33	4.41	4.47	4.57	4.65	4.90
3.87	0.25	2.85	2.99	3.12	3.17	3.25	3.31	3.39	3.45	3.54	3.62	3.87
3.18	0.30	2.16	2.30	2.43	2.48	2.56	2.61	2.70	2.75	2.85	2.93	3.18
2.68	0.35	1.66	1.79	1.93	1.98	2.06	2.11	2.19	2.25	2.35	2.43	2.68
2.29	0.40	1.27	1.41	1.54	1.59	1.67	1.72	1.81	1.87	1.96	2.04	2.29
2.16	0.42	1.14	1.28	1.41	1.46	1.54	1.59	1.68	1.74	1.83	1.91	2.16
2.04	0.44	1.02	1.16	1.29	1.34	1.42	1.47	1.56	1.62	1.71	1.79	2.04
1.93	0.46	0.91	1.05	1.18	1.23	1.31	1.36	1.45	1.50	1.60	1.68	1.93
1.83	0.48	0.81	0.95	1.08	1.13	1.21	1.26	1.34	1.40	1.50	1.58	1.83
1.73	0.50	0.71	0.85	0.98	1.03	1.11	1.17	1.25	1.31	1.40	1.48	1.73
1.64	0.52	0.62	0.76	0.89	0.94	1.02	1.08	1.16	1.22	1.31	1.39	1.64
1.56	0.54	0.54	0.68	0.81	0.86	0.94	0.99	1.07	1.13	1.23	1.31	1.56
1.48	0.56	0.46	0.60	0.73	0.78	0.86	0.91	1.00	1.05	1.15	1.23	1.48
1.40	0.58	0.38	0.52	0.65	0.71	0.78	0.84	0.92	0.98	1.08	1.15	1.40
1.33	0.60	0.31	0.45	0.58	0.64	0.71	0.77	0.85	0.91	1.00	1.08	1.33
1.27	0.62	0.25	0.38	0.52	0.57	0.65	0.70	0.78	0.84	0.94	1.01	1.27
1.20	0.64	0.18	0.32	0.45	0.50	0.58	0.63	0.72	0.77	0.87	0.95	1.20
1.14	0.66	0.12	0.26	0.39	0.44	0.52	0.57	0.65	0.71	0.81	0.89	1.14
1.08	0.68	0.06	0.20	0.33	0.38	0.46	0.51	0.59	0.65	0.75	0.83	1.08
1.02	0.70	–	0.14	0.27	0.32	0.40	0.45	0.54	0.59	0.69	0.77	1.02
0.96	0.72		0.08	0.21	0.27	0.34	0.40	0.48	0.54	0.63	0.71	0.96
0.91	0.74		0.03	0.16	0.21	0.29	0.34	0.42	0.48	0.58	0.66	0.91
0.86	0.76		–	0.11	0.16	0.24	0.29	0.37	0.43	0.53	0.60	0.86
0.80	0.78			0.05	0.10	0.18	0.24	0.32	0.38	0.47	0.55	0.80
0.75	0.80			–	0.05	0.13	0.18	0.27	0.32	0.42	0.50	0.75
0.70	0.82				–	0.08	0.13	0.21	0.27	0.37	0.45	0.70
0.65	0.84					0.03	0.08	0.16	0.22	0.32	0.40	0.65
0.59	0.86					–	0.03	0.11	0.17	0.26	0.34	0.59
0.54	0.88						–	0.06	0.11	0.21	0.29	0.54
0.48	0.90							–	0.06	0.16	0.23	0.48
0.43	0.92								–	0.10	0.18	0.43
0.36	0.94									0.03	0.11	0.36
0.29	0.96									–	0.01	0.29
0.20	0.98										–	0.20

Table 3.3-11: **Determination table for required compensation power**

4

Products and Devices

4. Products and Devices

4.1 High-Voltage Switching Devices

4.1.1 Circuit-Breakers for 72.5 kV up to 800 kV

Circuit-breakers are the central part of AIS and GIS switchgear. They have to meet high requirements in terms of:
- Reliable opening and closing
- Consistent quenching performance with rated and short-circuit currents even after many switching operations
- High-performance, reliable, maintenance-free operating mechanisms.

4

Technology reflecting the latest state of the art and years of operating experience are put to use in constant further development and optimization of Siemens circuit-breakers. This makes Siemens circuit-breakers able to meet all the demands placed on high-voltage switchgear.

The comprehensive quality system is certified according to DIN EN ISO 9001. It covers development, manufacturing, sales, commissioning and after-sales service. Test laboratories are accredited to EN 45001 and PEHLA/STL.

Main design elements
Circuit-breakers for air-insulated switchgear are individual components, and are assembled together with all individual electrical and mechanical components of an AIS installation on site.

Due to the consistent application of a modular design, all Siemens circuit-breaker types, whether air-insulated or gas-insulated, are made up of the same range of components based on our well-proven platform design (fig. 4.1-1):
- Interrupter unit
- Operating mechanism
- Sealing system
- Operating rod
- Control elements.

Interrupter unit – self-compression arc-quenching principle
The Siemens product range from 72.5 kV up to 800 kV includes high-voltage circuit-breakers with self-compression interrupter units – for optimum switching performance under every operating condition for every voltage level.

Self-compression circuit-breakers
3AP high-voltage circuit-breakers for the complete voltage range ensure optimum use of the thermal energy of the arc in the contact tube. This is achieved by the self-compression interrupter unit.

Siemens patented this method for arc quenching in 1973. Since that time, Siemens has continued to develop the technology of the self-compression interrupter unit. One of its technical innovations is that the arc energy is increasingly used to extinguish the arc. In short-circuit breaking operations, the actuating energy required is reduced to the energy needed for mechanical contact movement.

That means that the operating energy is truly minimized. The self-compression interrupter unit allows the use of a compact stored-energy spring mechanism that provides unrestricted high dependability.

Stored-energy spring mechanism – for the complete product range
The operating mechanism is a central part of the high-voltage circuit-breakers. The drive concept of the 3AP high-voltage circuit-breakers is based on the stored-energy spring principle. The use of such an operating mechanism for voltage ranges of up to 800 kV became appropriate as a result of the development of a self-compression interrupter unit that requires minimal actuating energy.

Advantages of the stored-energy spring mechanism are:
- Highest degree of operational safety: It is a simple and sturdy design and uses the same principle for rated voltages from 72.5 kV up to 800 kV with just a few moving parts. Due to the self-compression design of the interrupter unit, only low actuating forces are required.
- Availability and long service life: Minimal stressing of the latch mechanisms and rolling-contact bearings in the operating mechanism ensure reliable and wear-free transmission of forces.
- Maintenance-free design: The spring charging gear is fitted with wear-free spur gears, enabling load-free decoupling.

Siemens circuit-breakers for rated voltage levels from 72.5 kV up to 800 kV are equipped with self-compression interrupter units and stored-energy spring mechanisms.

For special technical requirements such as rated short-circuit breaking currents of 80 kA, Siemens can offer twin-nozzle circuit-breaker series 3AQ or 3AT with an electrohydraulic mechanism.

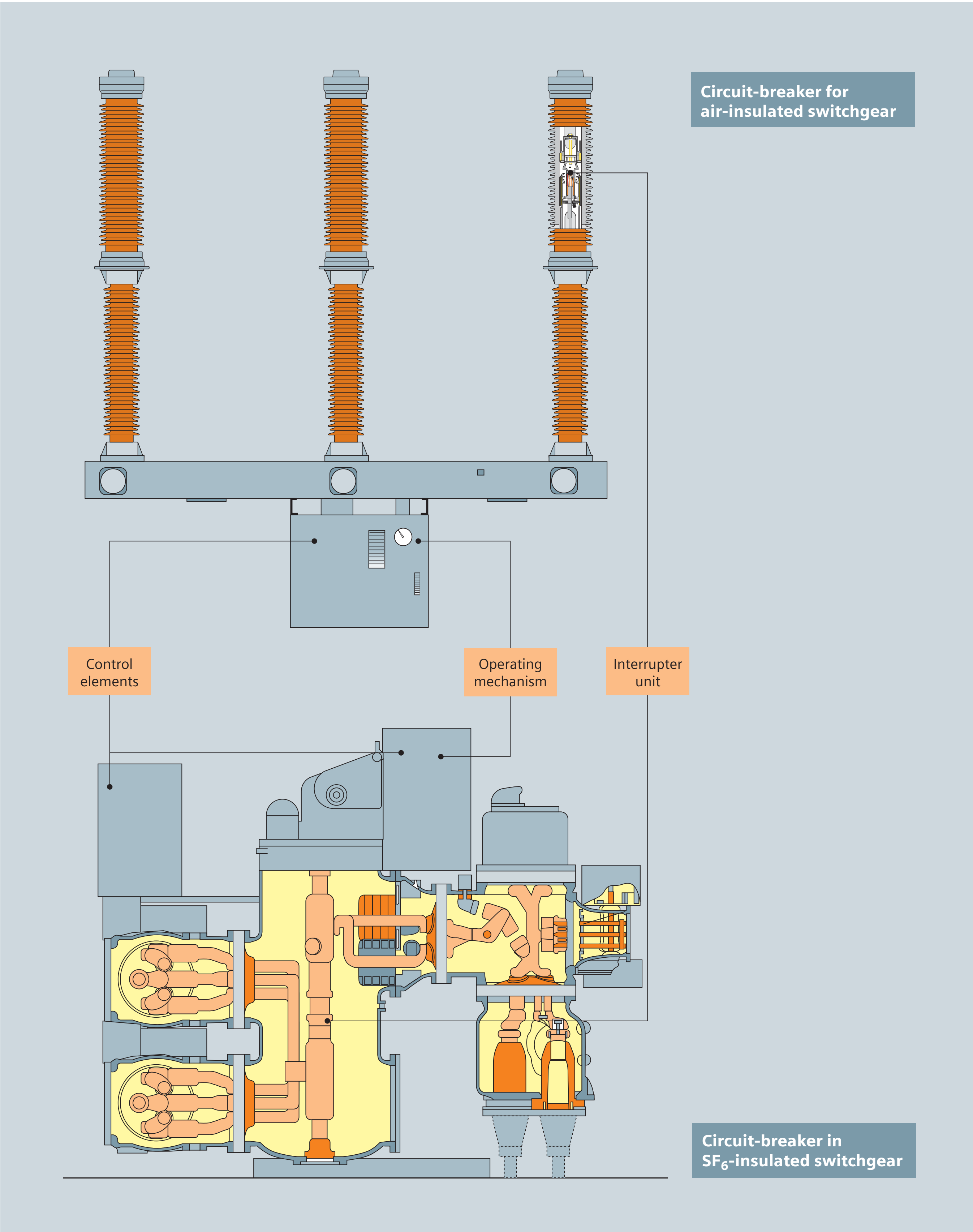


Fig. 4.1-1: **Circuit-breaker parts: circuit-breaker for air-insulated switchgear (top), circuit-breaker in SF_6-insulated switchgear (bottom)**

The interrupter unit: self-compression system

The conducting path
The current conducting path of the interrupter unit consists of the contact support (2), the base (7) and the movable contact cylinder (6). In the closed position, the current flows via the main contact (4) and the contact cylinder (6); (fig. 4.1-2).

Breaking operating currents
During the opening operation, the main contact (4) opens first, and the current commutates to the still closed arcing contact. During the further course of opening, the arcing contact (5) opens and an arc is drawn between the contacts. At the same time, the contact cylinder (6) moves into the base (7) and compresses the SF_6 gas located there. This gas compression creates a gas flow through the contact cylinder (6) and the nozzle (3) to the arcing contact, extinguishing the arc.

Breaking fault currents
In the event of interrupting high short-circuit breaking currents, the SF_6 gas is heated up considerably at the arcing contact due to the energy of the arc. This leads to a pressure increase in the contact cylinder. During the further course of opening, this increased pressure initiates a gas flow through the nozzle (3), extinguishing the arc. In this case, the arc energy is used to interrupt the fault current. This energy needs not be provided by the operating mechanism.

Major features:
- Self-compression interrupter unit
- Use of the thermal energy of the arc
- Minimized energy consumption
- High reliability for a long time

The operating mechanism

Stored-energy spring mechanism
Siemens circuit-breakers for voltages up to 800 kV are equipped with stored-energy spring mechanisms. These operating mechanisms are based on the same principle that has been proving its worth in Siemens low-voltage and medium-voltage circuit-breakers for decades. The design is simple and robust, with few moving parts and a vibration-isolated latch system of the highest reliability. All components of the operating mechanism, the control and monitoring equipment and all terminal blocks are arranged in a compact and convenient way in one cabinet.

Depending on the design of the operating mechanism, the energy required for switching is provided by individual compression springs (i.e., one per pole) or by springs that function

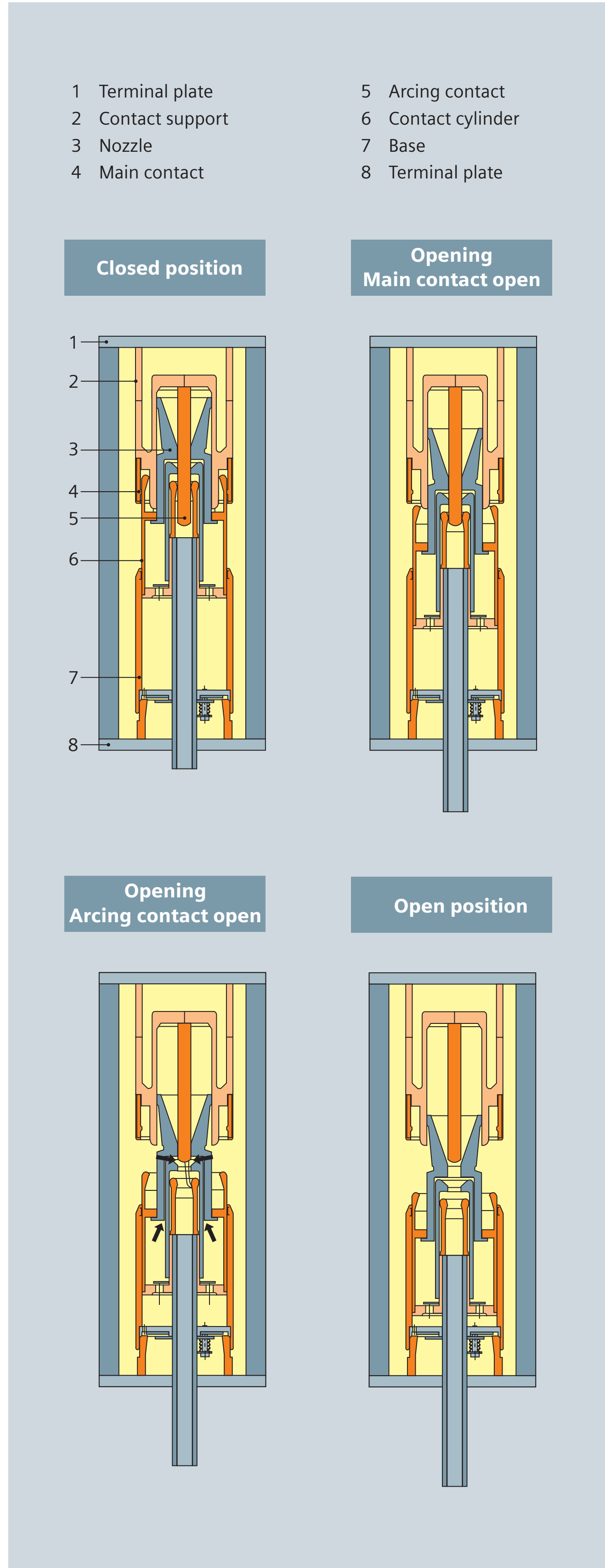
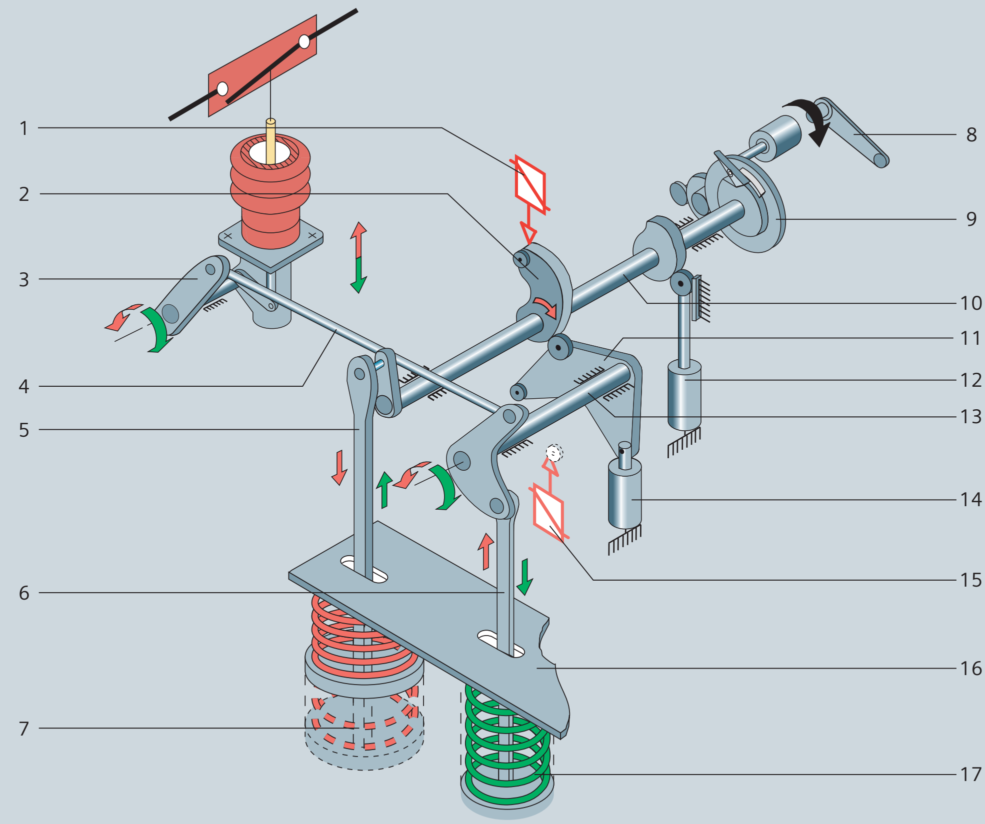


Fig. 4.1-2: **The interrupter unit**



1 Trip coil CLOSE
2 Cam plate
3 Corner gear
4 Connecting rod
5 Connecting rod for closing spring
6 Connecting rod for opening spring
7 Closing spring
8 Emergency hand crank
9 Charging gear
10 Charging shaft
11 Roller lever
12 Damper (for closing)
13 Operating shaft
14 Damper (for opening)
15 Trip coil OPEN
16 Operating mechanism housing
17 Opening spring

Fig. 4.1-3: **Operating mechanism**

jointly on a 3-pole basis.

The principle of the operating mechanism with charging gear and latching is identical on all types (fig. 4.1-3, fig. 4.1-4). Differences between mechanism types are in the number, size and arrangement of the opening and closing springs.

Main features at a glance:

- Uncomplicated, robust construction with few moving parts
- Maintenance-free
- Vibration-isolated latches
- Load-free uncoupling of charging mechanism
- Easy of access
- 10,000 operating cycles

Fig. 4.1-4: **Control cubicle**

4.1.2 Live-Tank Circuit-Breakers for 72.5 kV up to 800 kV

Circuit-breakers for air-insulated switchgear

Standard live-tank circuit-breakers – the design
All live-tank circuit-breakers are of the same general modular design, as shown in fig. 4.1-5 to 4.1-9.

They consist of the following main components based on our well established platform concept:
- Self-compression interrupter unit
- Stored-energy spring mechanism
- Insulator column (AIS)
- Operating rod
- Circuit-breaker base
- Control unit

The uncomplicated design of the circuit-breakers and the use of many similar components, such as interrupter units, operating rods, control cubicles and operating mechanisms, ensure high reliability. The experience Siemens has gained from the use of the many circuit-breakers in service has been applied in improvement of the design. The self-compression interrupter unit, for example, has proven its reliability in more than 100,000 installations all over the world.

The control unit includes all necessary devices for circuit-breaker control and monitoring, such as:
- Pressure/SF_6 density monitors
- Relays for alarms and lockout
- Operation counters (upon request)
- Local circuit-breaker control (upon request)
- Anti-condensation heaters

Transport, installation and commissioning are performed with expertise and efficiency. The routine-tested circuit-breaker is dismantled into a few subassemblies for transportation.

If desired, Siemens can provide appropriately qualified personnel for installation and commissioning.

Fig. 4.1-5: **800 kV circuit-breaker 3AP4**

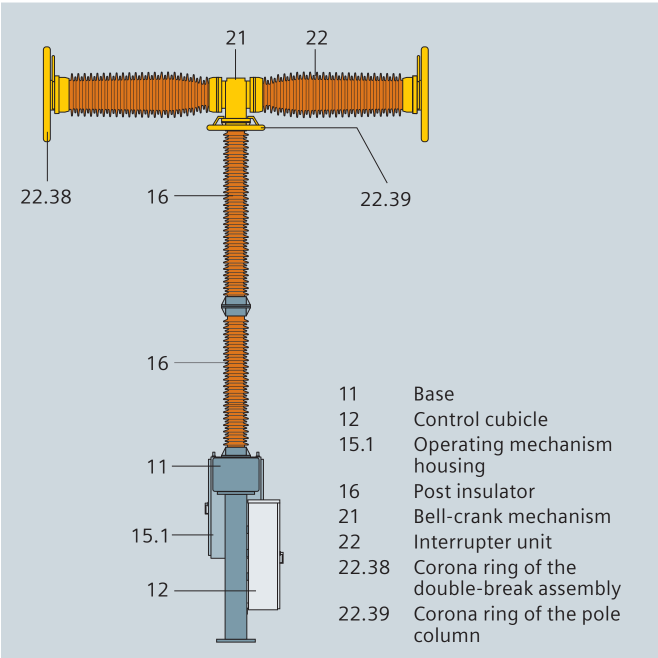


Fig. 4.1-6: **550 kV circuit-breaker 3AP2FI**

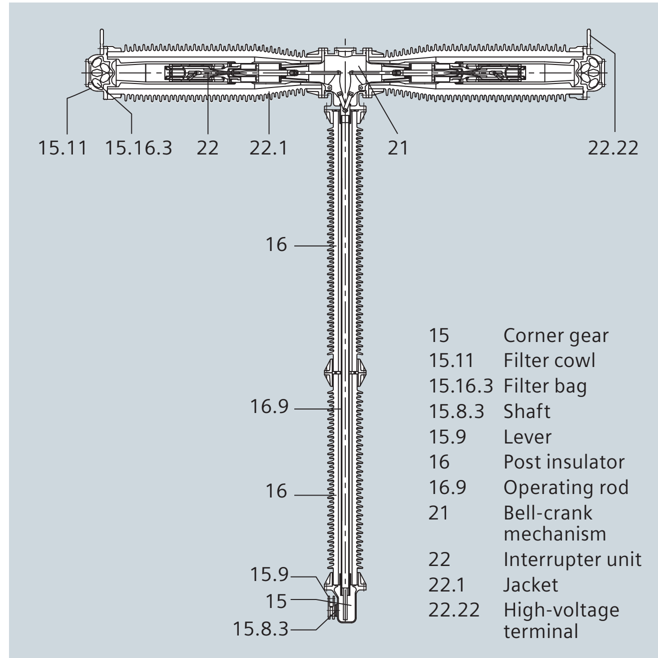


Fig. 4.1-7: **Sectional view of pole column**

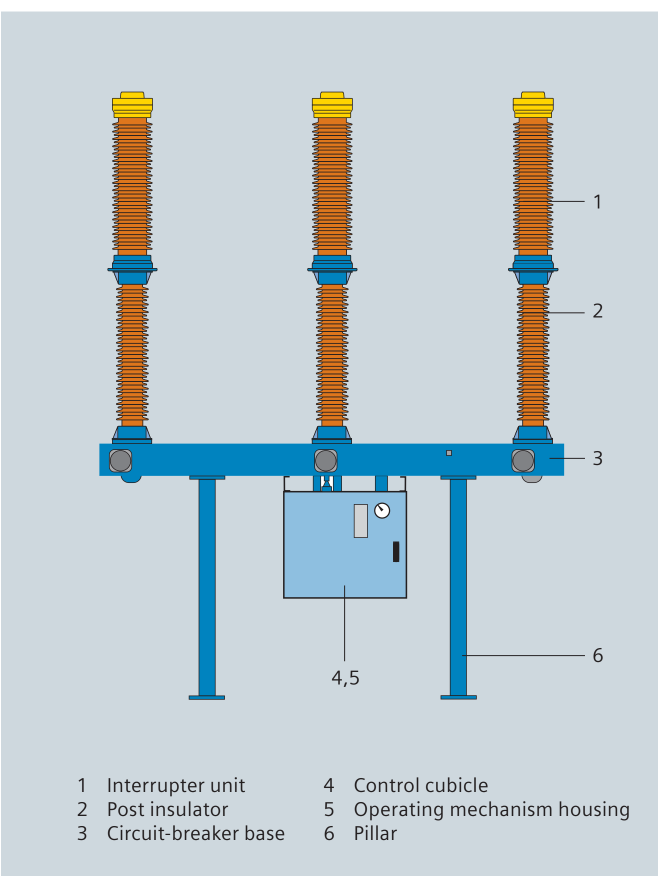


Fig. 4.1-8: **145 kV circuit-breaker 3AP1FG with 3-pole stored-energy spring mechanism**

Fig. 4.1-9: **3AP1FG on site**

Type	3AP1					3AP2				3AP4
Rated voltage [kV]	72.5	123	145	170	245	300	362	420	550	800
Number of interrupter units per pole	1					2				4
Rated power-frequency withstand voltage/min [kV]	140	230	275	325	460	460	520	610	800	830
Rated lightning impulse withstand voltage/min [kV]	325	550	650	750	1,050	1,050	1,175	1,425	1,550	2,100
Rated switching impulse withstand voltage/min [kV]	–	–	–	–	–	850	950	1,050	1,175	1,425
Rated normal current, up to [A]	4,000	4,000	4,000	4,000	4,000	4,000	5,000	5,000	5,000	5,000
Rated short-time withstand current (1 s – 3 s), up to $[kA_{(rms)}]$	40	40	40	40	50	40	50	50	63	63
Rated peak withstand current, up to $[kA_{(peak)}]$	108	108	108	108	135	108	170	170	170	170
Rated short-circuit breaking current, up to $[kA_{(rms)}]$	40	40	40	40	50	40	63	63	63	63
Rated short-circuit making current, up to $[kA_{(peak)}]$	108	108	108	108	135	108	170	170	170	170
Temperature range [°C]	– 30 or – 40 ... + 40 or + 50									
Rated operating sequence	0-0.3 s-CO-3 min-CO or CO-15 s-CO									
Rated break time	3 cycles					2 cycles				
Rated frequency [Hz]	50/60									50
Type of operating mechanism	Stored-energy spring mechanism									
Control voltage [V, DC]	48 ... 250									
Motor voltage [V, DC] [V, AC]	48/60/110/125/220/250 120 ... 240, 50 Hz; 120 ... 280, 60 Hz									
Flashover distance phase-to-earth [mm] across open circuit-breaker [mm]	700 1,200	1,250 1,200	1,250 1,200	1,500 1,400	1,900 1,900	2,200 2,200	3,400 3,200	3,400 3,200	3,800 3,800	5,850 7,600
Min. creepage distance phase-to-earth [mm] across open circuit-breaker [mm]	2,248 3,625	3,625 3,625	3,625 3,625	4,250 4,250	6,125 6,125	7,626 8,575	10,375 10,500	10,375 10,500	14,450 15,126	20,000 30,352
Dimensions height [mm] width [mm] depth [mm]	3,810 3,180 660	4,360 3,880 660	4,360 3,880 660	4,810 4,180 660	6,050 6,640 880	6,870 8,235 880	6,200 8,847 4,380	6,200 9,847 4,380	7,350 13,050 5,050	9,740 19,400 10,470
Phase spacing (min.) [mm]	1,350	1,700	1,700	1,850	2,800	3,600	4,000	4,500	6,000	9,000
Circuit-breaker mass [kg]	1,350	1,500	1,500	1,680	2,940	3,340	5,370	5,370	7,160	16,200
Maintenance after	25 years									
Values in accordance with IEC; other values available on request										

Table 4.1-1: **Technical data of circuit-breakers 3AP1, 3AP2 and 3AP4**

4.1.3 Dead-Tank Circuit-Breakers for 72.5 kV up to 550 kV

Circuit-breakers in dead-tank design
For certain substation designs, dead-tank circuit-breakers might be required instead of the standard live-tank circuit-breakers. The main feature of dead-tank technology is that the interrupter unit is accommodated in an earthed metal housing. The dead-tank circuit-breaker offers particular advantages if the protection design requires the use of several current transformers per pole assembly. For this purpose, Siemens can offer dead-tank circuit-breaker types (fig. 4.1-10, fig. 4.1-11).

Main features at a glance:

- Reliable opening and closing
  - Proven contact and self-compression arc-quenching system
  - Consistent quenching performance with rated and short-circuit currents – even after many switching operations
  - Similar uncomplicated design for all voltage levels
- High-performance, reliable operating mechanisms
  - Easy-to-actuate spring operating mechanisms
  - Low maintenance, economical and long service life
- Economy
  - Perfect finish
  - Simplified, quick installation process
  - Long maintenance intervals
  - High number of operating cycles
  - Long service life
- Individual service
  - Close proximity to the customer
  - Order-specific documentation
  - Solutions tailored to specific problems
  - After-sales service available promptly worldwide
- The right qualifications
  - Expertise in all power supply matters
  - More than 40 years of experience with SF_6-insulated circuit-breakers
  - A quality system certified to ISO 9001, covering development, manufacture, sales, installation and after-sales service
  - Test laboratories accredited to EN 45001 and PEHLA/STL

Fig. 4.1-10: **3AP1 dead-tank circuit-breaker 145 kV**

Fig. 4.1-11: **SPS-2 circuit-breaker 72.5 kV**

4

Dead-tank circuit-breaker

Type SPS-2 and 3AP1/2-DT

The type SPS-2 power circuit-breaker (table 4.1-2) is used for the US and ANSI markets, and the 3AP1/2-DT is offered in IEC markets. Both types are designed as general, definite-purpose circuit-breakers for use at maximum rated voltages of 72.5 kV up to 550 kV.

The design

Dead-tank circuit-breakers (except for the 550 kV version) consist of three identical pole units mounted on a common support frame. The opening and closing spring of the FA-type operating mechanism is transferred to the moving contacts of the interrupter unit through a system of connecting rods and a rotating seal at the side of each phase.

The connection to the overhead lines and busbars is realized by SF_6-insulated air bushings. The insulators are available in either porcelain or composite (epoxy-impregnated fiberglass tube with silicone rubber sheds) materials.

The tanks and the bushings are charged with SF_6 as at a rated pressure of 6.0 bar. The SF_6 serves is used for insulation and arc-quenching purposes.

The 3AP2/3-DT for 550 kV (fig. 4.1-12, fig. 4.1-13) consists of two interrupter units in a series that features a simple design.

The proven Siemens arc-quenching system ensures faultless operation, consistently high arc-quenching capacity and a long service life, even at high switching frequencies.

Thanks to constant further development, optimization and consistent quality assurance, Siemens self-compression arc-quenching systems meet all the requirements placed on modern high-voltage technology.

A control cubicle mounted at one end of the circuit-breaker houses the spring operating mechanism and circuit-breaker control components.

The interrupter units are located in the aluminum housings of each pole unit. The interrupters use the latest Siemens self-compression arc-quenching system.

The stored-energy spring mechanism is the same design as used within the Siemens 3AP live-tank circuit-breakers, GIS and compact switchgear. This design has been documented in service for more than 10 years, and has a well-documented reliability record.

Operators can specify up to four (in some cases, up to six) bushing-type current transformers (CT) per phase. These CTs, mounted externally on the aluminum housings, can be removed without dismantling the bushings.

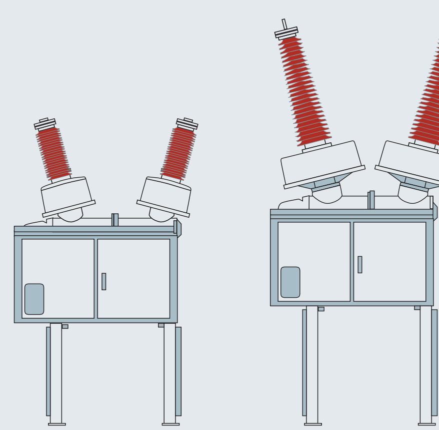
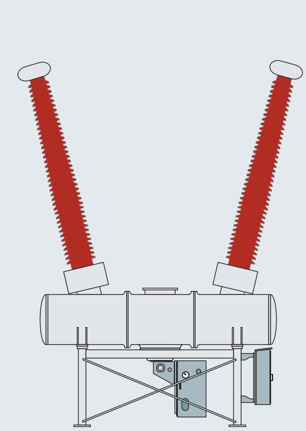
Technical data						
Type		**SPS-2/3AP1 DT**				**3AP2/3 DT**
Rated voltage	[kV]	72.5	123	145	245	550
Rated power-frequency withstand voltage	[kV]	140	230	275	460	620
Rated lighting impulse withstand voltage	[kV]	325	550	650	1,050	1,800
Rated switching impulse withstand voltage	[kV]	–	–	–	–	1,300
Rated nominal current up to	[A]	4,000	4,000	4,000	4,000	4,000
Rated breaking current up to	[A]	40	40	63	63	63
Operating mechanism type		Stored-energy spring mechanism				

Table 4.1-2: **Technical data of dead-tank circuit-breaker**

Operating mechanism
The mechanically and electrically trip-free spring mechanism type FA is used on type SPS-2 and 3AP1/2-DT circuit-breakers. The closing and opening springs are loaded for "O-C-O" operations.

A weatherproofed control cubicle (degree of protection IP55) has a large door, sealed with rubber gaskets, for easy access during inspection and maintenance. Condensation is prevented by heaters that maintain a difference in inside/outside temperature, and by ventilation.

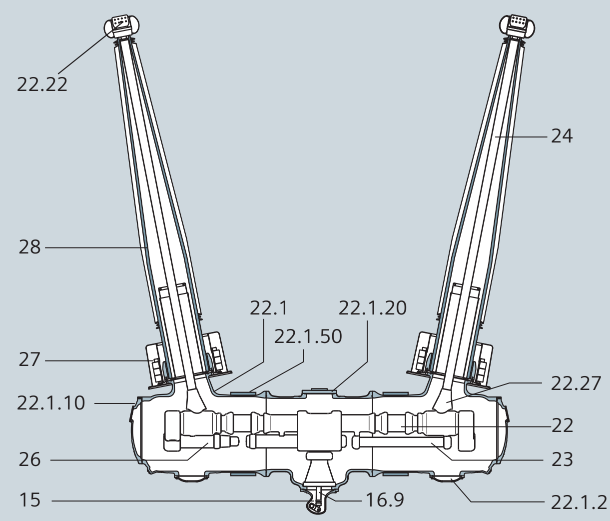
The control system includes all the secondary technical components required for operating the circuit-breaker, which are typically installed in the control cubicle. The current transformer connections are also located in the control cubicle.

The control, tripping, motor and heating power supplies are selectable in a great extent. Depending on customer requirements, two standard control versions are available.

Basic version
The basic variant includes all control and monitoring elements that are needed for operation of the circuit-breaker. In addition to the elementary actuation functions, it includes:
- 19 auxiliary switch contacts (9 normally open, 9 normally closed, 1 passing contact)
- Operations counter
- Local actuator

Compact version
In addition to the basic version, this type includes:
- Spring monitoring by motor runtime monitoring
- Heating monitoring (current measuring relay)
- Luminaire and socket attachment with a common circuit-breaker to facilitate servicing and maintenance work
- Overvoltage attenuation
- Circuit-breaker motor
- Circuit-breaker heating

For further information, please contact:
Fax: + 49 30 386-25867



15	Corner gear	22.1.50	Additional heating
16.9	Operating rod	22.22	High-voltage terminal
22	Interrupter unit	22.27	Conductor connection
22.1	Housing	23	Grading capacitor
22.1.10	Cover	24	Bushing conductor
22.1.10.1	Cover	26	Closing resistor
22.1.20	Cover with bursting disc	27	Current transformer
22.1.21	Cover with filter material	28	Bushing

Fig. 4.1-12: **Sectional view of a 3AP2/3-DT circuit-breaker pole**

Fig. 4.1-13: **3AP2-DT 550 kV**

4.1.4 Compact Switchgear up to 245 kV

Dead-tank based compact switchgear from 145 kV up to 245 kV

The latest development from Siemens is the 3AP1 DTC (Dead-Tank Compact) switchgear family for voltages up to 245 kV. It features all the functions needed in a substation. The elements of this compact switchgear are a dead-tank circuit-breaker fitted with one or two current transformers, one or more disconnectors, earthing switches and bushings, as applicable for connection to the busbar system. The result is a compact space-saving design that compares favorably to a conventional air-insulated substation (fig. 4.1-15).

The modular design

Based on the well-proven modular design, the core components of the main units are based on the same technology that is used in the well-established high-voltage circuit-breakers, disconnectors and GIS product family of Siemens. These components are:

- Self-compression arc-quenching interrupter unit of the AIS 3AP circuit-breaker
- Stored-energy spring mechanism
- SF_6-insulated disconnector/earthing switch from the GIS type 8DN8
- Outdoor earthing switch from our disconnector product range

The concept

Due to the compact design and the flexible use of predefined and multi-extendable modules, different layouts can be realized with a minimum of engineering effort. The basic DTC concept offers the following standard arrangements:

- In/Out-modules
- Single-busbar modules
- Double-busbar modules and
- Combined disconnecting modules

The In/Out version (fig. 4.1-16) represents the basic module: a dead-tank circuit-breaker with current transformer on the incoming side and earthing switch/disconnector on the outgoing side. If further disconnector/earthing switches on the line side or busbar side are required, the single-busbar version offers the right solution. A combination of earthing switch/disconnecting and earthing switch is also available.

Used as a double-busbar version (fig. 4.1-17), gastight insulating partitions are available upon request. They subdivide each device into functionally distinct gas compartments (circuit-breaker and disconnector). This arrangement follows the fundamental idea of a double-busbar. A further version is the circuit-breaker with combined function and outdoor earthing switches, which offers the function of a combined disconnecting circuit-breaker. Additional elements in this arrangement are current transformers and earthing switches attached on both sides of the module.

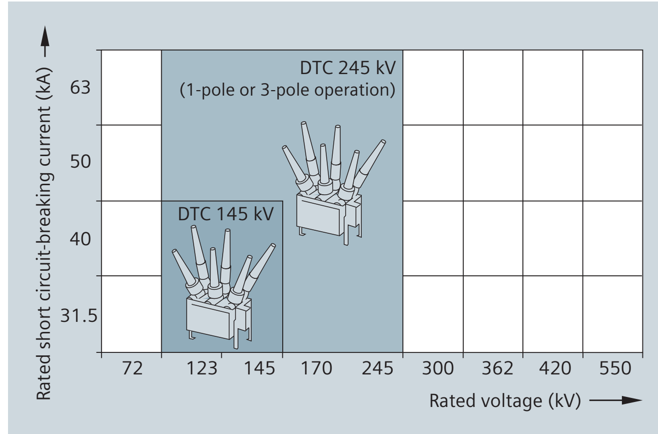


Fig. 4.1-14: **Product range DTC**

Fig. 4.1-15: **3AP1 DTC 145 kV**

High-voltage compact switchgear		3AP1 DTC		
Rated voltage	[kV]	123	145	245
Rated nominal current	[A]	2,500	2,500	3,150
Rated frequency	[Hz]	50/60	50/60	50/60
Rated lightning impulse withstand voltage	[kV]	550	650	1050
Rated power-frequency withstand voltage	[kV]	230	275	460
Rated power-frequency current (3 s)	[kA]	40	40	63
Rated peak withstand current	[kA]	108	108	170

Table 4.1-3: **Technical data of 3AP1 DTC**

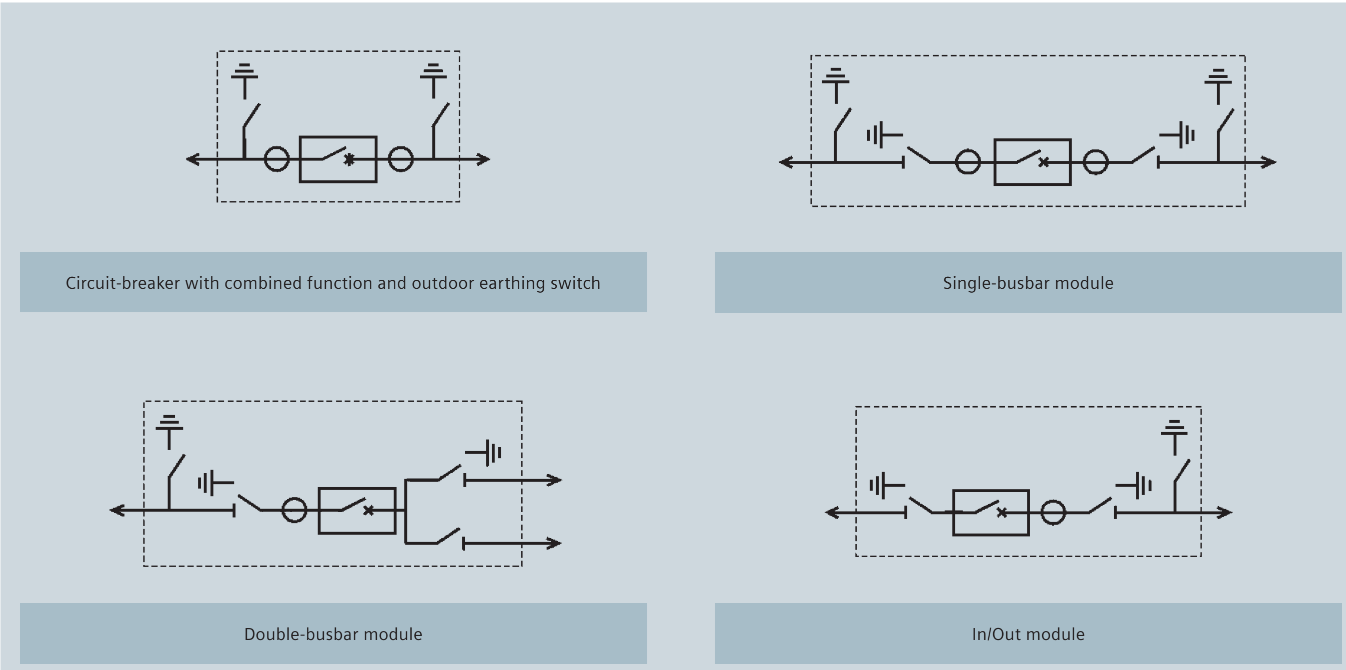


Fig. 4.1-16: **Examples of DTC single-line diagrams**

Fig. 4.1-17: **3AP1 DTC 245 kV, double-busbar version**

4.1.5 Disconnectors up to 800 kV

General

Disconnectors are an essential part of electrical power substations. They indicate a visible isolating distance in air isolated gap.

Modern production technologies and investments in our production sites worldwide ensure sustained product and process quality in accordance with the high standards of Siemens.

Siemens disconnectors fulfil the system operators' requirements for low life-cycle costs with maximum availability and continuous economic service by:

- Delivery of completely routine-tested and pre-adjusted assembly groups
- Easy erection and commissioning
- Maintenance-free bearings and contact systems
- Lifetime technical support
- The contact systems have proved their reliability through decades of service.

The most important features are:

- Self-resilient contact fingers – no further spring elements are necessary to generate the contact force
- Silver-plated contact surface provides maximum conductivity without regular greasing lubrication
- Factory set contact forces; no re-adjustments required during service life
- Ice layers up to 20 mm can be broken without difficulties
- Maintenance-free contact system for up to 25 years

The reliability of Siemens disconnectors and earthing switches over many decades is ensured by a comprehensive testing and quality assurance system certified according to DIN EN ISO 9001.

Center-break disconnectors

The center-break disconnector is the most frequently used disconnector type. The disconnector base supports the operating mechanism and two rotating porcelain support insulators. The current path arms which are fixed to the insulators open in the center. Each rotating unit comprises two high-quality ball bearings and is designed for high mechanical loads. They are lubricated and maintenance-free for the entire service life (fig. 4.1-18).

The current path of the center-break disconnector consists of only a few components, thus the number of contact resistances is reduced to a minimum. The main contact system of block contact and spread contact fingers assures a steady contact force even after decades of operation (fig. 4.1-19).

Fig. 4.1-18: **Center-break disconnector**

Fig. 4.1-19: **Block and finger contact system**

Pantograph disconnectors
This type is generally used in double-busbar systems to connect the two busbars or a busbar to a line.
The main components of a pantograph disconnector are (fig. 4.1-20):

- Scissor arms (1)
- Bearing frame (2)
- Support insulator (3)
- Rotating insulator (4)
- Motor operating mechanism (5)

Rotary contact systems inside the joints, which have thermal and dynamic current carrying capacity, are used for current transfer. The geometry of the pantograph ensures optimum operational behavior.

The specific contact force is adjusted in the factory and remains unchanged during service life. Ice loads of up to 20 mm can be broken without difficulties.

In both end positions of the disconnector, the rotary arm in the bearing frame is switched beyond the dead center point. The switch position cannot be changed by external forces. The rigidity of the scissor arms prevents opening during a short-circuit.

Pantograph disconnectors with rated voltages from 123 kV up to 362 kV are optionally equipped with group operating mechanisms or 1-pole operating mechanisms. All pantograph disconnectors for higher rated voltages are equipped with 1-pole operating mechanisms.

Vertical-break disconnectors
The current path of the vertical-break disconnector opens vertically and requires a minimum phase distance (fig. 4.1-21).

The current path performs two movements:

- A vertical swinging movement
- A rotary movement around its own longitudinal axis

The rotary movement generates the contact force and breaks possible ice layers.

In both end positions, the rotary arm is switched beyond the dead center point. This locks the current path in the short-circuit-proof CLOSED position, and prevents the current path from switching to the OPEN position under external forces.

The ample distance between support insulator and rotating insulator ensures dielectric strength of the parallel insulation even under saline fog conditions.

The movable part of the current path is one single subassembly which is pre-adjusted and routine-tested at the factory. This allows for easy and quick installation and commissioning on site.

Double-side break disconnectors
The double-side break disconnector features three support insulators. The support insulator in the center is mounted

Fig. 4.1-20: **Components of the pantograph disconnector**
1. *Scissor arms*
2. *Bearing frame*
3. *Support insulator*
4. *Rotating insulator*
5. *Motor operating mechanism*

Fig. 4.1-21: **Vertical-break disconnector**

on a rotating unit and carries the current path. Both end support insulators are fixed.

The main application of double-side break disconnectors are substations with limited phase distances and where vertical opening of the current path is not possible. High mechanical terminal loads are possible due to the compact and stable design. It can also be combined with an integrated surge arrester (fig. 4.1-22).

For voltage levels up to 245 kV, the contact fingers of the double-side break disconnectors are integrated into the current path tube, and the fixed contacts consist of contact blocks. The current path performs a horizontal swinging movement, and the contact force is generated by spreading the contact fingers while sliding on the contact blocks.

For voltage levels higher than 245 kV, contact strips are attached to the ends of the current path tubes. The contact fingers are part of the fixed contacts. In this design, the current path performs a combined swinging and rotary movement. After completion of the swinging movement, the contact force is generated by the rotation of the current path around its own axis.

Knee-type disconnectors

This disconnector type has the smallest horizontal and vertical space requirements. The knee-type disconnector has two fixed and one rotating insulator. Thanks to its folding-arm design, only limited overhead clearance is required, which results in lower investment costs (fig. 4.1-23).

Fig. 4.1-22: **Double-side break disconnector with integrated surge arrester**

Fig. 4.1-23: **Knee-type disconnector**

Earthing switches
The use of earthing switches (fig. 4.1-24) ensures absolute de-energization of high-voltage components in a circuit or switchgear.

Free-standing earthing switches are available for all voltage levels up to 800 kV.

Suitable built-on earthing switches are available for all disconnector types of the Siemens scope of supply.

According to the system operators' requirements, built-on earthing switches can be arranged laterally or in integrated arrangement with respect to the position of the main current path of the disconnector when needed.

Optionally, all earthing switches can be designed for switching induced inductive and capacitive currents according to IEC 62271-102, Class A or Class B.

Motor operating mechanisms
The motor operating mechanisms consist of three main subassemblies:

- Corrosion-resistant housing
- Gear unit with motor
- Electrical equipment with auxiliary switch

The motor operating mechanism can also be operated manually by a hand crank which can be inserted in the cubicle. The insertion of the hand crank automatically isolates the motor circuit for safety purposes. Heaters are provided to prevent condensation (fig. 4.1-25).

The auxiliary switch is custom-fit to the gear unit and signals the switch position with absolute reliability. This ensures safe substation operation.

After the motor starts, the auxiliary switch moves and the switch position signal is cancelled. The disconnector operates thereafter until the end position is reached.

The auxiliary switch then moves again and issues the switch position signal.

This sequence ensures that the CLOSED position is indicated only after the disconnector is locked and short-circuit-proof, and the rated current can be carried. The OPEN position is indicated only after the opened current path has reached the nominal dielectric strength.

An overview of Siemens disconnectors is shown in table 4.1-4 to table 4.1-8.

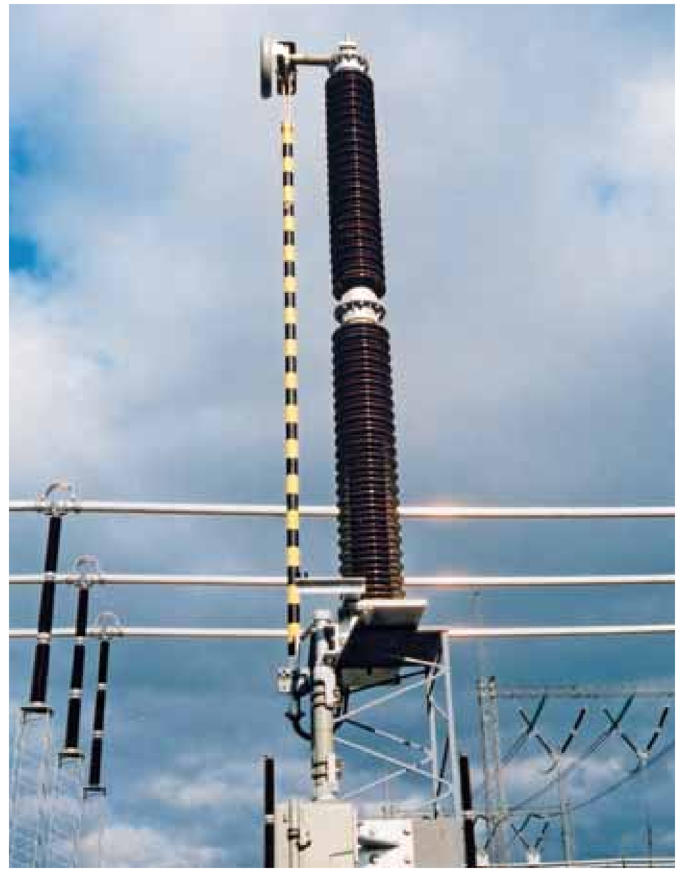


Fig. 4.1-24: **Free-standing earthing switch**

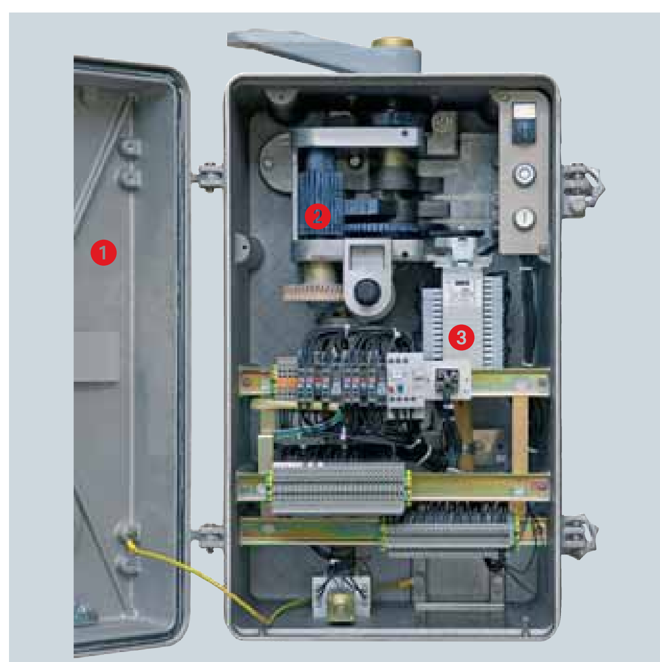


Fig. 4.1-25: **Motor operating mechanism: Cast-aluminum housing with door (1) – degree of protection IP55; gear unit (2) with motor; electrical equipment with auxiliary switch (3)**

4

4

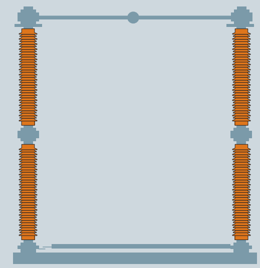
Technical data									
									
Design	Center break								
Rated voltage	72.5	123	145	170	245	300	362	420	550
Rated power-frequency withstand voltage 50 Hz/1 min									
To earth and between phases [kV] Across the isolating distance [kV]	140 160	230 265	275 315	325 375	460 530	380 435	450 520	520 610	620 800
Rated lightning impulse withstand voltage 1.2/50 µs									
To earth and between phases [kV] Across the isolating distance [kV]	325 375	550 630	650 750	750 860	1,050 1,200	1,050 1,050 (+170)	1,175 1,175 (+205)	1,425 1,425 (+240)	1,550 1,550 (+315)
Rated switching impulse withstand voltage 250/2,500 µs									
To earth and between phases [kV] Across the isolating distance [kV]	– –	– –	– –	– –	– –	850 700 (+245)	950 800 (+295)	1,050 900 (+345)	1,175 900 (+450)
Rated normal current up to [A]	4,000								
Rated peak withstand current up to [kA]	160								
Rated short-time withstand current up to [kA]	63								
Rated duration of short circuit [s]	1/3								
Icing class	10/20								
Temperature range [°C]	–50/+50								
Operating mechanism type	Motor operation/Manual operation								
Control voltage [V, DC] [V, AC]	60/110/125/220 220...230, 1~, 50/60 Hz								
Motor voltage [V, DC] [V, AC]	60/110/125/220 110/125/220, 1~, 50/60 Hz 220/380/415, 3~, 50/60 Hz								
Maintenance	25 years								

Table 4.1-4: **Center-break disconnector**

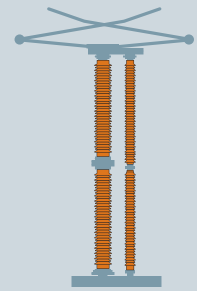
Technical data								
								
Design	Pantograph							
Rated voltage	123	145	170	245	300	362	420	550
Rated power-frequency withstand voltage 50 Hz/1 min								
To earth and between phases [kV] Across the isolating distance [kV]	230 265	275 315	325 375	460 530	380 435	450 520	520 610	620 800
Rated lightning impulse withstand voltage 1.2/50 µs								
To earth and between phases [kV] Across the isolating distance [kV]	550 630	650 750	750 860	1,050 1,200	1,050 1,050 (+170)	1,175 1,175 (+205)	1,425 1,425 (+240)	1,550 1,550 (+315)
Rated switching impulse withstand voltage 250/2,500 µs								
To earth and between phases [kV] Across the isolating distance [kV]	– –	– –	– –	– –	850 700 (+245)	950 800 (+295)	1,050 900 (+345)	1,175 900 (+450)
Rated normal current up to [A]	5,000							
Rated peak withstand current up to [kA]	200							
Rated short-time withstand current up to [kA]	80							
Rated duration of short circuit [s]	1/3							
Icing class	10/20							
Temperature range [°C]	–50/+50							
Operating mechanism type	Motor operation/Manual operation							
Control voltage [V, DC] [V, AC]	60/110/125/220 220…230, 1~, 50/60 Hz							
Motor voltage [V, DC] [V, AC]	60/110/125/220 110/125/220, 1~, 50/60 Hz 220/380/415, 3~, 50/60 Hz							
Maintenance	25 years							

Table 4.1-5: **Pantograph disconnector**

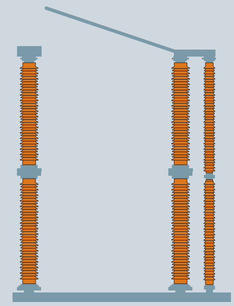
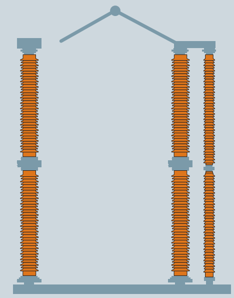
Technical data									
Design		Vertical break							
Rated voltage		123	145	170	245	300	362	420	550
Rated power-frequency withstand voltage 50 Hz/1 min									
To earth and between phases	[kV]	230	275	325	460	380	450	520	620
Across the isolating distance	[kV]	265	315	375	530	435	520	610	800
Rated lightning impulse withstand voltage 1.2/50 µs									
To earth and between phases	[kV]	550	650	750	1,050	1,050	1,175	1,425	1,550
Across the isolating distance	[kV]	630	750	860	1,200	1,050 (+170)	1,175 (+205)	1,425 (+240)	1,550 (+315)
Rated switching impulse withstand voltage 250/2,500 µs									
To earth and between phases	[kV]	–	–	–	–	850	950	1,050	1175
Across the isolating distance	[kV]	–	–	–	–	700 (+245)	800 (+295)	900 (+345)	900 (+450)
Rated normal current up to	[A]	4,000							
Rated peak withstand current up to	[kA]	160							
Rated short-time withstand current up to	[kA]	160							
Rated duration of short circuit	[s]	1/3							
Icing class		10/20							
Temperature range	[°C]	–50/+50							
Operating mechanism type		Motor operation/Manual operation							
Control voltage	[V, DC] [V, AC]	60/110/125/220 220…230, 1~, 50/60 Hz							
Motor voltage	[V, DC] [V, AC]	60/110/125/220 110/125/230, 1~, 50/60 Hz 220/380/415, 3~, 50/60 Hz							
Maintenance		25 years							

Table 4.1-6: **Vertical-break disconnector**



Technical data			
Design		Knee type	
Rated voltage		123	550
Rated power-frequency withstand voltage 50 Hz/1 min			
To earth and between phases Across the isolating distance	[kV] [kV]	230 265	620 800
Rated lightning impulse withstand voltage 1.2/50 µs			
To earth and between phases Across the isolating distance	[kV] [kV]	550 630	1,550 1,550 (+315)
Rated switching impulse withstand voltage 250/2,500 µs			
To earth and between phases Across the isolating distance	[kV] [kV]	– –	1,175 900 (+450)
Rated normal current up to	[A]	4,000	
Rated peak withstand current up to	[kA]	100	160
Rated short-time withstand current up to	[kA]	40	63
Rated duration of short circuit	[s]	1/3	
Icing class		10/20	
Temperature range	[°C]	–50/+50	
Operating mechanism type		Motor operation/Manual operation	
Control voltage	[V, DC] [V, AC]	60/110/125/220 220…230, 1~, 50/60 Hz	
Motor voltage	[V, DC] [V, AC]	60/110/125/220 110/125/230, 1~, 50/60 Hz 220/380/415, 3~, 50/60 Hz	
Maintenance		25 years	

Table 4.1-7: **Knee-type disconnector**

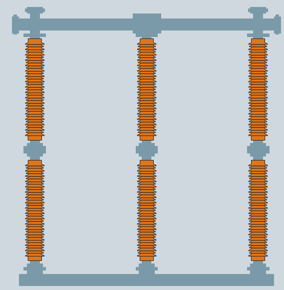
Technical data									
Design		Double-side break							
Rated voltage		123	145	170	245	300	420	550	800
Rated power-frequency withstand voltage 50 Hz/1 min									
To earth and between phases Across the isolating distance	[kV] [kV]	230 265	275 315	325 375	460 530	380 435	520 610	450 520	830 1,150
Rated lightning impulse withstand voltage 1.2/50 µs									
To earth and between phases Across the isolating distance	[kV] [kV]	550 630	650 750	750 860	1,050 120	1,050 1,050 (+170)	1,425 1,425 (+240)	1,550 1,550 (+315)	2,100 2,100 (+455)
Rated switching impulse withstand voltage 250/2,500 µs									
To earth and between phases Across the isolating distance	[kV] [kV]	– –	– –	– –	– –	850 700 (+245)	1,050 900 (+345)	1,175 900 (+450)	1,550 1200 (+650)
Rated normal current up to	[A]	4000							
Rated peak withstand current up to	[kA]	160							
Rated short-time withstand current up to	[kA]	63							
Rated duration of short circuit	[s]	1/3							
Icing class		10/20							
Temperature range	[°C]	–50/+50							
Operating mechanism type		Motor operation/Manual operation							
Control voltage	[V, DC] [V, AC]	60/110/125/220 220…230, 1~, 50/60 Hz							
Motor voltage	[V, DC] [V, AC]	60/110/125/220 110/125/230, 1~, 50/60 Hz 220/380/415, 3~, 50/60 Hz							
Maintenance		25 years							

Table 4.1-7: **Double-side break**

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4.2 Vacuum Switching Technology and Components for Medium Voltage

4.2.1 Overview of Vacuum Switching Components

Medium-voltage equipment is available in power stations (in generators and station supply systems) and in transformer substations (of public systems or large industrial plants) of the primary distribution level. Transformer substations receive power from the high-voltage system and transform it down to the medium-voltage level. Medium-voltage equipment is also available in secondary transformer or transfer substations (secondary distribution level), where the power is transformed down from medium to low voltage and distributed to the end consumer.

The product line of the medium-voltage switching devices contains (fig. 4-2-1):

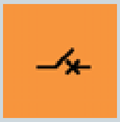
- Circuit-breakers
- Switches
- Contactors
- Disconnectors
- Switch-disconnectors
- Earthing switches

Requirements

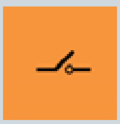
In CLOSED condition, the switching device has to offer minimum resistance to the flow of normal and short-circuit currents. In OPEN condition, the open contact gap must withstand the appearing voltages safely. All live parts must be sufficiently isolated to earth and between phases when the switching device is open or closed.

The switching device must be able to close the circuit if voltage is applied. For disconnectors, however, this condition is only requested for the de-energized state, except for small load currents.

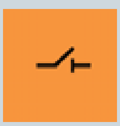
The switching device should be able to open the circuit while current is flowing. This is not requested for disconnectors. The switching device should produce switching overvoltages as low as possible.



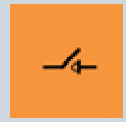
Circuit-breakers
Circuit-breakers must make and break all currents within the scope of their ratings, from small inductive and capacitive load currents up to the short-circuit current, and this must occur under all fault conditions in the power supply system, including earth faults and phase opposition. Outdoor circuit-breakers have the same applications, but are also exposed to weather influences.



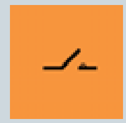
Switches
Switches must make and break normal currents up to their rated normal current, and be able to make on existing short circuits (up to their rated short-circuit making current). However, they cannot break any short-circuit currents.



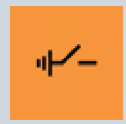
Contactors
Contactors are load breaking devices with a limited making and breaking capacity. They are used for high switching rates but can neither make nor break short-circuit currents.



Disconnectors
Disconnectors are used for no-load closing and opening operations. Their function is to "isolate" downstream equipment so they can be worked on.



Switch-disconnectors
A switch-disconnector is to be understood as the combination of a switch and a disconnector, or a switch with isolating distance.



Earthing switches
Earthing switches earth isolated circuits. Make-proof earthing switches earth circuits without danger, even if voltage is present, that is, also in the event that the circuit to be earthed was accidentally not isolated.

Fig. 4.2-1: **Product line of medium-voltage switching devices**

4.2.2 Selection of Components by Ratings

The switching devices and all other equipment must be selected for the system data available at the place of installation. This system data defines the ratings of the components (table 4.2-1)

Rated insulation level
The rated insulation level is the dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance.

The dielectric strength is the capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages). The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2/50 µs and a power-frequency withstand voltage test (50 Hz/1 min).

Rated voltage
The rated voltage is the upper limit of the highest system voltage the device is designed for. Because all high-voltage switching devices are zero-current interrupters – except for some fuses – the system voltage is the most important dimensioning criterion. It determines the dielectric stress of the switching device by means of the transient recovery voltage and the recovery voltage, especially while switching off.

Rated normal current
The rated normal current is the current that the main circuit of a device can continuously carry under defined conditions. The heating of components – especially of contacts – must not exceed defined values. Permissible temperature rises always refer to the ambient air temperature. If a device is mounted in an enclosure, it is possible that it may not be loaded with its full rated current, depending on the quality of heat dissipation.

Rated peak withstand current
The rated peak withstand current is the peak value of the first major loop of the short-circuit current during a compensation process after the beginning of the current flow that the device can carry in closed state. It is a measure for the electrodynamic (mechanical) load of an electrical component. For devices with full making capacity, this value is not relevant (see the paragraph "Rated short-circuit making current" later in this section).

Rated breaking current
The rated breaking current is the load breaking current in normal operation. For devices with full breaking capacity and without a

critical current range, this value is not relevant (see the paragraph "Rated short-circuit breaking current" later in this section).

Rated short-circuit breaking current
The rated short-circuit breaking current is the root-mean-square value of the breaking current in the event of short-circuit at the terminals of the switching device.

Rated short-circuit making current
The rated short-circuit making current is the peak value of the making current in the event of short-circuit at the terminals of the switching device. This stress is greater than that of the rated peak withstand current, because dynamic forces may work against the contact movement.

Standards
The switching devices, and also non-switching components, are subject to national and international standards.

Table 4.2-2 shows the different international standards and their German equivalents.

Component designation	Rated insulation level	Rated voltage	Rated normal current	Rated peak withstand current	Rated breaking current	Rated short-circuit breaking current	Rated short-circuit making current
Switching devices							
Circuit-breaker	■	■	■	–	–	■	■
Switch	■	■	■	–	■	■ 1)	■
Switch-disconnector	■	■	■	–	■	–	■
Disconnector	■	–	■	■	–	–	–
Earthing switch	■	–	–	■	–	–	–
Make-proof earthing switch	■	■	–	–	–	–	■
Contactor	■	■	■	–	■	■ 1)	■ 1)

■ Influence on selection of component – No influence on selection of component 1) Limited short-circuit making capacity

Table 4.2-1: **Table of switching devices according to ratings**

International	German	Designation
EN 5010	VDE 0105-100	Operation of electrical equipment
IEC 60044	VDE 0414	Instrument transformers
IEC 60099	VDE 0675	Surge arresters
IEC 60265-1	VDE 0670-301	High-voltage switches – Part 1: Switches for rated voltages above 1 kV and less than 52 kV
IEC 60282	VDE 0670-4	High-voltage fuses – Part 1: Current-limiting fuses
IEC 60470	VDE 0670-501	High-voltage alternating current contactors and contactor-based motor starters
IEC 60644	VDE 0670-401	Specification for high-voltage fuse-links for motor circuit applications
IEC 60694	VDE 0670-1000	Common specification for high-voltage switchgear and controlgear standards
IEC 60787	VDE 0670-402	Application guide for the selection of high-voltage current-limiting fuse-links for transformer circuits
IEC 62271-100	VDE 0671-100	High-voltage alternating current circuit-breakers
IEC 62271-102	VDE 0671-102	Alternating current disconnectors and earthing switches
IEC 62271-105	VDE 0671-105	Alternating current switch-fuse combinations

Table 4.2-2: **The numbers of the standards for switching devices and switchgear will change in the coming years or have already been partly changed. In future, IEC will summarize all standards of one commission under one group number, so that the standards of a specific technical field will be easy to locate**

4

4.2.3 Vacuum Circuit-Breakers

Siemens medium-voltage vacuum circuit-breakers are available with rated voltages up to 36 kV and rated short-circuit breaking currents up to 72 kA (table 4.2-3). They are used:

- For universal installation in all customary medium-voltage switchgear types
- As 1-pole or multi-pole medium-voltage circuit-breakers for all switching duties in indoor switchgear
- For breaking resistive, inductive and capacitive currents
- For switching generators
- For switching contact lines (1-pole traction circuit-breakers).

Switching duties

The switching duties of the circuit-breaker depend partly upon its type of operating mechanism:

- Stored-energy mechanism
  – For synchronizing and rapid load transfer
  – For auto-reclosing
- Spring-operated mechanism (spring CLOSED, stored-energy OPEN) for normal closing and opening.

Switching duties in detail

Synchronizing

The closing times during synchronizing are so short that, when the contacts touch, there is still sufficient synchronism between the systems to be connected in parallel.

Rapid load transfer

The transfer of consumers to another incoming feeder without interrupting operation is called rapid load transfer. Vacuum circuit-breakers with stored-energy mechanisms feature the very short closing and opening times required for this purpose. Beside other tests, vacuum circuit-breakers for rapid load transfer have been tested with the operating sequence O-3 min-CO-3 min-CO at full rated short-circuit breaking current according to the standards. They even control the operating sequence O-0.3 s-CO-3 min-CO up to a rated short-circuit breaking current of 31.5 kA.

Auto-reclosing

This is required in overhead lines to clear transient faults or short-circuits that could be caused by, for example, thunderstorms, strong winds or animals. Even at full short-circuit current, the vacuum circuit-breakers for the switching duty K leave such short dead times between closing and opening that the de-energized time interval is hardly noticeable to the power supply to the consumers. In the event of unsuccessful auto-reclosing, the faulty feeder is shut down definitively. For vacuum circuit-breakers with the auto-reclosing feature, the operating sequence O-0.3 s-CO-3 min-CO must be complied with according to IEC 62 271-100, whereas an unsuccessful auto-reclosing only requires the operating sequence O-0.3 s-CO.

Auto-reclosing in traction line systems

To check the traction line system via test resistors for the absence of short-circuits after a short-circuit shutdown, the operating sequence is O-15 s-CO.

Multiple-shot reclosing

Vacuum circuit-breakers are also suitable for multiple-shot reclosing, which is mainly applicable in English-speaking countries. The operating sequence O-0.3 s-CO-15 s-CO-15 s-CO is required.

Switching of transformers

In the vacuum circuit-breaker, the chopping current is only 2 to 3 A due to the special contact material used, which means that no hazardous overvoltages will appear when unloaded transformers are switched off.

Breaking of short-circuit currents

While breaking short-circuit currents at the fault location directly downstream from transformers, generators or current-limiting reactors, the full short-circuit current can appear first; second, the initial rate of rise of the transient recovery voltage can be far above the values according to IEC 62 271-100. There may be initial rates of rise up to 10 kV/s, and while switching off short-circuits downstream from reactors, these may be even higher. The circuit-breakers are also adequate for this stress.

Switching of capacitors

Vacuum circuit-breakers are specifically designed for switching capacitive circuits. They can switch off capacitors up to the maximum battery capacities without restrikes, and thus without overvoltages. Capacitive current breaking was tested up to a rated voltage of 12 kV with up to 600 A, for 24 kV up to 300 A, and for 36 kV up to 200 A. These values are technically conditioned by the testing laboratory. Operational experience has shown that capacitive currents are generally controlled up to 70 % of the rated normal current of the circuit-breaker. When capacitors are connected in parallel, currents up to the short-circuit current can appear, which may be hazardous for parts of the system due to their high rate of rise. Making currents up to 10 kA (peak value) are permissible; higher values are can be achieved if specifically requested.

Switching of overhead lines and cables

When unloaded overhead lines and cables are switched off, the relatively small capacitive currents are controlled without restrikes, and thus without overvoltages.

Switching of motors

When small high-voltage motors are stopped during start-up, switching overvoltages may arise. This concerns high-voltage motors with starting currents up to 600 A. The magnitude of these overvoltages can be reduced to harmless values by means of special surge limiters. For individually compensated motors, no protective circuit is required.

Switching of generators
When generators with a short-circuit current of ≥ 600 A are operated, switching overvoltages may arise. In this case, surge limiters or arresters should be used.

Switching of filter circuits
When filter circuits or inductor-capacitor banks are switched off, the stress for the vacuum circuit-breaker caused by the recovery voltage is higher than when switching capacitors. This is due to the series connection of the inductor and the capacitor, and must be taken into account for the rated voltage when the vacuum circuit-breaker is selected.

Switching of arc furnaces
Up to 100 operating cycles are required per day. The vacuum circuit-breaker type 3AH4 is especially adequate for this purpose. Due to the properties of the load circuit, the currents can be asymmetrical and distorted. To avoid resonance oscillations in the furnace transformers, individually adjusted protective circuits are necessary.

Designs
The different types of vacuum circuit-breakers are shown in fig. 4.2-2a to fig. 4.2-2f.

SION
The standard circuit-breaker for variable application:
- Available as standard circuit-breaker or complete slide-in module
- Up to 10,000 operating cycles
- Retrofit solution possible

3AH5
The standard circuit-breaker for small switching capacities:
- Up to 10,000 operating cycles.

3AH3
The circuit-breaker for high switching capacities:
- Rated short-circuit breaking currents of up to 63 kA
- Rated normal currents of up to 4,000 A
- Up to 10,000 operating cycles

3AH4
The circuit-breaker for a high number of operating cycles:
- Up to 120,000 operating cycles

3AH37/3AH38
The circuit-breaker for high-current and generator applications
- Rated normal currents up to 6,300 A
- Up to 10,000 operating cycles
- According to IEEE C37.013

3AH47
The circuit-breaker for applications in traction systems
- System frequency $16\frac{2}{3}$, 50 or 60 Hz
- 1-pole or 2-pole
- Up to 60,000 operating cycles

Fig. 4.2-2a: **SION**

Fig. 4.2-2b: **3AH5**

Fig. 4.2-2c: **3AH3**

Fig. 4.2-2d: **3AH4**

Fig. 4.2-2e: **3AH37/3AH38**

Fig. 4.2-2f: **3AH47**

Rated short-circuit breaking current	Rated normal current	Rated voltage and frequency												
		7.2 kV 50/60 Hz	12 kV 50/60 Hz		15 kV 50/60 Hz	17.5 kV 50/60 Hz		17.5 kV 16 ⅔ Hz	24 kV 50/60 Hz			27.5 kV 50/60 Hz	36 kV 50/60 Hz	
12.5 kA	800 A					SION			SION					
	1,250 A					SION			SION					
13.1 kA	800 A		3AH5											
16 kA	800 A	SION	SION	3AH5		SION			SION	3AH5				
	1,250 A	SION	SION			SION			SION				3AH5	
	2,000 A					SION			SION					
	2,500 A					SION			SION					
20 kA	800 A	SION	SION	3AH5					SION					
	1,250 A	SION	SION	3AH5					SION	3AH5				
	2,000 A		3AH5						SION	3AH5				
	2,500 A								SION	3AH5				
25 kA	800 A	SION	SION	3AH5		SION	3AH5		SION					
	1,250 A	SION	SION	3AH5		SION	3AH5		SION		3AH5	3AH47	3AH5	
	2,000 A	SION	SION			SION		3AH47	SION			3AH47	3AH5	
	2,500 A		SION	3AH5		SION	3AH5		SION		3AH5	3AH47		
31.5 kA	800 A	SION	SION			SION								
	1,250 A	SION	SION	3AH5		SION	3AH5					3AH47	3AH3	3AH4
	2,000 A	SION	SION			SION		3AH47				3AH47	3AH3	3AH4
	2,500 A	SION	SION	3AH5		SION	3AH5					3AH47	3AH3	3AH4
40 kA	1,250 A	SION	SION			SION								
	2,000 A	SION	SION			SION								
	2,500 A	SION	SION			SION		3AH47	3AH3	3AH4			3AH3	3AH4
	3,150 A	SION	SION		3AH1	SION								
50 kA	1,250 A	3AH3	3AH3		3AH3	3AH3								
	2,500 A	3AH3	3AH3		3AH3	3AH3		3AH47						
	3,150 A	3AH3	3AH3		3AH3	3AH3	3AH38							
	4,000 A	3AH3	3AH3		3AH3	3AH3	3AH38							
	5,000 A					3AH37								
	6,300 A					3AH37								
63 kA	1,250 A	3AH3	3AH3		3AH3	3AH3								
	2,500 A	3AH3	3AH3		3AH3	3AH3								
	3,150 A	3AH3	3AH3		3AH3	3AH38								
	4,000 A	3AH3	3AH3		3AH3	3AH38								
	5,000 A					3AH37								
	6,300 A					3AH37								
72 kA	3,150 A					3AH38								
	4,000 A					3AH38								
	5,000 A					3AH37								
	6,300 A					3AH37								

Table 4.2-3: **Portfolio of vacuum circuit-breakers**

4.2.4 Outdoor Vacuum Circuit-Breakers

Outdoor vacuum circuit-breakers (table 4.2-3) perform the same functions as indoor circuit-breakers and cover a similar product range. Due to their special design, they are preferred for use in power systems with a large extent of overhead lines. When using outdoor vacuum circuit-breakers, it is not necessary to provide for closed service locations for their installation.

The design comprises a minimum of moving parts and a simple structure in order to guarantee a long electrical and mechanical service life. At the same time, these circuit-breakers offer all advantages of indoor vacuum circuit-breakers.

In live-tank circuit-breakers (fig. 4.2-3), the vacuum interrupter is housed inside a weatherproof insulating enclosure, e.g., made of porcelain. The vacuum interrupter is at electrical potential, which means live.

The significant property of the dead-tank technology is the arrangement of the vacuum interrupter in an earthed metal enclosure (fig. 4.2-4).

The portfolio of outdoor vacuum circuit-breakers is shown in table 4.2-4.

Fig. 4.2-3: **Live-tank circuit-breaker**

Fig. 4.2-4: **Dead-tank circuit-breaker**

Type	3AG0	3AF034	3AF014	3AF015	SDV6	SDV6
Rated voltage	12 kV	17.5 kV	36 kV	36 kV	15–38 kV	38 kV
Rated short-duration power-frequency withstand voltage	28 kV	38 kV	70 kV	70 kV	50–70 kV	80 kV
Rated lightning impulse withstand voltage	75 kV	95 kV	170 kV	170 kV	110–170 kV	200 kV
Rated normal current	1,600 A	1,600/2,000 A	1,600/2,000 A	1,600/2,000 A	600–3,000 A	1,200/2,000 A
Rated short-circuit breaking current	25 kA	25 kA	25 kA	31.5 kA	25/40 kA	20/25 kA
Rated short-circuit making current	63 kA	63 kA	63 kA	80 kA	65/104 kA	52/65 kA
Design	Live-tank	Live-tank	Live-tank	Live-tank	Dead-tank	Dead-tank

Table 4.2-4: **Portfolio of outdoor vacuum circuit-breakers**

4.2.5 Reclosers

Vacuum reclosers offer dependable protection for overhead lines in order to provide improved reliability of the distribution network. At the core of the system, the controller provides a high level of protection, easiest operation, and high operating efficiency.

Up to 90 % of the faults in overhead line networks are temporary in nature. In case of a fault, a vacuum recloser trips to interrupt the fault current. After a few cycles, it recloses again and will remain closed if a transient fault has disappeared. This cycle is performed up to five times in order to bring the line back to service before the device finally switches to a lockout state should a permanent network fault be present.

Siemens vacuum reclosers can easily be installed anywhere on the overhead line, so network operators can choose an easily accessible location. The reclosers will be parameterized to sequentially protect the feeder in either star, ring or meshed networks.

The included trouble-free operating features are:

- Advanced vacuum switching technology
- A sophisticated solid epoxy insulation system with integrated sensors
- A dual-coil low-energy magnetic actuator
- The advanced Siemens controller
- A weatherproof control cubicle
- Reliable operation due to self-monitoring and standby

Controller

The controller (fig. 4.2-5) – the "brain" of the recloser – comprises indicators and control elements, communication interfaces, and a USB port for convenient connection of a laptop. Access to the user level is protected by multi-level password authentication. The controller is mounted in a cubicle which also contains the auxiliary power supply and a battery-backed UPS unit, fuses, and a general purpose outlet to power a laptop.

The controller provides comprehensive protection functions as:

- Earth fault and sensitive earth fault detection along with overcurrent-time protection (definite and inverse)
- Inrush restraint
- Load shedding

Further features of the controller are:

- A multitude of inputs and outputs for customer use
- Additional communication modules for data transfer
- Self-monitoring and measuring functions

Switch unit

The switch unit (fig. 4.2-6) contains integrated current transformers and optionally also voltage sensors. It consists of one or three poles and the actuator housing. The poles are made of weatherproof epoxy resin which holds the vacuum interrupter. A switching rod connects the vacuum interrupter with the magnetic actuator.

Fig. 4.2-5: **Argus-M controller**

Fig. 4.2-6: **Vacuum recloser with cubicle and controller**

A mechanical lockout handle, which allows for mechanical tripping and lockout, sticks out of the actuator housing. As long as this handle is extended, the unit can neither be closed electrically nor mechanically. The lockout handle needs to be reset manually to activate the unit.

For switchover tasks in open ring networks (so called loop automation), reclosers with voltage sensors on both sides (source and load side) are available. In the open state, they are able to detect voltage on either side of the recloser individually. A position indicator is located underneath the housing. Thanks to its size and the application of reflective materials, the indicator is highly visible from the ground and the switching state can be clearly recognized even at night.

4.2.6 Vacuum Switches

Vacuum switches (table 4.2-4) are switches for indoor installations that use the vacuum switching principle for interrupting normal currents, thus exceeding the electrical and mechanical data of conventional switches. For example, a rated current of 800 A can be interrupted up to 10,000 times without maintenance. The operating mechanism has to be greased only every 10 years.

The switches are suitable for installation in withdrawable switchgear, and for combination with high-voltage high-rupturing-capacity fuses.

The application of vacuum switches in combination with circuit-breaker switchgear is advisable to fully exploit the mentioned advantages. Because they can break the rated normal current very often, it is possible, for example, to switch off unloaded transformers in industrial power systems daily in order to minimize no-load losses, thus reducing operational costs.

Short-circuit protection is taken over by fuses, just as with other switches. As switch-fuse combinations, vacuum switches can be combined with all HV HRC fuses up to maximum normal currents.

The switching duties of vacuum switches are:

- Switching of overhead lines and cables
- Switching of transformers
- Switching of motors
- Switching of capacitors
- Switching under earth-fault conditions

Switching under earth-fault conditions means switching applications that can arise in power supply systems without neutral earthing. Two cases have to be distinguished:

- Fault location downstream from the switch (rated earth-fault breaking current):
  The capacitive earth-fault current of the galvanically interconnected power system flows through the fault location. Depending on the size of the system, fault currents up to 500 A may occur. The full magnitude of these currents can be interrupted by the 3CG switch (fig. 4.2-7).
- Fault location upstream from the switch (rated cable-charging breaking current under earth-fault conditions):
  The fault current is not interrupted by the switch. Only the charging current of the downstream-connected cable is interrupted, but with phase-to-phase voltage as recovery voltage, because the earth-fault in one phase increases the voltage in the two healthy phases accordingly. The charging current usually only reaches a few amperes. The difficulty in this case may be that a higher load current is superimposed on the small capacitive current. In this special case, conventional switches are often overstrained. 3CG vacuum switches control this switching duty without restrictions.

Fig. 4.2-7: **Vacuum switch 3CG**

Type	3CG			
Rated voltage	7.2 kV	12 kV	15 kV	24 kV
Rated frequency	50/60 Hz	50/60 Hz	50/60 Hz	50/60 Hz
Rated lightning impulse withstand voltage	60 kV	75 kV	95 kV	125 kV
Rated normal current	800 A	800 A	800 A	800 A
Rated short-time withstand current (3 s)	20 kA	20 kA	20 kA	16 kA
Rated short-circuit making current	50 kA	50 kA	50 kA	40 kA
Rated closed-loop breaking current	800 A	800 A	800 A	800 A
Rated no-load transformer breaking current	10 A	10 A	10 A	10 A
Rated single capacitor bank breaking current	800 A	800 A	800 A	800 A
Rated cable-charging breaking current	63 A	63 A	63 A	63 A
Rated breaking current for motors with locked rotor	2,500 A	1,600 A	1,250 A	–
Inductive switching capacity (cos w ≤ 0.15)	2,500 A	1,600 A	1,250 A	1,250 A
Number of operating cycles at rated normal current	10,000	10,000	10,000	10,000

Table 4.2-4: **Portfolio of vacuum switches**

4.2.7 Vacuum Contactors

3TL vacuum contactors (fig. 4.2-8 to fig. 4.2-10) are 3-pole contactors with electromagnetic operating mechanisms for medium-voltage switchgear. They are load breaking devices with a limited short-circuit making and breaking capacity for applications with high switching rates of up to 1 million operating cycles. Vacuum contactors are suitable for operational switching of alternating current consumers in indoor switchgear.

They can be used, e.g., for the following switching duties:

- AC-3: Squirrel-cage motors: Starting, stopping of running motor
- AC-4: Starting, plugging and inching
- Switching of three-phase motors in AC-3 or AC-4 operation (e.g., in conveying and elevator systems, compressors, pumping stations, ventilation and heating)
- Switching of transformers (e.g., in secondary distribution switchgear, industrial distributions)
- Switching of reactors (e.g., in industrial distribution systems, DC-link reactors, power factor correction systems)
- Switching of resistive consumers (e.g., heating resistors, electrical furnaces)
- Switching of capacitors (e.g., in power factor correction systems, capacitor banks)

Further switching duties are:

- Switching of motors
- Switching of transformers
- Switching of capacitors

In contactor-type reversing starter combinations (reversing duty), only one contactor is required for each direction of rotation if high-voltage high-rupturing capacity fuses are used for short-circuit protection.

The portfolio of the vacuum contactors is shown in table 4.2-5.

Fig. 4.2-8: **Vacuum contactor 3TL6**

Fig. 4.2-9: **Vacuum contactor 3TL71**

Fig. 4.2-10: **Vacuum contactor 3TL81**

Type	3TL81	3TL61	3TL65	3TL71
Rated voltage	7.2 kV	7.2 kV	12 kV	24 kV
Rated frequency	50/60 Hz	50/60 Hz	50/60 Hz	50/60 Hz
Rated normal current	400 A	450 A	400 A	800 A
Rated making current*	4,000 A	4,500 A	4,000 A	4,500 A
Rated breaking current*	3,200 A	3,600 A	3,200 A	3,600 A
Mechanical endurance of the contactor*	1 million operating cycles	3 million operating cycles	1 million operating cycles	1 million operating cycles
Electrical endurance of the vacuum interrupter (rated current)*	0.25 million operating cycles	1 million operating cycles	0.5 Million operating cycles	0.5 million operating cycles
* Switching capacity according to utilization category AC-4 (cos φ = 0.35)				

Table 4.2-5: **Portfolio of vacuum contactors**

4.2.8 Contactor-Fuse Combination

Contactor-fuse combinations 3TL62/63/66 are type-tested units comprising contactors and HV HRC (high-voltage high-rupturing capacity) fuses. They have been specially developed for flexible use in restricted spaces and do not require any additional room for HV HRC fuses or any additional conductors between contactor and fuse. The components are laid out on the base plate so as to enable optimum ventilation, thereby allowing a high normal current. This design even meets the high dielectric strength standards required in countries such as China.

A number of different designs are available for integration in the switchgear panel, for example with different pole-center distances and contact gaps. A choice of single and double fuse holders, control transformer and an extensive range of other accessories are available as delivery versions (table 4.2-6).

Construction
The contactor-fuse combination (fig. 4.2-11, fig. 4.2-12) consists of the components vacuum contactor (1), insulating cover with fuse holder (2), fuse-links (3), isolating contacts (4) and optionally a control transformer (5). These are accommodated on a base plate (6).

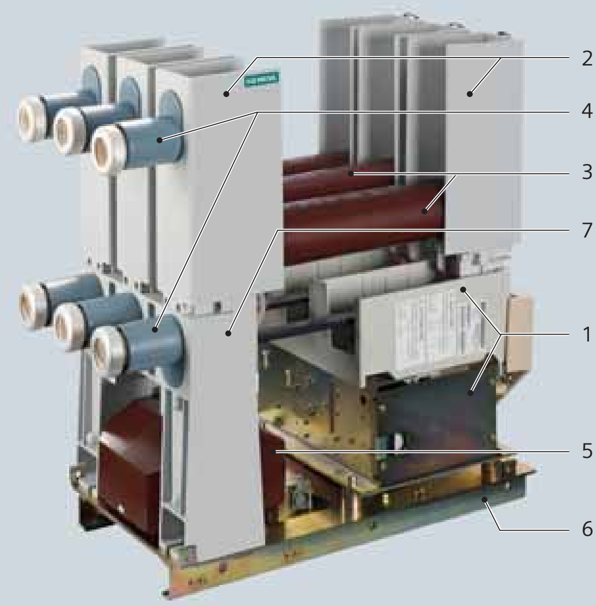
In normal operation, the vacuum contactor (1) breaks the corresponding currents reliably. To do this, the vacuum switching technology, proven for more than 30 years, serves as arc-quenching principle by using vacuum interrupters. The vacuum interrupters are operated by the magnet system through an integral rocker.

The insulating cover with fuse holder (2) is mounted on one side of the contactor. On the other side it stands on a cross-member under which there is room for the optional control transformer. The holders, which are especially conceived for the use of two HV HRC fuse-links, ensure a uniform distribution of the current to the two fuse-links of one phase.

Fuse links from different manufacturers can be used (3). When designing the fuse for an operational scenario, the technical limit values such as heating due to power dissipation, the limit switching capacity and the maximum let-through current must be taken into account.

The isolating contacts (4) are used to establish the connection to the busbar compartment and the cable compartment via bushings, which can also be delivered optionally.

The optional control transformer (5) is connected to the high-voltage terminals of the contactor-fuse combination on its primary part, so that no additional cables are required. To protect the transformer, a separate upstream fuse is series-connected on the primary side and accommodated in the cross-member. Due to its different versions, the control transformer can be optimally adjusted to the existing power system.



1 Vacuum contactor
2 Insulating cover with fuse holder
3 Fuse element
4 Disconnecting contacts
5 Optional control transformer
6 Base plate
7 Cross-member

Fig. 4.2-11: **Construction of the contactor-fuse combination 3TL6**

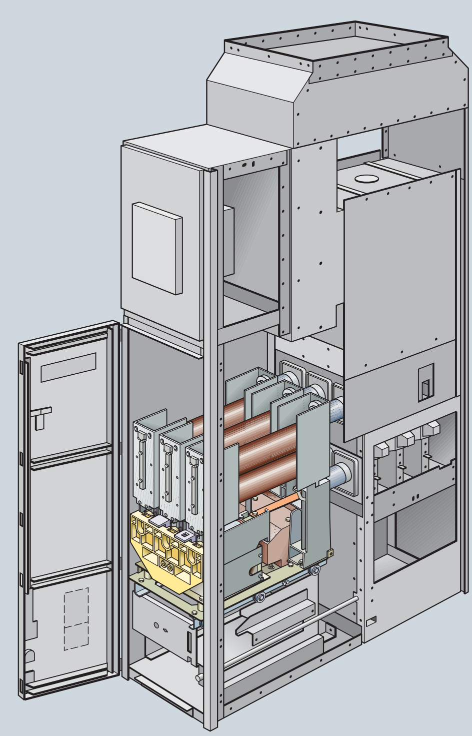


Fig. 4.2-12: **Installation of the contactor-fuse combination in the contactor panel**

Mode of operation

Basically, there are three different modes or states of operation: normal operation, short circuit and overload.

During normal operation, the combination behaves like a contactor.

In case of short circuit, the main fuse-elements of the HV HRC fuse melt and evaporate at all bottlenecks already during the current rise. Arcs burn at these bottlenecks, which are cooled so effectively by the arc-quenching medium that their total arc voltage is higher than the operating voltage. This results in a rapid decrease of the current, which is interrupted while it is still rising. When the main fuse-elements melt, the secondary fuse-element evaporates as well and releases the thermal striker, which activates an indication and operates the vacuum contactor additionally. In the optimum time sequence, the fuse has already interrupted the short-circuit current at this time.

In case of overload, a high continuous current overloads the fuse-link thermally, thus tripping the thermal striker. The contactor already operates within the arcing time of the fuse, making a take-over current flow through the vacuum interrupters. The take-over current must not exceed 5 kA, as this could damage the vacuum interrupter. This is prevented by selecting the correct fuse.

Application examples

Contactor-fuse combinations are suitable for operational switching of alternating-current consumers in indoor switchgear. They are used, for example, for the following switching functions:

- Starting of motors
- Plugging or reversing the direction of rotation of motors
- Switching of transformers and reactors
- Switching of resistive consumers (e.g., electric furnaces)
- Switching of capacitors and compressors

With these duties, contactor-fuse combinations are used in conveyor and elevator systems, pumping stations, air conditioning systems as well as in systems for reactive power compensation, and can therefore be found in almost every industrial sector.

Standards

Contactor-fuse combinations 3TL62/63/66 are designed in open construction, with degree of protection IP00, according to IEC 60470. They conform to the standards for high-voltage alternating current contactors above 1 kV to 12 kV:

- IEC/EN 60470
- IEC/EN 60529
- IEC/EN 60721
- IEC/EN 62271-1
- IEC/EN 60282-1
- D/L 404

Advantages at a glance

- Up to one million electrical operating cycles
- Usable for all kinds of switching duties
- Maintenance-free, reliable operation of vacuum interrupter and magnetic operating mechanism for maximum cost-efficiency
- Wide range of types for the most varied requirements
- Type-tested, compact construction (also for installation in narrow switchgear panels)
- Specially developed fuse holders for uniform current distribution
- Optimized construction for high power density
- Reliable for optimized availability
- Excellent environmental compatibility
- Over 35 years experience with vacuum contactors

Type	3TL62	3TL63	3TL66
Rated voltage	7.2 kV	7.2 kV	12 kV
Standard	IEC 60470	D/L404 China	IEC 60470
Rated normal current (depending on installation, fuses)	up to 400 A		
Rated short-circuit breaking current I_{SC} r.m.s.	50 kA		
Max. let-through current I_D	46 kA		
Rated lightning impulse withstand voltage (ground/exposed line section)	60 kV/40 kV	60 kV/60 kV	75 kV/60 kV
Rated power-frequency withstand voltage	20 kV	32 kV	28 kV
Switching rate	1,200 operating cycles/h	600 operating cycles/h	600 operating cycles/h
Endurance	Mechanical endurance: 1 million		
Limit switching capability	5 kA	4.5 kA	4.5 kA
Number of fuses per phase	1 or 2		
Pole-center distances	120 mm, 140 mm (others on request)		
Widths across flats	205 mm, 275 mm, 310 mm (others on request)		
Various different contact systems and comprehensive accessories are available			

Table 4.2-6: **Portfolio of contactor-fuse combination 3TL6**

4.2.9 Disconnectors and Switch-Disconnectors

Disconnectors (also called isolators) are used for almost no-load opening and closing of electrical circuits. While doing so, they can break negligible currents (these are currents up to 500 mA, e.g., capacitive currents of busbars or voltage transformers), or higher currents if there is no significant change of the voltage between the terminals during breaking, e.g., during busbar transfer in double-busbar switchgear, when a bus coupler is closed in parallel.

The actual task of disconnectors is to establish an isolating distance in order to work safely on other operational equipment that has been "isolated" by the disconnector (fig. 4.2-14). For this reason, stringent requirements are placed on the reliability, visibility and dielectric strength of the isolating distance.

The different disconnectors and their properties are shown in table 4.2-7.

Switch-disconnectors (table 4.2-7, fig. 4.2-13) combine the functions of a switch with the establishment of an isolating distance (disconnector) in one device, and they are therefore used for breaking load currents up to their rated normal current.

While connecting consumers, making on an existing short circuit cannot be excluded. That is why switch-disconnectors today feature a short-circuit making capacity. In combination with fuses, switches (switch-disconnectors) can also be used to break short-circuit currents. The short-circuit current is interrupted by the fuses. Subsequently, the fuses trip the three poles of the switch (switch-disconnector), disconnecting the faulty feeder from the power system.

Rated short-time withstand current	Rated normal current	Rated voltage		
		12 kV	24 kV	36 kV
20 kA	630 A	3DC	3DC/3DA	3DC
31.5 kA	630 A	3DC		
	1,250 A	3DC	3DC/3DA	3DC
	1,600 A	3DC	3DC/3DA	3DA
	2,500 A	3DC	3DC	3DC
	3,000 A			3DC
50 kA	1,250 A	3DC		
	1,600 A	3DC		
	2,500 A	3DC		
	3,000 A	3DC		
63 kA	1,250 A	3DC		
	1,600 A	3DC		
	2,500 A	3DC		
	3,000 A	3DC		

Table 4.2-6: **Portfolio of disconnectors**

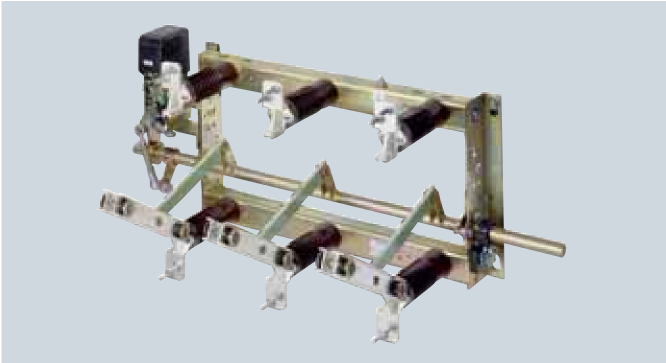


Fig. 4.2-13: **Disconnector in disconnected position**

Type	3CJ2			
Rated voltage	12 kV	17.5 kV	24 kV	36 kV
Rated short-duration power-frequency withstand voltage	28 kV/32 kV	38 kV/45 kV	50 kV/60 kV	70 kV/80 kV
Rated lightning impulse withstand voltage	75 kV/85 kV	95 kV/110 kV	125 kV/145 kV	170 kV/195 kV
Rated normal current	400 A	400 A	400 A	630 A
Rated normal current – without fuse-link	630 A/1000 A	630 A	630 A/1000 A	630 A/1000 A
Rated short-time withstand current (1 sec)	25 kA	25 kA	25 kA	20 kA
Rated short-circuit making current	63 kA	63 kA	50 kA	25 kA
Rated closed-loop breaking current	400 A/630 A	400 A/630 A	400 A/630 A	630 A
Rated cable-charging breaking current	50 A	75 A	50 A	25 A
Rated earth-fault breaking current	150 A	200 A	150 A	70 A
Rated cable-charging breaking current under earth-fault conditions	86 A	100 A	86 A	40 A
Number of mechanical operating cycles	2,500	2,500	2,500	1,000
Torque of spring-operated/stored-energy mechanism	44/60	54/62	64/64	90/150
Torque of earthing switch	60	65	70	120
Standard fuse reference dimension "e"	292	362	442	538

Table 4.2-7: **Portfolio of switch-disconnectors**

4

Arc-extinguishing principle
Switch-disconnectors operate according to the principle of a hard-gas switch, and so the arc is not extinguished in a vacuum interrupter. The arc splits off some gas from an insulating material that surrounds the arc closely and this gas quenches the arc.

Because the material providing the gas cannot regenerate itself, the number of operating cycles is lower than in vacuum interrupters. Nevertheless, switch-disconnectors that use the hard-gas principle are used most frequently because of their good cost/performance ratio.

3CJ2 switch-disconnectors operate with a flat, hard-gas arcing chamber, (1) in fig. 4.2-15. During the opening movement, the contact blade, (2) in fig. 4.2-15, is separated first. Because the auxiliary blade, (3) in fig. 4.2-15, guided in the arcing chamber is still touching, the current now flows through the auxiliary blade. When the switching blades reach the isolating distance, the auxiliary blade opens the connection suddenly. The opening arc burns in a small gap, and the thermal effect releases enough gas to extinguish the arc rapidly and effectively.

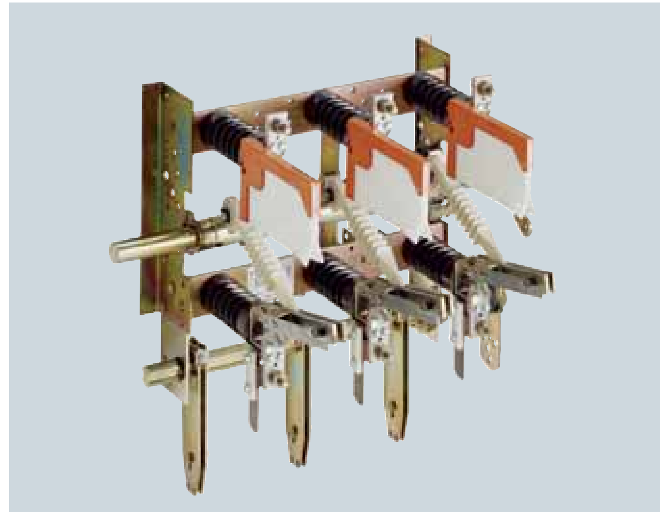


Fig. 4.2-14: **Switch-disconnector**

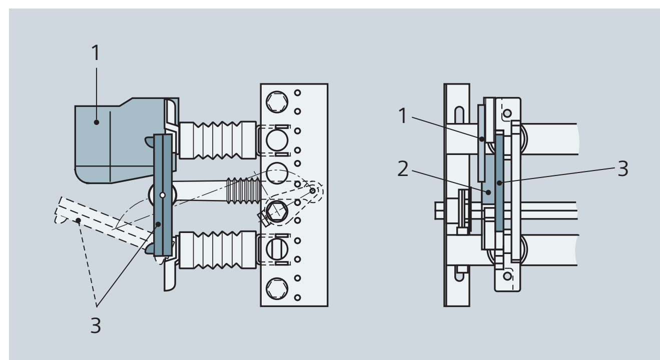


Fig. 4.2-15: **3CJ2 switch-disconnector:**
(1) flat hard-gas arcing chamber
(2) contact blade
(3) auxiliary blade

4.2.10 Earthing Switches

Earthing switches (table 4.2-8) are used in order to earth and short-circuit switchgear parts, cables and overhead lines. They make it possible to work without danger on the previously earthed operational equipment. Their design is similar to that of vertical-break disconnectors. They are often mounted on disconnectors or switch-disconnectors and then interlocked with these devices in order to prevent earthing on applied voltages. If earthing switches with making capacity (make-proof earthing switches) are used instead of the normal earthing switches, earthing and short-circuiting presents no danger even if the circuit was accidentally not isolated before (fig. 4.2-16, fig. 4.2-17).

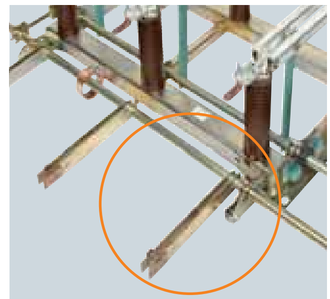


Fig. 4.2-16: **Earthing switch in OPEN position with closed disconnector**

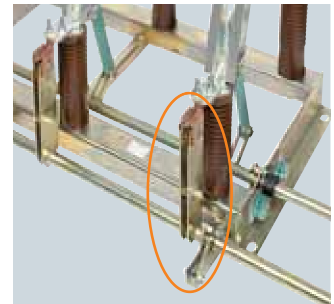


Fig. 4.2-17: **Earthing switch in CLOSED position with open disconnector**

Earthing switches		Rated voltage		
Rated short-time withstand current	**Rated peak withstand current**	**12 kV**	**24 kV**	**36 kV**
20 kA	50 kA	3DE	3DE/3DD	3DE
31.5 kA	80 kA	3DE	3DE/3DD	3DE
50 kA	125 kA	3DE		
63 kA	160 kA	3DE		

Make-proof earthing switches			Rated voltage			
Rated lightning impulse withstand voltage	**Rated power-frequency withstand voltage**	**Rated short-circuit making current**	**7.2 kV**	**12 kV**	**15 kV**	**24 kV**
60 kV	20 kV	63 kA	3CX50			
60 kV	28 kV	50 kA		3CX50		
75 kV	28 kV	50 kA		3CX50		
95 kV	38 kV	52 kA			3CX50	
95 kV	50 kV	40 kA				3CX50
125 kV	50 kV	40 kA				3CX50

Table 4.2-8: **Portfolio of earthing switches**

4.3 Low-Voltage Devices

4.3.1 Requirements on the Switchgear in the Three Circuit Types

Device application in the supply circuit
The system infeed is the most "sensitive" circuit in the entire power distribution. A failure here would affect the whole network, leaving the building or the production concerned without power. This worst-case scenario must be considered during the planning. Redundant system supplies and selective protection settings are important preconditions for a safe network configuration. The selection of the correct protective devices is therefore of elementary importance in order to create these preconditions. Some of the key dimensioning data is described in the following.

Rated current
The feeder circuit-breaker in the LVMD must be dimensioned for the maximum load of the transformer/generator. When using ventilated transformers, the higher normal current of up to 1.5 x I_N of the transformer must be taken into account.

Short-circuit strength
The short-circuit strength of the feeder circuit-breaker is determined by $(n–1)$ x $I_{k\ max}$ of the transformer or transformers (n = number of transformers). This means that the maximum short-circuit current that occurs at the place of installation must be known in order to specify the appropriate short-circuit strength of the protective device (I_{cu}). Exact short-circuit current calculations including attenuations of the medium-voltage levels or the laid cables can be made, for example, with the aid of the SIMARIS design dimensioning software. SIMARIS design determines the maximum and minimum short-circuit currents and automatically dimensions the correct protective devices.

Utilization category
When dimensioning a selective network, time grading of the protective devices is essential. When using time grading up to 500 ms, the selected circuit-breaker must be able to carry the short-circuit current that occurs for the set time. Close to the transformer, the currents are very high. This current carrying capacity is specified by the I_{cw} value (rated short-time withstand current) of the circuit-breaker; this means the contact system must be able to carry the maximum short-circuit current, i.e., the energy contained therein, until the circuit-breaker is tripped. This requirement is satisfied by circuit-breakers of utilization category B (e.g., air circuit-breakers, ACB). Current-limiting circuit-breakers (molded-case circuit-breakers, MCCB) trip during the current rise. They can therefore be constructed more compactly.

Release
For a selective network design, the release (trip unit) of the feeder circuit-breaker must have an LSI characteristic. It must be possible to deactivate the instantaneous release (I). Depending on the curve characteristic of the upstream and downstream protective devices, the characteristics of the feeder circuit-breaker in the overload range (L) and also in the time-lag short-circuit range (S) should be optionally switchable (I^4t or I^2t characteristic curve). This facilitates the adaptation of upstream and downstream devices.

Internal accessories
Depending on the respective control, not only shunt releases (previously: f releases), but also undervoltage releases are required.

Communication
Information about the current operating states, maintenance, error messages and analyses, etc. is being increasingly required, especially from the very sensitive supply circuits. Flexibility may be required with regard to a later upgrade or retrofit to the desired type of data transmission.

Device application in supply circuits (coupling)
If the coupling (connection of network 1 to network 2) is operated in open condition, the circuit-breaker (tie breaker) only has the function of a disconnector or main switch. A protective function (release) is not absolutely necessary.

The following considerations apply to closed operation:

- Rated current
  must be dimensioned for the maximum possible normal current (load compensation). The simultaneity factor can be assumed to be 0.9.
- Short-circuit strength
  The short-circuit strength of the feeder circuit-breaker is determined by the sum of the short-circuit components that flow through the coupling. This depends on the configuration of the component busbars and their supply.
- Utilization category
  As for the system supply, utilization category B is also required for the current carrying capacity (I_{cw}).
- Release
  Partial shutdown with the couplings must be taken into consideration for the supply reliability. As the coupling and the feeder circuit-breakers have the same current components when a fault occurs, similar to the parallel operation of two transformers, the LSI characteristic is required. The special zone selective interlocking (ZSI) function should be used for larger networks and/or protection settings that are difficult to determine.

Device application in the distribution circuit
The distribution circuit receives power from the higher level (supply circuit) and feeds it to the next distribution level (final circuit).

Depending on the country, local practices, etc., circuit-breakers and fuses can be used for system protection; in principle, all protective devices described in this chapter. The specifications for the circuit dimensioning must be fulfilled. The ACB has advantages if full selectivity is required. However for cost reasons, the ACB is only frequently used in the distribution circuit with a rated current of 630 A or 800 A. As the ACB is not a current-limiting device, it differs greatly from other protective devices such as MCCB, MCB and fuses.

Fig. 4.3-1 shows the major differences and limits of the respective protective devices.

Device application in the final circuit
The final circuit receives power from the distribution circuit and supplies it to the consumer (e.g., motor, lamp, non-stationary load (power outlet), etc.). The protective device must satisfy the requirements of the consumer to be protected by it.

Note:

All protection settings, comparison of characteristic curves, etc. always start with the load. This means that no protective devices are required with adjustable time grading in the final circuit.

		ACB air circuit-breaker	MCCB molded-case circuit-breaker	Fuse switch-disconnector	Switch-disconnector with fuses	MCB miniature circuit-breaker	Reference values, specifications
Standards	IEC	Yes	Yes	Yes	Yes	Yes	Region
Application	System protection	Yes	Yes	Yes	Yes	Yes	Power supply system
Installation	Fixed mounting	Yes	Yes	Yes	Yes	Yes	Availability
	Plug-in	–	Up to 800 A	–	Partly	–	
	Withdrawable unit	Yes	Yes	–	–	–	
Rated current	I_n	6,300 A	1,600 A	630 A	630 A	125 A	Normal current I_B
Short-circuit breaking capacity	I_{cu}	Up to 150 kA	Up to 100 kA	Up to 120 kA	Up to 120 kA	Up to 25 kA	Maximum short-circuit current $I_{k\,max}$
Current carrying capacity	I_{cw}	Up to 80 kA	Up to 5 kA	–	–	–	Circuit
Number of poles	3-pole	Yes	Yes	Yes	Yes	Yes	Power supply system
	4-pole	Yes	Yes	–	Partly	–	
Tripping characteristic	ETU	Yes	Yes	–	–	–	Power supply system
	TM	–	Up to 630 A	Yes	Yes	Yes	
Tripping function	LI	Yes	Yes	Yes*	Yes*	Yes	Power supply system
	LSI	Yes	Yes	–	–	–	
	N	Yes	Yes	–	–	–	
	G	Yes	Yes	–	–	–	
Characteristics	Fixed	–	Yes	Yes	Yes	Yes	Power supply system
	Adjustable	Yes	Yes	–	–	–	
	Optional	Yes	Yes	–	–	–	
Protection against electric shock, tripping condition	Detection of $I_{k\,min}$	No limitation	Depends on cable length	Depends on cable length	Depends on cable length	Depends on cable length	Minimum short-circuit current $I_{k\,min}$
Communication (data transmission)	High	Yes	–	–	–	–	Customer specification
	Medium	Yes	Yes	–	–	–	
	Low	Yes	Yes	Yes	Yes	Yes	
Activation	Local	Yes	Yes	Yes	Yes	Yes	Customer specifications
	Remote (motor)	Yes	Yes	–		–	
Derating	Full rated current up to	60 °C	50 °C	30 °C	30 °C	30 °C	Switchgear
System synchronization		Yes	Up to 800 A	–	–	–	Power supply system

* According to the fuse characteristic

Fig. 4.3-1: **Overview of the protective devices**

4.3.2 Low-Voltage Protection and Switching Devices

The following chapter focuses on the relevant characteristics and selection criteria of the respective devices that are used in the main power distribution circuits in commercial buildings and in industry.

Note:

All figures apply for low-voltage power systems or distribution boards in IEC applications. Different regulations and criteria apply for systems according to UL standards.
Depending on the country, standard specifications, local practices, planning engineer, technical threshold values, etc., low-voltage power distribution systems are made up of various protective devices.*

Circuits and device assignment
(section 3.3.2 "Dimensioning of Power Distribution Systems")

Basic configuration of a low-voltage power distribution system and assignment of the protective devices including core functions
Core functions in the respective circuits:

- Supply circuit
  Task: System protection
  Protective device:
  – ACB (air circuit-breaker)
- Distribution circuit
  Task: System protection
  Protective devices:
  – ACB (air circuit-breaker)
  – MCCB (molded-case circuit-breaker)
  – SD (switch-disconnector)
- Final circuit
  Task: Motor protection
  Protective devices:
  – MCCB (circuit-breaker for motor protection)
  – SD (switch-disconnector)
  – MSP (3RT contactor, 3RU overload relay, 3UF motor protection and control devices

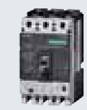
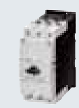
Circuit-breaker protected switchgear (circuit-breaker)		
ACB	**Air circuit-breaker** – Air circuit-breaker – Non-current-limiting circuit-breaker – Current-zero cut-off circuit-breaker	
MCCB	**Molded-case circuit-breaker** – Molded-case circuit-breaker – Current-limiting circuit-breaker	
MCB	**Miniature circuit-breaker** – Miniature circuit-breaker	
MSP	**Motor starter protector**	
MPCB	**Motor protector circuit-breaker** – Circuit-breaker for motor protection	

Fig. 4.3-2: **Overview of circuit-breaker protected switchgear**

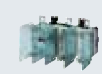
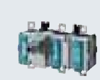
Fuse-protected switchgear (fuse switch-disconnector/switch-disconnector		
LTS	Switch-disconnector Depending on the type of operation, these devices are divided into two main groups:	
Operator-dependent		
– Without circuit-breaker latching system, with protection (fuse); with these devices, the fuse is also moved when making and breaking (= fuse switch-disconnector)		 
– With circuit-breaker latching system, with protection (fuse); with these devices, the fuse is not moved when making and breaking (= switch-disconnector with fuse		 
Operator-independent		
– With circuit-breaker latching system, without protection (without fuse); these devices are only used to interrupt the circuit, similar to a main switch (= switch-disconnector without fuse)		 

Fig. 4.3-3: **Overview of fuse-protected switchgear**

* *If you have questions on UL applications, please contact your local Siemens representative. We provide solutions for these applications, but they must be treated completely differently.*

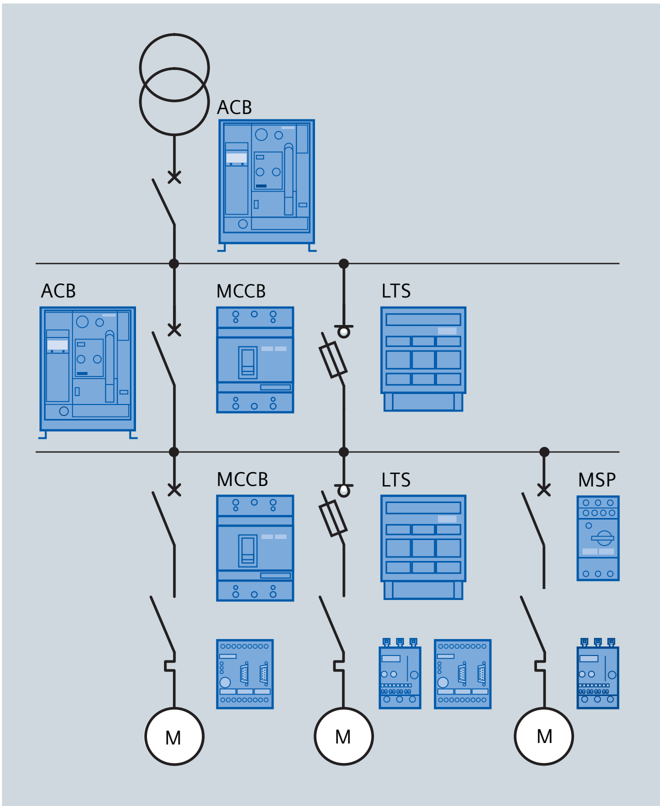


Fig. 4.3-4: **Core functions of the protective devices in the individual circuit types**

Criteria for device selection
A protective device is always part of a circuit and must satisfy the corresponding requirements (section 3.3.2 "Dimensioning of Power Distribution Systems"). The most important selection criteria are shown in the following.

Main selection criteria

Fig. 4.3-5 shows the seven most important selection criteria that must be at least taken into account for the device selection.

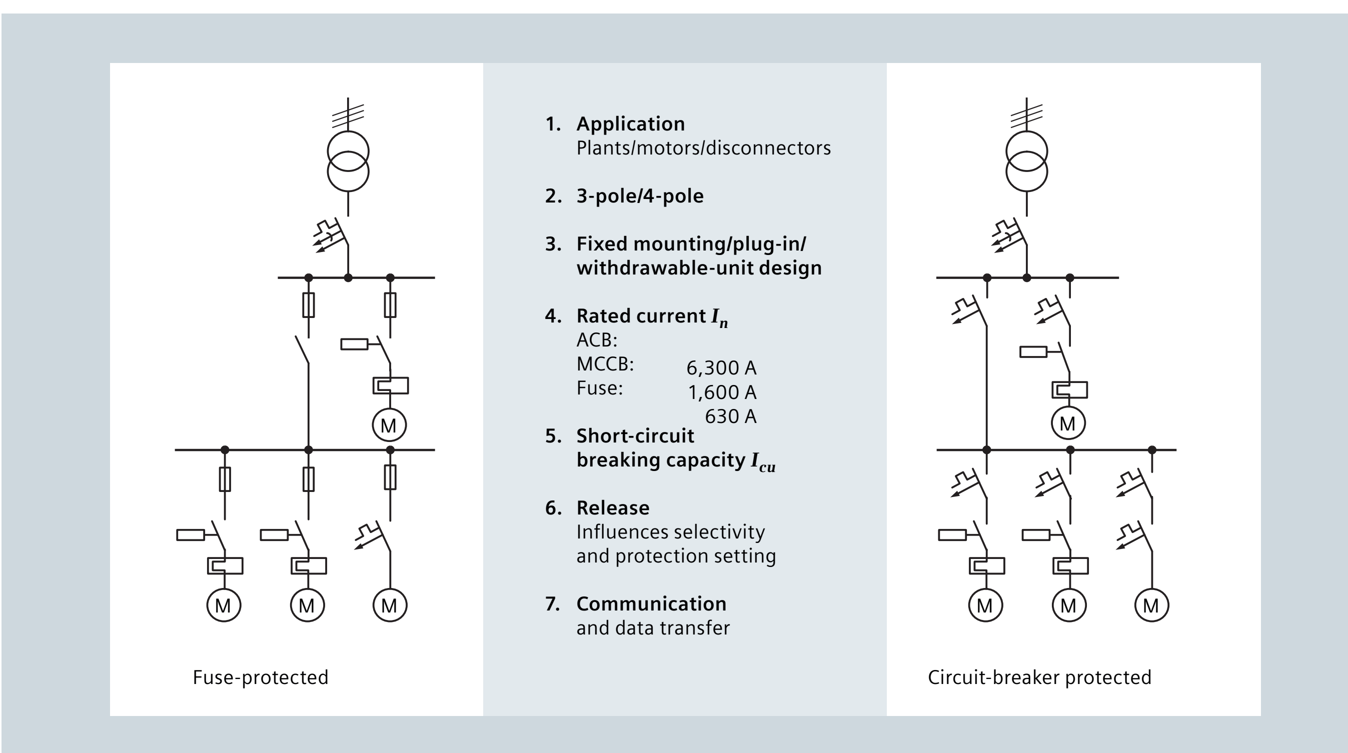


Fig. 4.3-5: **Main selection criteria**

4.3.3 Busbar Trunking Systems, Cables and Wires

Busbar trunking systems

When a planning concept for power supply is developed, it is not only imperative to observe standards and regulations, it is also important to discuss and clarify economic and technical interrelations. The rating and selection of electric equipment, such as distribution boards and transformers, must be performed in such a way that an optimum result for the power system as whole is kept in mind rather than focusing on individual components.

All components must be sufficiently rated to withstand normal operating conditions as well as fault conditions. Further important aspects to be considered for the preparation of an energy concept are:

- Type, use and shape of the building (e.g., high-rise building, low-rise building, number of story levels)
- Load centers and possible power transmission routes and locations for transformers and main distribution boards
- Building-related connection details according to specific area loads that correspond to the type of use of the building
- Statutory provisions and conditions imposed by building authorities
- Requirements by the power supply system operator

The result will never be a single solution. Several options have to be assessed in terms of their technical and economic impacts. The following requirements are of central importance:

- Easy and transparent planning
- High service life
- High availability
- Low fire load
- Flexible adaptation to changes in the building

Most applications suggest the use of suitable busbar trunking systems to meet these requirements. For this reason, engineering companies increasingly prefer busbar trunking to cable installation for power transmission and distribution.

Siemens offers busbar trunking systems ranging from 25 A to 6,300 A:

- the CD-K busbar system from 25 to 40 A for the supply of light fixtures and micro-consumers
- the BD01 busbar system from 40 to 160 A for supplying workshops with tap-offs up to 63 A
- the BD2 busbar system from 160 to 1,250 A for supplying medium-size consumers in buildings and industry
- the ventilated LD system from 1,100 to 5,000 A for power transmission and power distribution an production sites with a high energy demand
- the LX sandwich system from 800 to 5,000 A, mainly for power transmission insensitive to position in buildings with the requirements of degree of protection IP54 and special conductor configurations such as double N or insulated PE
- the encapsulated LR system from 630 to 6,300 A for power transmission for extreme environmental conditions (IP68)

For the configuration of a busbar system, the following points are to be noted:

Calculation/dimensioning:

- Electrical parameters, such as rated current, voltage, given voltage drop and short-circuit strength at place of installation

Technical parameters of the busbar systems:

- The conductor configuration depends on the mains system according to type of earth connection
- Reduction factors, e.g., for ambient air temperature, type of installation, (vertical) busbar position (horizontal on edge) and degree of protection
- Copper is required as conductor material; otherwise, aluminum has advantages such as weight, price, etc.
- How is the system supply to be carried out: as a TTA solution directly from the distribution board or by means of cables at the end or center of the busbar
- Max. cable connection options to infeed and tap-off units
- Power and size of the tap-off units including installation conditions
- Number of tapping points
- Use of bus systems possible
- Influence of a magnetic field (hospitals, broadcasting studios)
- Environmental conditions, especially ambient air temperature (e.g., where there are fire compartments in each floor of a vertical shaft)

Structural parameters and boundary conditions:
- Phase response (changes of direction in the busbar routing possible, differences in height, etc.)
- Functional sections (e.g., various environmental conditions or various uses)
- Check use in sprinkler-protected building sections
- Fire areas (provision of fire barriers –> what structural (e.g., type of walls) and fire fighting (local provisions) boundary conditions are there?
- Fire protection classes of the fire barriers (S90 and S120)
- Functional endurance classes (E60, E90, E120) and certifications of the busbar systems (observe relevant deratings)
- Fire loads/halogens (prescribed fire loads in certain functional sections, e.g., fire escape routes, must not be exceeded).

Fixing of the busbar systems to the structure:
- Maximum clearance from fixings taking into consideration location, weight of system and additional loads such as tap-off units, lighting, etc.
- Agreement on possible means of fixing with structural analyst
- Use of tested fixing accessories with busbar systems with functional endurance

- Observe derating for type of installation
- Dimensions of the distribution board, system supplies and tap-off units:
  - Installation clearance from ceiling, wall and parallel systems for the purpose of heat dissipation and installation options
  - Crossing with other installations (water, gas pipes, etc.)
  - Swing angle for installing and operating the tap-off units
  - Minimum dimensions for changes of direction in the busbar routing, fire protection compartmentalization, wall cutouts
  - Space requirement for distribution connection
  - Cutout planning (sizes and locations of the cutouts)
- Linear expansion (expansion units, if applicable).

More information:

Siemens AG, Totally Integrated Power Application Manual – Basics and Preliminary Planning, Nuremberg, 2006, Chapter 5

Technical data, dimension drawings, components, etc. are included in the technical catalogs LV70, LV71 T, LV 72 T of Siemens AG

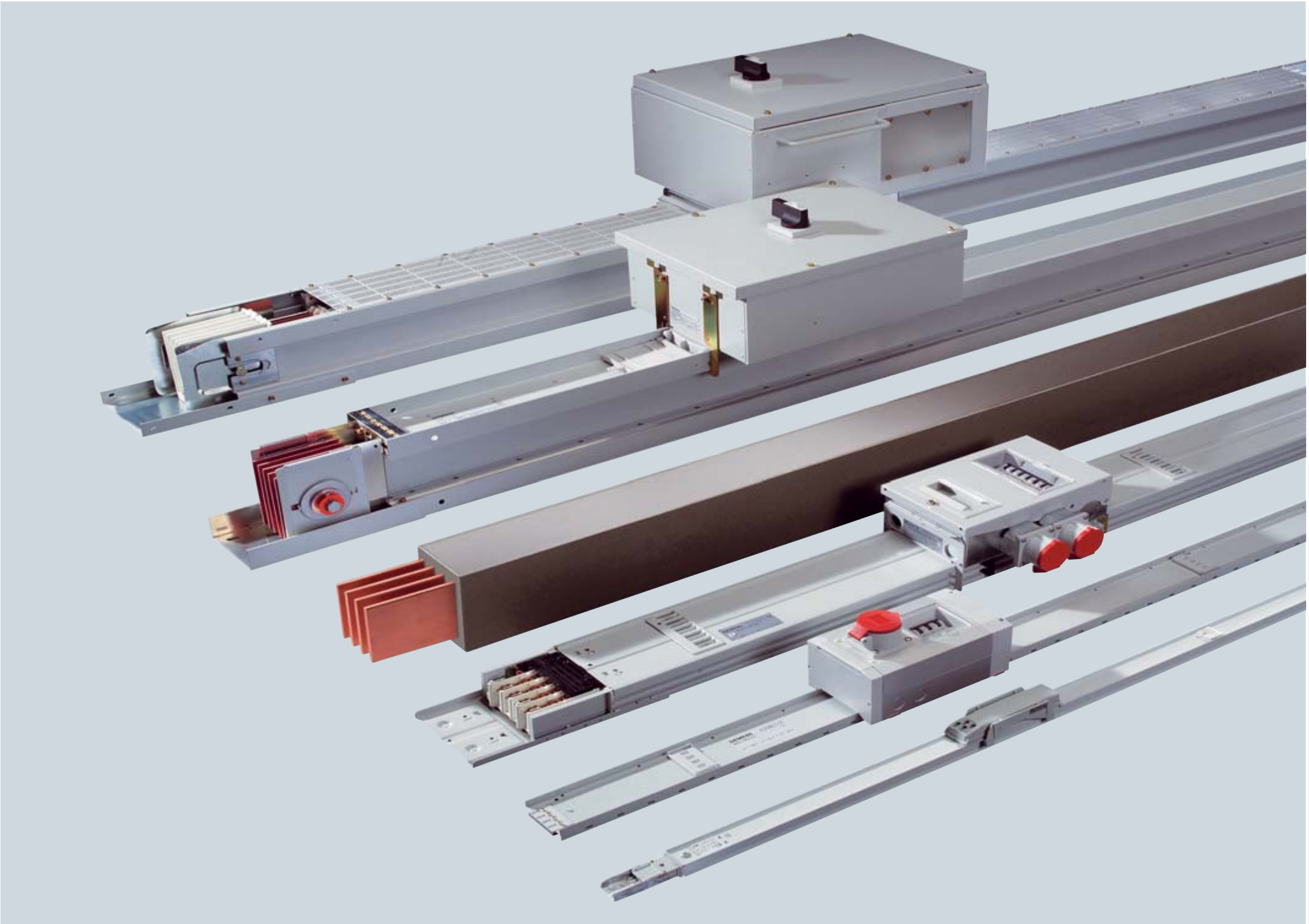


Fig. 4.3-6: **Busbar trunking systems**

4

CD-K system 25 A – 40 A
The system is designed for applications of 25 to 40 A and serves to provide an economical and flexible power supply for lighting systems and low-consumption equipment. Typical areas of application are department stores, supermarkets, storerooms or clean room technology.

1.Trunking unit
- 3, 4, 5-conductor
- Degree of protection: IP54, IP55
- Standard lengths: 2 m and 3 m
- Rated current: 30 A, 40 A, 2 x 25 A, 2 x 40 A
- Spacing of the tapping points: 0.5 m and 1 m
- Rated operating voltage: 400 V AC

2. Feeding unit
- Cable entry: from three sides

3. Tap-off component
- Pluggable while energized
- 3-pole for 10 A and 16 A
- Equipped as L1, L2 or L3 with N and PE
- 5-pole for 10 A and 16 A
- Codable

4. End flange

5. Possible supplementary equipment
- Fixing clamp
- Suspension hook
- Hanger
- Cable fixing
- Coding set

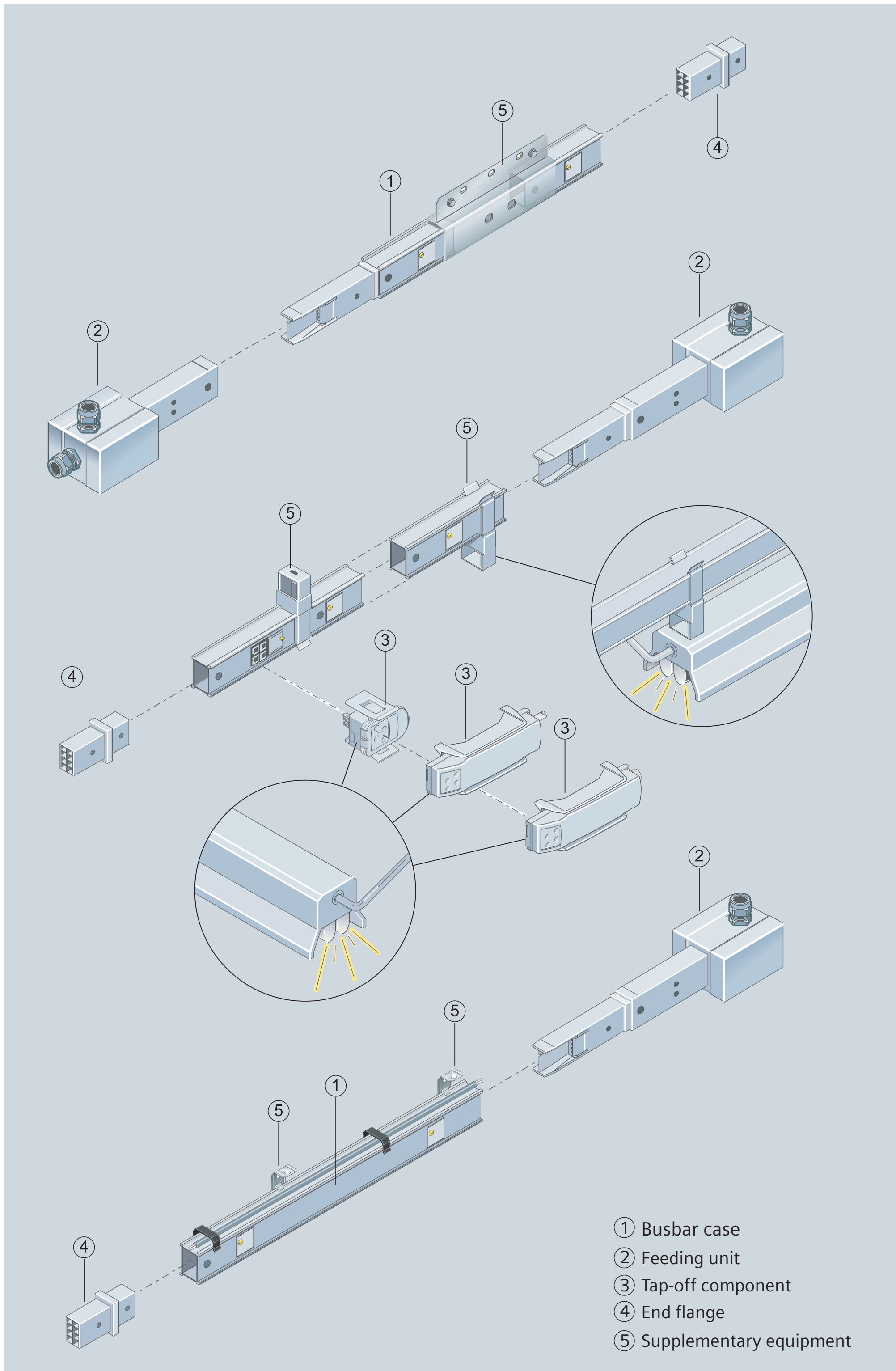


Fig. 4.3-7: **System components for CD-K system**

System BD01 40 A – 160 A
The BD01 busbar trunking system is designed for applications from 40 to 160 A. Five rated amperages are available for only one size, i.e., all other components can be used for all five rated currents irrespective of the power supply. The system is used primarily to supply smaller consumers, e.g., in workshops.

1. Trunking unit
- 4-conductor (L1, L2, L3, N, PE = casing)
- Degree of protection: IP54, IP55
- Standard lengths: 2 m and 3 m.
- Rated current: 40 A, 63 A, 100 A, 125 A, 160 A
- Spacing of the tapping points: 0.5 m and 1 m
- Rated operating voltage: 400 V AC

2. Directional change components
- Changes of direction in the busbar routing possible: flexible, length 0.5 m, 1 m

3. Feeding unit
- Universal system supply

4. Tap-off unit
- Up to 63 A, with fuses or miniature circuit-breaker (MCB) and with fused outlets
- With fittings or for customized assembly
- For 3, 4 or 8 modules (MW)
- With or without assembly unit

5. Device case
- For 4 or 8 modules (MW)
- With or without assembly unit
- With or without outlet installed

6. Possible supplementary equipment
- Installation sets for degree of protection IP55
- Fixing and suspension
- Coding set

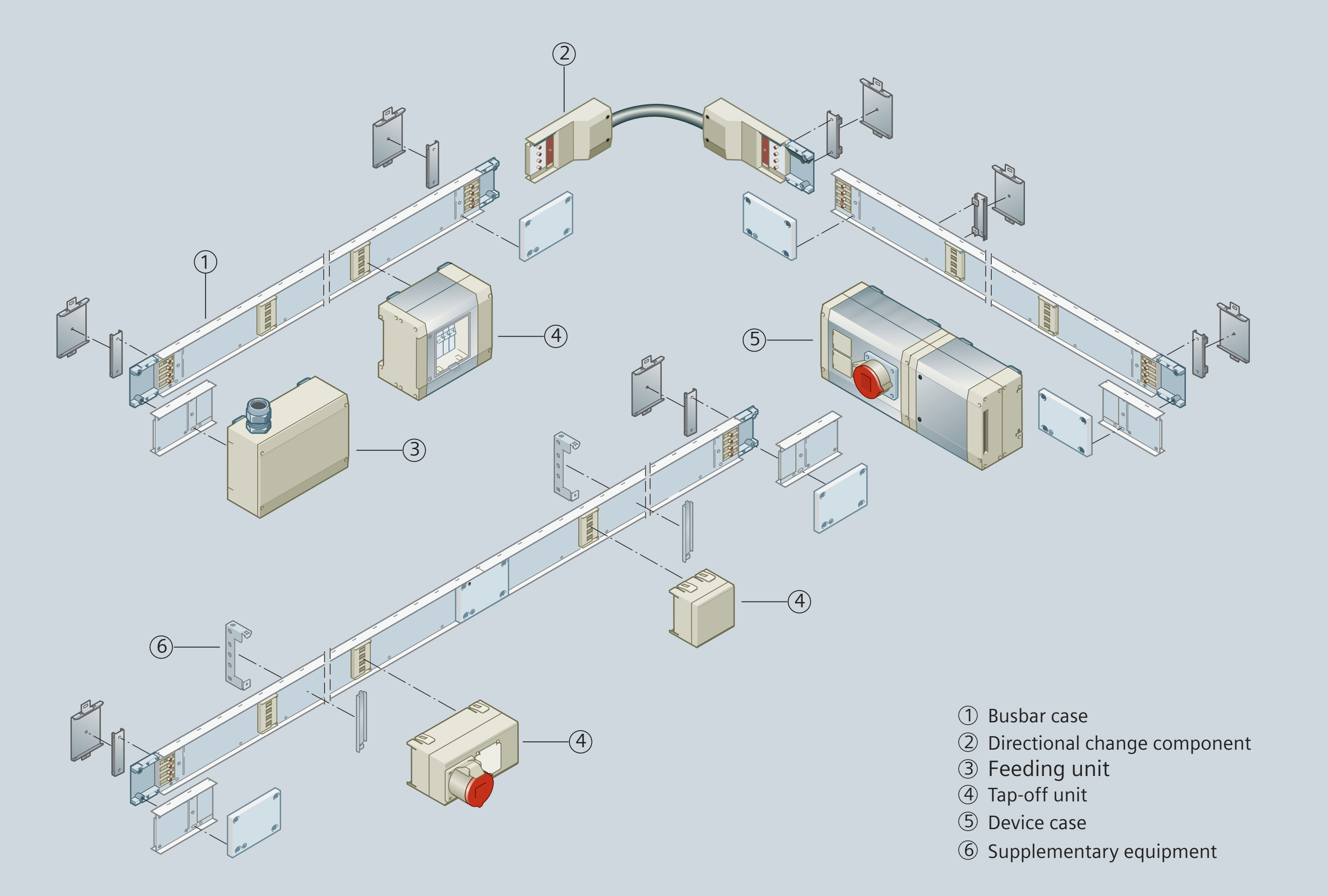


Fig. 4.3-8: **System components for BD01 system**

BD2 system 160 A–1,250 A
The BD2A/BD2C busbar trunking system (aluminum/copper) is suitable for universal use. It has not only been designed to provide flexible power supply and distribution for consumers in trade and industry, but it can also be used for power transmission from one supply point to another. In addition, the BD2 busbar trunking system is used as rising mains in multi-story buildings, and since a large number of changes of direction in the busbar routing are possible, it can be adapted to the building geometries perfectly.

1. Trunking unit
- 5-conductor (L1, L2, L3, N, PE, optional with half N and/or with half PE)
- Degree of protection: IP52, IP54, IP55
- Busbar material: copper or aluminum
- Rated current: 160 A, 250 A, 315 A, 400 A (68 mm x 167 mm) 500 A, 630 A, 800 A, 1,000 A, 1,250 A (126 mm x 167 mm)
- Standard lengths: 3.25 m, 2.25 m and 1.25 m
- Lengths available: from 0.5 m to 3.24 m
- Tapping points:
  – without
  – on both sides (0.5 m apart)
- Fire protection: fire safety class S90 and S120 in accordance with DIN 4102, pages 2 to 4

2. Directional change components
- On edge or flat position
- With or without fire protection
- Horizontal angle unit with or without user-configurable bracket
- Z-unit
- T-unit
- Cross unit
- Flexible changes of direction in the busbar routing possible up to 800 A

3. Feeding unit
- Feeding from one end
- Center feeding
- Stud terminal
- Cable entry from 1, 2 or 3 sides
- Distribution board feeding

4. Tap-off unit
- 25 A to 630 A
- With fuse, miniature circuit-breaker (MCB) or fused outlet installed

5. Device case
- For 8 modules (MW)
- With or without assembly unit

6. Possible supplementary equipment
- End flange
- For fixing:
  – Universal fixing clamp for on edge or flat position
  – Fixing elements for vertical phases, for fixing to walls or ceilings
- Terminal block

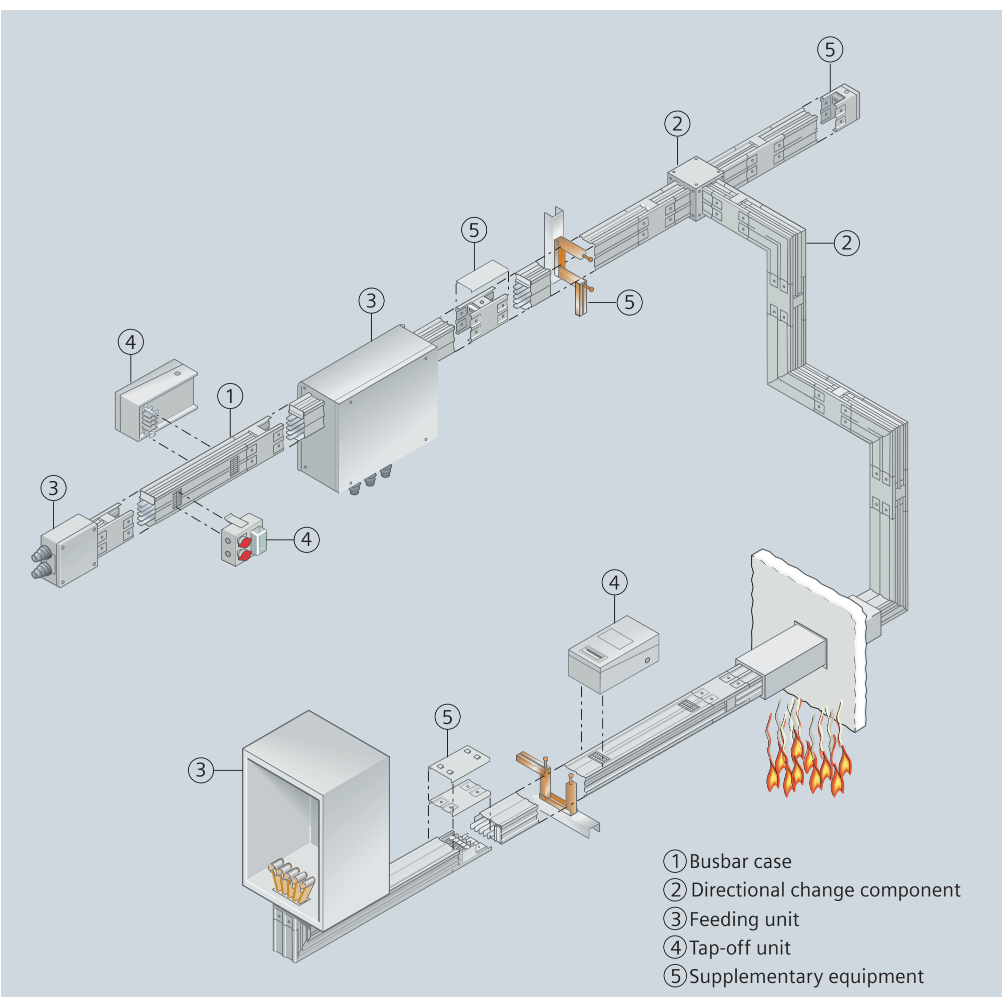


Fig. 4.3-9: **System components for BD2 system**

LDA/LDC system
1,100 A – 5,000 A
The LD busbar trunking system is used both for power transmission and power distribution. A special feature of the system is a high short-circuit strength and it is particularly suitable for connecting the transformer to the low-voltage main distribution and then to the subdistribution system. When there is a high power demand, conventional current conduction by cable means that parallel cables are frequently necessary. Here, the LD system allows optimal power distribution with horizontal and vertical phase responses. The system can be used in industry as well as for relevant infrastructure projects, such as hospitals, railroad stations, airports, trade fairs, office blocks, etc.

1. Trunking unit
- 4 and 5-conductor system
- Busbar material: copper or aluminum
- Rated current: 1,100 to 5,000 A
  – LDA1 to LDC3 (180 mm x 180 mm)
  – LDA4 to LDC8 (240 mm x 180 mm)
- Degree of protection: IP34 and IP54 (IP36 and IP56 upon request)
- Standard lengths: 1.6 m, 2.4 m and 3.2 m
- Lengths available: from 0.5 m to 3.19 m
- Tapping points:
  – Without
  – With user-configurable tapping points
- Fire protection partitions: fire resistance class S120 in accordance with DIN 4102-9

2. Directional change components
- With or without fire protection
- Horizontal angle unit with or without user-configurable bracket
- Z-unit
- U-unit
- T-unit

3. Tap-off unit
- Degree of protection IP30 and IP54 (IP55 upon request)
- With fuse switch-disconnector from 125 A to 630 A
- With circuit-breaker from 80 A to 1,250 A
- Leading PEN or PE connector
- Switching to load-free state following defined, forced-operation sequences
- Coding bracket

4. Feeding unit
- Cable feeding unit
- Universal terminal for transformers

5. Terminal boxes for connection to distribution board
- TTA distribution connection to the SIVACON system from the top/bottom
- Terminals for external distribution boards

6. Possible supplementary equipment
- End flange
- Terminal block

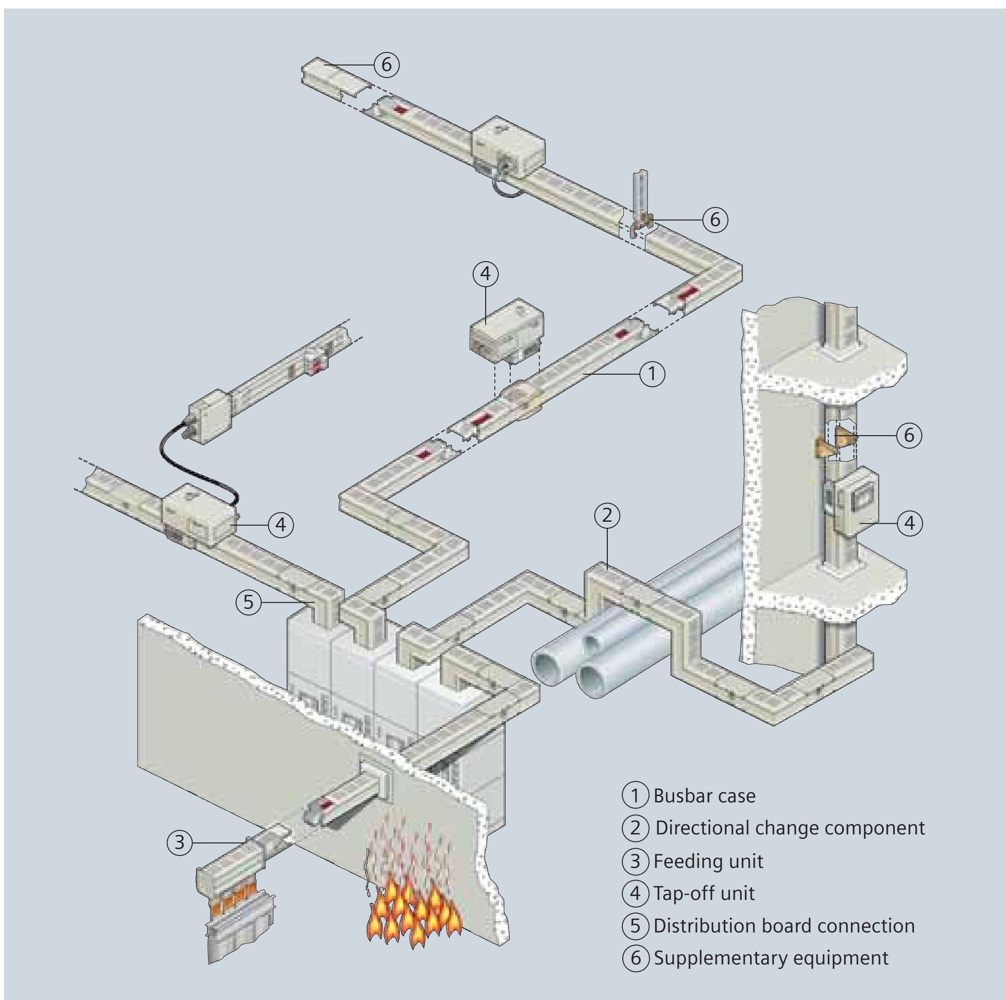


Fig. 4.3-10: **System components for LDA/LDC system**

LXA/LXC system
from 800 A – 5,000 A

The LX busbar trunking system is used both for power transmission and power distribution. Special features of the system include high flexibility and position insensitivity, and it is particularly suitable for power distribution in multi-story buildings. The high degree of protection IP54, which is standard for this system, and tap-off units up to 1,250 A also guarantee a safe supply if there is a high energy demand. It can be used in industry as well as for relevant infrastructure projects such as hospitals, railroad stations, airports, data centers, office blocks, etc.

1. Trunking unit

4 and 5-conductor system in various conductor configurations, including separate PE or double N

- Busbar material: copper or aluminum
- Rated current: 800 up to 5,000 A

Size (mm)	Aluminum	Copper
137 x 145	up to 1,000 A	up to 1,250 A
162 x 145	up to 1,250 A	up to 1,600 A
207 x 145	up to 1,600 A	up to 2,000 A
287 x 145	up to 2,500 A	up to 3,200 A
439 x 145	up to 3,200 A	up to 4,000 A
599 x 145	up to 4,500 A	up to 5,000 A

- Degree of protection: IP54 (IP55 optional)
- Standard lengths: 1 m, 2 m and 3 m
- Lengths available: from 0.35 m to 2.99 m
- Layout: horizontal and vertical without derating
- Tapping points:
  – On one side
  – On both sides
- Fire protection partitions: fire resistance class S120 in accordance with DIN 4102 Part 9

2. Directional change components

- With or without fire protection
- Horizontal angle unit with or without user-configurable bracket
- Z-unit
- U-unit
- T-unit

3. Tap-off unit

- Degree of protection IP54
- With fuse switch-disconnector from 125 A to 630 A
- With circuit-breaker from 80 A to 1,250 A
- Pluggable while energized up to 630 A
- Fixed installation up to 1,250 A (on terminal block)
- Leading PEN or PE connector
- Switching to load-free state following defined, forced-operation sequences
- Coding bracket

4. Feeding unit

- Cable feeding unit
- Universal terminal for transformers

5. Terminal boxes for connection to distribution board

- TTA distribution connection to the SIVACON system from the top/bottom
- Terminals for external distribution boards

6. Possible supplementary equipment

- End flange
- Flange for degree of protection increased from IP54 to IP55
- Terminal block

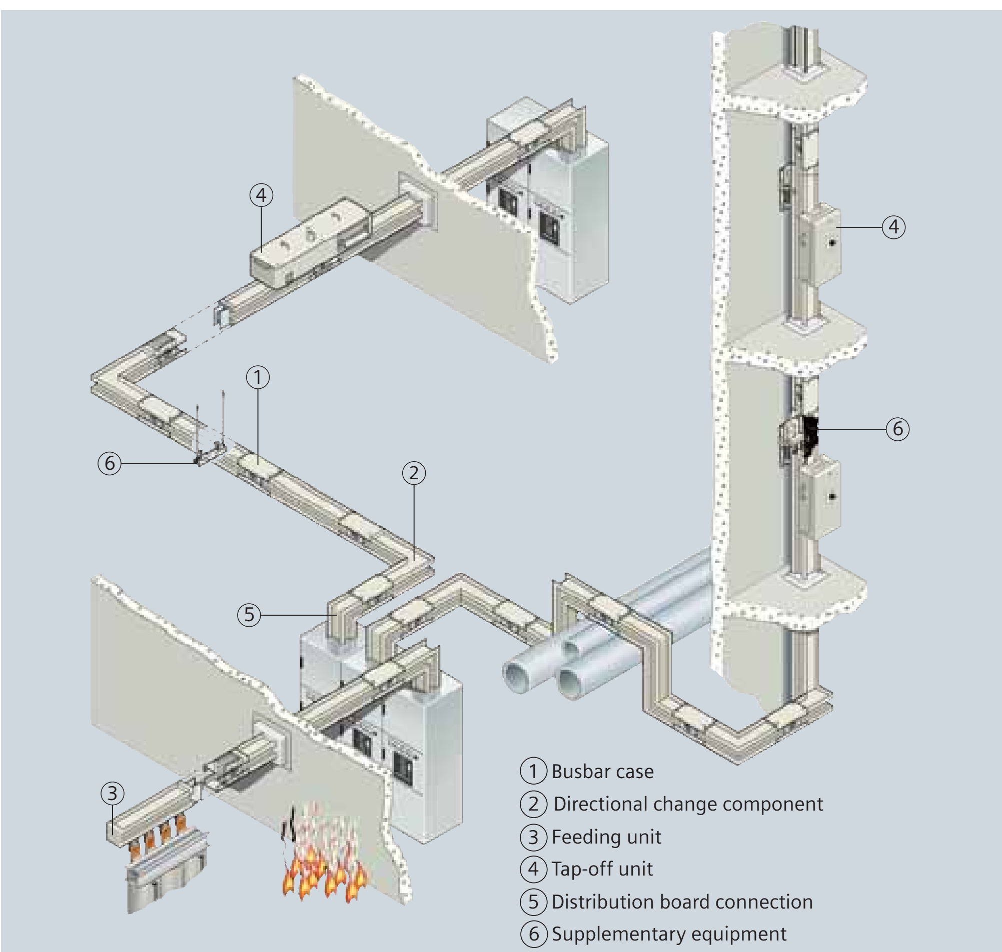


Fig. 4.3-11: **System components for LXA/LXC system**

LRC system
from 630 A – 6,300 A

The LRC busbar trunking system is used for power transmission. A special feature of the system is high resistance to external influences of chemical and corrosive substances, and it is particularly suitable for use in the open air and in environments with high air humidity. The high degree of protection IP68 is guaranteed with the encapsulated epoxy cast-resin casing, and serves to provide reliable power transmission when there is a high energy demand. The system can be used in industry as well as for relevant infrastructure projects such as railroad stations, airports, office blocks, etc.

1. Trunking unit

4 and 5-conductor system

- Busbar material: copper
- Degree of protection: IP68
- User-configurable lengths: from 0.30 m to 3.00 m
- Layout: horizontal and vertical without derating
- Fire barriers: fire resistance class S120 in accordance with DIN 4102 Part 9

2. Directional change components

- With or without fire protection
- Horizontal angle unit with or without offset
- Z-unit
- T-unit

3. Feeding unit and distributor units

- Universal terminals for transformers, external distributors and cable connection

4. Possible supplementary equipment

- End flange
- Terminal block

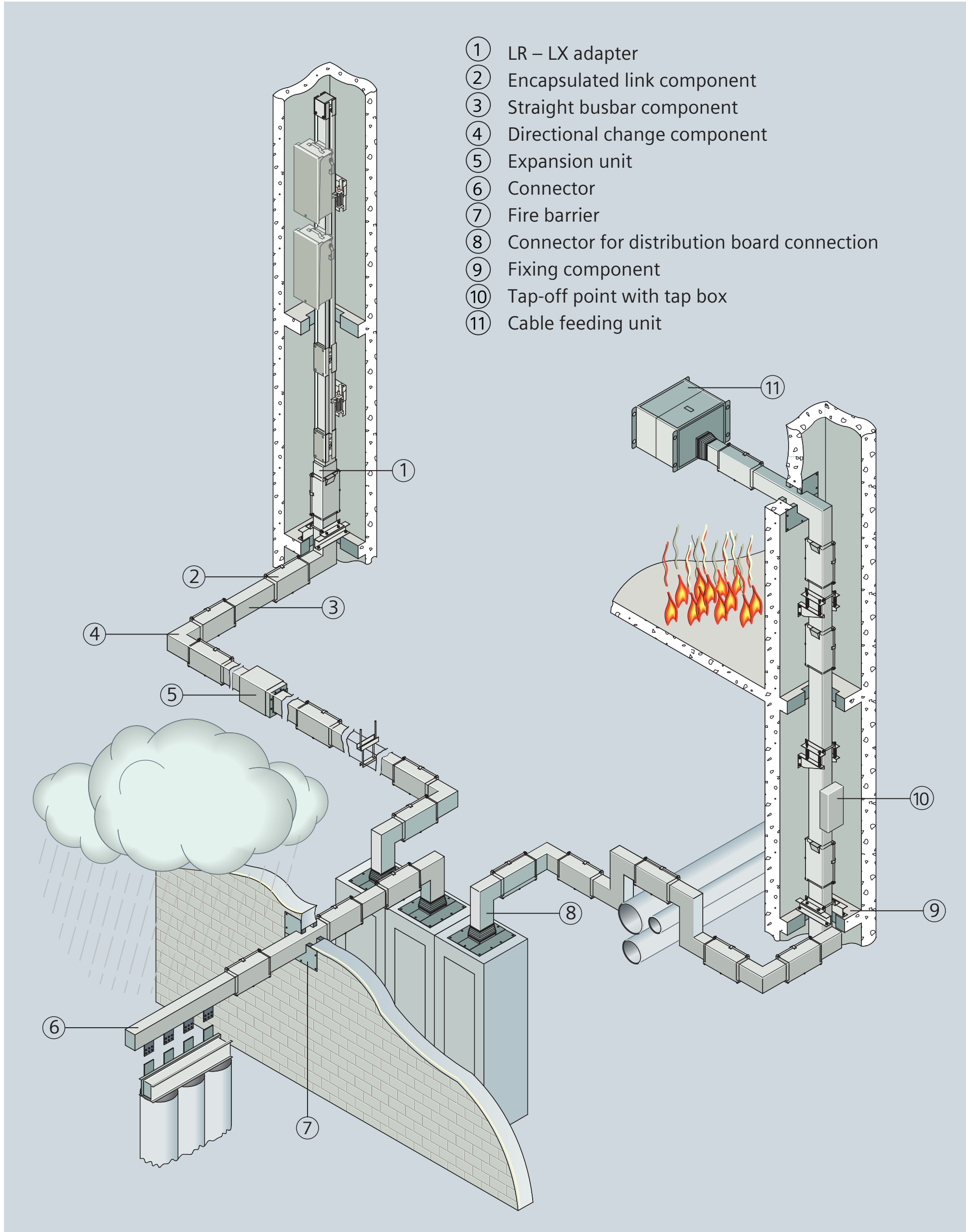


Fig. 4.3-12: **System components for LRC system**

4.3.4 Subdistribution Systems

General
Subdistribution systems, as an essential component for the reliable power supply to all consumers of a building, are used for the distributed supply of circuits. From the subdistribution boards, cables either lead directly or via ground contact outlets to the consumer. Protective devices are located within the subdistribution systems.

These are:
- Fuses
- Miniature circuit-breakers
- RCD (residual current devices)
- Circuit-breakers
- Overvoltage protection

They provide protection against personal injury and protect:
- Against excessive heating caused by non-permissible currents
- Against the effects of short-circuit currents and the resulting mechanical damage.

In addition to the protective devices, a subdistribution system also contains devices for switching, measuring and monitoring. These are:
- Disconnectors
- KNX/EIB components
- Outlets
- Measuring instruments
- Switching devices
- Transformers for extra-low-voltages
- Components of the building control systems

Configuration
The local environmental conditions and all operating data have utmost importance for the configuration of the subdistribution systems. The dimensioning is made using the following criteria:

Ambient conditions
- Dimensions
- Mechanical stress
- Exposure to corrosion
- Notes concerning construction measures
- Wiring spaces
- Environmental conditions

Electrical data
- Rated currents of the busbars
- Rated currents of the supply circuits
- Rated currents of the branches
- Short-circuit strength of the busbars
- Rating factor for switchgear assemblies
- Heat loss

Protection and installation type
- Degree of protection
- Observance of the upper temperature limit
- Protective measures
- Installation type (free-standing, floor-mounted distribution board, wall-mounted distribution board)
- Accessibility, e.g., for installation, maintenance and operating

Type of construction
- Number of operating faces
- Space requirements for modular installation devices, busbars and terminals
- Supply conditions

The number of subdistribution boards in a building is determined using the following criteria:

Floors
A high-rise building normally has at least one floor distribution board for each floor. A residential building normally has one distribution system for each apartment.

Building sections
If a building consists of several sections, at least one subdistribution system is normally provided for each building section.

Departments
In a hospital, separate subdistribution systems are provided for the various departments, such as surgery, OP theater, etc.

Safety power supplies
Separate distribution boards for the safety power supply are required for supplying the required safety equipment.
Depending on the type and use of the building or rooms, the relevant regulations and guidelines must be observed, such as VDE 0100-710 and -718 and the MLAR (Sample Directive on Fireproofing Requirements for Line Systems).

Standards to be observed for dimensioning
- IEC 60364-2-20, DIN VDE 0100-200 Low-voltage installations; Part 200 Definitions
- IEC 60364-3-30, DIN VDE 0100-300; Assessment of general characteristics of installations
- IEC 60364-4-41, DIN VDE 0100-410 Protection against electric shock
- IEC 60364-4-30/DIN VDE 0100-430 Protection against overcurrent
- IEC 60364-5-51/DIN VDE 0100-510 Selection and erection of electrical equipment; common rules
- IEC 60364-5-20/DIN VDE 0100-520 Wiring systems
- DIN VDE 0298-4 Recommended values for the current carrying capacity of sheathed and non-sheathed cables
- DIN VDE 0606-1 Connecting materials up to 690 V; Part 1 – Installation boxes for accommodation of equipment and/or connecting terminals
- DIN 18015-1 Electrical systems in residential buildings, planning principles

Selection of protective devices and connecting lines
The selection and setting of the protective devices to be used must satisfy the following three conditions:
- Protection against non-permissible contact voltage for indirect contact (electric shock)

- Overload protection
- Short-circuit protection

For detailed information on the three conditions, see section 3.3.2 “Dimensioning of Power Distribution Systems”.

An exact protective device selection and thus the dimensioning of subdistribution systems requires extensive short-circuit current and voltage drop calculations. Catalog data for the short-circuit energies, the selectivity and the backup protection of the individual devices and assemblies must also be consulted. In addition, the appropriate regulations and standards must be observed. At this point, a reference should be made to the SIMARIS design dimensioning tool that automatically takes account of the above mentioned conditions, catalog data, standards and regulations, and consequently automatically makes the device selection.

Selectivity and backup protection

Rooms used for medical purposes (VDE 0100-710) and meeting rooms (DIN VDE 0100-718) require the selection of protective devices in subareas. For other building types, such as computer centers, there is an increasing demand for a selective grading of the protective devices, because only the circuit affected by a fault would be disabled with the other circuits continuing to be supplied with power without interruption (chapter 6 “Protection and Substation Automation”).

Because the attainment of selectivity results in increased costs, it should be decided for which circuits selectivity is useful. Backup protection is the lower-cost option. In this case, an upstream protective device, e.g., an LV HRC fuse as group backup fuse, supports a downstream protective device in mastering the short-circuit current, i.e., both an upstream and a downstream protective device trip. The short-circuit current, however, has already been sufficiently reduced by the upstream protective device so that the downstream protective device can have a smaller short-circuit breaking capacity. Backup protection should be used when the expected solid short-circuit current exceeds the breaking capacity of the switching device or the consumers. If this is not the case, an additional limiting protective device unnecessarily reduces the selectivity or, indeed, removes it.

The following scheme should be followed for the selectivity or backup protection decision:

- Determine the maximum short-circuit current at the installation point,
- Check whether the selected protective devices can master this short-circuit current alone or with backup protection using upstream protective devices,
- Check at which current the downstream protective devices and the upstream protective devices are selective to each other.

Selectivity and backup protection exemplified for a data center

Computer centers place very high demands on the safety of supply. This is particularly true for the consumers attached to the uninterruptible power supply, and ensures a reliable data backup in case of a fault and service interruption. Those solutions providing selectivity and backup protection relying on

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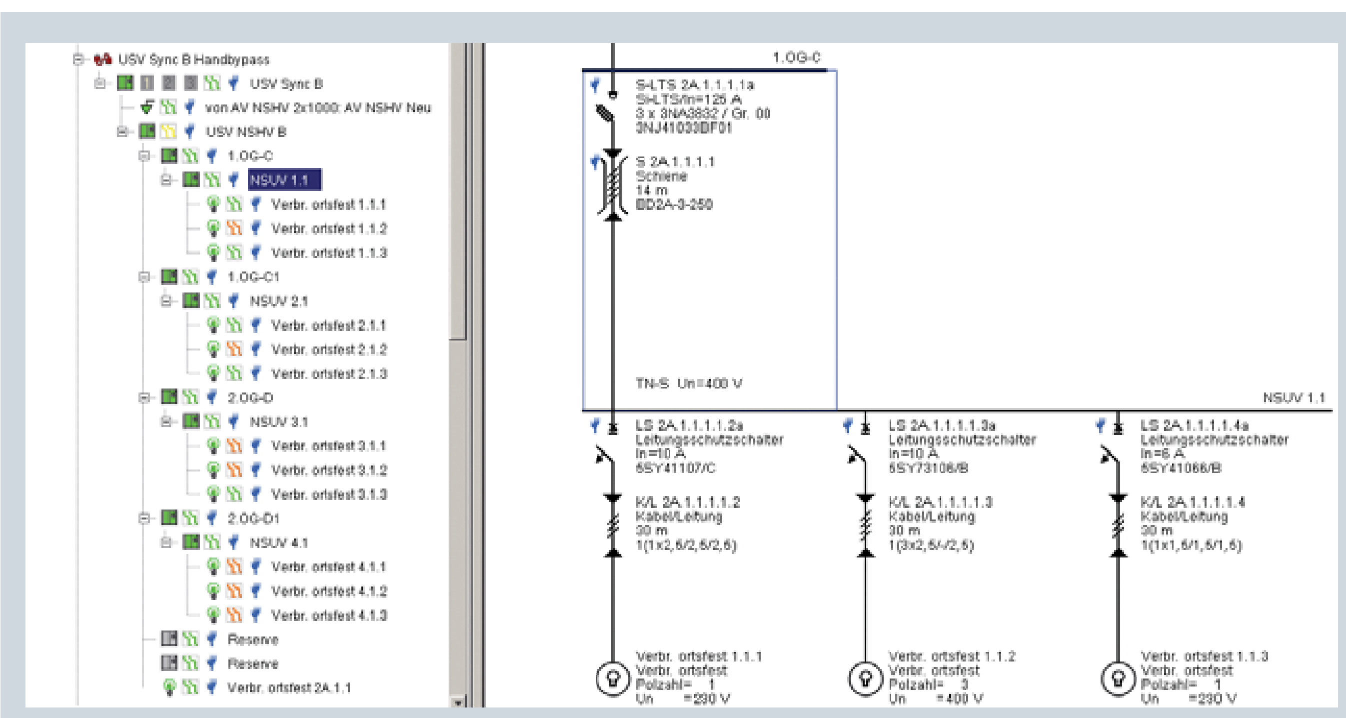


Fig. 4.3-13: **Subdistribution in a data center; display in SIMARIS design**

the previously mentioned SIMARIS design configuration tool should be presented at this point. Fig. 4.3-13 shows a subdistribution system in SIMARIS design. A SENTRON 3WL circuit-breaker as outgoing feeder switch of the main distribution is upstream to the subdistribution system shown here. The following figures show the selectivity diagrams for the considered subdistribution system automatically generated by SIMARIS design (fig. 4.3-14). SIMARIS design specifies the characteristic curve band of the considered circuit (yellow lines), the envelope curves of all upstream devices (blue line) and all downstream devices (red line). In addition to the specification of the minimum and maximum short-circuit currents, any selectivity limits for the individual circuits are also specified.

Fig. 4.3-15 shows the selective grading of the 3WL circuit-breaker from the main distribution system and the group backup fuse (125 A LV HRC fuse) of the subdistribution system. The consumers critical for functional endurance which are installed in a redundant manner in the subdistribution system should not be protected with the same backup fuse but rather be assigned to different groups.

The selectivity diagram shows the circuit diagram of a single-phase consumer in the subdistribution system. This circuit diagram is protected with a 10 A miniature circuit-breaker with characteristic C and for a maximum short-circuit current of 9,719 kA selective for the 125 A group backup fuse.

The same subdistribution system also contains an example for backup protection. Fig. 4.3-16 shows the selectivity diagram for the combination of the group backup fuse with a 10 A miniature circuit-breaker of the characteristic B. Up to the breaking capacity of the 15 kA miniature circuit-breaker, the two protective devices are selective to each other. Above this value, the current is limited by the fuse and the miniature circuit-breaker protected by a fuse; both devices trip.

SIMARIS design automatically generates these characteristic curves to provide exact information about the maximum and minimum short-circuit currents of the associated circuit. Fig. 4.3-16 also shows up to which current ($I_{sel\text{-}kurz}$) the protective devices are selective to each other.

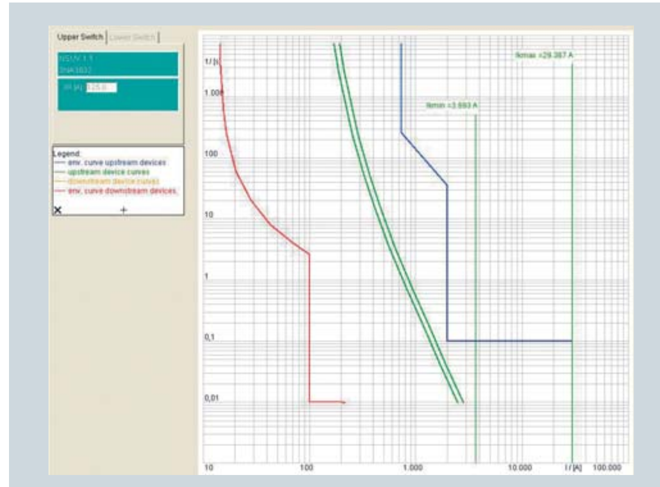


Fig. 4.3-14: **Selectivity of the group backup fuse to the upstream protective devices**

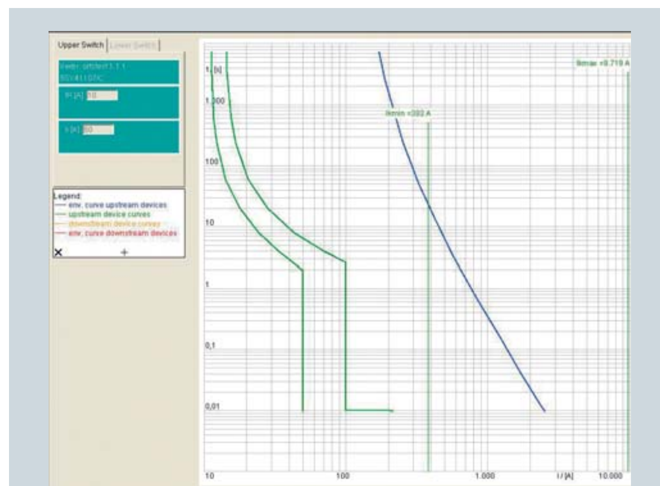


Fig. 4.3-15: **Selectivity of the group backup fuse/miniature circuit-diagram combination**

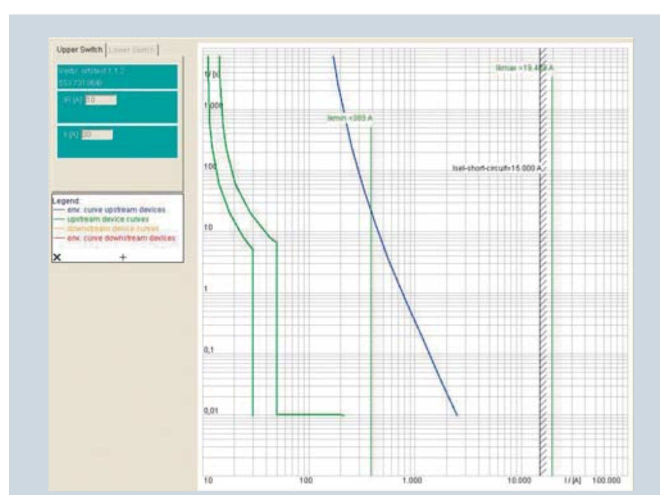


Fig. 4.3-16: **Backup protection of the group backup fuse/miniature circuit-breaker**

4.4 Surge Arresters

The main task of an arrester is to protect equipment from the effects of overvoltages. During normal operation, an arrester should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage. Non-linear resistors with the following properties fulfill these requirements:

- Low resistance during surges so that overvoltages are limited
- High resistance during normal operation so as to avoid negative effects on the power system
- Sufficient energy absorption capability for stable operation

With this kind of non-linear resistor, there is only a small flow of current when continuous operating voltage is being applied. When there are surges, however, excess energy can be quickly removed from the power system by a high discharge current.

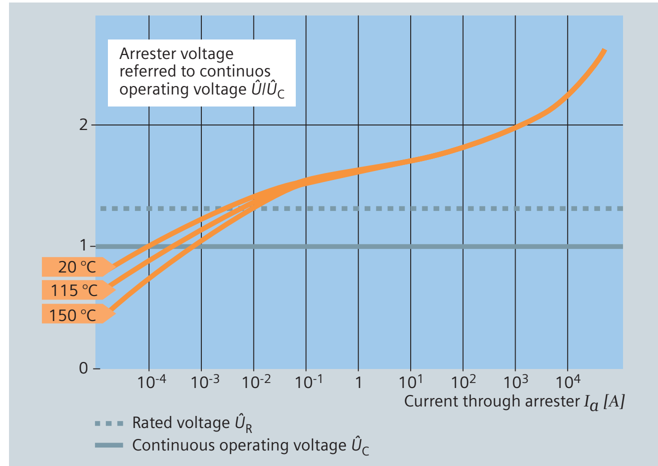


Fig. 4.4-1: **Current/voltage characteristics of a non-linear MO arrester**

4.4.1 High-Voltage Surge Arresters

Non-linear resistors

Non-linear resistors, comprising metal oxide (MO), have proved especially suitable for this use. The non-linearity of MO resistors is considerably high. For this reason, MO arresters, as the arresters with MO resistors are known today, do not need series gaps (fig. 4.4-1).

Siemens has many years of experience with arresters – with the previous gapped SiC arresters and the new gapless MO arresters – in low-voltage systems, distribution systems and transmission systems. They are usually used for protecting transformers, generators, motors, capacitors, traction vehicles, cables and substations. There are special applications such as the protection of:

- Equipment in areas subject to earthquakes or heavy pollution
- Surge-sensitive motors and dry-type transformers
- Generators in power stations with arresters that posses a high degree of short-circuit current strength
- Gas-insulated high-voltage metal-enclosed switchgear (GIS)
- Valves in HVDC transmission installations
- Static compensators
- Airport lighting systems
- Electric smelting furnaces in the glass and metals industries
- High-voltage cable sheaths
- Test laboratory apparatus

MO arresters are used in medium, high and extra-high-voltage power systems. Here, the very low protection level and the high energy absorption capability provided during switching surges are especially important. For high-voltage levels, the simple construction of MO arresters is always an advantage. Another very important advantage of MO arresters is their high degree of reliability when used in areas with a problematic climate, for example, in coastal and desert areas, or in regions affected by heavy industrial air pollution. Furthermore, some special applica-tions have become possible only with the introduction of MO

Fig. 4.4-2: **Surge arrester in traditional porcelain housing; available for system voltages up to 800 kV**

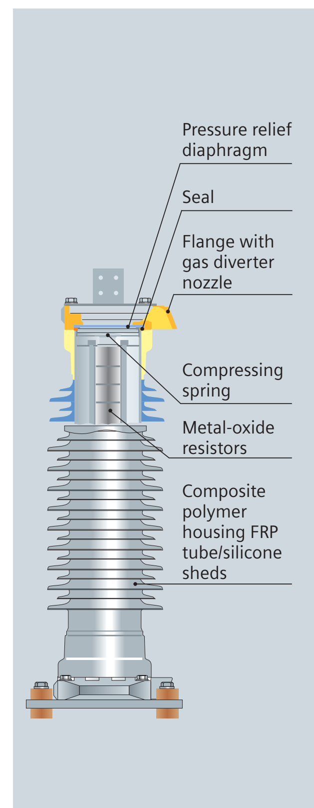


Fig. 4.4-3: **Cross-section of a polymer-housed arrester in cage design**

arresters. One instance is the protection of capacitor banks in series reactive-power compensation equipment that requires extremely high energy absorption capabilities.

Fig. 4.4-2 shows a Siemens MO arrester in a traditional porcelain housing, a well proven technology representing decades of Siemens experience. Siemens also offers surge arresters with polymer housings for all system voltages and mechanical requirements. These arresters are divided into two subgroups:

- Cage-design arresters
- Tube-design arresters

Fig. 4.4-3 shows the sectional view of a cage-design arrester. The housing consists of a fiberglass-reinforced plastic tube with insulating sheds made of silicone rubber. The advantages of this design, which has the same pressure relief device as an arrester with porcelain housing, are absolutely safe and reliable pressure relief characteristics, high mechanical strength even after pressure relief and excellent pollution-resistant properties. The very good mechanical features mean that Siemens arresters with a polymer housing (type 3EQ) can serve as post insulators as well. The pollution-resistant properties are the result of the water-repellent effect (hydrophobicity) of the silicone rubber, which even transfers its effects to pollution.

The newest types of polymer surge arresters also feature the cage-design. While using the same MO resistors, they have the same excellent electrical characteristics as the 3EP and 3EQ types. The difference is that the 3EL (fig. 4.4-4) types get their mechanical performance from a cage built up by fiber-reinforced plastic rods. Furthermore, the whole active part is directly and completely molded with silicone rubber to prevent moisture ingress and partial discharges. The polymer-housed high-voltage arrester design chosen by Siemens and the high-quality materials used by Siemens provide a whole series of advantages, including long life and suitability for outdoor use, high mechanical stability and ease of disposal.

Another important design are the gas-insulated metal-enclosed surge arresters (GIS arresters, fig. 4.4-5). Siemens has been making these arresters for more than 25 years. There are two reasons why, when GIS arresters are used with gas-insulated switchgear, they usually offer a higher protective safety margin than when outdoor-type arresters are used: First, they can be installed closer to the item to be protected so that traveling wave effects can be limited more effectively. Second, compared with the outdoor type, inductance of the installation is lower (both that of the connecting conductors and that of the arrester itself). This means that the protection offered by GIS arresters is much better than that offered by any other method, especially in the case of surges with a very steep rate of rise or high frequency, to which gas-insulated switchgear is exceptionally sensitive.

Monitoring

Siemens also offers a wide range of products for diagnosis and monitoring of surge arresters. The innovative Arrester Condition Monitor (fig. 4.4-6) is the heart of the future-proof (IEC 61850) monitoring product line.

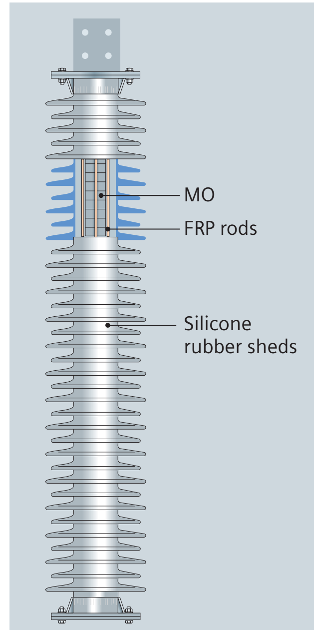


Fig. 4.4-4: **3EL-range surge arrester in cage design**

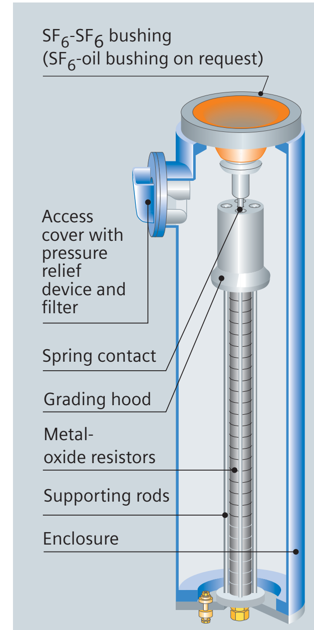


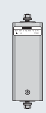
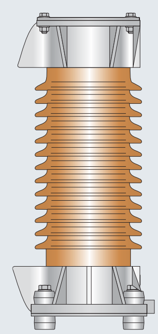
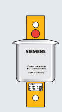
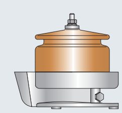
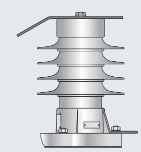
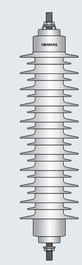
Fig. 4.4-5: **Gas-insulated metal-enclosed arrester (GIS arrester)**

Fig. 4.4-6: **Arrester condition monitor**

Fig. 4.4-7: **Medium-voltage MO arrester**

4.4.2 Low-Voltage and Medium-Voltage Surge Arresters and Limiters

Surge arresters and limiters protect operational equipment both from external overvoltages caused by lightning strikes in overhead lines and from internal overvoltages produced by switching operations or earth faults. Normally, the arrester is installed between phase and earth. The built-in stack of non-linear, voltage-dependent resistors (varistors) made of metal oxide (MO, fig. 4.4-7) or zinc oxide (ZnO) becomes conductive from a defined overvoltage limit value onward, so that the load can be discharged to earth. When the power-frequency voltage underflows this limit value, called discharge voltage, the

	Special applications		Railway applications			Medium-voltage distribution class
	3EF1; 3EF3; 3EF4; 3EF5	3EE2	3EB2	3EC3	3EB1	3EK7
						
Applications	Motors, dry-type transformers, airfield lighting systems, sheath voltage limiters, protection of converters for drives	Generators, motors, melting furnaces, 6-arrester connection, power plants	DC overhead contact lines	DC systems (locomotives, overhead contact lines)	AC and DC systems (locomotives, overhead contact lines)	Distribution systems and medium-voltage switchgear
Highest voltage for equipment (U_m) kV	12	36	2	4	30	72.5
Maximum rated voltage kV	15	45	2	4	37 (AC); 4 (DC)	60
Nominal discharge current kA	3EF1 1 3EF3 1 3EF4 10 3EF5 10	10	10	10	10	10
Maximum thermal energy absorption capability (per kV of U_r) kJ/kV	3EF1 0.8 3EF3 4 3EF4 12.5 3EF5 8	10	10	10	10	3.5[1)]
Maximum long-duration current impulse, 2 ms A	3EF4 1,500 3EF5 1,200	1,200	1,200	1,200	850 (AC); 1,200 (DC)	325
Maximum short-circuit rating kA	40	300	40	40	40	20
Housing material	Polyethylene	Porcelain	Silicone	Porcelain	Silicone	Silicone
Design principle	3EF1 – polyethylene directly molded onto MO; 3EF3/3EF4/3EF5 – Hollow insulator	Hollow insulator	Directly molded	Hollow insulator	Hollow insulator, silicone directly molded onto FRP tube	Cage-design, silicone directly molded onto MO
Pressure relief device	No	Yes	No	Yes	Yes	No

[1)] Energy absorption capacity under the conditions of the operating duty test according to IEC 60099-4

Fig. 4.4-8: **Medium-voltage metal-oxide surge arresters and limiters (300 V to 72.5 kV)**

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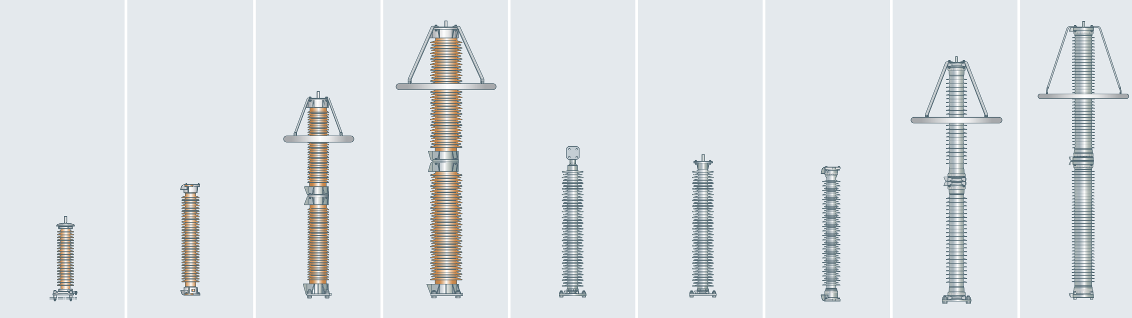
	Porcelain				Silicone				
	3EP5	3EP4	3EP2	3EP3	3EL1	3EL2	3EQ1	3EQ4	3EQ3
									
Applications	Medium and high-voltage systems, outdoor installations	Medium and high-voltage systems, outdoor installations	High-voltage systems, outdoor installations	High-voltage systems, outdoor installations, HVDC, SC&SVC applications	Medium and high-voltage systems, station and transmission line arrester	Medium and high-voltage systems, station and transmission line arrester	Medium and high-voltage systems, outdoor installations	High-voltage systems, outdoor installations	High-voltage systems, outdoor installations, HVDC, SC&SVC applications
Highest voltage for equipment (U_m) kV	123	362	550	800	170	550	362	550	800
Maximum rated voltage kV	96	288	468	612	156	420	288	468	612
Maximum nominal discharge current kA	10	10	20	20	10	20	10	20	20
Maximum line discharge class	3	3	5	5	2	4	3	5	5
Maximum thermal energy absorption capability (per kV of U_r) kJ/kV	8	8	13	25	5	10	8	18	27
Maximum long-duration current impulse, 2 ms A	850	850	1,600	5,000	500	1,200	850	2,100	5,500
Maximum short-circuit rating kA	40	65	65	100	50	65	50	65	80
Maximum permissible service load kNm	2[1)]	4.5[1)]	12.5[1)]	34[1)]	1.2	4.0[2)]	6[2)3)]	21[2)3)]	72[1)]
Housing material	Porcelain				Silicone	Silicone	Silicone		
Design principle	Hollow insulator				Silicone directly molded onto MO	Silicone directly molded onto MO	Hollow insulator, silicone directly molded onto FRP tube		
Pressure relief device	Yes				No	No	Yes		

[1)] MPDSL according to IEC 60099-4; [2)] MPSL according to IEC 60099-4; [3)] > 75 % of this value are maintained after pressure relief

Fig. 4.4-9: **High-voltage metal-oxide surge arresters (72.5 to 800 kV)** varistors return to their original resistance value so that only a so-called leakage current of a few mA flows at operating voltage. Because this leakage current heats up the resistors, and thus the arrester, the device must be designed according to the neutral-point treatment of the system in order to prevent impermissible heating of the arrester.

In contrast to the normal surge arrester, the surge limiter contains a series gap in addition to the MO resistor stack. If the load generated by the overvoltage is large enough, the series gap ignites, and the overvoltage can be discharged to earth until the series gap extinguishes and the varistors return to their non-conductive state. This process is repeated again and again throughout the entire duration of the fault. This makes it possible to design the device with a considerably lower discharge voltage as a conventional surge arrester, and is especially useful for the protection of motors with – normally – a poor dielectric strength. To guarantee a sufficient protective function, the discharge voltage value of the arresters or limiters must not exceed the dielectric strength of the operational equipment to be protected.

The medium-voltage product range includes (fig. 4.4-8):

- The 3EF group of surge arresters and limiters for the protection of motors, dry-type transformers, airfield lighting systems and cable sheath as well as for the protection of converters for drives.
- The 3EE2 porcelain-housed surge arrester for the protection of generators, motors, melting furnaces and power plants as well as for 6-arrester connections.
- The 3EK7 silicone-housed surge arrester for distribution systems, medium-voltage switchgear up to 72.5 kV and transmission line arresters for outdoor use.

An overview of the complete range of Siemens arresters appears in the fig. 4.4-8 to fig. 4.4-10.

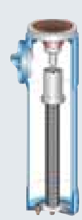
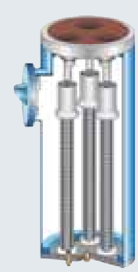
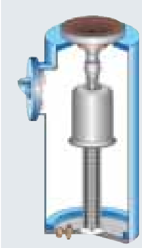
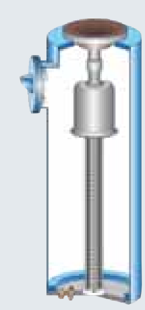
	3ES2-D/E 1-phase	3ES4-K 3-phase	3ES5-C 3-phase	3ES5-F/G/L 1-phase	3ES5-H 1-phase	3ES9-J 1-phase
						
Applications	High-voltage systems, protection of metal-enclosed, gas-insulated switchgear and transformers					
Highest voltage for equipment (U_m) kV	170/245	72.5	170	245/362	550	800
Maximum rated voltage kV	156/216	96	156	216/288	444	612
Maximum nominal discharge current kA	20	10	20	20	20	20
Maximum line discharge class	4	3	4	4/5	5	5
Maximum thermal energy absorption capability (per kV of U_r) kJ/kV	10	8	10	10/13	13	18
Maximum long-duration current impulse, 2 ms A	1,200	850	1,200	1,200/1,600	1,600	2,100
Maximum short-circuit rating kA	50	50	65	65	65	65
Maximum permissible service load kNm	–					
Housing material	Metal					
Pressure relief device	Yes					

Fig. 4.4-10: **Metal-oxide surge arresters for GIS (72.5 to 800 kV)**

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4

4.5 Instrument Transformers

4.5.1 High-Voltage Instrument Transformers

Introduction

Electrical instrument transformers transform high currents and voltages to standardized low and easily measurable values that are isolated from the high voltage. When used for metering purposes, instrument transformers provide voltage or current signals that are very accurate representations of the transmission line values in both magnitude and phase. These signals allow accurate determination of revenue billing.

When used for protection purposes, the instrument transformer outputs must accurately represent the transmission line values during both steady-state and transient conditions. These critical signals provide the basis for circuit-breaker operation under fault conditions, and as such are fundamental to network reliability and security.

Instrument transformers used for network control supply important information for determining the state of the operating conditions of the network.

Reliability and security

Reliability of an instrument transformer refers to its ability to consistently satisfy prescribed performance criteria over its expected useful lifetime under specified operating conditions. Security refers to the acceptability and consequences of the instrument transformer failure mode in the event that it does fail, due either to being subjected to stresses in excess of those for which it was designed, or due to its reaching the end of its expected service life.

The reliability and security characteristics of an instrument transformer are governed by the electrical and insulation design, the manufacturing and processing technology used and the specific physical arrangement. The partial discharge performance under in-service conditions is a key determining factor in the life expectancy and long-term reliability of an instrument transformer.

IEC standards require a partial discharge value of less than 10 pC at U_{max}. Due to the demanding requirements of today's HV and EHV networks, the Trench Group has elected to adopt even more stringent internal requirements. As such, Trench instrument transformers typically perform much better than required by these standards with proven field experience with tens of thousands of units in operation over more than 50 years in almost every country worldwide. Typical designs are oil-immersed or gas-insulated (fig. 4.5-1).

Oil-immersed instrument transformers

The reliability and security of Trench oil-insulated inductive instrument transformers is proven by in-service experience spanning up to 50 years and more than 10,000 units in service under a wide variety of different environmental conditions. The transformer is based on state-of-the-art design and a secure failure mode. In the event of unexpected stresses from the network, secure failure is achieved through the use of a "barrier construction" design in the free oil section. This approach consists of inserting insulating barriers at strategic points through the free oil space, thereby preventing the formation of fiber bridges.

Furthermore a rupture of the housing, particularly of the hollow insulator with built-in finely graded capacitor bushing, is improbable because of the over-dimensioning of the bushing and the solid electrical connection between the core housing and the ground.

If over pressure occurs, the protection is guaranteed by the:

- Very thin welded elastic housing
- Stainless-steel bellows for the oil expansion

Both the welded seam, which connects the upper and lower portions of the head housing, and the metallic bellows are designed to act as pressure relief points in the event of severe internal pressure buildup.

Because the unit has a normal internal oil pressure of approximately 1 bar absolute, it is possible to design these pressure relief points to rupture at very moderate pressures. Additional safety is achieved by the selection of composite insulators, available in the whole range as an alternative to the traditional porcelain.

Pressure relief for capacitive voltage transformers is provided by a bellows puncture pin and through the use of porcelain, which is strong enough to result in any rapid pressure rise being released through the seal plates at the ends of the porcelain rather than via explosion of the porcelain itself. Upon request, oil-immersed instrument transformers can also be supplied with composite insulators.

Gas-insulated instrument transformers

The reliability and security of Trench gas-insulated instrument transformers is based on:

- 50 years of experience as a manufacturer of instrument transformers covering epoxy resin and oil-paper
- Thousands of gas-insulated instrument transformers in service under a wide variety of different environmental conditions

Explosion-proof design

The present Trench gas-insulated instrument transformers were initially designed in 1965 at the request of customers who sought to achieve explosion-proof operation. SF_6 gas insulation, combined with composite insulators, is particularly suitable for this, because in the event of an internal flashover, the pressure increase will be linear and hence technically manageable. A controlled pressure relief device at the head of the transformer (rupture disc) eliminates unacceptable mechanical stresses in the housing; i.e., only the rupture disc is released. Gas escapes, but the complete transformer remains intact and no explosion occurs.

Most reliable insulation properties
SF_6 gas is the main insulation medium between high-voltage and earth potential. A stable quality can be guaranteed by the use of SF_6 gas according to ANSI/DIN and the fact that this inert gas shows no ageing even under the highest electrical and thermal stresses. The insulation properties remain unchanged throughout its lifetime. All of these features guarantee an operation period over many years without any control of the insulation condition.

Full functional security and monitoring
The guaranteed SF_6 leakage rate is less than 0.5 % per year. The gas pressure can be checked on site or by means of a remote control device, i.e., a densimeter with contacts for remote control. In the case of loss of SF_6 pressure, the transformer still operates at rated pressure.

Environmentally beneficial under extremely severe conditions
SF_6 gas is absolutely safe for humans. It bears no ecologically toxic potential and its decomposition products have no deleterious effects on the environment, e.g., groundwater pollution. This SF_6 gas insulation medium allows easy waste management of the transformers. Furthermore, the hydrophobic features of the composite insulator result in problem-free service even under saline fog or polluted conditions. As a long-term benefit, the change of cores or windings, even after years, can be realized easily for new requirements like additional metering.

Current transformers
All Trench current transformer (CT) designs are based on "head type" construction. CTs are available with either oil (fig. 4.5-2) or SF_6 gas dielectric systems (fig. 4.5-3).

Features of oil-immersed type
- Low weight and minimum oil volume
- Excellent seismic performance as a consequence of the optimized design of flanges, vast choice of porcelain strengths and their interconnection and low weight
- Available for the full voltage range of 72.5 kV up to 550 kV and full current range of 0.5 A up to 5,000 A multiple-turn primaries for small primary currents. Ratio change available either on primary side or secondary side
- Short, symmetrically arranged low-reactance bar-type primary conductor permits higher short-circuit currents up to 80 kA and avoids large voltage drop across the primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over a long period of time
- Perfect transient performance
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator

Fig. 4.5-1: **230 kV gas-insulated current transformers (on the left) and 230 kV oil-insulated capacitor voltage transformers (on the right)**

Fig. 4.5-2: **245 kV oil-immersed current transformers**

Fig. 4.5-3: **550 kV gas-insulated current transformer**

4

Features of gas-insulated transformer
- Explosion-proof design by the compressible insulation medium SF_6 gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- Available for the full voltage range of 72.5 kV up to 800 kV and full current range of 100 A up to 4,800 A
- Low-reactance, bar-type primary providing optimal short-circuit performance
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Multiple-turn primaries for small primary currents and uniformly distributed secondary windings guarantee accurate transformation at both rated and high currents
- Stable accuracy over a long period of time
- Perfect transient performance
- Exclusive use of corrosion-resistant materials
- Core changes after assembly do not require the destruction of the high-voltage insulation

Inductive voltage transformers

Inductive voltage transformers are designed for 72.5 kV to 800 kV systems and are used to provide voltage for metering and protection applications. They are available with either oil (fig. 4.5-4) or SF_6 gas dielectric systems (fig. 4.5-5).

Features of oil-immersed type
- Low weight and minimum oil volume
- Excellent seismic performance as a consequence of optimized designs of flanges, large choice of porcelain strengths and their interconnection and low weight
- Available for the full voltage range of 72.5 kV up to 550 kV
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Optimized high-voltage coil ensures identical electric stresses under both transient and steady-state conditions
- Essentially unaffected by stray external magnetic fields
- Hermetically sealed stainless-steel metallic bellows for units rated 123 kV and above
- Stable accuracy over a long period of time
- Perfect transient performance
- Suitable for line discharging
- Applicable as a low-cost alternative to small power transformer
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator

Features of gas-insulated transformer
- Explosion-proof design by the compressible insulation medium SF_6 gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- Available for the full voltage range of 72.5 kV up to 800 kV
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Wide range ferroresonance-free design without the use of an external damping device (please ask for details)
- Essentially unaffected by external stray magnetic fields

Fig. 4.5-4: **245 kV oil-immersed voltage transformer**

Fig. 4.5-5: **765 kV gas-insulated voltage transformer**

Fig. 4.5-6: **765 kV capacitor voltage transformer**

Fig. 4.5-7: **RC divider**

- Stable accuracy over a long period of time
- Suitable for line discharging
- Optimized high-voltage coil ensures identical electric stresses under both transient and steady state conditions
- Exclusive use of corrosion-resistant materials
- Applicable as a low-cost alternative to small power transformer

Capacitor voltage transformer (oil-immersed)
Coupling capacitors (CC) are utilized to couple high-frequency carrier signals to the power line. A CC supplied with an electromagnetic unit is called a capacitor voltage transformer (CVT) and is used to provide voltage for metering and protection applications (fig. 4.5-6).

Features
- Capable of carrier coupling PLC signals to the network
- Optimized insulation system design utilizing state-of-the-art processing techniques with either mineral oil or synthetic insulating fluids
- Stability of capacitance and accuracy over a long period of time due to superior clamping system design
- Oil expansion by way of hermetically sealed stainless-steel bellows ensures the integrity of the insulation system over time
- Bellows puncture pin provides for release of internal pressure in the event of severe service conditions leading to internal discharges
- Extra-high-strength porcelains provide both superior seismic performance and the ability to mount large line traps directly on the CVT with corresponding savings in installed cost
- Maintenance-free oil-filled cast aluminum basebox
- Superior transient response characteristics
- Internal company routine tests and quality requirements exceed those of international standards with impulse tests and partial discharge test being performed on a routine basis
- Not subject to ferroresonance oscillations with the network or circuit-breaker capacitor
- High-capacitance CVTs, when installed in close proximity to EHV circuit-breakers, can provide enhanced circuit-breaker short line fault/TRV performance

Electronic voltage measuring system for HVDC
Trench offers special voltage transformers for HVDC systems. These units are primarily used to control the HV valves of the rectifiers or inverse rectifiers. The measuring system consists of an RC voltage divider that provides inputs to a specially designed electronic power amplifier (fig. 4.5-7). The high-voltage divider can be supplied either for outdoor operation or for installation into SF_6 gas-insulated switchgear (GIS).

The resulting system can accurately transform voltages within a defined burden range with linear frequency response of up to approximately 10 kHz. Thus, the system is ideal for measurement of dynamic and transient phenomena and harmonics associated with HVDC systems.

Combined instrument transformer
The combined instrument transformer offers the station designer the ability of being able to accommodate the current transformer and the voltage transformer in one free-standing unit. This allows optimum use of substation space while yielding cost savings by elimination of one set of mounting pads and support structures. In addition, installation time is greatly reduced. CITs are available with either oil (fig. 4.5-8) or SF_6 gas dielectric systems (fig. 4.5-9).

Fig. 4.5-8: **245 kV oil-immersed combined instrument transformer**

Fig. 4.5-9: **245 kV gas-insulated combined instrument transformer**

4

Features of oil-immersed combined instrument transformers
- Low weight and minimum oil volume
- Short symmetrically arranged low-reactance, bar-type primary conductor permits higher short-circuit currents and avoids large voltage drop across primary winding
- Excellent control of internal and external insulation stresses through the use of a proprietary finely graded bushing system
- Available for the full voltage range of 72.5 kV up to 300 kV and full current range of 0.5 A up to 5,000 A
- Excellent seismic capability as a consequence of optimized design of flanges, large choice of porcelain strengths and their interconnection and low weight
- Hermetically sealed by stainless-steel metallic bellows and high-quality gaskets
- Only one foundation required in the switchyard as a consequence of combining the voltage and current-sensing functions in one transformer
- Uniformly distributed secondary windings guarantee accurate transformation at both rated and high current
- Essentially unaffected by stray external magnetic fields
- Stable accuracy over a long period of time
- Perfect transient performance
- Suitable for line discharging
- Exclusive use of corrosion-resistant materials
- Full range of products available with composite insulator

Features of gas-insulated combined instrument transformers
- Head-type design with voltage transformer section located on top of the current transformer
- Low weight and compact SF_6 design
- Explosion-proof design by the compressible insulation medium SF_6 gas and rupture disc
- Excellent seismic performance due to the properties of the composite insulator
- The single-section high-voltage coil (not cascaded) of the voltage transformer section enables a product range for combined instrument transformers of up to 800 kV
- Optimum field grading is accomplished by a fine condenser grading system especially developed for this application
- Wide-range ferroresonance-free design without the use of an external damping device
- Low-reactance type primary conductor allows for high short-circuit currents and covers all core standards
- Less foundation space required compared to individual current transformers and voltage transformers
- Suitable for line discharging
- Essentially unaffected by external stray magnetic fields
- Exclusive use of corrosion-resistant materials

Instrument transformer for GIS

In addition to the measurement of the voltages and currents, this instrument transformer type has the best discharge capabilities for HV lines (fig. 4.5-10).

Features of inductive type
- Custom-designed instrument transformers for each specific application and extended function designs comply with dimensional restrictions, flange sizes and insulator requirements
- Standard designs for 1-phase and 3-phase units
- Meets all national and international standards with regard to pressure vessel codes
- Prevention of occurrence of stable ferroresonances by integrated ferroresonance suppression
- Shielded against transient overvoltages in accordance with IEC standards. Special additional shielding is available
- Guaranteed SF_6 leakage rate of less than 0.5 % per year
- Equipped with pressure relief disc and deflection device
- All components are designed and tested for mechanical stress to withstand up to at least 20 g
- Accuracy classes in accordance with DIN VDE 0414, IEC 60044, ANSI: IEEE C57.13, AS 1243 (other standards or classes on request)
- Shock indicators warn against inadmissible acceleration during transportation

Features of RC type

Resistive-capacitive voltage dividers, also called resistive-capacitive voltage transformers, are designed for measurement of the voltage in HVDC transmission systems, air-insulated (AIS) or gas-insulated (GIS) switchgear (fig. 4.5-11). In AC transmission systems, the transformers are used for the measurement of harmonics and they give an accurate representation of the voltage over a wide frequency band (typically from DC up to 500 kHz).
- RC divider for voltage measurements
- Conform to microprocessor-based secondary technology
- Ferroresonance-free
- Able to surtain voltage test on site
- 1-phase or 3-phase system
- Significant size and weight reduction

Fig. 4.5-10: **145 kV inductive voltage transformer for GIS**

Fig. 4.5-11: **Voltage transducer 145 kV series RCT (active part) for HV GIS**

LoPo – the low-power transducers

The low-power current and voltage transducers (fig. 4.5-12) can be used for a wide range of medium and high-voltage applications in which they replace the conventional measuring transformers for measurement and protection purposes.

Features

- The voltage transducers are based on resistive as well as resistive-capacitive dividers
- The current transducers are based on an iron-core or an air-core design and provide a secondary voltage that represents the primary current
- Standard cables and connectors; twisted pair and double shielded cable
- Connection capability for multiple protection and measuring devices
- Metal-clad housing ensuring operator safety
- Immune to all methods of online switchgear and cable testing
- Current transducers provide a linear transmission up to short-circuit current
- Completely EMC shielded: immune to RFI/EMI

Advantages

- System conforms to low-power digital microprocessor-based technology for protection and metering
- Simple assembly with compact size and low weight
- No secondary circuit problems; voltage transducers are short-circuit-proof, current transducers can have an open secondary
- Voltage transducers are ferroresonance-free
- Environment-friendly (no oil)

An overview of the range of Trench instrument transformers appears in table 4.5-1.

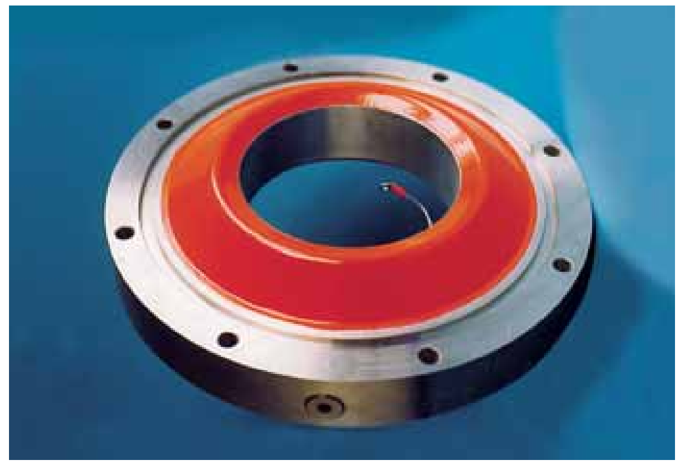

Fig. 4.5-12: **Voltage transducer 36 kV series LPVTG for MV metal-clad switchgear**

Application	Current measurement			Voltage measurement					Combined current and voltage measurement	
AIS substation	•	•		•	•	•	•		•	•
GIS substation			•					•		
Power transformer (low output)				•	•					
Line discharge				•	•					
Measurement of harmonics							•			
Type	IOSK	SAS	SAD/SA	VEOT/ VEOS	SVS	CVT	RCVT	SUD/SU	IVOKT	SVAS
Internal insulation technology	Oil-immersed	SF_6 gas-insulated		Oil-immersed	SF_6 gas-insulated	Oil-immersed			Oil-immersed	SF_6 gas-insulated
Metering technology				Inductive	Inductive	Capacitive	Resistive and capacitive			
Composite insulator	•	•		•	•	•	•		•	•
Porcelain insulator	•			•		•	•		•	
Replaceable cores		•			•					•
Voltage range (kV)	72.5–550	72.5–800	72.5–800	72.5–550	72.5–800	72.5–765		72.5–800	72.5–300	123–800
Max. test voltage 1 min (kV)	800	960		800	960	975		960	460	960
Max. impulse withstand 1.2/50 (kV)	1,800	2,100		1,800	2,100	2,425		2,100	1,050	2,100
Switching impulse test withstand voltage (kV)	1,300	1,550		1,300	1,550	1,200		1,550	850	1,550

Table 4.5-1: **Technical data of Trench instrument transformers**

4.5.2 Medium-Voltage Instrument Transformers

The task of instrument transformers is to transform high currents and voltages into small current or voltage values for measuring or protection purposes. Thus they are used either to measure and record the transmitted power, or to feed protection devices with evaluable signals, which enable the protection device, for example, to trip a switching device depending on the situation.

Current transformers
In this context, current transformers (fig. 4.5-13, left) can be regarded as transformers working in short circuit. The full normal current flows through their primary side. Devices connected on the secondary side are series-connected. Current transformers can have several secondary windings with magnetically separated cores of the same or different characteristics. For example, they can be equipped with two measuring cores of different accuracy, or with measuring and protection cores with different accuracy-limit factors.

Voltage transformers
Voltage transformers (fig. 4.5-13, right) contain only one magnet core. They are normally designed with one secondary winding only. If necessary, 1-pole insulated voltage transformers are provided with an additional winding for earth-fault detection in addition to the secondary winding (measuring winding).

Table 4.5-2 shows the Trench portfolio of medium-voltage instrument transformers.

Fig. 4.5-13: **Medium-voltage current (left) and voltage (right) transformer**

Current transformer type	4MA7 block-type current transformer	4MB1 block-type current transformer	4MC2 bushing-type current transformer	4MC3 bushing-type current transformer	4ME1 outdoor current transformer
Rated voltage	12 kV/24 kV/36 kV	12 kV/24 kV	12 kV/24 kV/ 36 kV	12 kV124 kV/ 36 kV	12 kV/24 kV 36 kV/52 kV
Rated normal current	10–2,500 A	1,500–6,000 A	150–3,000 A	1,000–10,000 A	5–1,200 A
Multiratio	primary or secondary multiratio	secondary multiratio	secondary multiratio	secondary multiratio	primary or secondary multiratio
Number of possible cores	3	3	4	4	3

Voltage transformer type	Rated voltage	Rated power/accuracy class			Thermal limit rating of earth-fault detection winding
4MR1, 4MR2 indoor, 1-pole and 2-pole, small type	12 kV 24 kV	20 VA/0.2 20 VA/0.2	100 VA/0.5 100 VA/0.5	200 VA/1 200 VA/1	230 VA/4 A*
41MR5, 41MR6 indoor, 1-pole and 2-pole large type	12 kV 24 kV 36 kV	30 VA/0.2 45 VA/0.2 50 VA/0.2	100 VA/0.5 100 VA/0.5 100 VA/0.5	200 VA/1 200 VA/1 200 VA/1	350 VA/6 A*
4MS3 outdoor, 1-pole	12 kV 24 kV	30 VA/0.2 30 VA/0.2	100 VA/0.5 100 VA/0.5	200 VA/1 200 VA/1	230 VA/4 A* 230 VA/4 A*
4MS4	36 kV	60 VA/0.2	150 VA/0.5	400 VA/1	

*Higher values on request

Table 4.5-2: **Portfolio of medium-voltage instrument transformers**

4.6 Coil Products

Introduction
With 40 years of successful field experience, Trench is the recognized world leader in the design and manufacture of air-core, dry-type, power reactors for all utility and industrial applications. The unique custom design approach, along with fully integrated engineering and manufacturing facilities in North America, Europe and China have enabled Trench to become the technical leader for high-voltage inductors world-wide.

A deep commitment to the power industry, along with extensive investment in engineering, manufacturing and test capability, give Trench customers the utmost in high-quality, reliable products that are individually designed for each application. Trench reactor applications have grown from small-distribution class, current-limiting reactors to complex EHV-applied reactors surpassing 300 MVA per coil.

Reactors are manufactured in accordance with the ISO 9001 quality standard. Trench's highly developed research and development program constantly addresses new technologies and their potential application in reactor products. Trench welcomes challenges for new applications for power reactors.

Design features
Design features of air-core dry-type reactors are:
- Epoxy impregnated, fiberglass-encapsulated construction
- Aluminum construction throughout with all current carrying connections welded
- Highest mechanical and short-circuit strength
- Essentially zero radial-voltage stress, with uniformly graded axial-voltage distribution between terminals
- Low noise levels are maintained throughout the life of the reactor
- Weatherproof construction, with minimum maintenance requirements
- Design service life in excess of 30 years
- Designs available in compliance with ANSI/IEEE, IEC and other major standards

Construction
A Trench air-core dry-type reactor consists of a number of parallel-connected, individually insulated, aluminum (copper on request) conductors (fig. 4.6-1). These conductors can be small wire or proprietary cables custom-designed and custom-manufactured. The size and type of conductor used in each reactor is dependent on the reactor specification. The various styles and sizes of conductors available ensure optimum performance at the most economical cost.

The windings are mechanically reinforced with epoxy resin-impregnated fiberglass, which after a carefully defined oven-cure cycle produces an encapsulated coil. A network of horizontal and vertical fiberglass ties coupled with the encapsulation minimizes vibration in the reactor and achieves the highest available mechanical strength. The windings are terminated at each end to a set of aluminum bars called a spider. This construction results in a very rigid unit capable of withstanding the stresses developed under the most severe short-circuit conditions.

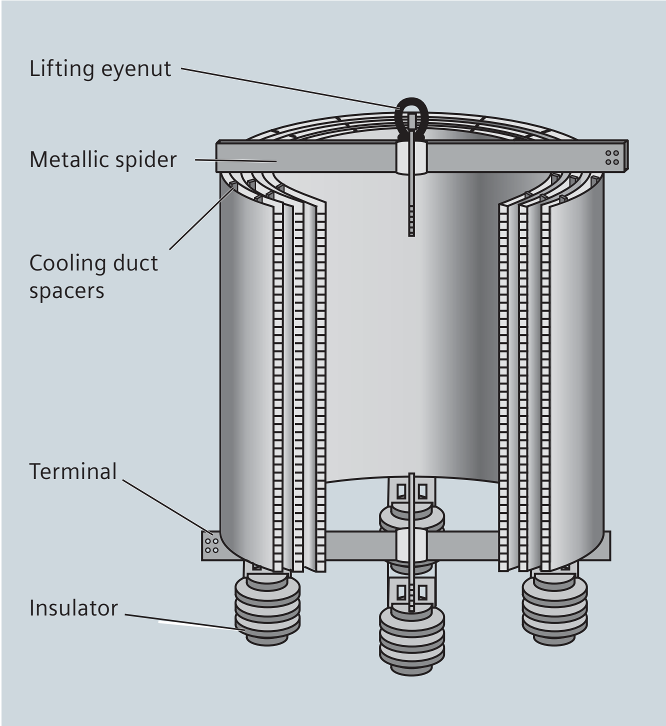

Fig. 4.6-1: **Typical Trench air-core dry-type reactor construction**

Exceptionally high levels of terminal pull, tensile strength, wind loading and seismic withstand can be accommodated with the reactor. This unique design can be installed in all types of climates and environments and still offer optimum performance.

Trench air-core dry-type reactors are installed in polluted and corrosive areas and supply trouble-free operation. In addition to the standard fixed reactance type of coil, units can be supplied with taps for variable inductance. A number of methods are available to vary inductance for fine-tuning or to provide a range of larger inductance steps.

In addition, Trench utilizes various other designs for reactors, e.g., iron-core and water-cooled.

Series reactors
Reactors are connected in series with the line or feeder. Typical uses are fault-current reduction, load balancing in parallel circuits, limiting inrush currents of capacitor banks, etc.

Current-limiting reactors
Current-limiting reactors reduce the short-circuit current to levels within the rating of the equipment on the load side of the reactor (fig. 4.6-2). Applications range from the simple distribution feeder reactor to large bus-tie and load-balancing reactors on systems rated up to 765 kV/2100 kV BIL.

Capacitor reactors
Capacitor reactors are designed to be installed in series with a shunt-connected capacitor bank to limit inrush currents due to switching, to limit outrush currents due to close-in faults, and to control the resonant frequency of the system due to the addition of the capacitor banks. Reactors can be installed on system voltages through 765 kV/2100 kV BIL. When specifying capacitor reactors, the requested continuous current rating should account for harmonic current content, tolerance on capacitors and allowable system overvoltage.

Buffer reactors for electric arc furnaces
The most effective use of buffer reactors for electric arc furnaces (EAF) is achieved by operating the furnace at low electrode current and long arc length. This requires the use of a series reactor in the supply system of the arc furnace transformer for stabilizing the arc.

Duplex reactors
Duplex reactors are current limiting reactors that consist of two half coils, wound in opposition. These reactors provide a desirable low reactance under normal conditions and a high reactance under fault conditions.

Load-flow control reactors
Load-flow control reactors are series-connected on transmission lines of up to 800 kV. The reactors change the line impedance characteristic such that load flow can be controlled, thus ensuring maximum power transfer over adjacent transmission lines.

Filter reactors
Filter reactors are used in conjunction with capacitor banks to form series tuned harmonic filter circuits, or in conjunction with capacitor banks and resistors to form broadband harmonic filter circuits. When specifying filter reactors, the magnitudes of fundamental and harmonic frequency current should be indicated. If inductance adjustment for fine-tuning is required, the required tapping range and tolerances must be specified. Many filter applications require a Q actor that is very much lower than the natural Q of the reactor. This is often achieved by connecting a resistor in the circuit.

An economical alternative is the addition of a de-Q'ing ring structure on a reactor. This can reduce the Q actor of the reactor by as much as one tenth without the necessity of installing additional damping resistors. These rings, mounted on the reactor, are easily coupled to the magnetic field of the reactor. This eliminates the concern of space, connection and reliability of additional components such as resistors.

Shunt reactors
Shunt reactors are used to compensate for capacitive VARs generated by lightly loaded transmission lines or underground cables. They are normally connected to the transformer tertiary winding but can also be directly connected on systems of up to 115 kV.

Fig. 4.6-2: **3-phase stacked current-limiting reactor**

Fig. 4.6-3: **Tertiary-connected shunt reactors**

Thyristor-controlled shunt reactors (TCR) are extensively used in static VAR systems in which reactive VARs are adjusted by thyristor circuits (fig. 4.6-3). Static VAR compensator reactor applications normally include:

- Thyristor-controlled shunt reactors. The compensating power is changed by controlling the current through the reactor by means of the thyristor valves.
- Thyristor-switched reactors (TSR)
- Thyristor-switched capacitor reactors (TSC)
- Filter reactors (FR)

HVDC reactors
HVDC lines are used for long-distance bulk power transmission as well as back-to-back interconnections between different transmission networks. HVDC reactors normally include smoothing reactors, AC and DC harmonic filter reactors, as well as AC and DC PLC noise filter reactors.

Smoothing reactors
Smoothing reactors (fig. 4.6-4) are used to reduce the magnitude of the ripple current in a DC system. They are used in power electronics applications such as variable-speed drives and UPS systems. They are also required on HVDC transmission lines for system voltages of up to 500 kV. Several design and construction techniques are offered by Trench.

Test lab reactors
Test lab reactors are installed in high-voltage and high-power test laboratories. Typical applications include current limiting, synthetic testing of circuit-breakers, inductive energy storage and artificial lines.

Neutral earthing reactors
Neutral earthing reactors limit the line-to-earth fault current to specified levels. Specification should also include unbalanced condition continuous current and duration.

Arc-suppression coils
Single-phase neutral earthing (grounding) reactors (arc-suppression coils) are intended to compensate for the capacitive line-to-earth current during a 1-phase earth fault. The arc-suppression coil (ASC) represents the central element of the Trench earth-fault protection system (fig. 4.6-5).

Because the electric system is subject to changes, the inductance of the ASC used for neutral earthing must be variable. The earth-fault detection system developed by Trench utilizes the plunger core coil (moveable-core design). Based on extensive experience in design, construction and application of ASCs, Trench products can meet the most stringent requirements for earth-fault compensating techniques.

Fig. 4.6-4: **HVDC smoothing reactor**

Fig. 4.6-5: **Arc-suppression coil 110 kV**

4.7 Bushings

4.7.1 High-Voltage Bushings

A bushing is an electrical engineering component that insulates a high-voltage conductor passing through a metal enclosure or a building. Bushings are needed on:

- Transformers
- Buildings
- Gas-insulated switchgear (GIS)
- Generators
- Other high-voltage equipment

Typical environmental conditions are:

- Oil-to-air
- Oil-to-gas
- Oil-to-oil
- SF_6-to-air
- Air-to-air

The internal insulation of a bushing is made of a combination of different isolation materials:

- Oil-impregnated paper
- Epoxy resin-impregnated paper
- SF_6 gas

The external insulation is made of:

- Epoxy resin for indoor applications
- Porcelain or fiberglass tubes with silicone rubber sheds for outdoor application

Selected state-of-the-art bushing designs are described in the sections that follow.

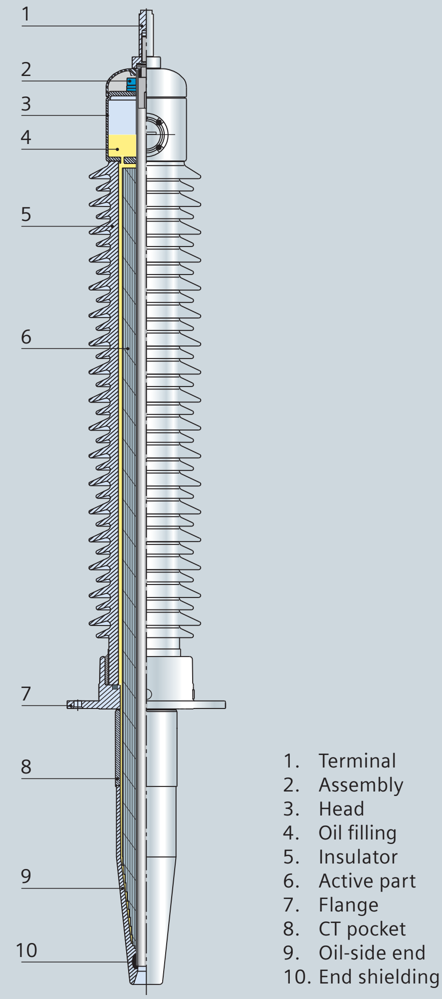

Fig. 4.7-1: **General design of an oil-impregnated paper transformer bushing (sectional view)**

Transformer bushings
oil-impregnated paper (OIP) design
An oil-impregnated paper transformer bushing is made of the following components (fig. 4.7-1):

1. Terminal
Terminal (Al or Cu) for connection of overhead lines or busbars and arcing horns. State-of-the-art designs provide maintenance-free termination and ensures that the connection will not become loose in service.

2. Assembly
The whole bushing is tightened together by the central tube or conductor.

3. Head
Al-casted head with oil expansion chamber and oil level indicator. The chamber is hermetically sealed against the atmosphere.

4. Oil filling
State-of-the-art bushings are filled with dried, degassed insulating mineral oil.

5. Insulator
Porcelain insulator made of high-grade electrotechnical porcelain according to IEC 815. The insulator is connected to the mounting flange using Portland cement and sealed with O-ring gasket. Composite insulators are increasingly demanded and are readily available.

6. Active part
The active part is made of oil-impregnated wide-band paper with layers of aluminum foil to control the electrical field radially and axially. Depending on the current rating, the paper and foil are wound on either a central tube or a solid conductor.

7. Flange
The mounting flange with integrated test tap made of corrosion free aluminum alloy is machined to ensure an excellent seal between the bushing and the transformer.

8. CT pocket
If current transformers are required on the bushing, the ground sleeve can be extended.

9. Oil-side end
The insulator on the oil side is made of an epoxy resin tube. It is designed to stay installed during the in-tank drying process of the transformer and can withstand temperatures of up to 130 °C.

10. End shielding
For voltages starting with 52 kV, a special aluminum electrode is cast into the end of the epoxy resin tube. This end shielding controls the electrical field strength in this area to earth.

Transformer bushings:
epoxy resin-impregnated paper (ERIP) design

Modular system
Modern ERIP bushings (fig. 4.7-2) are constructed in a modular system. They have standardized components. An adaptation to requested creepage distances, flange dimensions and so on is easily possible.

Connections
The modular bushing systems offer a large choice of connecting systems. At the upper end of the bushing head, there is a clamp through which the conductor or the cable bolt is fixed. A releasable cross-pinned fitting at the clamping device prevents it from slipping into the transformer during operation. In addition, it serves as locking element. The bolt is sealed through double seals. The clamp is made of stainless steel and all screws are of non-corrosive steel. The venting of the central tube is located on one side under the edge of the clamp and can be operated independently of the conductor bolt. In addition to the cable bolt, solid conductor bolts are available, e.g., for higher-current applications. These bolts are wedged against the inner wall of the central tube with insulated spacers. Solid conductor bolts can be provided with a separation point, preferably at the flange or to suit any particular case. The bolts are equipped with a threaded hole at the top, so that a draw wire or a rod can be screwed in and the bolt pulled through the central tube.

Transformer bushings: high current
High current bushings for transformer-to-phase busbar-isolated connections are designed for 17.5 kV to 36 kV and currents from 6,300 A to 31,500/40,000 A. Conductors are either aluminum or copper. The main insulation is vacuum-impregnated epoxy condenser (fig. 4.7-3).

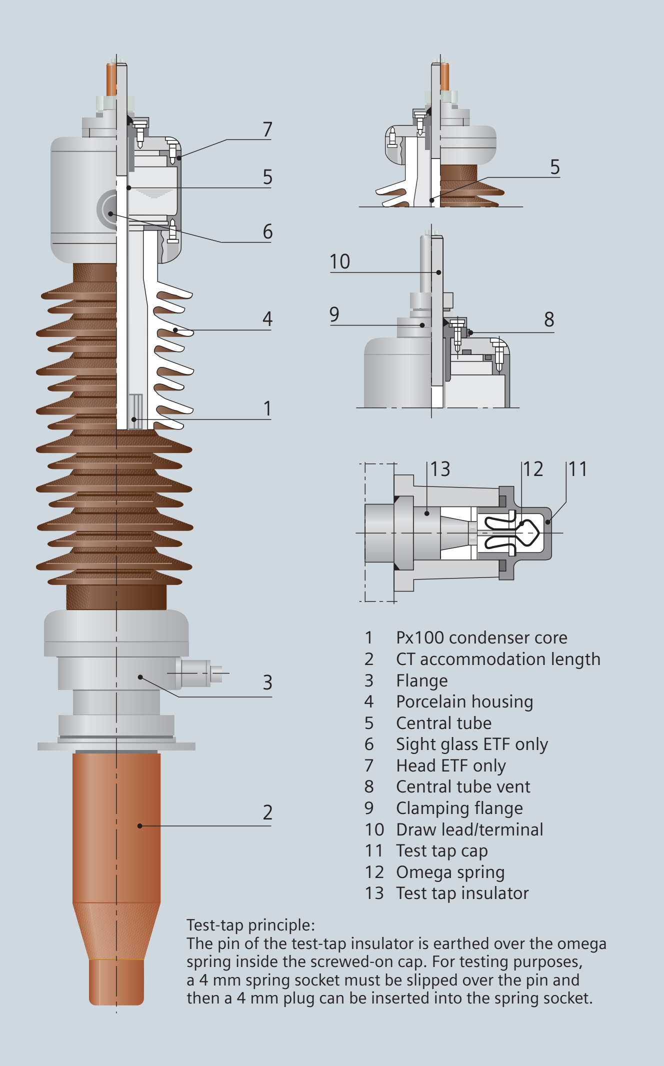

Fig. 4.7-2: **Transformer bushing – epoxy resin-impregnated paper (ERIP) design**

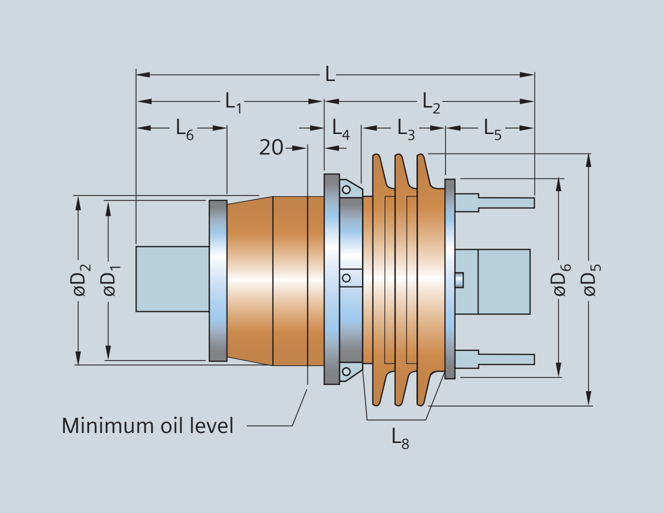

Fig. 4.7-3: **Transformer bushing – high current**

Other transformer bushings: oil-to-gas and oil-to-oil
Oil-to-gas types are intended for the direct connection of power transformers to gas-insulated switchgear: Oil-to-oil types are intended for the direct connections within the power transformer (fig. 4.7-4). Both consist of a main insulating body of RIP (epoxy resin-impregnated paper). The condenser core is made of special epoxy resin vacuum-impregnated paper incorporating grading foils to ensure uniform voltage distribution. This insulation has proven its reliability in over 40 years of service in various network applications. A high-quality insulation enables a compact design. Bushings with this insulation have, furthermore, a low partial discharge level, not only at service voltage but far in excess.

HVDC bushings: transformer and wall
The growing demand for HVDC transmission requires reliable and efficient transformer and wall bushings of up to 800 kV DC (fig. 4.7-5). ERIP solutions are often preferred due to their superior performance in heavily polluted areas or due to their mechanical strength especially the seismic behavior. Examples of state-of-the-art solutions are the project Tian-Guang/China (fig. 4.7-6), which has:
- 515 kV wall bushings
- 412/212 kV transformer bushings

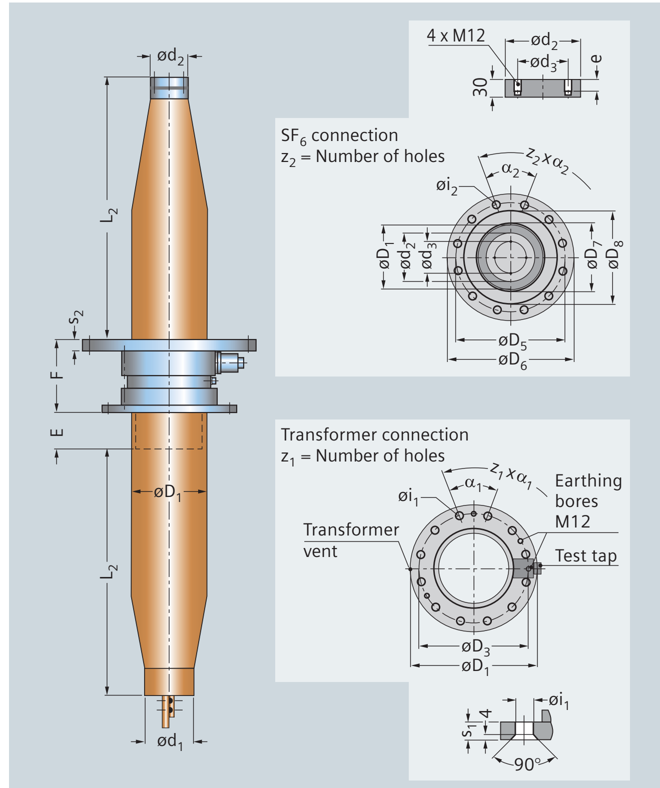

Fig. 4.7-4: **Transformer bushing – oil-to-gas**

Fig. 4.7-5: **800 kV UHV DC transformer bushing**

Fig. 4.7-6: **500 kV DC HVDC bushings – Three Gorges, China**

Wall bushings

Wall bushings (fig. 4.7-7, fig. 4.7-8) are designed for use in high-voltage substations as roof or wall by their positioning:

- Indoor/indoor bushings for dry indoor conditions
- Outdoor/indoor bushings for use between open air (outer atmosphere) and dry indoor conditions
- Outdoor/outdoor bushings where both ends are in contact with the open air (outer atmosphere)

The main insulating body is capacitive-graded. A number of conductive layers are coaxially located at calculated distances between the central tube and the flange, and this leads to a virtual linearization of the axial distribution of voltage on the bushing surface, resulting in minimum stress on the surrounding air.

GIS bushings

These bushings are designed for use in GIS substations, mainly to connect to overhead lines. Designs are either electrode design up to 245 kV and condenser design above 245 kV (fig. 4.7-9). Composite design are increasingly demanded, especially for higher voltage ranges and polluted areas.

Generator bushings

Generator bushings (fig. 4.7-10) are designed for leading the current induced in the stator windings through the pressurized hydrogen-gastight, earthed generator housing. Generator bushings are available from 12 kV through 36 kV and current ratings of up to 45,000 A. They are natural, gas or liquid-cooled.

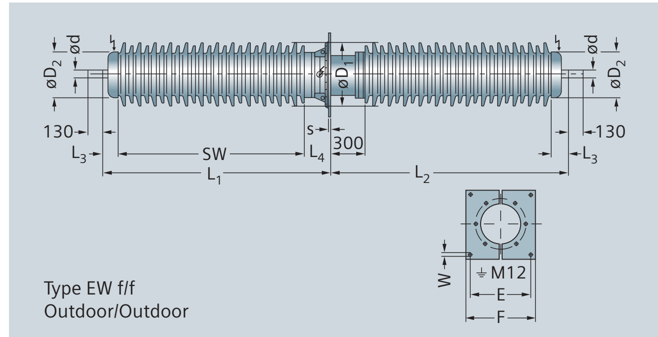

Fig. 4.7-7: **Wall bushings**

Fig. 4.7-8: **HVDC wall bushing testing**

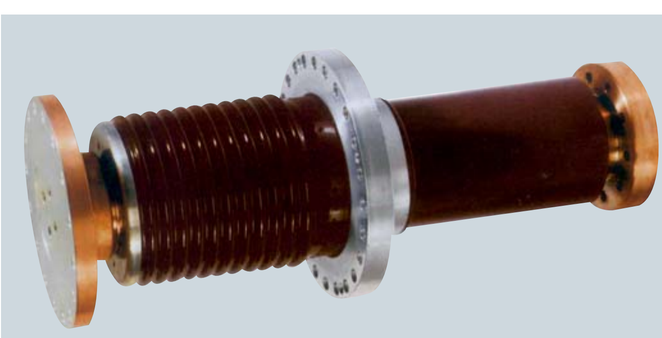

Fig. 4.7-10: **Generator bushing**

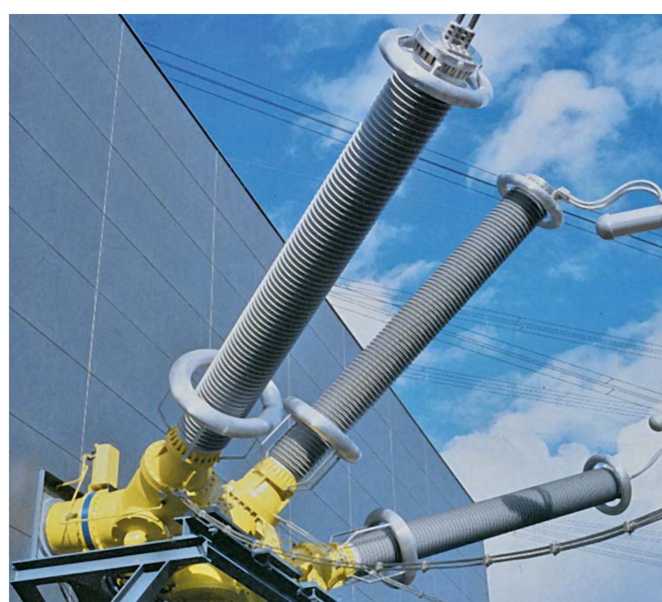

Fig. 4.7-9: **SF_6 outdoor bushings with composite housing**

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4.7.2 Medium-Voltage Insulators and Bushings

Insulators (post insulators and bushings) are used to insulate live parts from one another and to fulfill mechanical carrying and supporting functions. The materials for insulators are various cast resins and porcelains. The use of these materials, which have proved themselves over many years of exposure in the roughest operating and ambient conditions, and their compliance with the quality standard DIN/ISO 9001, ensure a high degree of reliability for these insulators.

Post insulators type 3FA and bushings type 3FH/3FM
Special ribbed forms ensure high electrical strength even when materials are deposited on the surface and occasional condensation is formed (fig. 4.7-11 to fig. 4.7-13). Post insulators and bushings are manufactured in various designs for indoor and outdoor use depending on the application. Innovative solutions, such as the 3FA4 divider post insulator with an integrated expulsion-type arrester (table 4.7-1), provide optimum utility for the customer.

Special designs are possible on request.

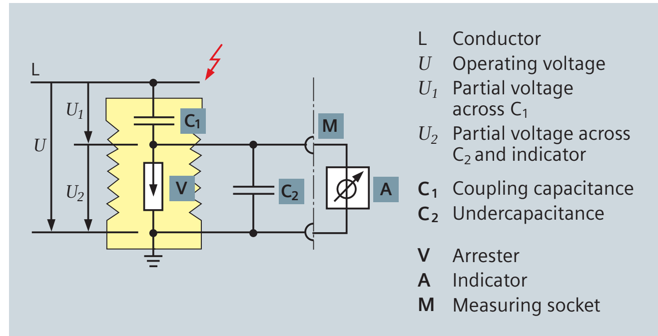


Fig. 4.7-13: **The principle of capacitive voltage indication with the 3FA4 divider post insulator**

Fig. 4.7-11: **Draw-lead bushing type 3FH5/6**

Fig. 4.7-12: **Post insulators type 3FA1/2**

Rated					
Voltage	kV	**3.6**	**12**	**24**	**36**
Lightning impulse withstand voltage	kV	60–65	65–90	100–145	145–190
Power-frequency withstand voltage	kV	27–40	35–50	55–75	75–105
Minimum failing load	kN	3.75–16	3.75–25	3.75–25	3.75–16

Table 4.7-1: **Ratings for post insulators type 3FA1/2**

4.8 Medium-Voltage Fuses

HV HRC (high-voltage high-rupturing-capacity) fuses are used for short-circuit protection in high-voltage switchgear (frequency range of 50 to 60 Hz). They protect devices and parts of the system such as transformers, motors, capacitors, voltage transformers and cable feeders against the dynamic and thermal effects of high short-circuit currents by breaking them when they arise.

Fuses consist of the fuse-base and the fuse-links. The fuse-links are used for one single breaking of overcurrents and then they must be replaced. In a switch-fuse combination, the thermal striker tripping of the 3GD fuse prevents the thermal destruction of the fuse. The fuses are suitable both for indoor and outdoor switchgear. They are fitted in fuse-bases available as individual 1-phase or 3-phase components, or as built-in components in combination with the corresponding switching device.

Fig. 4.8-2: **3-phase fuse-link with fuse monitor**

Fig. 4.8-1: **Fuse-link**

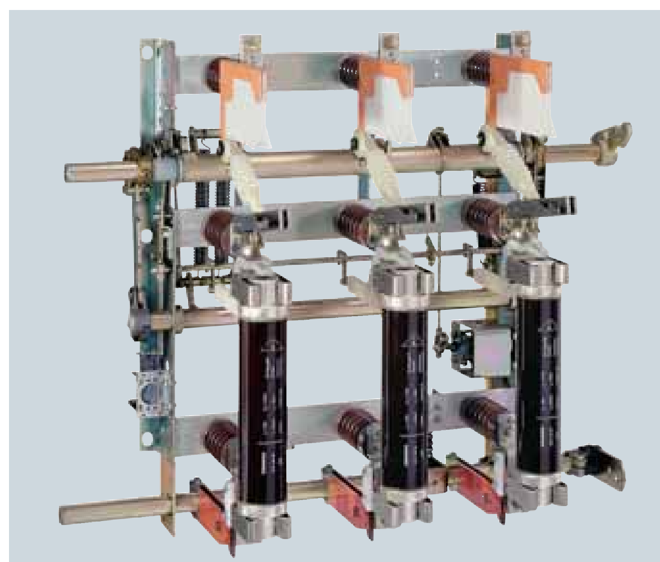


Fig. 4.8-3: **Switch-disconnector with fuse-links**

Rated voltage	Reference dimension	Rated current (A)														
		6	10	16	20	25	32	40	50	63	80	100	125	160	200	250
3.6/7.2 kV	192 mm	•	•	•	•	•	•	•	•	•	•	•				
	442 mm												•	•	•	•
12 kV	292 mm	•	•	•	•	•	•	•	•	•	•	•				
	442 mm												•	•		
24 kV	442 mm	•	•	•	•	•	•	•	•	•	•	•				
36 kV	537 mm	•	•	•	•	•	•	•								

Table. 4.8-1: **Portfolio of fuses**

5

Transformers

5 Transformers

5.1 Introduction

5.1.1 Overview

Whether in infrastructure systems, industry or households, transformers always play a key role in the reliable transmission and distribution of power. The construction, rated power, voltage level and scope of the application are all key factors that determine the transformer's design.

Siemens provides the right transformer for every need – from compact distribution transformers to large power transformers with ratings far above 1,000 MVA. The Siemens product range covers all mainstream requirements like UHV DC applications, low noise emission and environmentally friendly products with alternative insulation liquids, also embedded in a complete power system from generation via transmission to distribution networks. The long-term reliability of a transformer begins with its initial high quality. Then transformer lifecycle management measures maintain that quality throughout the transformer's entire life.

5

Fig. 5.1-1 and table 5.1-1 are an overview of how various transformers can be used in a network.

Global Footprint
Emerging countries are not just "extended workbenches" for producing goods. First and foremost, they are important future markets. Through its own local production and sales locations, Siemens provides service to customers in the most important global markets. The local presence of Siemens in many countries also ensures that customers have better access to Siemens services and that they benefit from an efficient and effective distribution of Siemens resources as part of a global network. As Siemens factories around the world develop and produce their products, Siemens also encourages them to share their expertise.

Siemens meets the growing global demand for transformers in a variety of ways: by further optimization of value-added steps in the worldwide network, by use of approaches such as vertical integration and by the pursuit of programs for boosting productivity.

For further information please contact:
support.energy@siemens.com
www.siemens.com/transformers

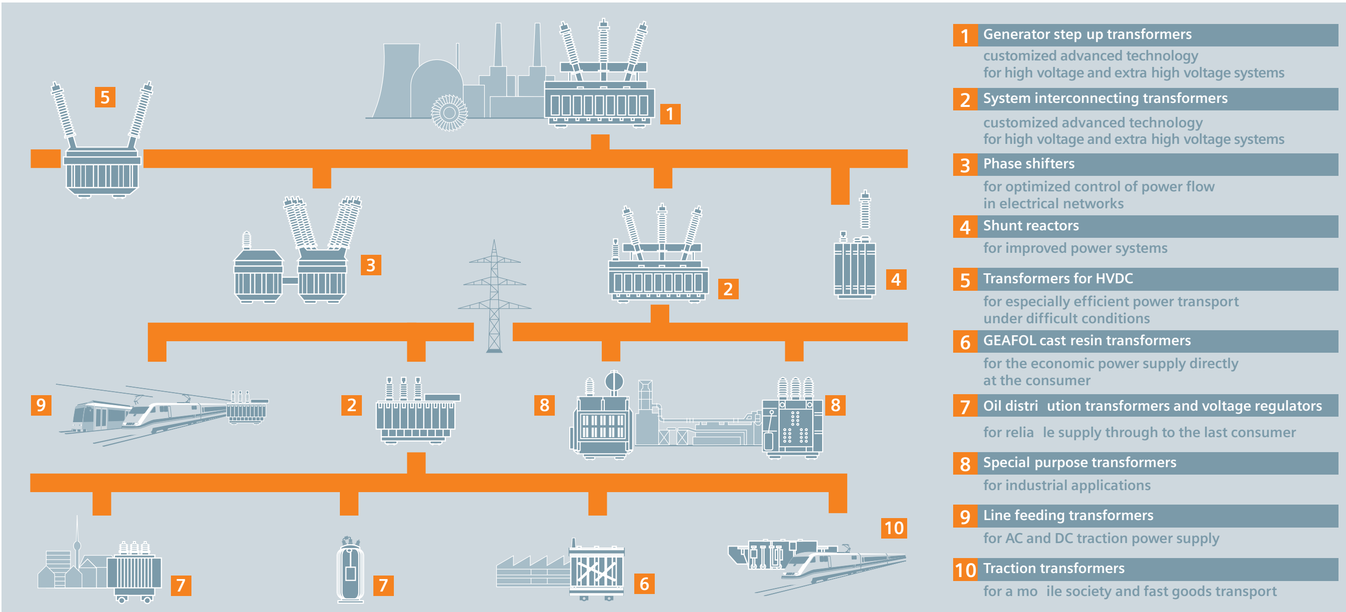


Fig. 5.1-1: **Product range of Siemens transformers**

Generator and System Transformers	■ Above 2.5 MVA up to more than 1,000 MVA, above 30 kV up to 1,500 kV (system and system interconnecting transformers, with separate windings or auto-connected), with on-load tap changers or off-circuit tap changers, of 3-phase or 1-phase design
Phase Shifters	■ To control the amount of active power by changing the effective phase displacement
Reactors	■ Liquid-immersed shunt and current-limiting reactors up to the highest rated powers ■ Reactors for HVDC transmission systems
HVDC Transformers	■ Transformers and smoothing reactors for bulk power transmission systems up to 800 kV DC ■ Transformers for DC coupling of different AC networks
Cast-Resin Distribution and Power Transformers GEAFOL	■ 100 kVA to more than 40 MVA, highest voltage for equipment up to 36 kV, of 3-phase or 1-phase design, GEAFOL-SL substations
Oil-Immersed Distribution Transformers	■ 50 to 2,500 kVA, highest voltage for equipment up to 36 kV, with copper or aluminum windings, hermetically sealed or with conservator of 3- or 1-phase design
Special Transformers for Industry	■ Electric arc furnace transformers ■ Electric arc furnace series reactors ■ DC electric arc furnace transformers ■ Rectifier transformers ■ Converter transformers for large drives
Traction Transformers	■ Traction transformers mounted on rolling stock
Transformer Lifecycle Management	■ Erection & commissioning, installation, transport & hauling ■ Condition assessment, fleet screening, site testing, monitoring, engineering, consulting, training ■ On-site maintenance, life extension, end-of-life management ■ Repair in workshops/on site

Table 5.1-1: **Product range of Siemens transformers**

5.2 Reliability and Project Performance

The quality strategy in the transformer business is based on the three cornerstones of product, people and process quality (fig. 5.2-1). The objective is to achieve the greatest customer satisfaction with efficient processes. This is only possible if all employees involved in the processes have a profound understanding of the specific requirements.

The strategy is implemented in the form of mandatory elements. These elements cover product and service quality, which is visible to customers; personnel quality, which is achieved by training and ongoing education; and process quality in all processes used. Business and process-specific indicators must be used to ensure that each single element is measurable and transparent.

Nine mandatory elements are defined:
- Customer integration
- Embedded quality in processes and projects
- Consequent supplier management
- Business-driven quality planning
- Focused quality reporting
- Qualification of employees on quality issues
- Continuous improvement
- Management commitment
- Control and support role of quality manager

Elements of quality (mandatory elements)

Customer integration
Customer integration depends on the consistent use of:
- Analytic tools for customer requirements
- Professional management of feedback from and to the customer
- Complaint management

Customer requirements need to be precisely defined in a specification. And the specification must be continuously updated throughout the definition phase of a transformer project. The actual requirements must also be available to all responsible employees.

Rapid feedback loops – in both directions – are essential in order to increase customer trust and satisfaction.

Siemens resolves customer complaints to the customer's satisfaction in a timely manner through its complaint management system.

Embedded quality in processes and projects
The quality of the processes used to produce a product has a significant impact on the quality of the product that is actually produced. Process discipline and process stability can be achieved by a high degree of process standardization. All processes should be standardized for all employees based on simple procedures. If this condition is met, it is possible to implement clearly defined work instructions.

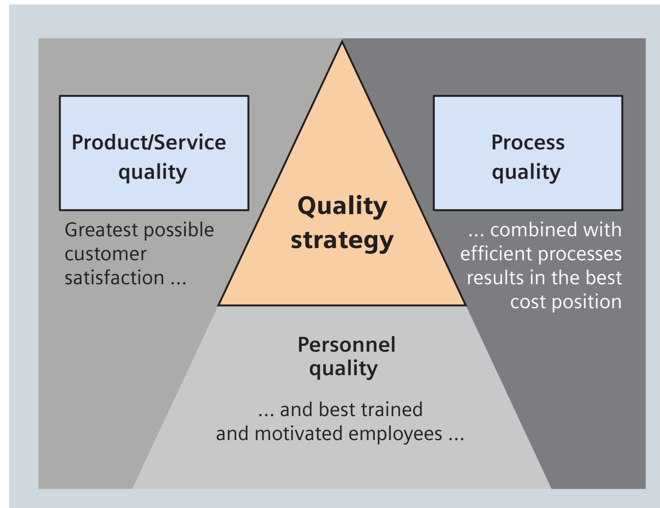


Fig. 5.2-1: **Cornerstones of quality strategy**

Quality gates are placed at points in the process at which quality-relevant decisions are necessary. The following quality gates are mandatory for the power transformer business (fig. 5.2-2).
- Bid approval
- Entry order clarified
- Release of design
- Release of fully assembled transformer
- Evaluation of project

For each quality gate, there is a clear definition of participants, preconditions, results (traffic light) and the escalation process, if necessary. If the result is not acceptable, the process must be stopped until all requirements are fulfilled.

Supplier management
The quality of the product depends not only on the quality of the processes but also on the quality of the suppliers. Quality problems caused by inadequate supplier quality can be reduced only by a systematic supplier management process that includes:
- Selection
- Assessment
- Classification
- Phasing out of suppliers

A further condition for a high level of supplier quality is close cooperation with the suppliers. Joint development of requirements for suppliers and processes leads to continuous improvements in quality. In this context, supplier know-how can be used to create innovations. This aspect of the relationship with suppliers is becoming more and more important, especially in the transformer business.

Business-driven quality planning
Planning quality means analyzing possible future scenarios and anticipated problems and taking preventive steps to solve those problems. It is crucial that both current and future critical business factors are considered in planning. That means that quality is based on business-driven planning and specific objectives, activities and quantitative indicators.

Focused quality reporting
Reporting is based on:
- Focused key performance indicators such as non-conformance costs, external failure rate, internal failure rate and on-time delivery
- Concrete quality incidents
- Root cause analysis of quality problems that may occur

For customers, the reliability of transformers is of special importance. ANSI C57.117 has made an attempt to define failures. Based on this definition, statistics on in-service failures and reliability values can be derived. An example for power transformers appears in table 5.2-1.

Qualification of employees on quality issues
People are the decisive factor influencing quality. Therefore, all employees involved in the processes must have the skills and abilities appropriate to the quality aspects of the process steps they perform. Any qualification measures that may be necessary must be determined on the basis of a careful analysis of existing deficits (fig. 5.2-3).

Continuous improvement
Because there is nothing that cannot be improved, continuous improvement must be integrated into all processes. The objective is to continue optimizing each process step. This is also the purpose of improvement teams. Appropriate coaching of these teams should make it possible to reach almost all employees.

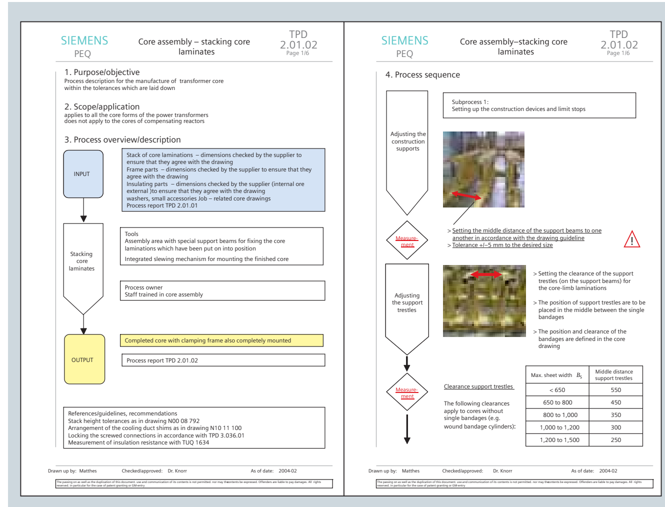


Fig. 5.2-2: **Example of standardized working instruction**

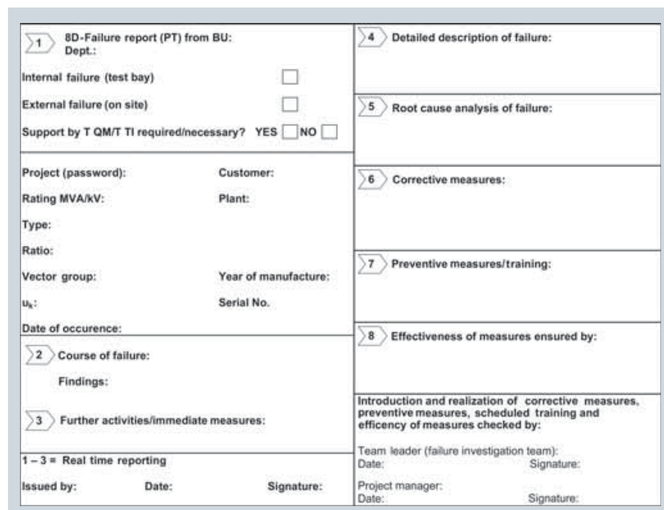


Fig. 5.2-3: **8D report for employee qualification**

Siemens Power Transformers – In-Service Failure Statistic 1998–2007														
based on ANSI C 57.117														
	E T TR	Plant 1	Plant 2	Plant 3	Plant 4*	Plant 5	Plant 6	Plant 7	Plant 8	Plant 9	Plant 10	Plant 11	Plant 12**	Plant 13
N	9,898	439	1,523	683	594	776	438	651	837	852	616	837	667	985
SY	4,4290	1,750	6,506	3,586	1,624	3,861	1,685	2,892	3,346	4,889	3,389	3,697	2,136	4,929
n_F	69	4	5	8	7	0	10	4	2	3	9	5	1	11
FRe (%)	0.16	0.23	0.08	0.22	0.43	0.00	0.59	0.14	0.06	0.06	0.27	0.14	0.05	0.22
MTBF (yrs)	642	438	1,301	448	232	∞	169	723	1,673	1,630	377	739	2,136	448

* Plant 4 years 1999–2007; ** Plant 12 years 2001–2007

N = No. of units in service
SY = No. of service years
n_F = No. of units failed
FRe (%) = Failure rate = n_F•100/SY
MTBF (yrs) = Mean time between failures = 100/FRe

FRe ≤ 0.5 %	excellent
0.5 % < FRe ≤ 1.0 %	good
1.0 % < FRe ≤ 1.5 %	satisfactory
1.5 % < FRe ≤ 2.0 %	acceptable
FRe > 2.0 %	not acceptable

Table 5.2-1: **In-service failure statistic**

Methods like CIP and Kaizen, and elements of Six Sigma, are helpful in supporting this continuous improvement process.

Management commitment
Every manager in a company bears responsibility for quality. Thus, each manager's actions must be characterized by a high level of quality awareness (fig. 5.2-4).

The level of commitment shown by all levels of management in the event of quality problems, the establishment of quality demands and the creation of targeted quality controls in day-to-day work together produce a culture in which there is a high level of quality.

Control and support role of the quality manager
The role of the quality manager is of fundamental importance for processes that run well. The quality manager combines a supporting role with that of a neutral controller. Quality management must be directly involved in processes and projects. The independence of the quality department and individual project managers in processes and projects must be guaranteed and agreed to by top management.

Conclusion
The quality of a transformer is based on the quality of all processes that are necessary – from project acquisition to project closing. The quality of the processes depends essentially on people. Only well-trained and motivated employees are able to guarantee that a process will be performed with a high degree of quality.

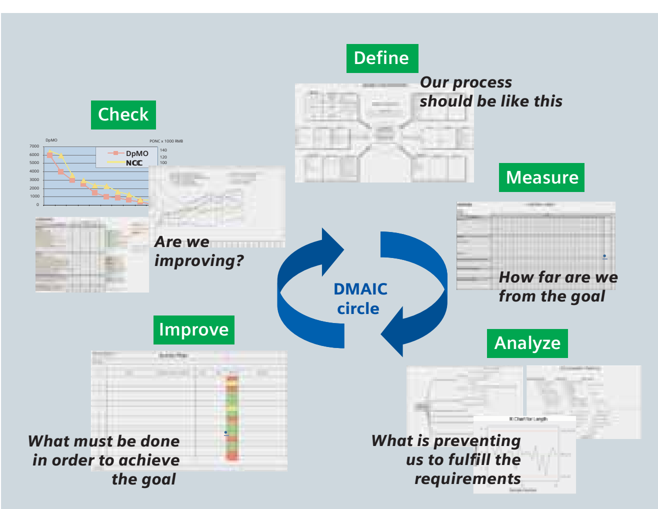


Fig. 5.2-4: **DMAIC circle**

ANSI Standard C57.117, 1986,
Guide for Reporting Failure Data for Power Transformers and Shunt Reactors on Electric Utility Power Systems.

5.3 Transformer Loss Evaluation

The sharply increased cost of electrical energy has made it almost mandatory for buyers of electrical machinery to carefully evaluate the inherent losses of these items. For distribution and power transformers, which operate continuously and most frequently in loaded condition, this consideration is especially important. As an example, the added cost of loss-optimized transformers can in most cases be recovered via savings in energy use in less than three years.

Low-loss transformers use more and better materials for their construction and are thus intially more expensive than low-cost transformers. By stipulating loss evaluation figures in the transformer inquiry, the manufacturer receives the necessary incentive to provide a loss-optimized transformer rather than the low-cost model. Detailed loss evaluation methods for transformers have been developed and are described accurately in the literature. These methods take the project-specific evaluation factors of a given customer into account.

A simplified method for a quick evaluation of different quoted transformer losses makes the following assumptions:

- The transformers are operated continuously.
- The transformers operate at partial load, but this partial load is constant.
- Additional cost and inflation factors are not considered.
- Demand charges are based on 100 % load.

The total cost of owning and operating a transformer for one year is thus defined as follows:

- Capital cost (C_C), taking into account the purchase price (C_p), the interest rate (p) and the depreciation period (n)
- Cost of no-load loss (C_{P0}) based on the no-load loss (P_0) and energy cost (C_e)
- Cost of load loss (C_{Pk}) based on the load loss (P_k), the equivalent annual load factor (a) and energy cost (C_e)
- Cost resulting from demand charges (C_d) based on the amount set by the utility and the total kW of connected load (fig. 5.3-1)

The following examples show the difference between a low-cost transformer and a loss-optimized transformer (fig. 5.3-2).

Note that the lowest purchase price is unlike the total cost of ownership.

Capital cost

taking into account the purchase price C_p, the interest rate p, and the depreciation period n

$$C_c = C_p \cdot r/100 \quad \text{[amount/year]}$$

C_p = purchase price

$r = p \cdot q^n/(q^n - 1)$ = depreciation factor
$q = p/100 + 1$ = interest factor
p = interest rate in % p.a
n = depreciation period in years

Cost of no-load loss

based on the no-load loss P_0, and energy cost C_e

$$C_{P0} = C_e \cdot 8{,}760\ \text{h/year} \cdot P_0$$

C_e = energy charges [amount/kWh]
P_0 = no-load loss [kW]

Cost of load loss

based on the load loss P_k, the equivalent anual load factor a, and energy cost C_e

$$C_{Pk} = C_e \cdot 8{,}760\ \text{h/year}\ a^2\ P_k$$

a = constant opperation load/rated load
P_k = copper loss [kW]

Cost resulting from demand charges

based on the no-load loss P_0, and energy cost C_e

$$C_D = C_d\,(P_0 + P_k)$$

C_d = demand charges [amount/(kW · year)]

Fig. 5.3-1: **Calculation of the individual operation cost of a transformer in one year**

Example: Distribution transformer

Depreciation period	n = 20 years; p = 12 % p.a. → Depreciation factor r = 13.39
Interest rate	p = 12 % p.a.
Energy charge	C_e = 0.25 €/kWh
Demand charge	C_d = 350 €/(kW · year)
Equivalent annual load factor	α = 0.8

A. Low-cost transformer	B. Loss-optimized transformer
P_0 = 19 kW no-load loss P_k = 167 kW load loss C_p = € 521,000 purchase price	P_0 = 16 kW no-load loss P_k = 124 kW load loss C_p = € 585,000 purchase price
$C_c = \frac{521{,}000 \cdot 13.39}{100}$ = € 69,762/year	$C_c = \frac{585{,}000 \cdot 13.39}{100}$ = € 78,332/year
C_{P0} = 0.2 · 8,760 · 19 = € 33,288/year	C_{P0} = 0.2 · 8,760 · 16 = € 28,032/year
C_{Pk} = 0.2 · 8,760 · 0.64 · 167 = € 187,254/year	C_{Pk} = 0.2 · 8,760 · 0.64 · 124 = € 139,039/year
C_D = 350 · (19 + 167) = € 65,100/year	C_D = 350 · (16 + 124) = € 49,000/year
Total cost of owning and operating this transformer is thus: **€ 355,404/year**	Total cost of owning and operating this transformer is thus: **€ 294,403/year**

The energy saving of the optimized distribution transformer of **€ 61,001 per year** pays for the increased purchase price in less than one year.

Fig. 5.3-2: **Example for cost saving with optimized distribution transformer**

5.4 Power Transformers

5.4.1 Large Power Transformers

In the power range above 200 MVA, generator and network intertie transformers with off-load or on-load tap changers, or a combination of both, are recommended. Depending on the on-site requirements, they can be designed as multiwinding transformers or autotransformers, in 3-phase or 1-phase versions. Even with ratings of more than 1,000 MVA and voltages up to 765 kV (800 kV), the feasibility limits have not yet been reached. We manufacture these units according to IEC 60076 as well as other international and national standards (e.g., ANSI/IEEE), (fig. 5.4-1).

Generator step-up (GSU) transformers
GSU transformers take the voltage from the generator voltage level up to the transmission voltage level, which may go up to a 800 kV system voltage. Such transformers are usually YNd-connected.

In order to make an inquiry regarding a GSU power transformer, the technical data for the items in this section are required.

Step-down transformers
Step-down transformers take the voltage down from the transmission voltage to an appropriate distribution level. The power rating of step-down transformers may range up to the power rating of the transmission line.

System interconnecting transformers
System interconnecting transformers connect transmission systems with different voltages together so that active as well as reactive power can be exchanged between the systems.

Main specification data
- Standard
- Installation – indoor/outdoor
- Max. ambient air temperature
- Rated frequency f
- Vector group
- Rated power S
- Primary rated voltage U_{rHV}
- Tapping range/taps
- Voltage regulation
- Secondary rated voltage U_{rLV}
- Impedance u_k at S_r and U_r
- Max. sound power level L_{WA}
- Insulation level HV-Ph – $U_m/AC/LI$
- Insulation level HV-N – $U_m/AC/LI$
- Insulation level LV-Ph – $U_m/AC/LI$
- Type of cooling
- HV connection technique
- LV connection technique
- Transportation medium
- Losses

Fig. 5.4-1: **Large power transformer**

5.4.2 Medium Power Transformers

Medium power transformers with a power range from 40 to 250 MVA and a voltage of over 72.5 kV are used as network and generator step-up transformers (fig. 5.4-2).

Specific items
- Transformer design according to national and international standards (IEC/ANSI) with or without voltage regulation
- 3-phase or 1-phase
- Tank-attached radiators or separate radiator banks

Main specification data
- Number of systems (HV, LV, TV)
- Voltage and MVA rating
- Regulation range and type
- Vector group
- Frequency
- Losses or capitalization
- Impedances
- Type of cooling
- Connection systems (bushing, cable)
- Noise requirements (no-load, load and/or total noise)
- Special insulation fluid
- Application of high temperature/extra small size operation

Fig. 5.4-2: **Medium power transformator with natural oil based insulation fluid**

5.4.3 Small Power Transformers

Small power transformers are distribution transformers from 5 to 30 MVA with a maximum service voltage of 145 kV. They are used as network transformers in distribution networks (fig. 5.4-3).

This type of transformer is normally a 3-phase application and designed according to national and international standards. The low-voltage windings should be designed as foil or layer windings. The high-voltage windings should use layer or disc execution, including transposed conductors. Normally, the cooling type is ONAN (oil-natural, air-natural) or ONAF (oil-natural, air-forced). The tapping can be designed with no-load or on-load tap changers (NLTC or OLTC).

Main specification data
- Voltage and MVA rating
- Frequency
- Regulation range and type
- Vector group
- Losses or capitalization
- Impedances
- Noise requirements
- Connection systems (bushing, cable)
- Weight limits
- Dimensions
- Information about the place of installation
- Special insulation fluid
- Application of high temperature/extra small size operation

Fig. 5.4-3: **Large distribution transformer**

5.5 Reactors

In AC networks, shunt reactors and series reactors are widely used in the system to limit the overvoltage or to limit the short-circuit current. With more high-voltage overhead lines with long transmission distance and increasing network capacity, both types of reactors play an important role in the modern network system.

Fig. 5.5-1: **Reactor**

Shunt reactors

For extra-high-voltage (EHV) transmission lines, due to the long distance, the space between the overhead line and the ground naturally forms a capacitor parallel to the transmission line, which causes an increase of voltage along the distance. Depending on the distance, the profile of the line and the power being transmitted, a shunt reactor is necessary either at the line terminals or in the middle. An oil-immersed shunt reactor is a solution. The advanced design and production technology will ensure the product has low loss and low noise level.

Series reactors

When the network becomes larger, sometimes the short-circuit current on a transmission line will exceed the short-circuit current rating of the equipment. Upgrading of system voltage, upgrading of equipment rating or employing high-impedance transformers are far more expensive than installing oil-immersed series reactors in the line. The oil-immersed design can also significantly save space in the substation.

Specification

Typically, 3-phase or 1-phase reactors should be considered first. Apart from the insulation level of the reactor, the vector group, overall loss level, noise level and temperature rise should be considered as main data for the shunt reactor.

Although the above data are also necessary for series reactors, the rated current, impedance and thermal/dynamic stability current should also be specified.

5.6 Special Transformers for Industrial Applications

A number of industry applications require specific industrial transformers due to the usage of power (current) as a major resource for production. Electric arc furnaces (EAF), ladle furnaces (LF) and high-current rectifiers need a specific design to supply the necessary power at a low voltage level. These transformer types, as well as converter transformers for large drive applications are called special-purpose or industrial transformers, whose design is tailor-made for high-current solutions for industry applications.

Electric arc furnace transformers

EAF and LF transformers are required for many different furnace processes and applications. They are built for steel furnaces, ladle furnaces and ferroalloy furnaces, and are similar to short or submerged arc furnace transformers (fig. 5.6-1).

EAF transformers operate under very severe conditions with regard to frequent overcurrents and overvoltages generated by short-circuits in the furnace and the operation of the HV circuit-breaker. The loading is cyclic. Big units have either a regulation transformer in front of them or a built-in unit inside the same tank.

Specific items

EAF transformers are rigidly designed to withstand repeated short-circuit conditions and high thermal stress, and to be protected against operational overvoltages resulting from the arc processes.

Design options

- Direct or indirect regulation
- On-load or no-load tap changer (OLTC/NLTC)
- Built-in reactor for long arc stability
- Secondary bushing arrangements and designs, air or water-cooled
- Internal secondary phase closure (internal delta)

Technical features

- Ratings up to 250 MVA
- Secondary voltage up to 1,500 V (LF down to 80 V)
- Electrode current (steel): up to 120 kA
- Electrode current (Fe-alloy): up to 180 kA

Fig. 5.6-1: **Electric arc furnace transformer**

Electric arc furnace series reactors
Most AC steel furnaces require a series reactor in the primary. For long-arc steel furnace operation, additional reactance is normally required to stabilize the arc and optimize the operation of the furnace application process. Big EAF transformer units have either a series reactor built in the same tank or use separate stand-alone series reactor units (fig. 5.6-2).

Specific items
The reactor will have the same heavy duty as the furnace transformer itself. Therefore, the design has to be very rugged in order to maintain stability and linearity of the reactance. The Siemens EAF reactors for this kind of application are built as 3-phase type with an iron core, with or without magnetic return circuits.

Design options
- Decision whether tap changer will or will not be used for operational flexibility
- Under oil or air (not from Siemens)
- On-load or no-load tap changer (OLTC/NLTC)
- Secondary bushing arrangements and designs

Technical features
- Ratings up to 60 MVA

DC electric arc furnace transformers
Direct-current electric arc furnace (DC EAF) transformers are required for many different furnace processes and applications. They are built for steel furnaces with a thyristor rectifier. DC EAF transformers operate under very severe conditions, like EAF transformers in general but using rectifier transformers for furnace operation. The loading is cyclic.

Specific items
DC EAF transformers are rigidly designed to withstand repeated short-circuit conditions and high thermal stress, and to be protected against operational overvoltages resulting from the arc processes. They are normally designed in a double-stack configuration with one LV winding in the delta connection and one LV winding in delta connection and one LV winding in wye connection, connected to two 6-pulse rectifiers (adding a 12-pulse system) or two parallel 6-pulse systems.

Design options
- 6- or 12-pulse system
- Intermediate yoke required (if double tier)
- On-load or no-load tap changer (OLTC/NLTC)
- Secondary bushing arrangements and designs on one or opposite side of the tank
- Air or water-cooled
- Filter winding possible

Technical features
- Ratings up to 130 MVA
- Secondary voltage up to 1,300 V
- Electrode current (steel): up to 120 kA

Fig. 5.6-2: **Active part of an electric arc furnace series reactor**

Rectifier transformers

Rectifier transformers are combined with a diode or thyristor rectifier. The applications range from very large aluminum electrolysis to various medium-size operations. The transformers may have a built-in or a separate voltage regulation unit. Due to a large variety of applications, they can have various designs up to a combination of voltage regulation, rectifier transformers in double-stack configuration, phase-shifting, interphase reactors, transductors and filter-winding (fig. 5.6-3).

Specific items

Thyristor rectifiers require voltage regulation with a no-load tap changer, if any. A diode rectifier will, in comparison, have a longer range and a higher number of small voltage steps than an on-load tap changer. Additionally, an auto-connected regulating transformer can be built in the same tank (depending on transport and site limitations).

Design options

- Thyristor or diode rectifier
- Double-tier design or triple-tier
- Voltage range and step voltage
- On-load or no-load tap changer (OLTC/NLTC)/filter winding
- 12-pulse or higher systems require additional phase-shifting windings
- Interphase reactor, transductors
- Secondary bushing arrangements and designs, air-cooled
- Numerous different vector groups and phase shifts possible

Technical features

- Ratings up to 120 MVA
- Secondary voltage 0–1,500 V, depending on the application

Fig. 5.6-3: **Rectifier transformer for an aluminum plant**

Converter transformers for large drive applications

Converter transformers are combined with a thyristor rectifier for variable speed drive systems. The drive systems can drive all kinds of large drives such as pumping stations, rolling stock for the mining industry and wind tunnels as well as blast furnaces (fig. 5.6-4).

Converter transformers for large drives combined with a frequency converter will supply the input for variable speed drive systems. The duty for converter transformers depends on the duty requirements of the corresponding industrial application and varies a lot (e.g., start-up application, duty application in the metal industry like rolling stock and pump solutions with continuous load).

Specific items

Converter transformers are mostly built as double-tier, with two secondary windings, allowing a 12-pulse rectifier operation. Such transformers normally have an additional winding as a filter to take out harmonics.

Design options

- Double-tier design
- No-load tap changer (NLTC)
- Filter winding
- Secondary bushing arrangements and designs, air or water-cooled
- Numerous different vector groups and phase shifts possible

Technical features

- Ratings up to 120 MVA
- Secondary voltage between 800 V and 14 kV, depending on the drive

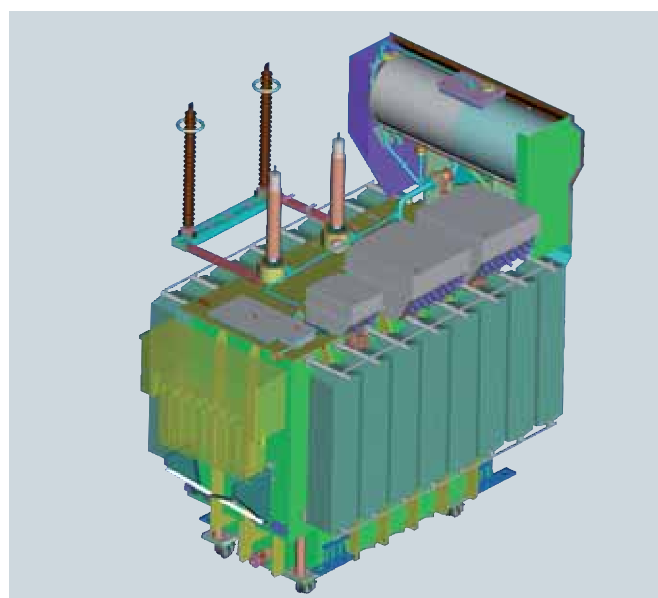


Fig. 5.6-4: **Converter transformer**

5.7 Phase-Shifting Transformers

A phase-shifting transformer is a device for controlling the power flow through specific lines in a complex power transmission network.The basic function of a phase-shifting transformer is to change the effective phase displacement between the input voltage and the output voltage of a transmission line, thus controlling the amount of active power that can flow in the line.

Fig. 5.7-1: **Phase-shifting transformer**

Guidance on necessary information

Beside the general information for transformers, the following specific data are of interest (fig. 5.7-1):

- Rated MVA
  The apparent power at rated voltage for which the phase-shifting transformer is designed.
- Rated voltage
  The phase-to-phase voltage to which operating and performance characteristics are referred to – at no-load.
- Rated phase angle
  Phase angle achieved when the phase-shifting transformer is operated under no-load condition, or if stated at full load, at which power factor.
- Phase shift direction
  In one or both directions. Changeover from and to under load or no-load condition.
- Tap positions
  Minimum and/or maximum number of tap positions.
- Impedance
  Rated impedance at rated voltage, rated MVA and zero phase shift connection as well as permissible change in impedance with voltage and phase angle regulation.
- System short-circuit capability
  When the system short-circuit level is critical to the design of phase-shifting transformers, the maximum short-circuit fault level shall be specified.
- BIL
  Basic impulse level (BIL) of source, load and neutral terminals.
- Special design tests
  Besides the standard lightning impulse tests at all terminals, it has to be considered that the lightning impulse might occur simultaneously at the source and the load terminal in case of closed bypass breaker. If such a condition is likely to appear during normal operation, a BIL test with source and load terminals connected might be useful to ensure that the phase-shifting transformer can withstand the stresses of lightning strokes in this situation.
- Special overload condition
  The required overload condition and the kind of operation (advance or retard phase angle) should be clearly stated. Especially for the retard phase angle operation, the overload requirements may greatly influence the cost of the phase-shifting transformer.
- Operation of phase-shifting transformer
  Operation with other phase-shifting transformers in parallel or series.
- Single or dual tank design
  In most cases, a dual core design requires a dual tank design as well.
- Symmetric or non-symmetric type
  Symmetric means that under a no-load condition the voltage magnitude at the load side is equal to that of the source side. For non-symmetric phase-shifting transformers, the permissible variation in percent of rated voltage at maximum phase angle must be stated.
- Quadrature or non-quadrature type
  A quadrature-type phase-shifting transformer is a unit where the boost voltage, which creates the phase shift between source and load terminals, is perpendicular to the line voltage on one terminal.
- Internal varistors
  It has to be clarified whether internal metal oxide varistors are allowed or not.

5.8 HVDC Transformers

HVDC transformers are a major part in HVDC stations that are located at the ends of long-distance DC transmission lines or DC sea cables. These transformers react as coupling elements between the connected AC grids and the rectifiers, and are necessary for adapting the voltage. They insulate the rectifier itself from the AC grid and generate a phase shift (fig. 5.8-1).

Design options

Depending on the transferred power, the transformers can be 3-phase or 1-phase and can have one or two valve windings per phase. The valve windings are exposed to AC and DC stress and therefore a special insulation design is necessary. Additionally, the load current contains a considerable amount of harmonic that leads to higher losses and higher noise. Above all, special bushings are necessary for the valve windings, where normally both ends are brought outside the transformer tank. Special DC and polarity reversal tests have to be performed to check these windings.

Technical items

Besides the standard parameters of each transformer, special parameters must be known for the design of an HVDC transformer. These parameters are normally determined by the designer of the HVDC station in consultation with the transformer designer in order to reach a cost-effective design for both the transformer and the whole HVDC station.

Such special parameters are:

- Harmonic spectrum of the load current, phase relation
- Magnetic coupling requirements of winding
- DC voltage, long-time DC and polarity reversal AC insulation levels
- DC bias in load and current and transformer-neutral
- di/dt of the load current
- Overload requirements

Fig. 5.8-1: **Power transformer for HVDC transmission**

5.9 Distribution Transformers

5.9.1 Oil-Immersed Distribution Transformers for European/US/Canadian Standard

On the last transformation step from the power station to the consumer, distribution transformers (DT) provide the necessary power for systems and buildings. Accordingly, their operation must be reliable, efficient and, at the same time, silent.

Distribution transformers are used to convert electrical energy of higher voltage, usually up to 36 kV, to a lower voltage, usually 250 or 435 V, with an identical frequency before and after the transformation. Application of the product is mainly within suburban areas, public supply authorities and industrial customers. Distribution transformers are usually the last item in the chain of electrical energy supply to households and industrial enterprises.

Distribution transformers are fail-safe, economical and have a long life expectancy. These fluid-immersed transformers can be 1-phase or 3-phase. During operation, the windings can be exposed to high electrical stress by external overloads and high mechanical stress by short-circuits. They are made of copper or aluminum. Low-voltage windings are made of strip or flat wire, and the high-voltage windings are manufactured from round wire or flat wire.

Three product classes – standard, special and renewable – are available, as follows:

- Standard distribution transformers:
  - Pole mounted (fig. 5.9-1), wound core or stacked core technology distribution transformer (≤ 2,500 kVA, U_m ≤ 36 kV) (fig. 5.9-2)
  - Wound core or stacked core technology medium distribution transformer (> 2,500 ≤ 6,300 kVA, U_m ≤ 36 kV)
  - Large distribution transformer (> 6.3 MVA, U_m ≤ 72.5 kV)
  - Voltage regulator
- Special distribution transformers: self-protected DT, regulating DT (OLTC), low-emission DT or others (autotransformer, transformer for converters, double-tier, multiwinding transformer, earthing transformer)
- Renewable distribution transformers: Used in wind power stations, solar power plants or sea flow/generator power plants

Fig. 5.9-1: **Pole mounted, USA**

Fig. 5.9-2: **Oil-immersed distribution transformer**

5.9.2 Voltage Regulators

Siemens invented the voltage regulator in 1932 and pioneered its use in the United States. Voltage regulators are tapped step autotransformers used to ensure that a desired level of voltage is maintained at all times. A voltage regulator comprises a tapped autotransformer and a tap changer. The voltage regulator provides ±10 % adjustment in 32 steps of ⅝ % each.

Voltage regulators are oil-immersed and can be 1-phase or 3-phase. They may be self-cooled or forced air-cooled. Available at 50 or 60 Hz and with 55 or 65 °C temperature rise, they can be used in any electrical system to improve voltage quality.

Voltage regulator ratings are based on the percent of regulation (i.e., 10 %). For example, a set of three 1-phase 333 kVA regulators would be used with a 10 MVA transformer (e.g., 10 MVA • 0.10/3 = 333 kVA). 1-phase voltage regulators are available in ratings ranging from 2.5 kV to 19.9 kV and from 38.1 kVA to 889 kVA (fig. 5.9-3). 3-phase voltage regulators are available at 13.2 kV or 34.5 kV and from 500 kVA to 4,000 kVA.

Voltage regulators can be partially or completely untanked for inspection and maintenance without disconnecting any internal electrical or mechanical connections. After the unit is untanked, it is possible to operate the voltage regulator mechanism and test the control panel from an external voltage source without any reconnections between the control and the regulator.

Standard external accessories

The standard accessories are as follows:

- External metal-oxide varistor (MOV) bypass arrester
- Cover-mounted terminal block with a removable gasketed cover. It allows easy potential transformer reconnections for operation at different voltages
- Oil sampling valve
- Two laser-etched nameplates
- External oil sight gauge that indicates oil level at 25 °C ambient air temperature and oil color
- External position indicator that shows the tap changer position
- Mounting bosses for the addition of lightning arresters to the source (S), load (L) and source-load (SL) bushings. They shall be fully welded around their circumference.

Accessories and options

Remote mounting kit

Extra-long control cable shall be provided for remote mounting of the control cabinet at the base of the pole.

Sub-bases

To raise the voltage regulator to meet safe operating clearances from the ground to the lowest live part.

Auxiliary PT

Operation at different voltages.

Testing

All voltage regulators shall be tested in accordance with the latest ANSI C57.15 standards.

Standard tests include:

- Resistance measurements of all windings
- Ratio tests on all tap locations
- Polarity test
- No-load loss at rated voltage and rated frequency
- Excitation current at rated voltage and rated frequency
- Impedance and load loss at rated current and rated frequency
- Applied potential
- Induced potential
- Insulation power factor test
- Impulse test
- Insulation resistance

Fig. 5.9-3: **1-phase voltage regulator, JFR**

5.9.3 GEAFOL Cast-Resin Transformers

GEAFOL transformers have been in successful service since 1965. Many licenses have been granted to major manufacturers throughout the world since then. Over 80,000 units have proven themselves in power distribution or converter operation all around the globe.

Advantages and applications

GEAFOL distribution and power transformers in ratings from 100 to approximately 40,000 kVA and lightning impulse (LI) values up to 250 kV are full substitutes for oil-immersed transformers with comparable electrical and mechanical data. They are designed for indoor installation close to their point of use at the center of the major load consumers. The exclusive use of flame-retardant insulating materials frees these transformers from all restrictions that apply to oil-filled electrical equipment, such as the need for oil collecting pits, fire walls, fire extinguishing equipment. For outdoor use, specially designed sheet metal enclosures are available.

GEAFOL transformers are installed wherever oil-filled units cannot be used or where use of oil-immersed transformers would require major constructive efforts such as inside buildings, in tunnels, on ships, cranes and offshore platforms, inside wind turbines, in groundwater catchment areas and in food processing plants. For outdoor use, specially designed sheet metal enclosures are available.

Often these transformers are combined with their primary and secondary switchgear and distribution boards into compact substations that are installed directly at their point of use.

When used as static converter transformers for variable speed drives, they can be installed together with the converters at the drive location. This reduces construction requirements, cable costs, transmission losses and installation costs.

GEAFOL transformers are fully LI-rated. Their noise levels are comparable to oil-filled transformers. Taking into account the indirect cost reductions just mentioned, they are also mostly

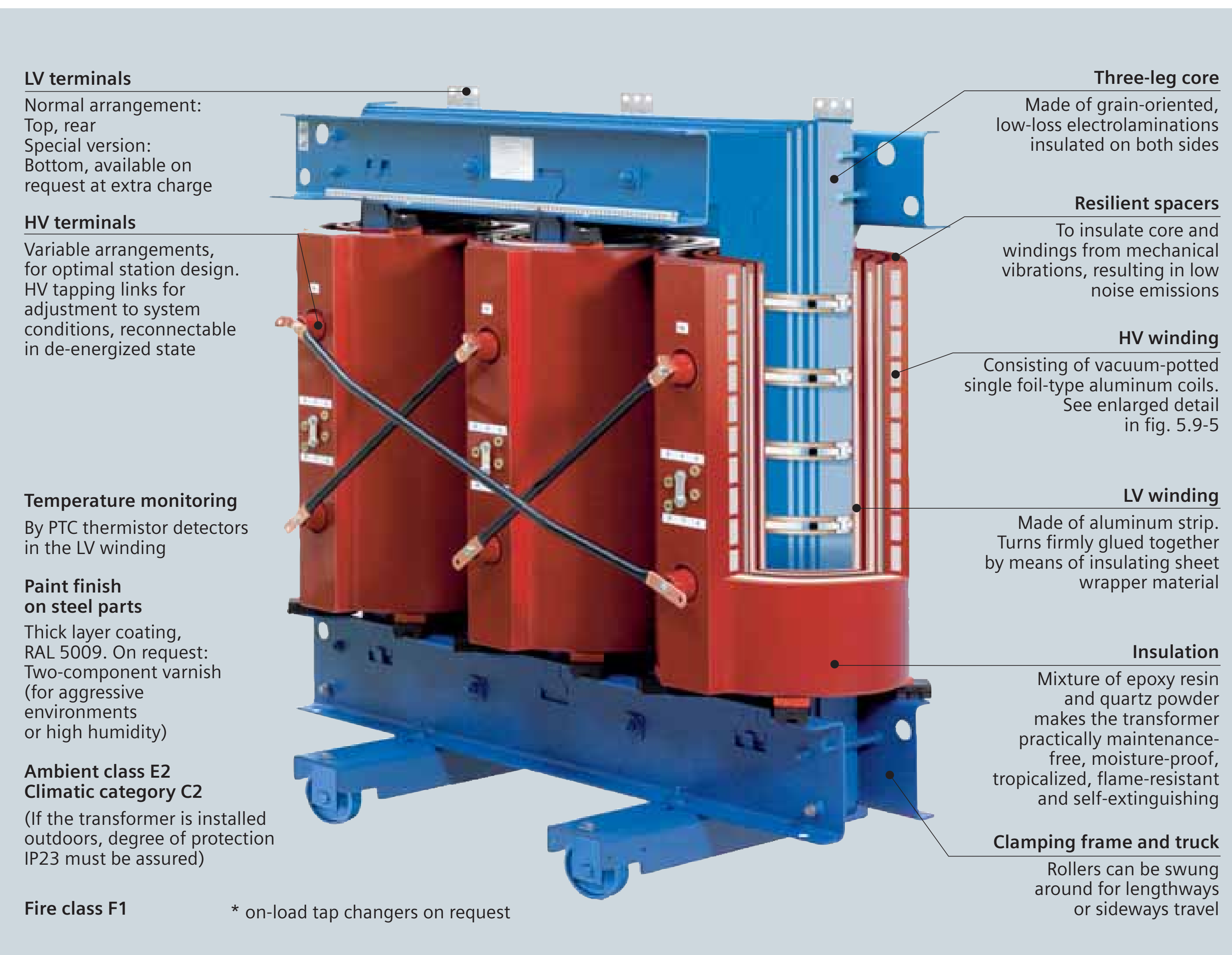


Fig. 5.9-4: **GEAFOL cast-resin dry-type transfomer properties**

cost-competitive. By virtue of their design, GEAFOL transformers are practically maintenance-free.

Standards and regulations
GEAFOL cast-resin dry-type transformers comply with IEC 60076-11, EN 60726, CENELEC HD 464, HD 538 and DIN 42 523.

Characteristic properties (fig. 5.9-4)

HV winding
The high-voltage windings are wound from aluminum foil interleaved with high-grade insulating foils. The assembled and connected individual coils are placed in a heated mold and are potted in a vacuum furnace with a mixture of pure silica (quartz sand) and specially blended epoxy resins. The only connections to the outside are casted brass nuts that are internally bonded to the aluminum winding connections.

The external delta connections are made of insulated copper or aluminum connectors to guarantee an optimal installation design. The resulting high-voltage windings are fire-resistant, moisture-proof and corrosion-proof, and they show excellent aging properties under all operating conditions.

The foil windings combine a simple winding technique with a high degree of electrical safety. The insulation is subjected to less electrical stress than in other types of windings. In a conventional round-wire winding, the interturn voltages can add up to twice the interlayer voltage. In a foil winding, it never exceeds the voltage per turn, because a layer consists of only one winding turn. This results in high AC voltage and impulse voltage withstand capacity.

Aluminum is used because the thermal expansion coefficients of aluminum and cast resin are so similar that thermal stresses resulting from load changes are kept to a minimum (fig. 5.9-5).

LV winding
The standard low-voltage winding with its considerably reduced dielectric stresses is wound from single aluminum sheets with interleaved cast-resin impregnated fiberglass fabric (prepreg).

The assembled coils are then oven-cured to form uniformly bonded solid cylinders that are impervious to moisture. Through the single-sheet winding design, excellent dynamic stability under short-circuit conditions is achieved. Connections are submerged arc-welded to the aluminum sheets and are extended either as aluminum or copper bars to the secondary terminals.

Fire safety
GEAFOL transformers use only flame-retardant and self-extinguishing materials in their construction. No additional substances, such as aluminum oxide trihydrate, which could negatively influence the mechanical stability of the cast-resin molding material, are used. Internal arcing from electrical faults

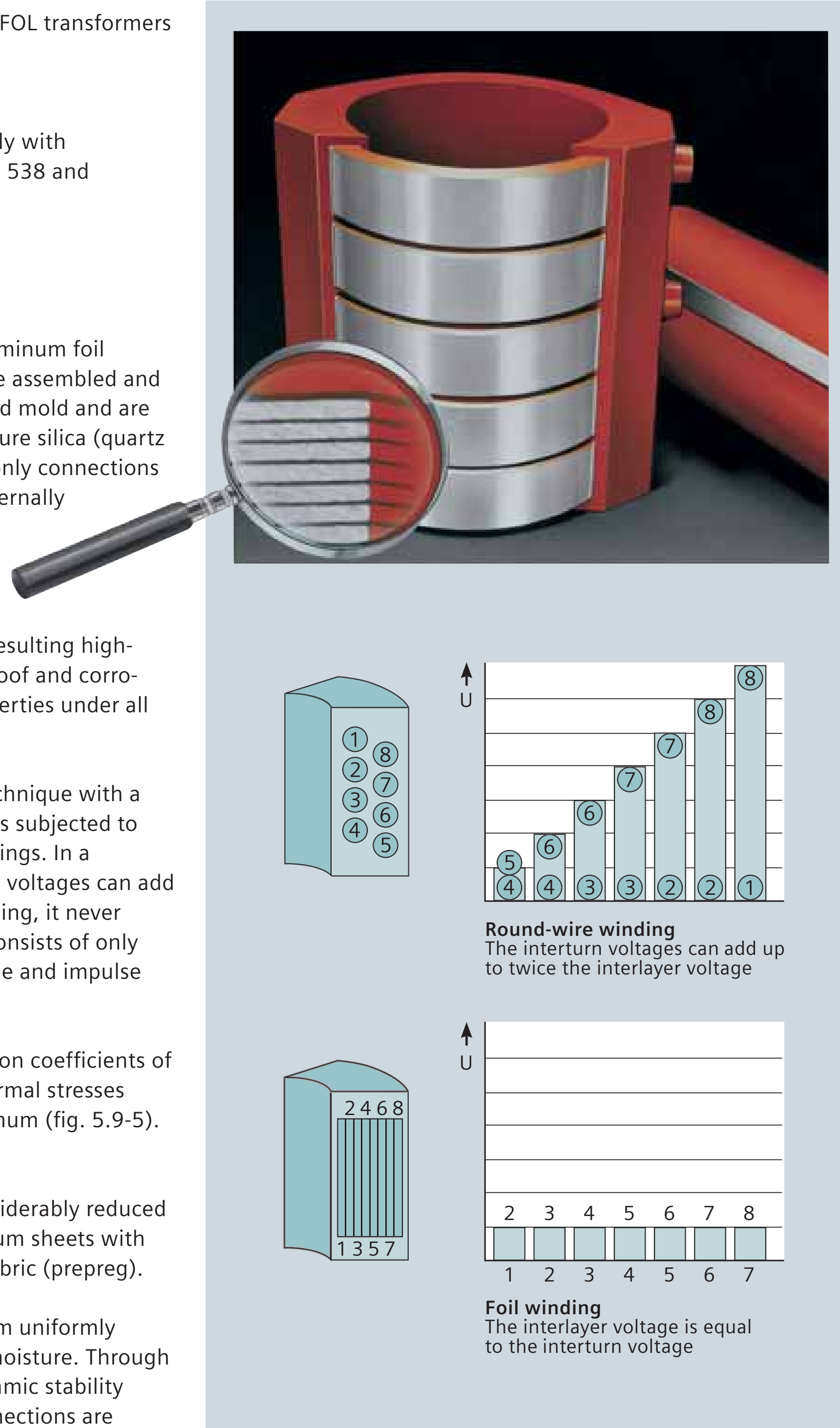


Fig. 5.9-5: **High-voltage encapsulated winding design of GEAFOL cast-resin transformer and voltage stress of a conventional round-wire winding (above) and the foil winding (below)**

and externally applied flames do not cause the transformers to burst or burn. After the source of ignition is removed, the transformer is self-extinguishing. This design has been approved by fire officials in many countries for installation in populated buildings and other structures. The environmental safety of the combustion residues has been proven in many tests (fig. 5.9-6).

Categorization of cast-resin transformers
Dry-type transformers have to be classified under the categories listed below:
- Environmental category
- Climatic category
- Fire category

These categories have to be shown on the rating plate of each dry-type transformer.

The properties laid down in the standards for ratings within the category relating to environment (humidity), climate and fire behavior have to be demonstrated by means of tests.

These tests are described for the environmental category (code numbers E0, E1 and E2) and for the climatic category (code numbers C1 and C2) in IEC 60076-11. According to this standard, the tests are to be carried out on complete transformers. The tests of fire behavior (fire category code numbers F0 and F1) are limited to tests on a duplicate of a complete transformer that consists of a core leg, a low-voltage winding and a high-voltage winding.

GEAFOL cast-resin transformers meet the requirements of the highest defined protection classes:
- Environmental category E2
- Climatic category C2
- Fire category F1

Insulation class and temperature rise
The high-voltage winding and the low-voltage winding utilize class F insulating materials with a mean temperature rise of 100 K (standard design) (table 5.9-1).

Overload capability
GEAFOL transformers can be overloaded permanently up to 50 % (with a corresponding increase in impedance voltage and load losses) if additional radial cooling fans are installed (dimensions can increase by approximately 100 mm in length and width.) Short-time overloads are uncritical as long as the maximum winding temperatures are not exceeded for extended periods of time (depending on initial load and ambient air temperature).

Temperature monitoring
Each GEAFOL transformer is fitted with three temperature sensors installed in the LV winding, and a solid-state tripping device with relay output. The PTC thermistors used for sensing are selected for the applicable maximum hot-spot winding temperature.

Fig. 5.9-6: **Flammability test of cast-resin transformer**

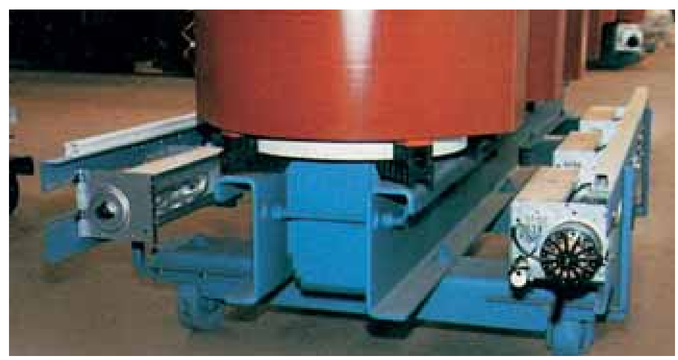


Fig. 5.9-7: **Radial cooling fans on GEAFOL transformer for AF cooling**

U_m (kV)	*LI* (kV)	*AC* (kV)
1.1	–	3
12	75	28
24	95*	50
36	145*	70

* other levels upon request

Table 5.9-1: **Insulation level of GEAFOL**

Additional sets of sensors with lower temperature points can be installed for them and for fan control purposes. Alternatively, Pt100 sensors are available. For operating voltages of the LV winding of 3.6 kV and higher, special temperature measuring equipment can be provided.

Auxiliary wiring is run in a protective conduit and terminated in a central LV terminal box (optional). Each wire and terminal is identified, and a wiring diagram is permanently attached to the inside cover of this terminal box.

Installation and enclosures
Indoor installation in electrical operating rooms or in various sheet metal enclosures is the preferred method of installation. The transformers need to be protected only against access to the terminals or the winding surfaces, against direct sunlight and against water. Unless sufficient ventilation is provided by the installation location or the enclosure, forced-air cooling must be specified or provided by others (fig. 5.9-8).

Instead of the standard open terminals, plug-type elbow connectors can be supplied for the high-voltage side with LI ratings up to 170 kV. Primary cables are usually fed to the transformer from trenches below but can also be connected from above.

Secondary connections can be made by multiple insulated cables, or by connecting bars from either below or above. Secondary terminals are either aluminum or copper busbar stubs that are drilled to specification (fig. 5.9-9).

A variety of indoor and outdoor enclosures in different protection classes are available for the transformers alone, or for indoor compact substations in conjunction with high-voltage and low-voltage switchgear panels. PEHLA-tested housings are also available.

Cost-effective recycling
The oldest of the GEAFOL cast-resin transformers that entered production in the mid-1960s are approaching the end of their service life. Much experience has been gathered over the years with the processing of faulty or damaged coils from such transformers. This experience shows that all of the metal materials used in GEAFOL cast-resin transformers, that is, approximately 90 % of their total mass, are fully recyclable. The process used is non-polluting. Given the value of secondary raw materials, the procedure is often cost-effective, even with the small amounts currently being processed.

Detailed information and figures can be found at www.siemens.com/geafol

Fig. 5.9-8: **GEAFOL transformer in protective housing to IP20/40**

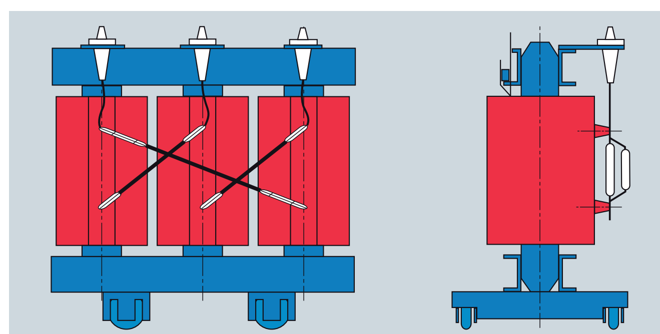


Fig. 5.9-9: **GEAFOL transformer with plug-type cable connections**

Selection tables, technical data, dimensions and weights
- Standard: DIN 42523
- Rated power: 100–40,000 kVA
- Rated frequency: 50 Hz
- HV rating: up to 36 kV
- LV rating: up to 780 V;
  special designs for higher voltages are possible
- Tappings on HV side: ± 2.5 % or ± 2 x 2.5 %
- Connection: HV winding: delta
- LV winding: star
- Impedance voltage at rated current: 4–8 %
- Insulation class: HV/LV = F/F
- Temperature rise: HV/LV = 100/100 K
- Color of metal parts: RAL 5009
  (other parts: several colors are available)

5.9.4 GEAFOL Special Transformers

GEAFOL cast-resin transformers with oil-free on-load tap changers
The voltage-regulating cast-resin transformers connected on the load side of the medium-voltage power supply system feed the plant-side distribution transformers. The on-load tap changer controlled transformers used in these medium-voltage systems need to have appropriately high ratings.

Siemens offers suitable transformers in its GEAFOL design (fig. 5.9-10), which has proved successful over many years and is available in ratings of up to 40 MVA. The range of rated voltage extends to 36 kV, and the maximum impulse voltage is 200 kV. The main applications of this type of transformer are in modern industrial plants, hospitals, office and apartment blocks and shopping centers.

5

Linking 1-pole tap changer modules together by means of insulating shafts produces a 3-pole on-load tap changer for regulating the output voltage of 3-phase GEAFOL transformers. In its nine operating positions, this type of tap changer has a rated current of 500 A and a rated voltage of 900 V per step. This allows voltage fluctuations of up to 7,200 V to be kept under control. However, the maximum control range utilizes only 20 % of the rated voltage.

Transformers for static converters
These are special oil-immersed or cast-resin power transformers that are designed for the special demands of thyristor converter or diode rectifier operation.

The effects of such conversion equipment on transformers and additional construction requirements are as follows:
- Increased load by harmonic currents
- Balancing of phase currents in multiple winding systems (e.g., 12-pulse systems)
- Overload factor up to 2.5
- Types for 12-pulse systems, if required

Siemens supplies oil-filled converter transformers of all ratings and configurations known today, and dry-type cast-resin converter transformers up to 40 MVA and 250 kV LI (fig. 5.9-11).

To define and quote for such transformers, it is necessary to know considerable details on the converter to be supplied and

Fig. 5.9-10: **16/22-MVA GEAFOL cast-resin transformer with oil-free on-load tap changer**

on the existing harmonics. These transformers are almost exclusively inquired about together with the respective drive or rectifier system and are always custom-engineered for the given application.

Neutral earthing transformers

When a neutral earthing reactor or earth-fault neutralizer is required in a 3-phase system and no suitable neutral is available, a neutral earthing must be provided by using a neutral earthing transformer.

Neutral earthing transformers are available for continuous operation or short-time operation. The zero impedance is normally low. The standard vector groups are zigzag or wye/delta. Some other vector groups are also possible.

Neutral earthing transformers can be built by Siemens in all common power ratings in oil-immersed design and in cast-resin design.

Fig. 5.9-11: **Dry-type converter transformer GEAFOL**

For further information, please contact:
Fax: ++49 (0)7021-508-0
www.siemens.com/transformers

5.10 Traction Transformers

Siemens produces transformers for railway applications called traction transformers. These transformers are installed in electric cars such as high-speed trains, electric multiple units (EMUs) and electric locomotives. Their main purpose is transform the overhead contact line voltage, which range mainly from 15 kV or 25 kV, to voltages suitable for traction converters (between 0.7 kV and 1.5 kV) (fig. 5.10-1).

Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings, voltage levels and customer-specific requirements.

All products are optimized with regard to individual customer requirements such as:

- Frequency, rating and voltage
- Required dimensions and weights
- Losses and impedance voltage characteristics
- Operational cycles and frequency response behavior
- Environmental requirements

Characterization

Technically, traction transformers are in general characterized as follows:

- 1-phase transformers
- Ratings up to 10 MVA and above
- Operating frequencies from 16⅔ to 60 Hz
- Voltages: 1.5 kV DC, 3 kV DC, 15 kV, 25 kV, 11.5 kV or other specific solutions
- Weight: < 15 t
- Auxiliary windings and/or heater windings according to customer specification
- Single or multiple system operation
- Under floor, machine room or roof assembly
- Traction windings to be used as line filters

Fig. 5.10-1: **Traction transformer for locomotives**

- Integrated absorption circuit reactors
- Various cooling media for all ratings: mineral oil, silicone or ester fluid for highest environmental compatibility

In case of customer request:

- With cooling plant – integrated in one frame together with the transformer or stand-alone solution
- Nomex insulation for highest energy density

Examples

The examples shown in the table are typical applications where traction transformers from Siemens were used (table 5.10-1).

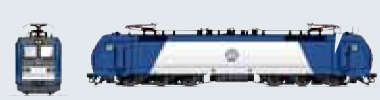
High speed train AVE S102 for RENFE Spain	Electric locomotive for ÖBB Austria (1216 Series) for cross-european haulage	World's most powerful series-production freight locomotive for China
Operation: Madrid – Barcelona Travel time: 2 h 30 min for 635 km Number of cars: 8 Power system: 25 kV/50 Hz Maximum power at wheel: 8,800 kW Max. speed: 350 km/h Number of seats: 404	4 system operation AC 15 kV: 16⅔ Hz AC 25 kV 50 Hz DC 3 kV DC 1.5 kV Speed: 200 – 230 km/h Weight 87 t	6 axle machine 9,600 kW on 6 axles hauling of 20,000 t trains
		

Table 5.10-1: **Siemens develops and produces traction transformers for rolling stock applications of all relevant ratings and voltage levels**

5.11 Transformer Lifecycle Management

Introduction
Power transformers usually perform their work, humming quietly for decades, without any interruption. Operators have thus come to rely on their solid transformer capacity, often performing only minimal maintenance using traditional techniques. Today, load requirements, additional environmental constraints and recent corporate sustainability objectives to keep a close eye on the operational value of the equipment, have led Siemens to provide a comprehensive set of solutions to keep the equipment at peak level under any operational circumstances. A new generation of asset managers is interested in the "operational" value, including the replacement cost, instead of the depreciated book-value over decades, which is often close to zero.

Power transformers are long-lasting capital investment goods. Purchasing and replacement require long periods of planning engineering and procurement. Each individual conception is specially adapted to the specific requirements. The corresponding high replacement value, and the important lead time are in the focus.

What is TLM?
Siemens Transformer Lifecycle Management (TLM) includes highly experienced transformer experts who provide the most effective lifecycle solutions for power transformers of any age and any brand.

Maintaining customers' power transformers at peak operating level is the prime objective of the Siemens TLM set of solutions.

Siemens TLM is based on the expertise available in all Siemens transformer factories, which are well-known for high quality and low failure rates. In addition to the existing locations, TLM is progressively expanding with new TLM service hubs.

The TLM scope of services is explained in the following briefly:

1. Installation and Commissioning
Siemens technical experts and engineers who work on projects that include installing new transformers or changing the locations of old transformers, have decades of experience. They are expert at disassembly and preparation for transport, storing and handling of delicate components. Assembly is the daily work of these Siemens experts, and Siemens offers its exhaustive experience for complete solutions for customers so that their equipment value remains at its peak for a long time.

2. Condition Assessment
The Siemens TLM Condition Assessment and Diagnostics is a modular and multilevel approach to evaluating the operational value of the highest possible quality – second to none. The process includes non-invasive diagnostics, special measures and tests during normal operation as well as particular analysis, which requires minimum outages. Siemens also provides high-voltage tests on site – again, with a quality that is second to none. It is particularly helpful to customers to evaluate the partial discharge levels and applied voltage tests with a quality that is similar to what our best tests can perform in the factories. The HV level is limited to 800 kV 50/60 Hz for the time being, including HVDC testing. TLM's comprehensive fleet assessment provides a master plan for asset management. Because remedial action until replacements can be acquired today requires several years of advance planning, TLM provides such remedial action for all your power transformers – from any manufacturer, and of any age.

TLM relies on expertise from Siemens factories and design engineers to bring new solutions to customers' old transformers, and integrates its many years of experience in working with old and ageing transformers with current practice.

3. Online Monitoring
The new Siemens third-generation SITRAM Online transformer monitoring range is providing compatible, modular and customized solutions for individual power transformers (new and retrofit) and solutions for entire transformer fleets.

Scope	Elements
Transport, Installation and Commissioning	Disassembly & Preparation for Transport, Shipping & Transport Management, Installation & Commissioning
Condition Assessment and On-Site Diagnostics	Oil Laboratory Services, Condition Assessment, Fleet Screening, Lifecycle Assessment, Advanced Electrical Measurement, High-Voltage Tests on Site
Online Monitoring	Single Sensors, SITRAM.GUARDs, SITRAM Condition Monitor, SITRAM Integrated Conditon Monitoring System
Lifecycle Maintenance	Preventive, Curative and Corrective Maintenance, Long-Term Maintenance Concepts, Online Drying & Degassing, Active Part Drying, Oil Regeneration, End-of-Life Management, Scrapping
Troubleshooting, Repair and Retrofit	Failure Diagnostics, Repair on Site, Repair & Modifications In-House, Refurbishment, Retrofit, Modernization, Upgrading
Consulting, Expertise and Training	Engineering Service, Advice & Recommendations for Preventive, Curative and Corrective Actions, Educational Seminars and Workshops
Spare Parts and Accessories	Bushings, Tap-Changer Motor Drives & Contacts, Coolers, Fans & Pumps, Protection Devices & Relays, ...

Table 5.11-1: **Set of Siemens TLM solutions**

In general, these systems allow a continuous monitoring of power transformers, which are going far beyond the traditional method of taking offline measurements. The experience demonstrates clearly, that with Online monitoring, an improved efficiency in the early detection of faults can be achieved. So that curative and corrective maintenance actions can be planned and scheduled well in advanced. It is also possible to use spare capacities up to the limits. This is resulting in a higher reliability, efficiency and longer service life of power transformers.

Siemens TLM provides three levels of online monitoring solutions:

- SITRAM.GUARDs:
  Standardized and approved sensor technologies as a single solution for individual transformers, e.g., online dissolved gas in oil analyzer (SITRAM GasGUARD 8).
- SITRAM Condition Monitor (SITRAM CM):
  The SITRAM Condition Monitor is a modular and customized system, which integrates information from single sensors and SITRAM.GUARDs for each transformer individually and is able to provide condition information about all key components. A local data storage module and a communication interface enable the user to access the information remotely.
- SITRAM Integrated Condition Monitoring System (SITRAM iCMS):
  This "Knowledge Module" solution is monitoring all transformers in transmission and distribution substations, power generation plants or in large industries to an existing or next generation protection and control system. Furthermore is it able to integrate the recorded data of a complete transformer fleet of a utility to a superordinated system. It is based on the modular hardware architecture of the SITRAM CM.

In addition to the monitoring hardware and software, Siemens TLM transformer experts are available for remote nursing solutions for questionable transformers, analyzing and interpretation of recorded monitoring data.

4. Lifecycle Maintenance
A very important issue for customers is the problem of making sure that transformers will continue to survive for a specific number of years. Here again, Siemens TLM offers a set of widely accepted solutions that are tailor-made for each transformer. Examples include a revolutionary online oil regeneration method, a process to reduce moisture and/or gases during normal operation, and may also include invasive corrections and modifications. For example, it can be advisable to exchange existing critical components (cable box connections) with up-to-date solutions (i.e., contact-safe plug-and-play connectors) for increased safety and improved exchangeability of similar transformers in the substation.

5. Repairs and Retrofit
One of the technological highlights of Siemens TLM is the complete repair – "as good as new" – and modifications of power transformers of any brand and any age. Siemens's on-site repairs can be nearly as good as the in-house factory repairs. Siemens's mobile workshops require considerable equipment and setting

Fig. 5.11-1: **Oil analysis and laboratory services**

Fig. 5.11-2: **Site service activities**

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up, very experienced site management, well-trained staff and detailed processes, but this "cost" is usually outweighed by the excessive down-time and transport costs that would otherwise be experienced by system operators if they had to send the equipment back to the factory.

In addition to the fact that TLM repairs bring transformers back into operation, system operators appreciate that their relationship to the environment is improved. Siemens's modern replacement winding sets are designed and manufactured with the latest technologies and solid insulation materials, which greatly reduces risk (e.g., replacement of asbestos gaskets). Siemens's end-of-life concepts make sure that any remaining environmental issues are kept to a strict minimum.

Siemens generally recommends that system operators start with a TLM condition analysis of their transformers. Based on the TLM fleet assessment, and depending on its outcome, Siemens's experts create a plan for preventive, curative and/or corrective actions, and any needed replacements. The result is a complete, comprehensive and detailed master plan for any brand and any age power transformers.

6. Consulting Expertise and Training
The Siemens TLM set of solutions integrates a wide range of services that are designed to considerably extend the life of the operator's transformers. Siemens's preferred approach is to integrate all transformers – of any age and any brand – in the plan that is prepared for customers so that they can make the best decision about replacement/extension and any related matters.

Siemens TLM also offers a series of standardized customer trainings. These programs are specifically designed to broaden customer awareness of the various concept and design options. Lifecycle management is, of course, an integral part of the training.

7. Spare Parts and Accessories
The supply of spare parts is another strong point of Siemens TLM. Upon request, Siemens may advise customers on what accessories will best fit their needs. Examples include Buchholz relays of various sizes, temperature sensors, oil flow alarms and oil level indicators. In order to provide the best solution, Siemens TLM will verify alternative products and strive to make technical improvements using state-of-the-art technologies, particularly important when original spare parts are not longer available.

All Siemens TLM solutions are designed to add value to the operation of the equipment. They contribute to an improved security for operational staff so that asset and maintenance managers can enjoy higher safety and peace of mind.

For further information, please contact:
Phone: +49 (180) 524 7000
Fax: +49 (180) 524 2471
E-mail: transformerservice@siemens.com
www.siemens.com/energy/tlm

6

Protection and Substation Automation

6 Protection and Substation Automation

6.1 Introduction

Totally Integrated Energy Automation
The demands on substation automation solutions are continually growing, which leads to greater complexity and more interfaces. High availability, with all individual components working together smoothly, is one of the most important system operator needs in the area of energy automation.

And that is exactly where Totally Integrated Energy Automation from Siemens comes in. With a comprehensive approach to the entire automation chain, the system operator gets an overview of the entire plant, from planning and start-up to operation and maintenance.

Totally Integrated Energy Automation is based on three main pillars that ensure simple operation:
- Reliable IT security through high-quality applications and seamless network structures
- Limitless communications by means of international standards and flexible expandability
- Efficient engineering for the entire automation chain, from the control center to the field device

Totally Integrated Energy Automation from Siemens means a simplified workflow, reliable operations and a significantly lower total cost of ownership. Siemens offers expert solutions that will continue to grow with the market's demands but still remain manageable. That is how Totally Integrated Energy Automation sets a new benchmark with energy automation that is clearly simpler and more efficient.

Energy automation that simply works
Siemens offers a uniform, universal technology for the entire functional scope of secondary equipment, both in the construction and connection of the devices and in their operation and communication. This results in uniformity of design, coordinated interfaces and the same operating principle being established throughout, whether in power system and generator protection, in measurement and recording systems, in substation control or protection or in telecontrol.

The devices are highly compact and immune to interference, and are therefore also suitable for direct installation in switchgear panels.

Complete technology from one partner
Siemens Energy Sector supplies devices and systems for:
- Power system protection SIPTOTEC
- Substation control and automation SICAM
- Remote control (RTUs)
- Measurement and recording SICAM
- Monitoring of power quality SICAM SAFIR

This technology covers all of the measurement, control, automation and protection functions for substations.

Furthermore, Siemens´s activities include:

- Consulting
- Planning
- Design
- Commissioning and service

This uniform technology from a single source saves the user time and money in the planning, assembly and operation of substations.

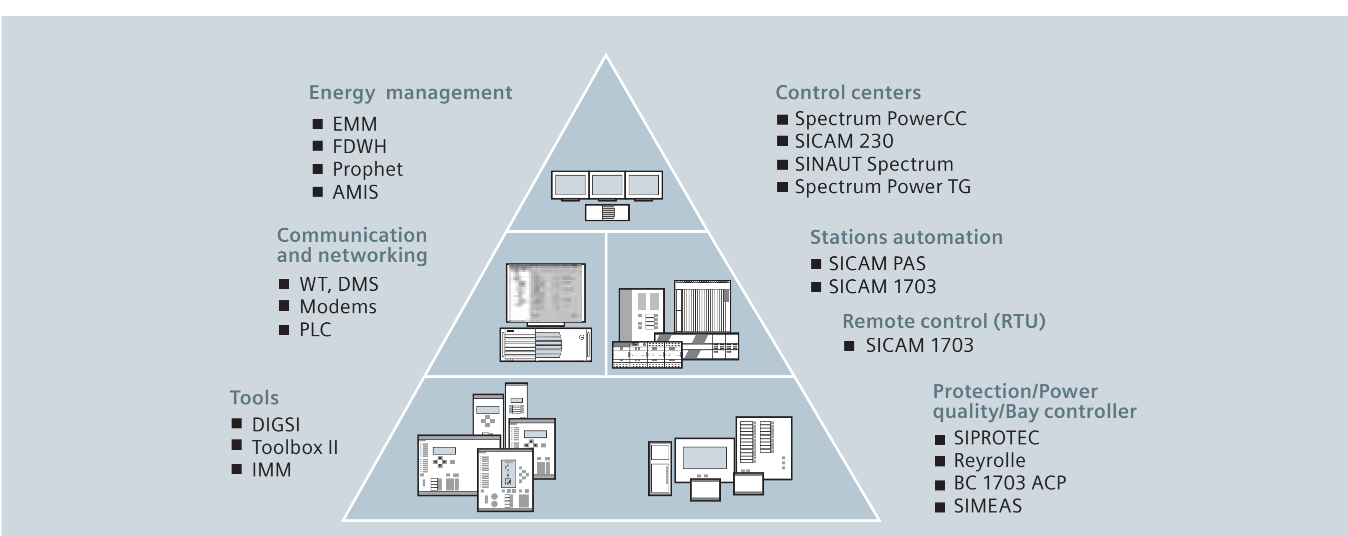

Fig. 6.1-1: **Siemens energy automation solutions**

6.2 Protection Systems

6.2.1 Introduction

SIPROTEC 4 is a flexible and powerful solution for protecting power systems. The ergonomic key path and graphic display ensure reliable operation. The powerful software tool DIGSI 4 assists the engineer in comprehensive relay management and fault analysis. Only one tool is required for all SIPROTEC relays. SIPROTEC 4 offers:

- Function mix of protection, control and measurement
- Choice of open communication standards like IEC 61850 and IEC 60870-5-103 protocol, DNP 3, MODBUS and PROFIBUS
- Communication modules also for retrofitting and upgrade to IEC 61850 communication

Siemens actively supports the international standard IEC 61850 and was the first manufacturer to offer protection relays and substation control systems with an IEC 61850-compliant communication protocol. At the end of 2007, there were more than 300 projects with approximately 30,000 SIPROTEC devices with IEC 61850 communication already in service.

SIPROTEC 4 has a flexibility that makes it a pleasure to use. As a pioneer in numerical protection and substation control, Siemens suggests taking advantage of SIPROTEC 4.

Section 6.2.2 gives an overview of the various product lines of the SIPROTEC family.

Section 6.2.3 offers application hints for typical protection schemes such as:

- Cables and overhead lines
- Transformers
- Motors and generators
- Busbars

To ensure a selective protection system, section 6.2.4 gives hints for coordinated protection setting and selection for instrument transformers. The „Relay Selection Guide“ in section 6.2.5 provides an overview of the relay function mix as a guide for selecting the right SIPROTEC relay for the corresponding protection application.

6.2.2 Overview of SIPROTEC Relay Families

Siemens is one of the world's leading suppliers of protection equipment for power systems.

Thousands of Siemens relays ensure first-class performance in transmission and distribution networks on all voltage levels, all over the world, in countries with tropical heat or arctic frost.

For many years, Siemens has also significantly influenced the development of protection technology:

- In 1976, the first minicomputer(process computer)-based protection system was commissioned: A total of 10 systems for 110/20 kV substations was supplied and is still operating satisfactorily today.
- In 1985, Siemens became the first company to manufacture a range of fully numerical relays with standardized communication interfaces.

Siemens now offers a complete range of protection relays for all applications with numerical busbar and machine protection.

More than 600,000 numerical protection relays from Siemens are providing successful service today as stand-alone units in traditional systems or as components of combined substation protection and substation control systems.

Meanwhile, the SIPROTEC 4 series has established itself right across the market, incorporating many years of operational experience with thousands of relays and user requirements (fig. 6.2-1).

State-of-the-art technology
Mechanical and solid-state (static) relays have been almost completely phased out of Siemens's production because numerical relays are now preferred by users due to their decisive advantages:

- Compact design and lower costs due to integration of many functions into one relay
- High availability and less maintenance due to integral self-monitoring
- No drift (aging) of measuring characteristics due to fully numerical processing
- High measuring accuracy due to digital filtering and optimized measuring algorithms
- Many integrated add-on functions, for example, for load-monitoring, event/fault recording and thermal monitoring
- Local operation keypad and display designed to modern ergonomic criteria
- Easy and reliable readout of information via serial interfaces with a PC, locally or remotely with DIGSI (one tool for all relays)
- Possibility to communicate with higher-level control systems using standardized protocols according to IEC 61850 via Ethernet communication

Fig. 6.2-1: **SIPROTEC family**

Modern protection management
All the functions, for example, of a line protection scheme, can be incorporated in one unit (fig. 6.2-2):

- Distance protection with associated add-on and monitoring functions
- Universal teleprotection interface by binary input/contacts or serial interface
- Auto-reclosure and synchronism check

Protection-related information can be called up on-line or off-line, such as:

- Distance to fault
- Fault currents and fault voltages
- Relay operation data
  (fault detector pickup, operating times, etc.)
- Set values
- Line load data (kV, A, MW, kVAr)

To fulfill vital protection redundancy requirements, only those functions that are interdependent and directly associated with each other are integrated into the same unit. For backup protection, one or more additional units should be provided.

All relays can stand fully alone. Thus, the traditional protection principle of separate main and backup protection as well as the external connection to the switchyard remain unchanged.

"One feeder, one relay" concept
Analog protection schemes have been engineered and assembled from individual relays. Interwiring between these relays and scheme testing has been carried out manually in the workshop.

Data sharing now allows for the integration of several protection and protection-related tasks into one single numerical relay. Only a few external devices may be required for completion of the total scheme. This has significantly lowered the costs of engineering, assembly, panel wiring, testing and commissioning. Scheme failure probability has also been lowered.

Engineering has moved from schematic diagrams toward a parameter definition procedure. The powerful user-definable logic of SIPROTEC 4 allows flexible customized design for protection, control and measurement.

Measuring included
For many applications, the accuracy of the protection current transformer is sufficient for operational measuring. The additional measuring current transformer was required to protect the measuring instruments under short-circuit conditions. Due to the low thermal withstand capability of the measuring instruments, they could not be connected to the protection current transformer. Consequently, additional measuring core current transformers and measuring instruments are now only necessary where high accuracy is required, e.g., for revenue metering.

Corrective rather than preventive maintenance
Numerical relays monitor their own hardware and software. Exhaustive self-monitoring and failure diagnostic routines are not restricted to the protection relay itself but are methodically carried through from current transformer circuits to tripping relay coils.

Equipment failures and faults in the current transformer circuits are immediately reported and the protection relay is blocked.

Thus, service personnel are now able to correct the failure upon occurrence, resulting in a significantly upgraded availability of the protection system.

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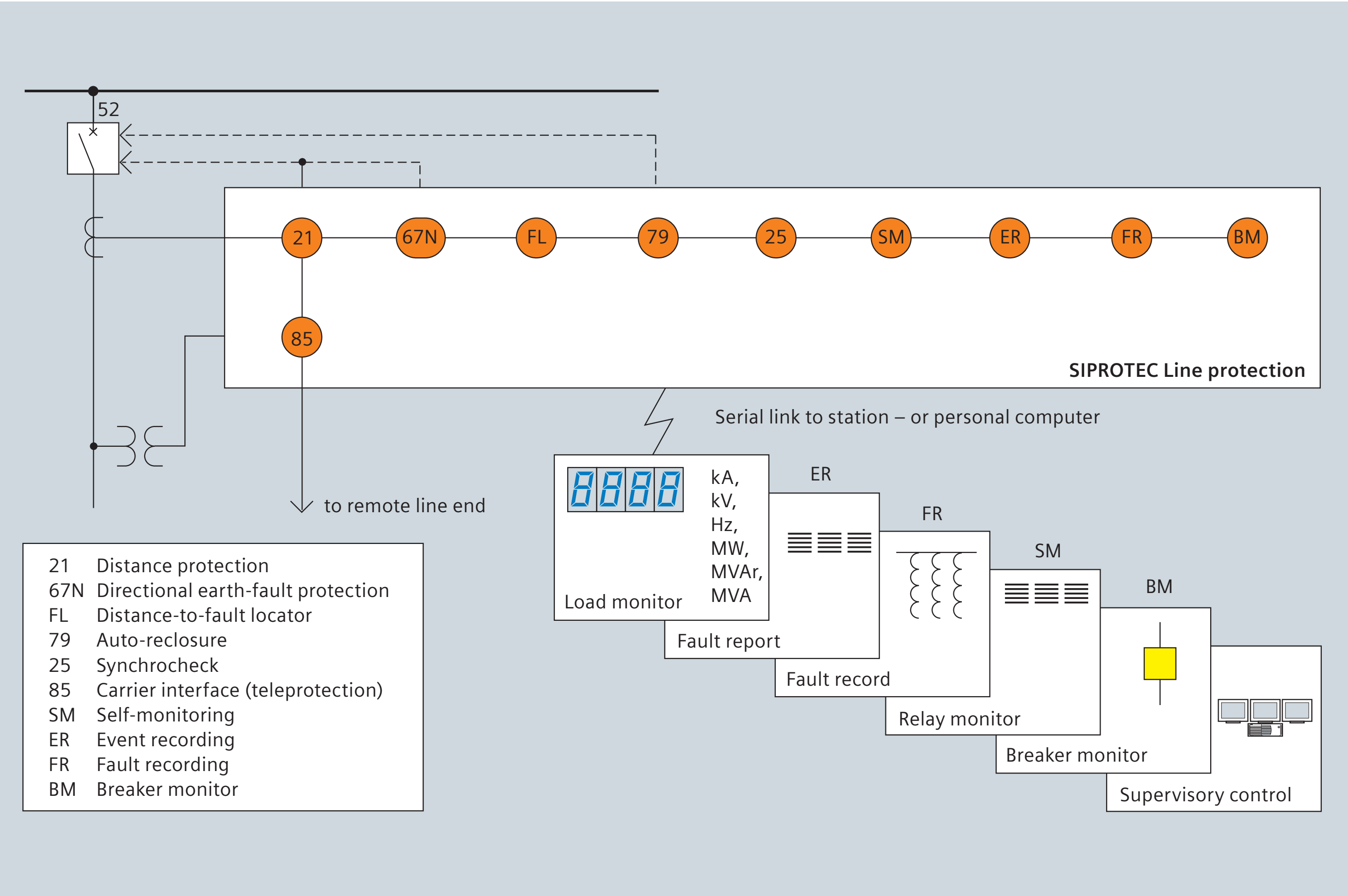


Fig. 6.2-2: **Numerical relays offer increased information availability**

Adaptive relaying
Numerical relays now offer reliable, convenient and comprehensive matching to changing conditions. Matching may be initiated either by the relay's own intelligence or from other systems via contacts or serial telegrams. Modern numerical relays contain a number of parameter sets that can be pretested during commissioning of the scheme. One set is normally operative. Transfer to the other sets can be controlled via binary inputs or a serial data link (fig. 6.2-3).

There are a number of applications for which multiple setting groups can upgrade the scheme performance, for example:

- For use as a voltage-dependent control of overcurrent-time relay pickup values to overcome alternator fault current decrement to below normal load current when the automatic voltage regulator (AVR) is not in automatic operation
- For maintaining short operation times with lower fault currents, e.g., automatic change of settings if one supply transformer is taken out of service
- For "switch-onto-fault" protection to provide shorter time settings when energizing a circuit after maintenance so that normal settings can be restored automatically after a time delay
- For auto-reclosure programs, that is, instantaneous operation for first trip and delayed operation after unsuccessful reclosure
- For cold load pickup problems where high starting currents may cause relay operation
- For "ring open" or "ring closed" operation.

Implemented functions
SIPROTEC relays are available with a variety of protective functions (please refer to section 6.2.5). The high processing power of modern numerical units allows further integration of non-protective add-on functions.

The question as to whether separate or combined relays should be used for protection and control cannot be unambiguously answered. In transmission-type substations, separation into independent hardware units is still preferred, whereas a trend toward higher function integration can be observed on the distribution level. Here, the use of combined feeder/line relays for protection, monitoring and control is becoming more common (fig. 6.2-4).

Relays with protection functions only and relays with combined protection and control functions are being offered. SIPROTEC 4 relays offer combined protection and control functions. SIPROTEC 4 relays support the "one relay one feeder" principle and thus contribute to a considerable reduction in space and wiring requirements.

With the well-proven SIPROTEC 4 family, Siemens supports both stand-alone and combined solutions on the basis of a single hardware and software platform. The user can decide within wide limits on the configuration of the control and protection, and the reliability of the protection functions (fig. 6.2-5).

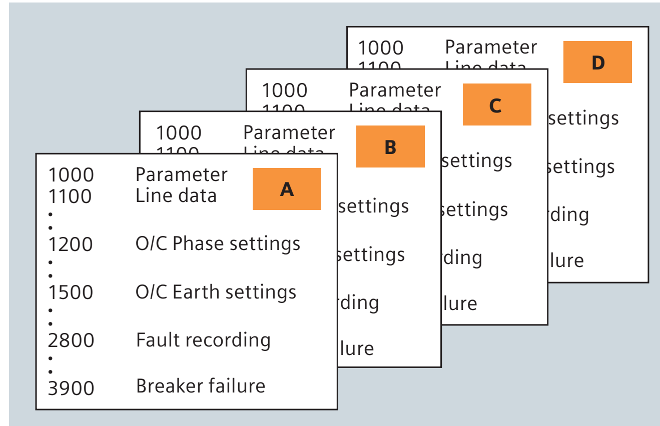


Fig. 6.2-3: **Alternate parameter groups**

Fig. 6.2-4: **Left: switchgear with numerical relay (7SJ62) and traditional control; right: switchgear with combined protection and control relay (7SJ64)**

The following solutions are available within one relay family:

- Separate control and protection relays
- Feeder protection and remote control of the line circuit-breaker via the serial communication link
- Combined relays for protection, monitoring and control.

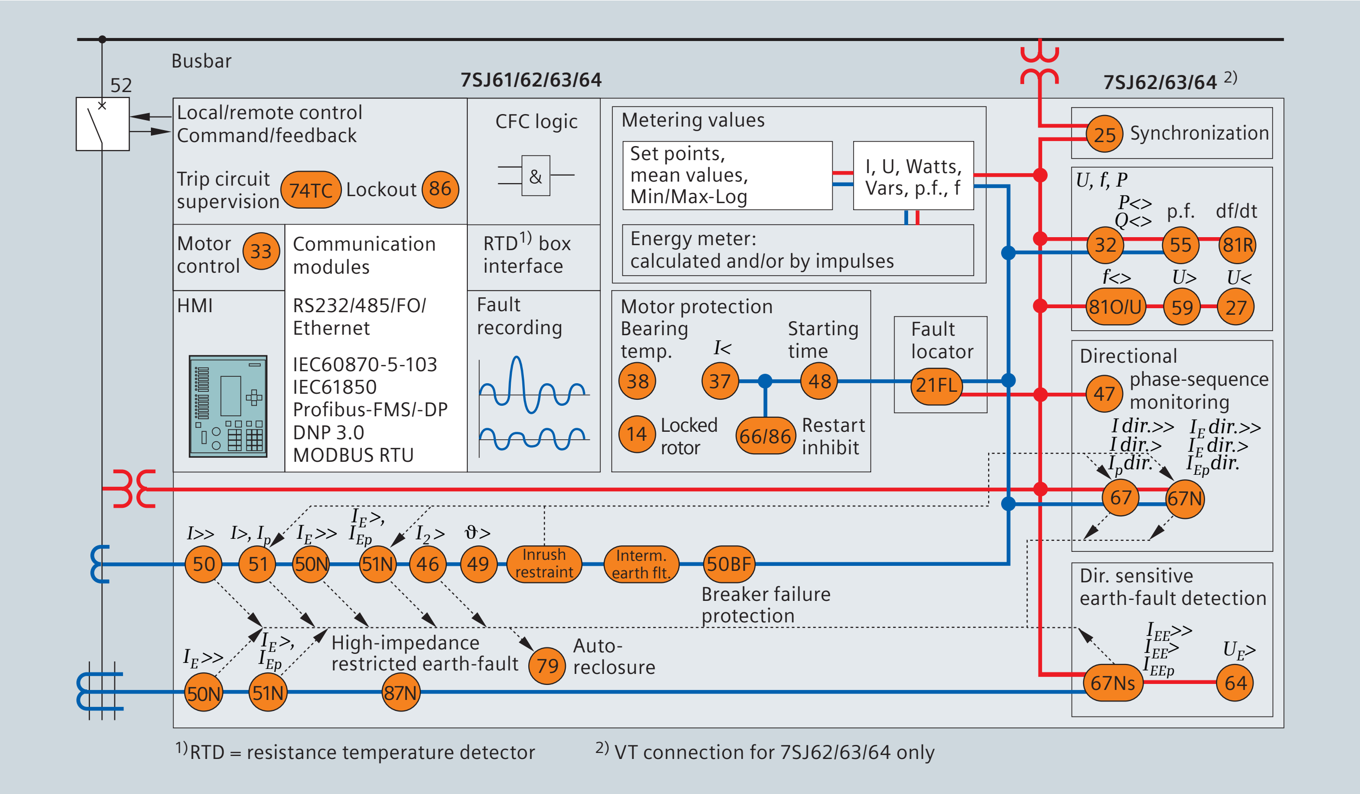


Fig. 6.2-5: **SIPROTEC 4 relays 7SJ61/62/63, 64 implemented functions**

Mixed use of the different relay types is possible on account of the uniform operation and communication procedures.

Siemens offers the user a uniform technique covering the whole range of protection applications. This includes uniform operation, uniform housing technology, common communication protocols and a uniform technology (fig. 6.2-6).

This offers a number of advantages for the user:

- Reduced engineering and testing efforts due to well-suited functions
- Reduced training due to uniform operation and setting for all relays
- Uniform data management due to a common operator program

Fig. 6.2-6: **DIGSI 4: tool for all SIPROTEC devices**

Mechanical Design

SIPROTEC 4 relays are available in 1/3 to 1/1 of 19” wide housings with a standard height of 243 mm. Their size is compatible with that of other relay families. Therefore, compatible exchange is always possible (fig. 6.2-7 to fig. 6.2-9).

All wires (cables) are connected at the rear side of the relay with or without ring cable lugs. A special relay version with a detached cable-connected operator panel (fig. 6.2-10) is also available. It allows, for example, the installation of the relay itself in the low-voltage compartment and of the operator panel separately in the door of the switchgear.

Terminals: Standard relay version with screw-type terminals

Current terminals	
Connection	W_{max} =12 mm
Ring cable lugs	*d1* =5 mm
Wire size	2.7 – 4 mm^2 (AWG 13 – 11)
Direct connection	Solid conductor, flexible lead, connector sleeve
Wire size	2.7 – 4 mm^2 (AWG 13 – 11)
Voltage terminals	
Connection	W_{max} =10 mm
Ring cable lugs	*d1* = 4 mm
Wire size	1.0 – 2.6 mm^2 (AWG 17 – 13)
Direct connection	Solid conductor, flexible lead, connector sleeve
Wire size	0.5 – 2.5 mm^2 (AWG 20 – 13)
Some relays are alternatively available with plug-in voltage terminals	
Current terminals	
Screw type (see standard version)	
Voltage terminals	
2-pin or 3-pin connectors	
Wire size	0.5 – 1.0 mm^2
	0.75 – 1.5 mm^2
	1.0 – 2.5 mm^2

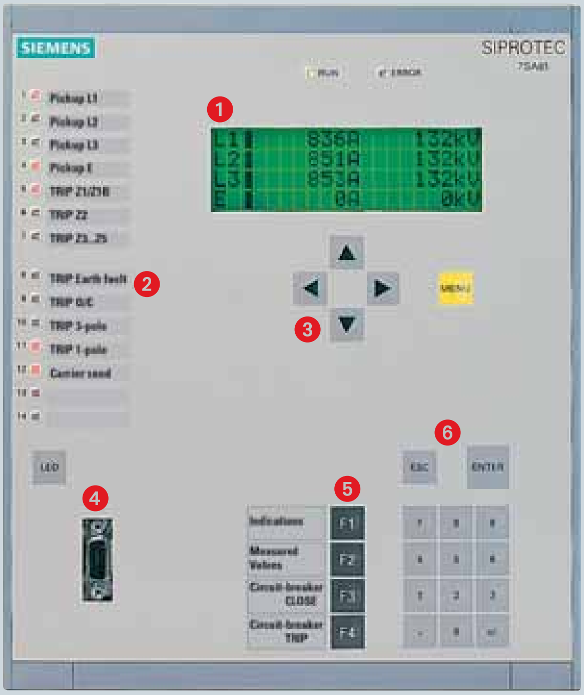
Fig. 6.2-7: **1/1 of 19” housing**

Fig. 6.2-8: **1/2 of 19” housing**

Fig. 6.2-9: **1/3 of 19” housing**

Fig. 6.2-10: **SIPROTEC 4 combined protection, control and monitoring relay 7SJ63 with detached operator panel**

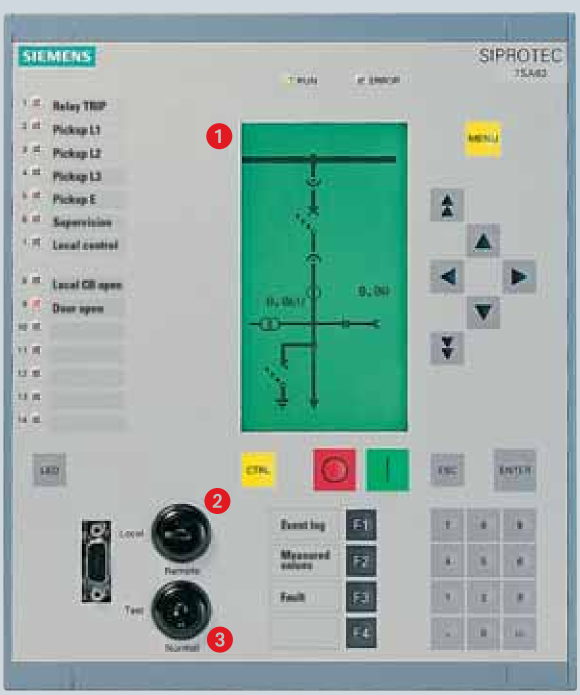
6



1. On the backlit LCD display, process and device information can be displayed as text.
2. Freely assignable LEDs are used to display process or device information. The LEDs can be labelled according to user requirements. An LED reset key resets the LEDs and can be used for LED testing.
3. Keys for navigation
4. RS232 operator interface (for DIGSI)
5. 4 configurable function keys permit the user to execute frequently used actions simply and fast.
6. Numerical keys

Fig. 6.2-11: **Local operation: All operator actions can be executed and information displayed via an integrated user interface. Two alternatives for this interface are available.**

6



1. Process and relay information can be displayed on the large illuminated LC display either graphically in the form of a mimic diagram or as text in various lists.
2. The keys mainly used for control of the switchgear are located on the “control axis” directly below the display.
3. Two key-operated switches ensure rapid and reliable changeover between “local“ and “remote“ control, and between “interlocked“ and “non-interlocked“ operation.

Fig. 6.2-12: **Additional features of the interface with graphic display**

Apart from the relay-specific protection functions, the SIPROTEC 4 units have a multitude of additional functions that

- provide the user with information for the evaluation of faults
- facilitate adaptation to customer-specific application
- facilitate monitoring and control of customer installations

Operational measured values

The large scope of measured and limit values permits improved power system management as well as simplified commissioning.

The r.m.s. values are calculated from the acquired current and voltage along with the power factor, frequency, active and reactive power. The following functions are available depending on the relay type

- Currents IL1, IL2, IL3, IN, IEE (67Ns)
- Voltages VL1,VL2, VL3, VL1-L2,VL2-L3, VL3-L1
- Symmetrical components I1, I2,3I0; V1, V2,3V0
- Power Watts, Vars, VA/P, Q, S
- Power factor p.f. (cos φ)
- Frequency
- Energy ± kWh ± kVarh, forward and reverse power flow
- Mean as well as minimum and maximum current and voltage values
- Operating hours counter
- Mean operating temperature of overload function
- Limit value monitoring
  Limit values are monitored using programmable logic in the CFC. Commands can be derived from this limit value indication.
- Zero suppression
  In a certain range of very low measured values, the value is set to zero to suppress interference.

Metered values (some types)

For internal metering, the unit can calculate energy metered values from the measured current and voltage values. If an external meter with a metering pulse output is available, some SIPROTEC 4 types can obtain and process metering pulses via an indication input.

The metered values can be displayed and passed on to a control center as an accumulation with reset. A distinction is made between forward, reverse, active and reactive energy.

Operational indications and fault indications with time stamp

The SIPROTEC 4 units provide extensive data for fault analysis as well as control. All indications listed here are stored, even if the power supply is disconnected.

- Fault event log
  The last eight network faults are stored in the unit. All fault recordings are time-stamped with a resolution of 1 ms.
- Operational indications
  All indications that are not directly associated with a fault (e.g., operating or switching actions) are stored in the status indication buffer. The time resolution is 1 ms (fig. 6.2-13, fig. 6.2-14).

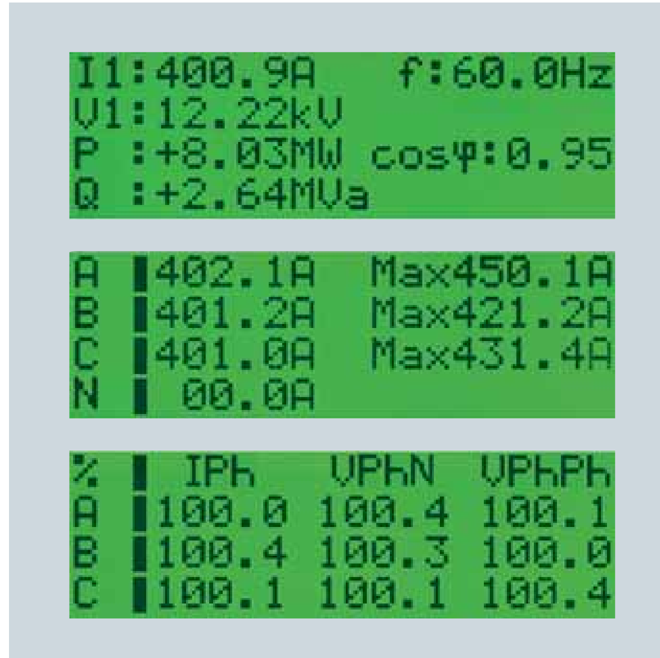


Fig. 6.2-13: **Operational measured values**

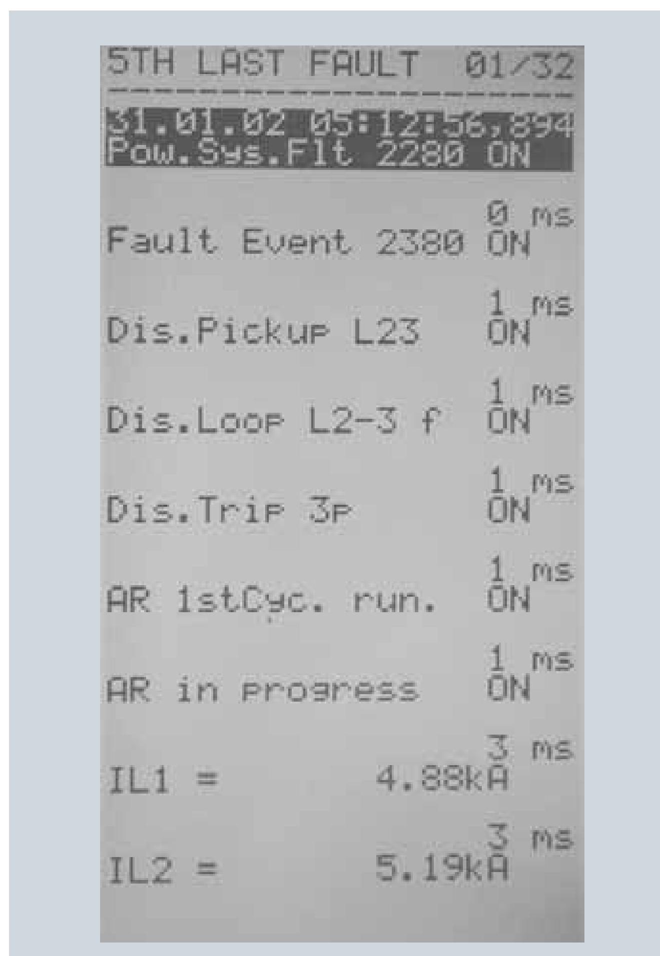


Fig. 6.2-14: **Fault event log on graphical display of the device**

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Display editor
A display editor is available to design the display on SIPROTEC 4 units with graphic display. The predefined symbol sets can be expanded to suit the user. The drawing of a single-line diagram is extremely simple. Load monitoring values (analog values) and any texts or symbols can be placed on the display where required.

Four predefined setting groups for adapting relay settings
The settings of the relays can be adapted quickly to suit changing network configurations. The relays include four setting groups that can be predefined during commissioning or even changed remotely via a DIGSI 4 modem link. The setting groups can be activated via binary inputs, via DIGSI 4 (local or remote), via the integrated keypad or via the serial substation control interface.

Fault recording up to five or more seconds
The sampled values for phase currents, earth (ground) currents, line and zero-sequence currents are registered in a fault record. The record can be started using a binary input, on pickup or when a trip command occurs. Up to eight fault records may be stored. For test purposes, it is possible to start fault recording via DIGSI 4. If the storage capacity is exceeded, the oldest fault record in each case is overwritten (fig. 6.2-15).

For protection functions with long delay times in generator protection, the RMS value recording is available. Storage of relevant calculated variables (V1, VE, I1, I2, IEE, P, Q, f-fn) takes place at increments of one cycle. The total time is 80 s.

Time synchronization
A battery-backed clock is a standard component and can be synchronized via a synchronization signal (DCF77, IRIG B via satellite receiver), binary input, system interface or SCADA (e.g., SICAM). A date and time is assigned to every indication.

Selectable function keys
Four function keys can be assigned to permit the user to perform frequently recurring actions very quickly and simply.

Typical applications are, for example, to display the list of operating indications or to perform automatic functions such as "switching of circuit-breaker."

Continuous self-monitoring
The hardware and software are continuously monitored. If abnormal conditions are detected, the unit immediately signals. In this way, a great degree of safety, reliability and availability is achieved.

Reliable battery monitoring
The battery provided is used to back up the clock, the switching statistics, the status and fault indications, and the fault recording in the event of a power supply failure. Its function is checked by the processor at regular intervals. If the capacity of the battery is found to be declining, an alarm is generated. Regular replacement is therefore not necessary.

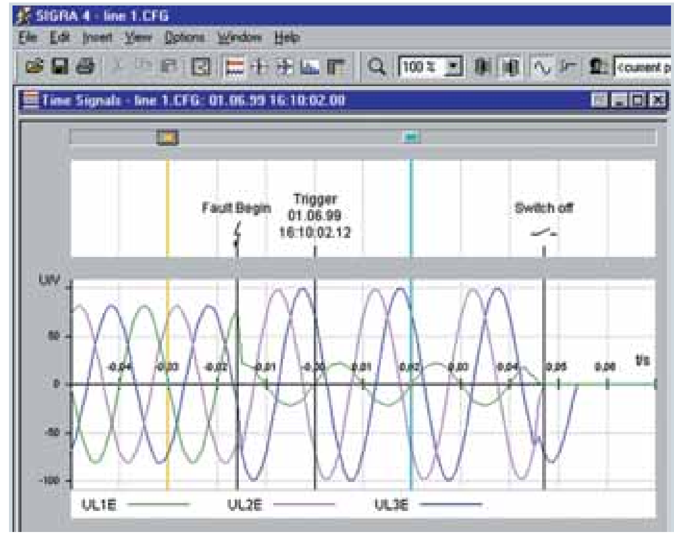

Fig. 6.2-15: **Display and evaluation of a fault record using SIGRA**

All setting parameters are stored in the Flash EPROM and are not lost if the power supply or battery fails. The SIPROTEC 4 unit remains fully functional.

Commissioning support
Special attention has been paid to commissioning. All binary inputs and output contacts can be displayed and activated directly. This can significantly simplify the wiring check for the user. Test telegrams to a substation control system can be initiated by the user as well.

CFC: Programming logic
With the help of the CFC (Continuous Function Chart) graphic tool, interlocking schemes and switching sequences can be configured simply via drag and drop of logic symbols; no special knowledge of programming is required. Logical elements, such as AND, OR, flip-flops and timer elements are available. The user can also generate user-defined annunciations and logical combinations of internal or external signals (fig. 6.2-16).

Communication interfaces
With respect to communication, particular emphasis has been placed on high levels of flexibility, data integrity and utilization of standards commonly used in energy automation. The design of the communication modules permits interchangeability on the one hand, and on the other hand provides openness for future standards.

Local PC interface
The PC interface accessible from the front of the unit permits quick access to all parameters and fault event data. Of particular advantage is the use of the DIGSI 4 operating program during commissioning.

Retrofitting: Communication modules
It is possible to supply the relays directly with two communication modules for the service and substation control interfaces or to retrofit the communication modules at a later stage. The modules are mounted on the rear side of the relay. As a standard, the time synchronization interface is always supplied.

The communication modules are available for the entire SIPROTEC 4 relay range. Depending on the relay type, the following protocols are available: IEC 60870-5-103, PROFIBUS DP, MODBUS RTU, DNP 3.0 and Ethernet with IEC 61850 (for some relays). No external protocol converter is required (fig. 6.2-17 to fig.6.2-21).

With respect to communication, particular emphasis is placed on the requirements in energy automation:

- Every data item is time-stamped at the source, that is, where it originates.
- The communication system automatically handles the transfer of large data blocks (e.g., fault records or parameter data files). The user can apply these features without any additional programming effort.
- For reliable execution of a command, the relevant signal is first acknowledged in the unit involved. When the command has been enabled and executed, a check-back indication is issued. The actual conditions are checked at every command-handling step. Whenever they are not satisfactory, controlled interruption is possible.

Safe bus architecture

- Fiber-optic double ring circuit via Ethernet
  The fiber-optic double ring circuit is immune to electromagnetic interference. Upon failure of a section between two units, the communication system continues to operate without interruption. If a unit were to fail, there is no effect on the communication with the rest of the system (fig. 6.2-22).
- RS485 bus
  With this data transmission via copper conductors, electromagnetic interference is largely eliminated by the use of twisted-pair conductors. Upon failure of a unit, the remaining system continues to operate without any faults (fig. 6.2-23).
- Star structure
  The relays are connected with a fiber-optic cable with a star structure to the control unit. The failure of one relay/connection does not affect the others (fig. 6.2-24).

Depending on the relay type, the following protocols are available:

- IEC 61850 protocol
  Since 2004, the Ethernet-based IEC 61850 protocol is the worldwide standard for protection and control systems used by power supply corporations. Siemens is the first manufacturer to support this standard. By means of this protocol, information can also be exchanged directly between feeder units so as to set up simple masterless systems for feeder and system interlocking. Access to the units via the Ethernet bus will also be possible with DIGSI.

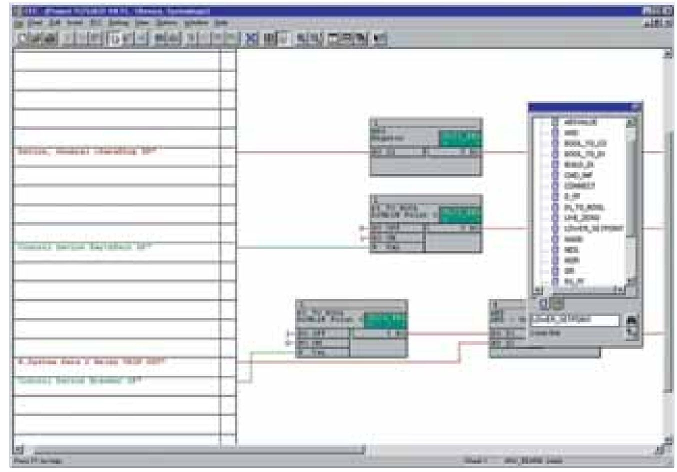

Fig. 6.2-16: **CFC logic with module library**

Fig. 6.2-17: **Protection relay**

Fig. 6.2-18: **Communication module, optical**

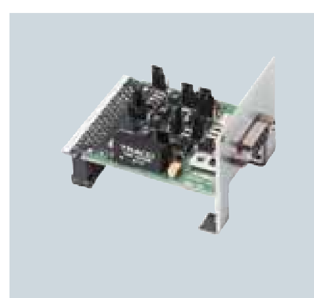

Fig. 6.2-19: **Communication module RS232,RS485**

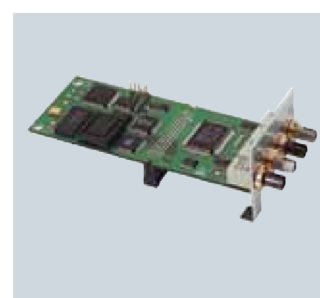

Fig. 6.2-20: **Communication module, optical, double-ring**

- IEC 60870-5-103
  IEC 60870-5-103 is an internationally standardized protocol for efficient communication between the protection relays and the central unit. Specific extensions that are published by Siemens can be used.

The following interfaces can be applied:

❶ **Service interface (optional)**
Several protection relays can be centrally operated with DIGSI 4, e.g., via a star coupler or RS485 bus. On connection of a modem, remote control is possible. This provides advantages in fault clearance, particularly in unmanned power stations. (Alternatively, the external temperature monitoring box can be connected to this interface.)

❷ **System interface (optional)**
This is used to carry out communication with a control system and supports, depending on the module connected, a variety of communication protocols and interface designs.

❸ **Time synchronization interface**
A synchronization signal (DCF 77, IRIG B via satellite receiver) may be connected to this input if no time synchronization is executed on the system interface. This offers a high-precision time tagging.

Fig. 6.2-21: **Rear view with wiring, terminal safety cover and serial interfaces**

- PROFIBUS DP
  For connection to a SIMATIC PLC, the PROFIBUS DP protocol is recommended. With the PROFIBUS DP, the protection relay can be directly connected to a SIMATIC S5/S7. The transferred data are fault data, measured values and control commands.

Master control unit

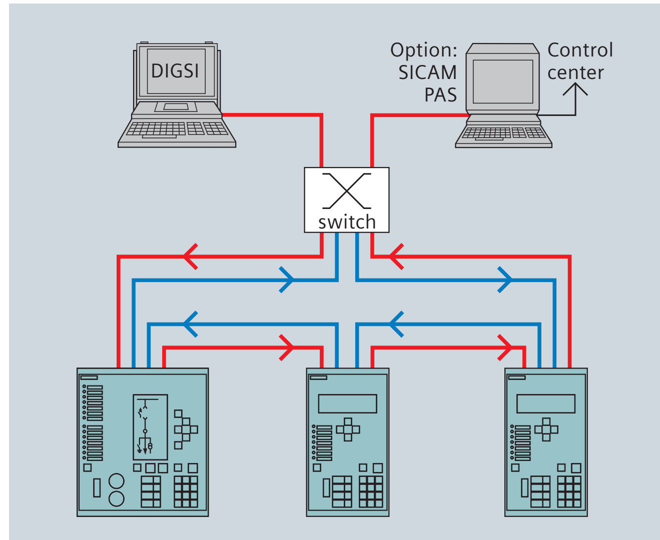

Fig. 6.2-22: **Bus structure for station bus with Ethernet and IEC 61850**

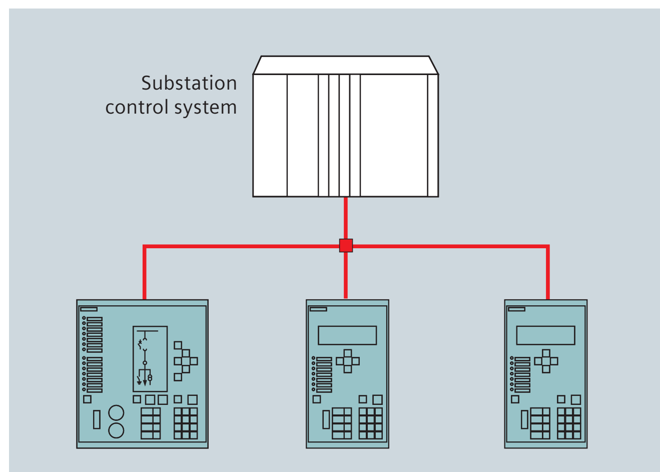

Fig. 6.2-23: **PROFIBUS: Electrical RS485 bus wiring**

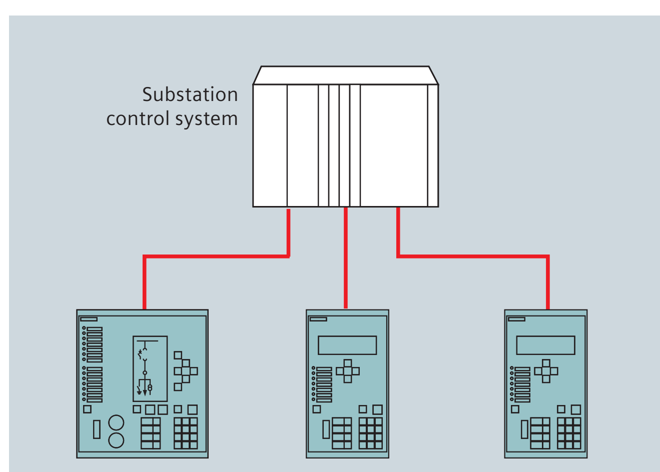

Fig. 6.2-24: **IEC 60870-5-103: Star structure with fiber-optic cables**

MODBUS RTU
MODBUS is also a widely utilized communication standard and is used in numerous automation solutions.

DNP 3.0
DNP 3.0 (Distributed Network Protocol, version 3) is a messaging-based communication protocol. The SIPROTEC 4 units are fully Level 1 and Level 2-compliant with DNP 3.0, which is supported by a number of protection unit manufacturers.

Control
In addition to the protection functions, the SIPROTEC 4 units also support all control and monitoring functions required for operating medium-voltage or high-voltage substations. The main application is reliable control of switching and other processes. The status of primary equipment or auxiliary devices can be obtained from auxiliary contacts and communicated to the relay via binary inputs.

Therefore, it is possible to detect and indicate both the OPEN and CLOSED positions or a faulty or intermediate breaker position. The switchgear can be controlled via:

- Integrated operator panel
- Binary inputs
- Substation control system
- DIGSI 4

Automation
With the integrated logic, the user can set specific functions for the automation of the switchgear or substation by means of a graphic interface (CFC). Functions are activated by means of function keys, binary inputs or via the communication interface.

Switching authority
The following hierarchy of switching authority is applicable: LOCAL, DIGSI 4 PC program, REMOTE. The switching authority is determined according to parameters or by DIGSI 4. If the LOCAL mode is selected, only local switching operations are possible. Every switching operation and change of breaker position is stored in the status indication memory with detailed information and time tag.

Command processing
The SIPROTEC 4 protection relays offer all functions required for command processing, including the processing of single and double commands, with or without feedback, and sophisticated monitoring. Control actions using functions, such as runtime monitoring and automatic command termination after output check of the external process, are also provided by the relays. Typical applications are:

- Single and double commands using 1, 1 plus 1 common or 2 trip contacts
- User-definable feeder interlocking
- Operating sequences combining several switching operations, such as control of circuit-breakers, disconnectors (isolators) and earthing switches
- Triggering of switching operations, indications or alarms by logical combination of existing information (fig. 6.2-25).

Fig. 6.2-25: **Protection engineer at work**

The positions of the circuit-breaker or switching devices are monitored by feedback signals. These indication inputs are logically assigned to the corresponding command outputs. The unit can therefore distinguish whether the indication changes as a consequence of a switching operation or due to a spontaneous change of state.

Indication derivation
A further indication (or a command) can be derived from an existing indication. Group indications can also be formed. The volume of information to the system interface can thus be reduced and restricted to the most important signals.

SIPROTEC '600 relays
SIPROTEC '600 relays are available in ⅙ of 19" wide housings with a standard height of 243 mm.

Their size is compatible with that of the SIPROTEC 3 and 4 families. Therefore, mixed installations are always possible. Versions for flush mounting and for surface mounting are available.

All wires (cables) are connected at the rear side of the relay via ring cable lugs (fig. 6.2-26).

SIPROTEC '80 relays
SIPROTEC '80 relays are available in ⅙ of 19" wide housings with a standard height of 243 mm. Their size is compatible with that of other relay families. Therefore, compatible exchange is always possible. Versions for flush mounting and for surface mounting are available.

All protection wires are connected at the rear side of the relay. The remote communication interfaces are located at the bottom of the relay.

Besides the SIPROTEC 4 features, the SIPROTEC ’80 relays offer the following design benefits:

- Illuminated 6-line display
- Numerical keypad
- 8 configurable LEDs
- 9 function keys
- USB front port
- Two control keys
- Battery cover

Pluggable current and voltage terminal blocks
Panel builders may complete and test the whole wiring without mounting the devices. Furthermore, the device can be replaced simply and securely because the terminal blocks – and therefore the whole wiring – can remain. The risk of open secondary circuits does not exist because the current transformers are integrated into the terminal block.

Terminals

USB front port
The USB front port offers modern and fast communication via the configuration and operation software DIGSI 4.

Adaption to substation environment
The secondary CT rated current IN (1A or 5A) and all binary input thresholds are set via address. Therefore, it is not necessary to open the device. Jumpers are no longer needed.

Remote Ethernet service interface (Port A)
The Ethernet interface was designed for fast access to a number of protection units via DIGSI. For motor protection devices, it is also possible to connect up to two external temperature monitoring boxes (RTD box for Ethernet) with a total of twelve measuring sensors to the Ethernet service interface.

System/service interface (Port B)
The following communication modules are available:

- IEC 61850: electrical double ring or optical double ring
- IEC 60870-5-103: RS232, RS485; RS485 redundant or optical
- PROFIBUS DP: RS485 or optical double ring
- MODBUS: RS485 or optical
- DNP 3.0: RS485 or optical

Current terminals – ring cable lugs	
Connection	W_{max} = 9.5 mm
Ring cable lugs	*d1* = 4.3 – 5.2 mm
Wire size	2.6 – 5.2 mm² (AWG 13 – 10)
Current terminals – single conductors	
Conductor cross-section	2.0 – 4.0 mm² (AWG 14 – 11)
Insulation stripping length	15 mm
Voltage terminals – single conductors	
Conductor cross-section	0.5 – 2.5 mm² (AWG 20 – 13)
Insulation stripping length	12 mm

Fig. 6.2-26: **SIPROTEC compact overcurrent relay**

Fig. 6.2-27: **Rear view**

Fig. 6.2-28: **Voltage terminals**

Fig. 6.2-29: **Current terminals**

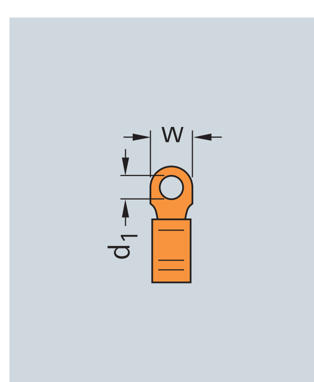

Fig. 6.2-30: **Ring cable lug**

6.2.3 Typical Protection Schemes

1. Cables and overhead lines

Radial systems

Notes:

1) Auto-reclosure (ANSI 79) only with overhead lines.
2) Negative sequence overcurrent protection 46 as sensitive backup protection against asymmetrical faults.

General notes:

- The relay at the far end (D) is set with the shortest operating time. Relays further upstream have to be time-graded against the next downstream relay in steps of about 0.3 s.
- Inverse time or definite time can be selected according to the following criteria:
  - Definite time:
    Source impedance is large compared to the line impedance, that is, there is small current variation between near and far end faults.
  - Inverse time:
    Longer lines, where the fault current is much less at the far end of the line than at the local end.
  - Strong or extreme inverse-time:
    Lines where the line impedance is large compared to the source impedance (high difference for close-in and remote faults), or lines where coordination with fuses or reclosers is necessary. Steeper characteristics also provide higher stability on service restoration (cold load pickup and transformer inrush currents).

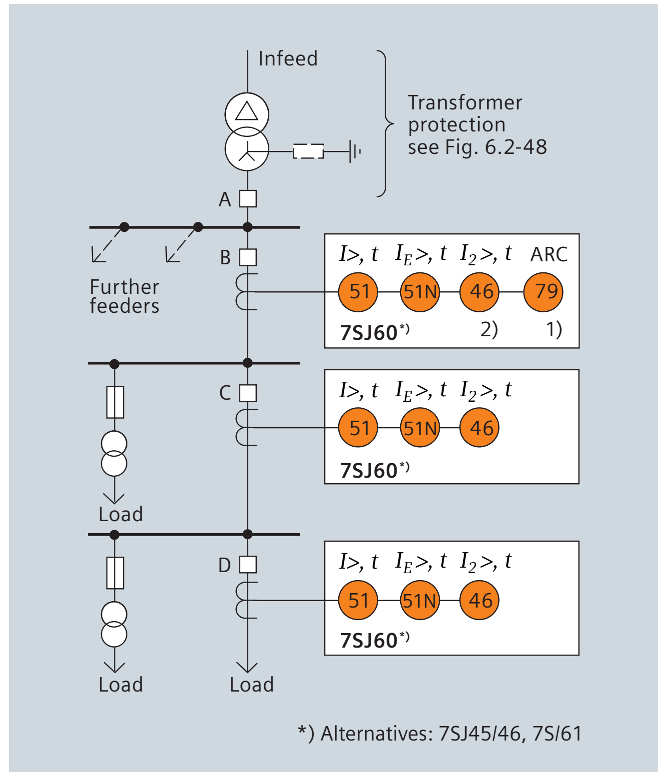

Fig. 6.2-31: **Radial systems**

Ring-main circuit

General notes:

- Operating time of overcurrent relays to be coordinated with downstream fuses of load transformers (preferably with strong inverse-time characteristic with about 0.2 s grading-time delay)
- Thermal overload protection for the cables (option)
- Negative sequence overcurrent protection (46) as sensitive protection against asymmetrical faults (option)

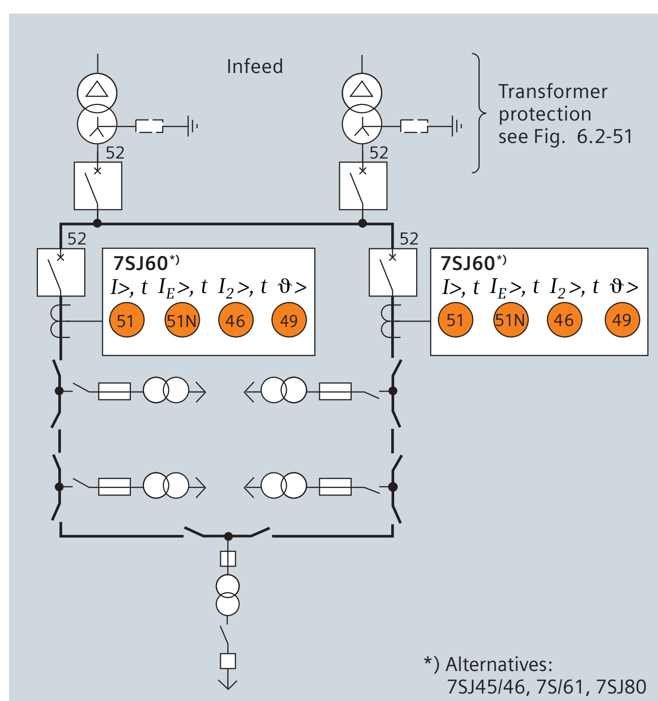

Fig. 6.2-32: **Ring-main circuit**

Switch-onto-fault protection

If switched onto a fault, instantaneous tripping can be effected. If the internal control function is used (local, via binary input or via serial interface), the manual closing function is available without any additional wiring. If the control switch is connected to a circuit-breaker bypassing the internal control function, manual detection using a binary input is implemented.

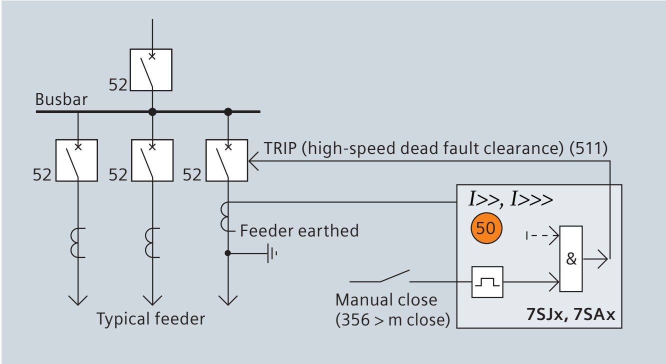

Fig. 6.2-33: **Switch-onto-fault protection**

Directional comparison protection (cross-coupling)

Cross-coupling is used for selective protection of sections fed from two sources with instantaneous tripping, that is, without the disadvantage of time coordination. The directional comparison protection is suitable if the distances between the protection stations are not significant and pilot wires are available for signal transmission. In addition to the directional comparison protection, the directional coordinated time-overcurrent protection is used for complete selective backup protection. If operated in a closed-circuit connection, an interruption of the transmission line is detected.

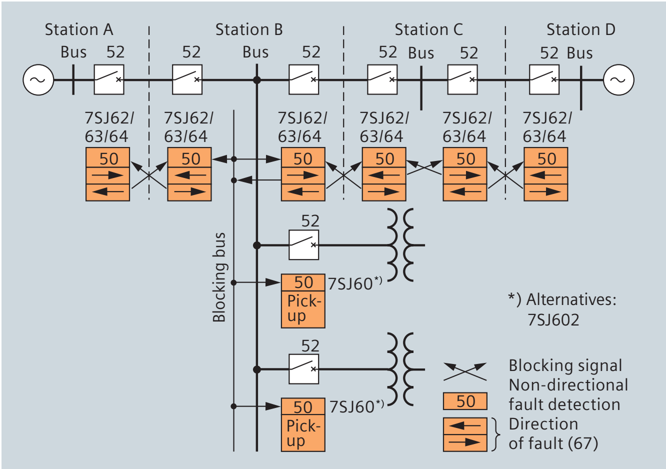

Fig. 6.2-34: **Directional comparison protection**

Distribution feeder with reclosers

General notes:

- The feeder relay operating characteristics, delay times and auto-reclosure cycles must be carefully coordinated with downstream reclosers, sectionalizers and fuses.
  The 50/50N instantaneous zone is normally set to reach out to the first main feeder sectionalizing point. It has to ensure fast clearing of close-in faults and prevent blowing of fuses in this area ("fuse saving"). Fast auto-reclosure is initiated in this case. Further time-delayed tripping and reclosure steps (normally two or three) have to be graded against the recloser.
- The overcurrent relay should automatically switch over to less sensitive characteristics after long breaker interruption times in order to enable overriding of subsequent cold load pickup and transformer inrush currents.

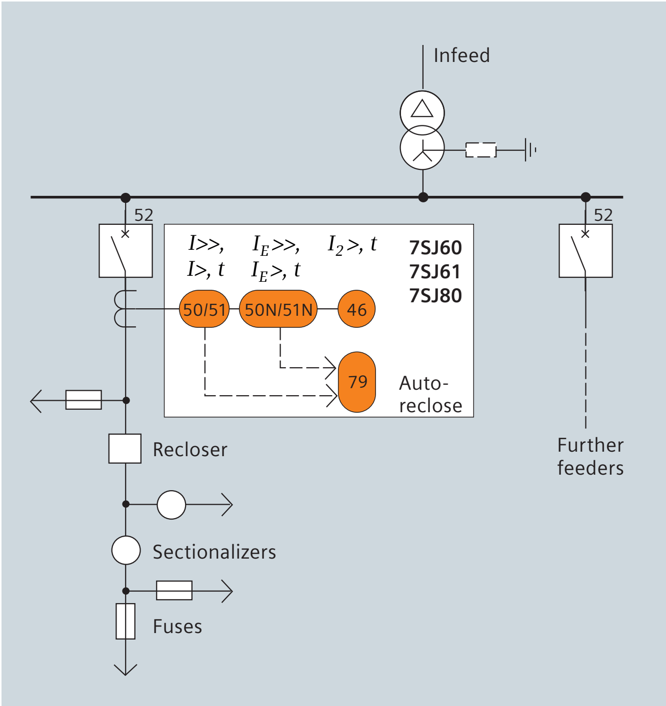

Fig. 6.2-35: **Distribution feeder with reclosers**

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3-pole multishot auto-reclosure (AR, ANSI 79)
Auto-reclosure (AR) enables 3-phase auto-reclosing of a feeder that has previously been disconnected by overcurrent protection.

The SIPROTEC 7SJ61 allows up to nine reclosing shots. The first four dead times can be set individually. Reclosing can be blocked or initiated by a binary input or internally. After the first trip in a reclosing sequence, the high-set instantaneous elements ($I>>>$, $I>>$, $I_E>>$) can be blocked. This is used for fuse-saving applications and other similar transient schemes using simple overcurrent relays instead of fuses. The low-set definite-time ($I>$, $I_E>$) and the inverse-time (I_p, I_{Ep}) overcurrent elements remain operative during the entire sequence.

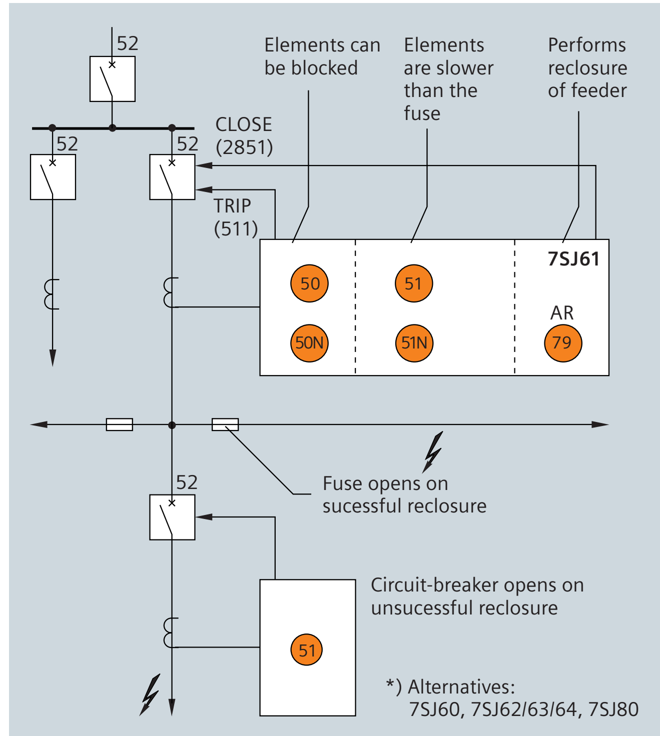


Fig. 6.2-36: **3-pole multishot auto-reclosure (AR, ANSI 79)**

Parallel feeder circuit

General notes:

- The preferred application of this circuit is in the reliable supply of important consumers without significant infeed from the load side.
- The 67/67N directional overcurrent protection trips instantaneously for faults on the protected line. This saves one time-grading interval for the overcurrent relays at the infeed.
- The 51/51N overcurrent relay functions must be time-graded against the relays located upstream.

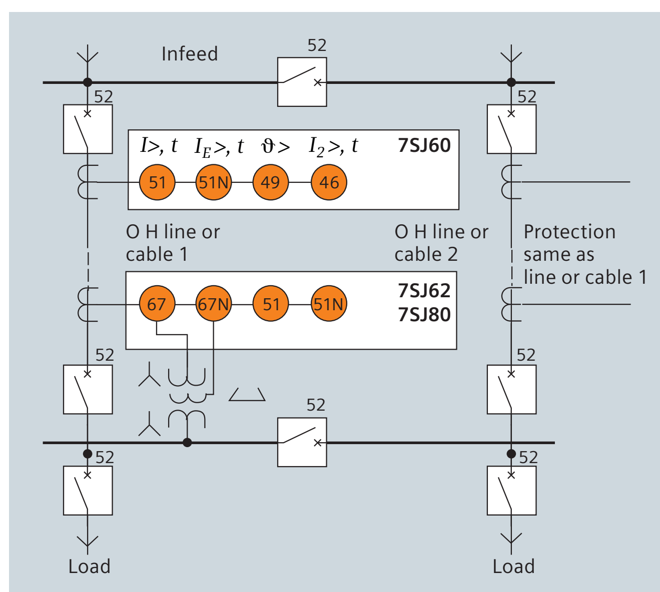


Fig. 6.2-37: **Parallel feeder circuit**

Reverse-power monitoring at double infeed

If a busbar is fed from two parallel infeeds and a fault occurs on one of them, only the faulty infeed should be tripped selectively in order to enable supply to the busbar to continue from the remaining supply. Unidirectional devices that can detect a short-circuit current or energy flow from the busbar toward the incoming feeder should be used. Directional time-overcurrent protection is usually set via the load current. However, it cannot clear weak-current faults. The reverse-power protection can be set much lower than the rated power, thus also detecting the reverse-power flow of weak-current faults with fault currents significantly below the load current.

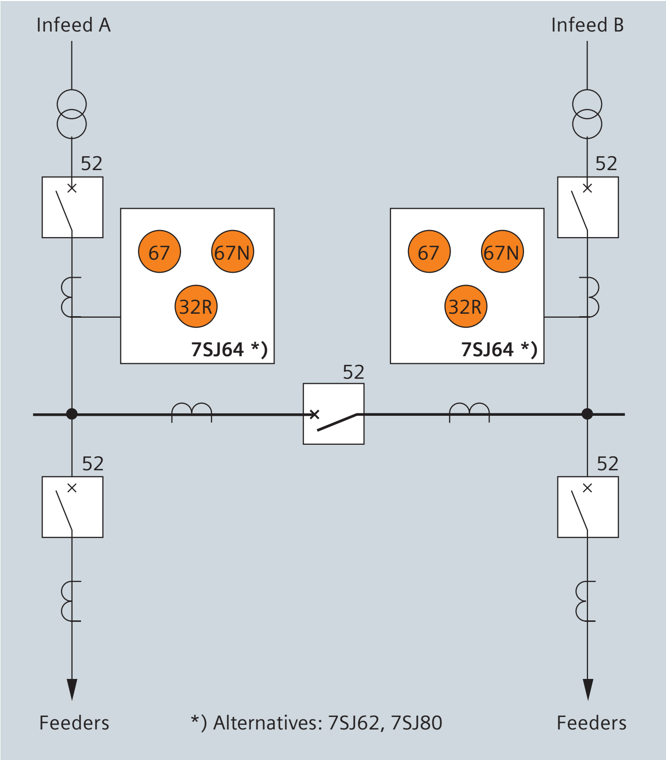


Fig. 6.2-38: **Reverse-power monitoring at double infeed**

Synchronization function

Note:
Also available in relays 7SA6, 7SD5, 7SA522, 7VK61.

General notes:
- When two subnetworks must be interconnected, the synchronization function monitors whether the subnetworks are synchronous and can be connected without risk of losing stability.
- This synchronization function can be applied in conjunction with the auto-reclosure function as well as with the control function CLOSE commands (local/remote).

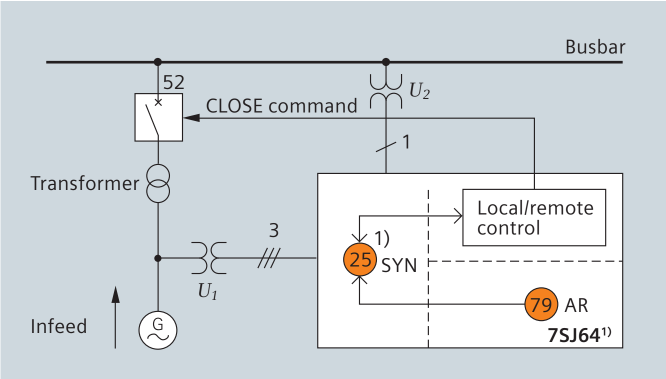


Fig. 6.2-39: **Synchronization function**

Cables or short overhead lines with infeed from both ends

Notes:

1) Auto-reclosure only with overhead lines

2) Differential protection options:

- Type 7SD5 or 7SD610 with direct fiber-optic connection up to about 100 km or via a 64 kbit/s channel (optical fiber, microwave)
- Type 7SD52 or 7SD610 with 7XV5662 (CC-CC) with 2 and 3 pilot wires up to about 30 km
- Type 7SD600 with 2 pilot wires up to 12 km 7SD600 is a cost-effective solution where only the function 87L is required (external current summation transformer 4AM4930 delivered separately).

3) Functions 49 and 79 only with 7SD5 and 7SD610 relays.

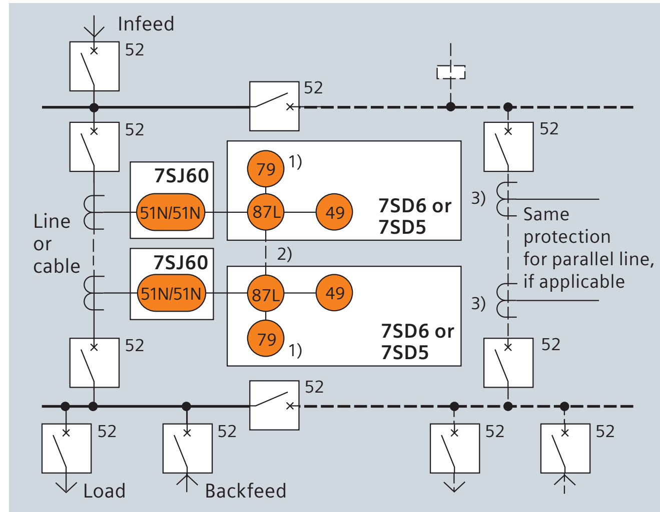


Fig. 6.2-40: **Cables or short overhead lines with infeed from both ends**

Overhead lines or longer cables with infeed from both ends

Notes:

1) Teleprotection logic (85) for transfer trip or blocking schemes. Signal transmission via pilot wire, power line carrier, digital network or optical fiber (to be provided separately). The teleprotection supplement is only necessary if fast fault clearance on 100 % line length is required, that is, second zone tripping (about 0.3 s delay) cannot be accepted for far end faults. For further application notes on teleprotection schemes, refer to the table on the following page.

2) Directional earth-fault protection 67N with inverse-time delay against high-resistance faults

3) Single or multishot auto-reclosure (79) only with overhead lines.

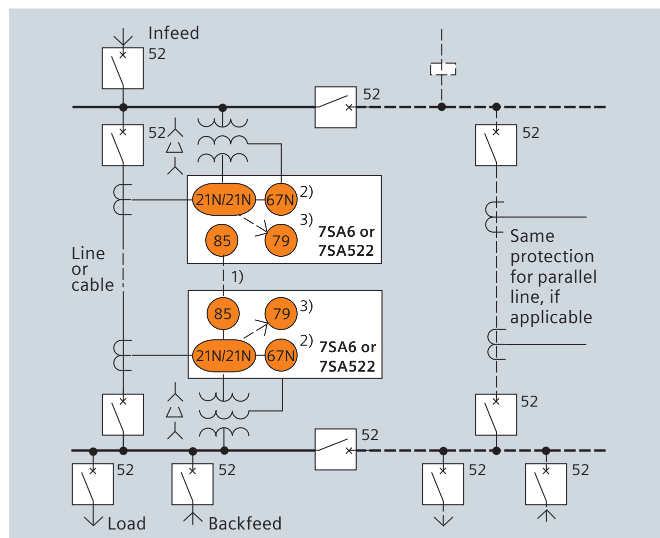


Fig. 6.2-41: **Overhead lines or longer cables with infeed from both ends**

6

Subtransmission line

Note:

Connection to open delta winding if available. Relays 7SA6/522 and 7SJ62 can, however, also be set to calculate the zero-sequence voltage internally.

General notes:

- Distance teleprotection is proposed as main protection and time-graded directional overcurrent as backup protection.
- The 67N function of 7SA6/522 provides additional high-resistance earth-fault protection. It can be used in parallel with the 21/21N function.
- Recommended teleprotection schemes: PUTT on medium and long lines with phase shift carrier or other secure communication channel POTT on short lines. BLOCKING with On/Off carrier (all line lengths).

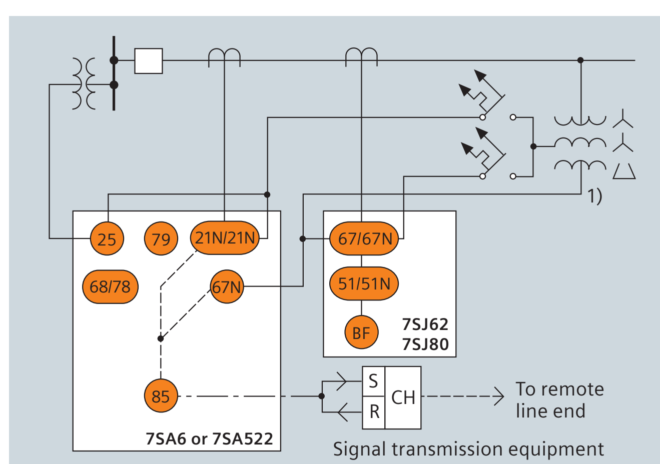


Fig. 6.2-42: **Subtransmission line**

		Permissive underreach transfer trip (PUTT)	Permissive overreach transfer trip (POTT)	Blocking	Unblocking
Preferred application	Signal transmission system	Dependable and secure communication channel: • Power line carrier with frequency shift modulation. HF signal coupled to 2 phases of the protected line, or even better, to a parallel circuit to avoid transmission of the HF signal through the fault location. • Microwave radio, especially digital (PCM) • Fiber-optic cables		Reliable communication channel (only required during external faults) • Power line carrier with amplitude modulation (ON/OFF). The same frequency may be used on all terminals)	Dedicated channel with continuous signal transfer • Power line carrier with frequency shift keying. Continuous signal transmission must be permitted.
	Characteristic of line	Best suited for longer lines – where the underreach zone provides sufficient resistance coverage	• Excellent coverage on short lines in the presence of fault resistance. • Suitable for the protection of multi-terminal lines with intermediate infeed	All line types – preferred practice in the US	Same as POTT
Advantages		• Simple technique • No coordination of zones and times with the opposite end required. The combination of different relay types therefore presents no problems	• Can be applied without underreaching zone 1 stage (e.g., overcompensated series uncompensated lines) • Can be applied on extremely reshort lines (impedance less than minimum relay setting) • Better for parallel lines as mutual coupling is not critical for the overreach zone • Weak infeed terminals are no problem (Echo and Weak Infeed logic is included)	Same as POTT	Same as POTT but: • If no signal is received (no block and no uncompensated block) then tripping by the overreach zone is released after 20 ms
Drawbacks		• Overlapping of the zone 1 reaches must be ensured. On parallel lines, teed feeders and tapped lines, the influence of zero sequence coupling and intermediate infeeds must be carefully considered to make sure a minimum overlapping of the zone 1 reach is always present. • Not suitable for weak infeed terminals	• Zone reach and signal timing coordination with the remote end is necessary (current reversal)	Same as POTT • Slow tripping – all teleprotection trips must be delayed to wait for the eventual blocking signal • Continuous channel monitoring is not possible	Same as POTT

Table 6.2-1: **Application criteria for frequently used teleprotection schemes**

6

Transmission line with reactor (fig. 6.2-43)

Notes:

1) 51N only applicable with earthed reactor neutral.
2) If phase CTs at the low-voltage reactor side are not available, the high-voltage phase CTs and the CT in the neutral can be connected to a restricted earth-fault protection using one 7VH60 high-impedance relay.

General notes:

- Distance relays are proposed as main 1 and main 2 protection. Duplicated 7SA6 is recommended for series-compensated lines.
- Operating time of the distance relays is in the range of 15 to 25 ms depending on the particular fault condition. These tripping times are valid for faults in the underreaching distance zone (80 to 85 % of the line length). Remote end faults must be cleared by the superimposed teleprotection scheme. Its overall operating time depends on the signal transmission time of the channel, typically 15 to 20 ms for frequency shift audio-tone PLC or microwave channels, and lower than 10 ms for ON/OFF PLC or digital PCM signaling via optical fibers. Teleprotection schemes based on distance relays therefore have operating times on the order of 25 to 30 ms with digital PCM coded communication. With state-of-the-art two-cycle circuit-breakers, fault clearing times well below 100 ms (4 to 5 cycles) can normally be achieved.
- Dissimilar carrier schemes are recommended for main 1 and main 2 protection, for example, PUTT, and POTT or Blocking/Unblocking.
- Both 7SA522 and 7SA6 provide selective 1-pole and/or 3-pole tripping and auto-reclosure. The earth-current directional comparison protection (67N) of the 7SA6 relay uses phase selectors based on symmetrical components. Thus, 1-pole auto-reclosure can also be executed with high-resistance faults. The 67N function of the 7SA522 relay can also be used as time-delayed directional overcurrent backup.
- The 67N functions are provided as high-impedance fault protection. 67N is often used with an additional channel as a separate carrier scheme. Use of a common channel with distance protection is only possible if the mode is compatible (e.g., POTT with directional comparison). The 67N may be blocked when function 21/21N picks up. Alternatively, it can be used as time-delayed backup protection.

6

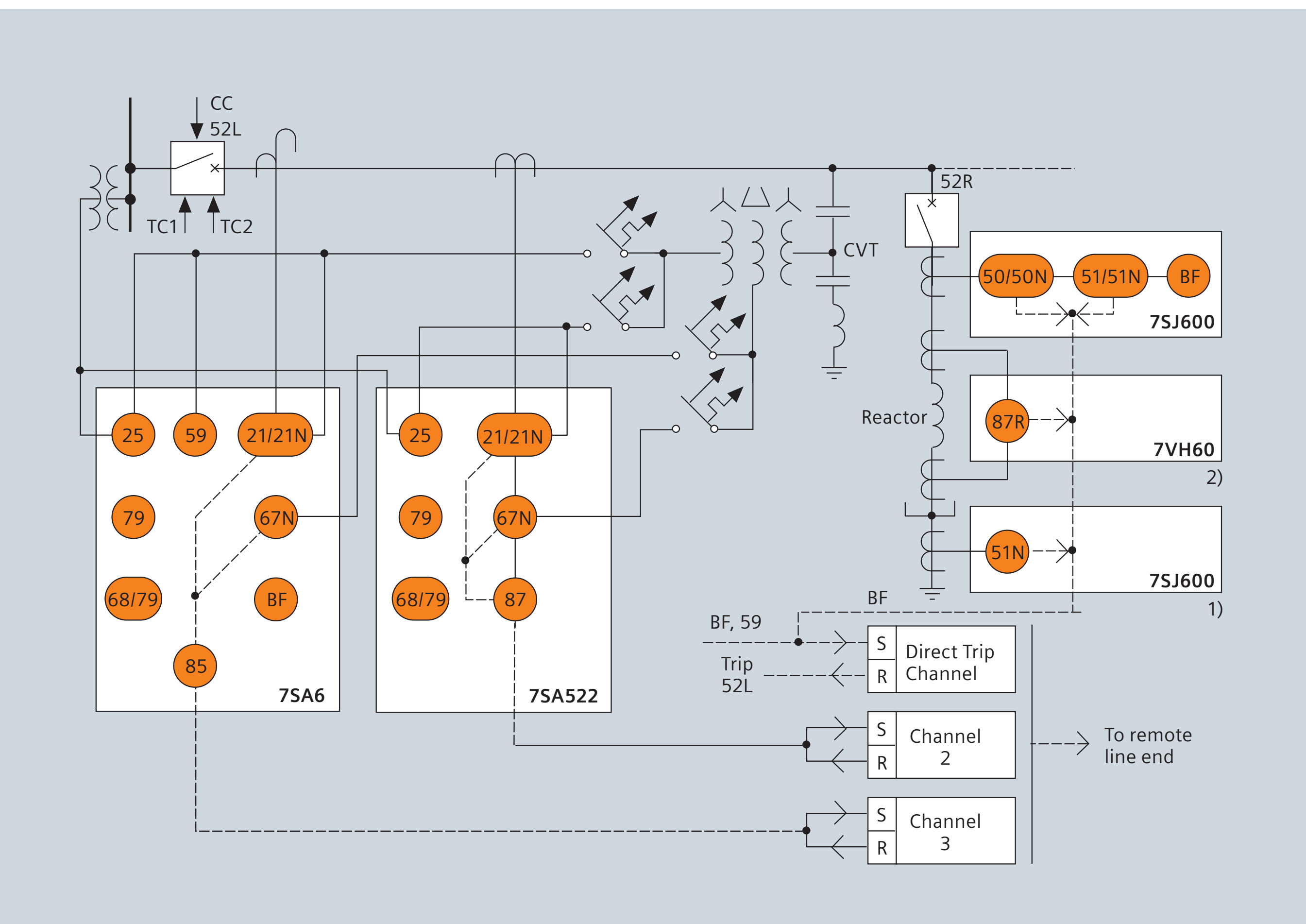


Fig. 6.2-43: **Transmission line with reactor**

Transmission line or cable (with wide-band communication)

General notes:

- Digital PCM-coded communication (with n x 64 kbit/s channels) between line ends is becoming more and more frequently available, either directly by optical or microwave point-to-point links, or via a general-purpose digital communication network.
  In both cases, the relay-type current differential protection 7SD52/61 can be applied. It provides absolute phase and zone selectivity by phase-segregated measurement and is not affected by power swing or parallel line zero-sequence coupling effects. It is, furthermore, a current-only protection that does not need a VT connection. For this reason, the adverse effects of CVT transients are not applicable.
  This makes it particularly suitable for double and multi-circuit lines where complex fault situations can occur.
  The 7SD5/61 can be applied to lines up to about 120 km in direct relay-to-relay connections via dedicated optical fiber cores (see also application 10), and also to much longer distances of up to about 120 km by using separate PCM devices for optical fiber or microwave transmission.
  The 7SD5/61 then uses only a small part (64-512 64 kbit/s) of the total transmission capacity (on the order of Mbits/s).
- The 7SD52/61 protection relays can be combined with the distance relay 7SA52 or 7SA6 to form a redundant protection system with dissimilar measuring principles complementing each other (fig. 6.2-44). This provides the highest degree of availability. Also, separate signal transmission ways should be used for main 1 and main 2 line protection, e.g., optical fiber or microwave, and power line carrier (PLC).
  The current comparison protection has a typical operating time of 15 ms for faults on 100 % line length, including signaling time.

General notes for fig. 6.2-45:

- SIPROTEC 7SD5 offers fully redundant differential and distance relays accommodated in one single bay control unit and provides both high-speed operation of relays and excellent fault coverage, even under complicated conditions. Precise distance-to-fault location avoids time-consuming line patrolling and reduces the downtime of the line to a minimum.
  The high-speed distance relay operates fully independently from the differential relay. Backup zones provide remote backup for upstream and downstream lines and other power system components

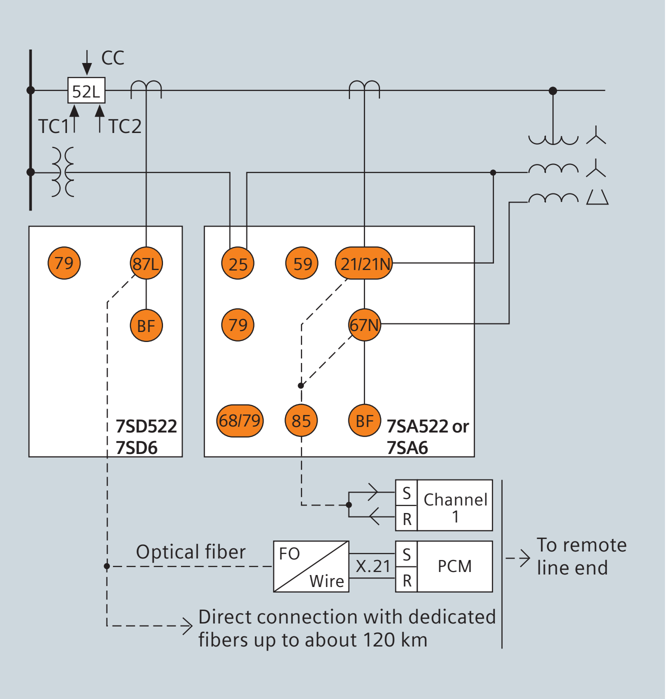


Fig. 6.2-44: **Redundant transmission line protection**

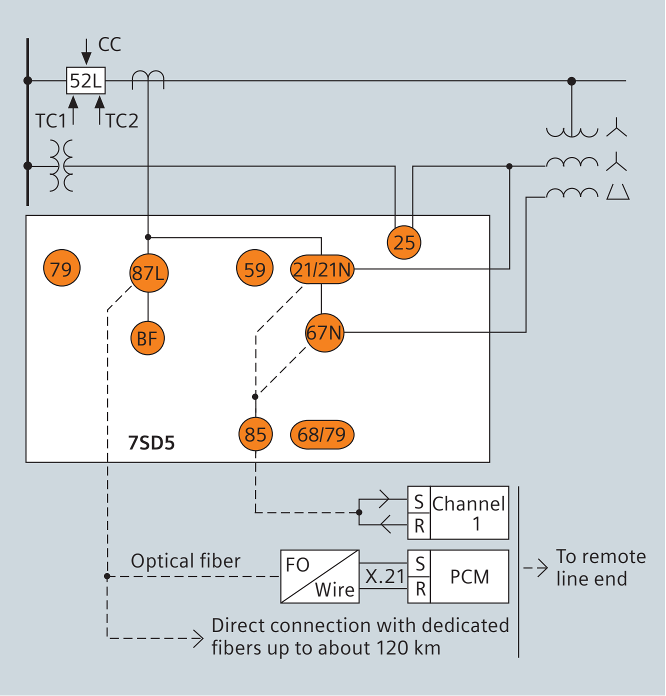


Fig. 6.2-45: **Transmission line protection with redundant algorithm in one device**

6

Transmission line, breaker-and-a-half terminal

Notes:

1) When the line is switched off and the line line disconnector (isolator) is open, high through-fault currents in the diameter may cause maloperation of the distance relay due to unequal CT errors (saturation).
   Normal practice is therefore to block the distance protection (21/21N) and the directional earth-fault protection (67N) under this condition via an auxiliary contact of the line line disconnector (isolator). A standby overcurrent function (50/51N, 51/51N) is released instead to protect the remaining stub between the breakers ("stub" protection).
2) Overvoltage protection only with 7SA6/52.

General notes:

- The protection functions of one diameter of a breaker-and-a-half arrangement are shown.
- The currents of two CTs have each to be summed up to get the relevant line currents as input for main 1 and 2 line protection.
  The location of the CTs on both sides of the circuit-breakers is typical for substations with dead-tank circuit-breakers. Live-tank circuit-breakers may have CTs only on one side to reduce cost. A fault between circuit-breakers and CT (end fault) may then still be fed from one side even when the circuit-breaker has opened. Consequently, final fault clearing by cascaded tripping has to be accepted in this case.
  The 7VK61 relay provides the necessary end fault protection function and trips the circuit-breakers of the remaining infeeding circuits.

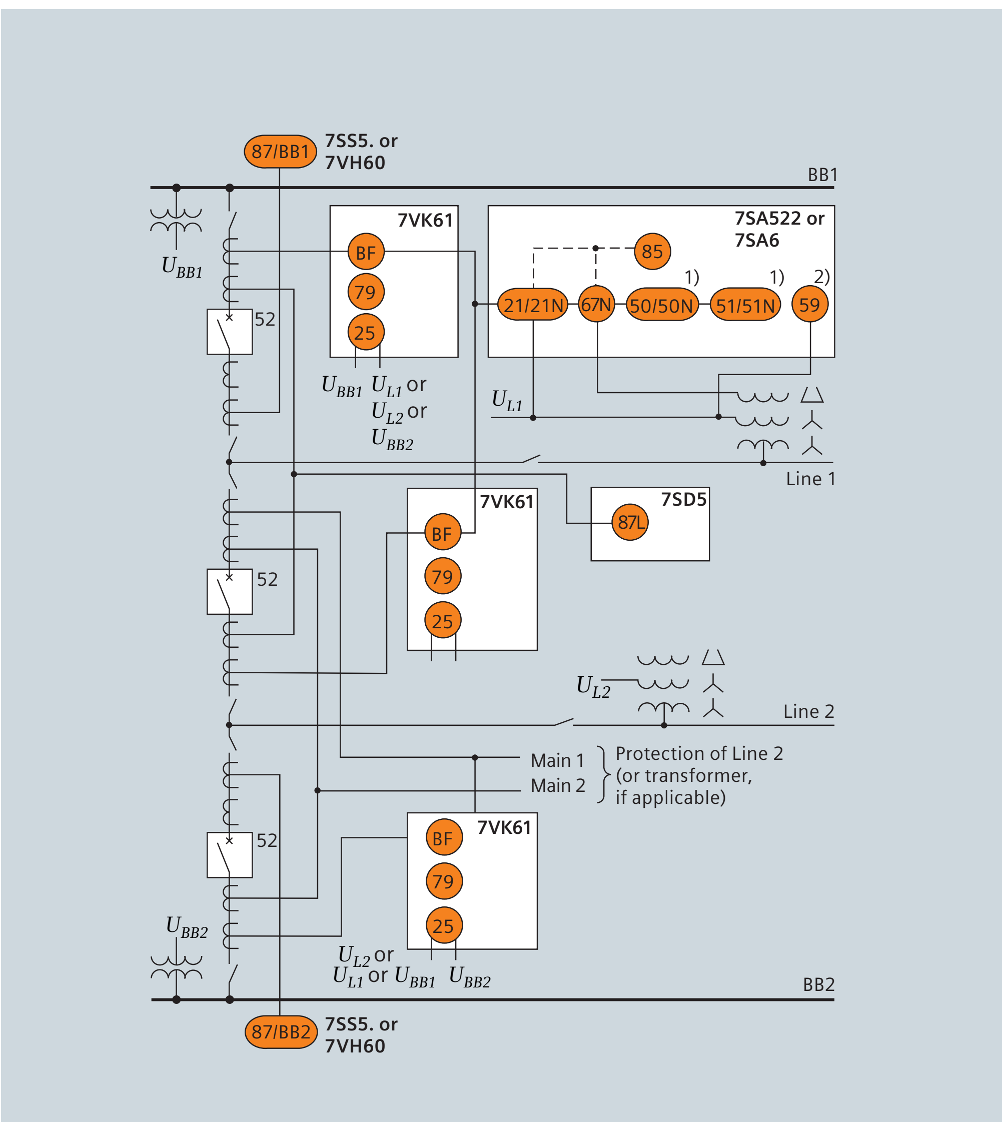


Fig. 6.2-46: **Transmission line, breaker-and-a-half terminal, using 3 breaker management relays 7VK61**

General notes for fig. 6.2-46 and 6.2-47:

- For the selection of the main 1 and main 2 line protection schemes, the comments of application examples 6.2-41 and 6.2-42 apply.
- Auto-reclosure (79) and synchrocheck function (25) are each assigned directly to the circuit-breakers and controlled by main 1 and 2 line protection in parallel. In the event of a line fault, both adjacent circuit-breakers have to be tripped by the line protection. The sequence of auto-reclosure of both circuit-breakers or, alternatively, the auto-reclosure of only one circuit-breaker and the manual closure of the other circuit-breaker, may be made selectable by a control switch.
- A coordinated scheme of control circuits is necessary to ensure selective tripping interlocking and reclosing of the two circuit-breakers of one line (or transformer feeder).
- The voltages for synchrocheck have to be selected according to the circuit-breaker and disconnector (isolator) position by a voltage replica circuit.

General notes for fig. 6.2-47:

- In this optimized application, the 7VK61 is only used for the center breaker. In the line feeders, functions 25, 79 and BF are also performed by transmission line protection 7SA522 or 7SA6.

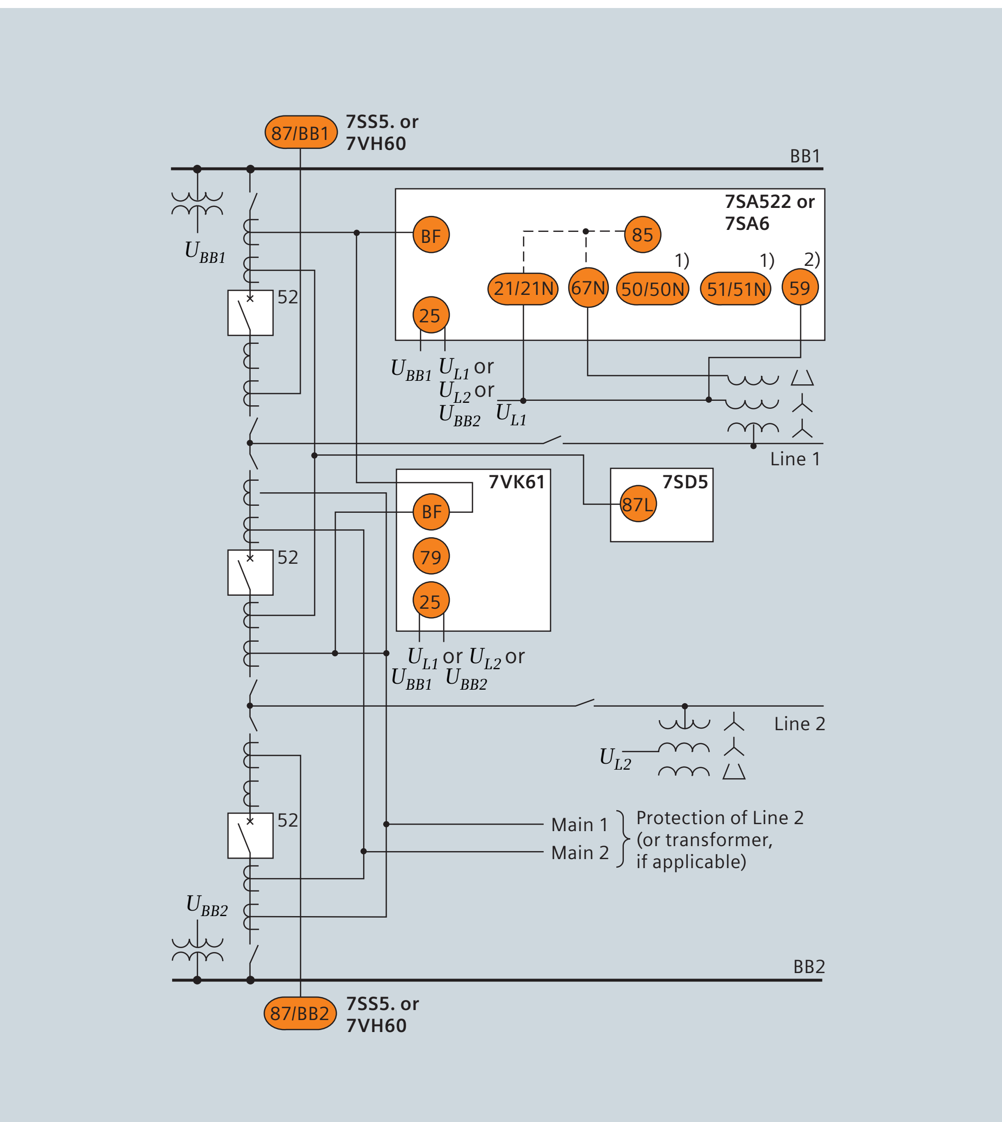


Fig. 6.2-47: **Tranmission line, breaker-and-a-half terminal, using 1 breaker management relay 7VK61**

2. Transformers

Small transformer infeed

General notes:

- Earth faults on the secondary side are detected by current relay 51N. However, it has to be time-graded against downstream feeder protection relays.
  The restricted earth-fault relay 87N can optionally be applied to achieve fast clearance of earth faults in the transformer secondary winding.
  Relay 7VH60 is of the high-impedance type and requires class X CTs with equal transformation ratios.
- Primary circuit-breaker and relay may be replaced by fuses.

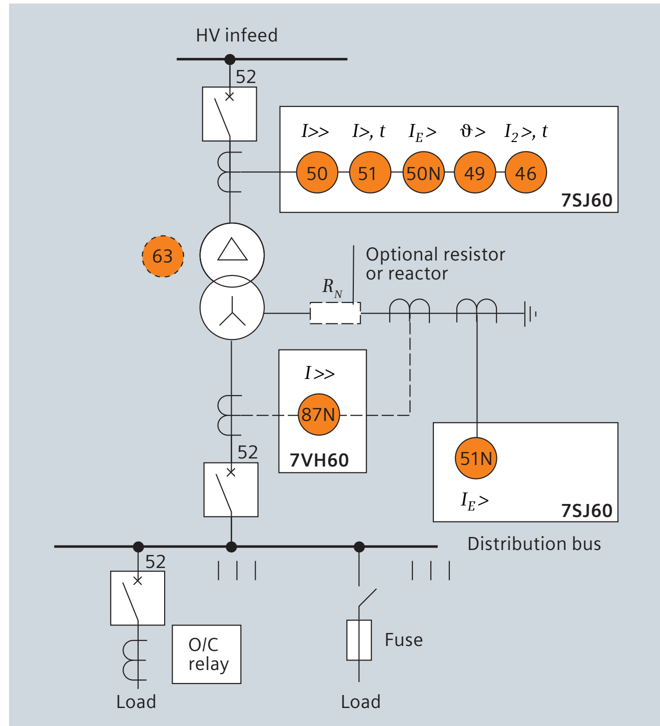


Fig. 6.2-48: **Small transformer infeed**

Large or important transformer infeed

General note:

- Relay 7UT612 provides numerical ratio and vector group adaptation. Matching transformers as used with traditional relays are therefore no longer applicable.

Notes:

1) If an independent high-impedance-type earth-fault function is required, the 7VH60 earth-fault relay can be used instead of the 87N inside the 7UT612. However, class X CT cores would also be necessary in this case (see small transformer protection).
2) 51 and 51N may be provided in a separate 7SJ60 if required.

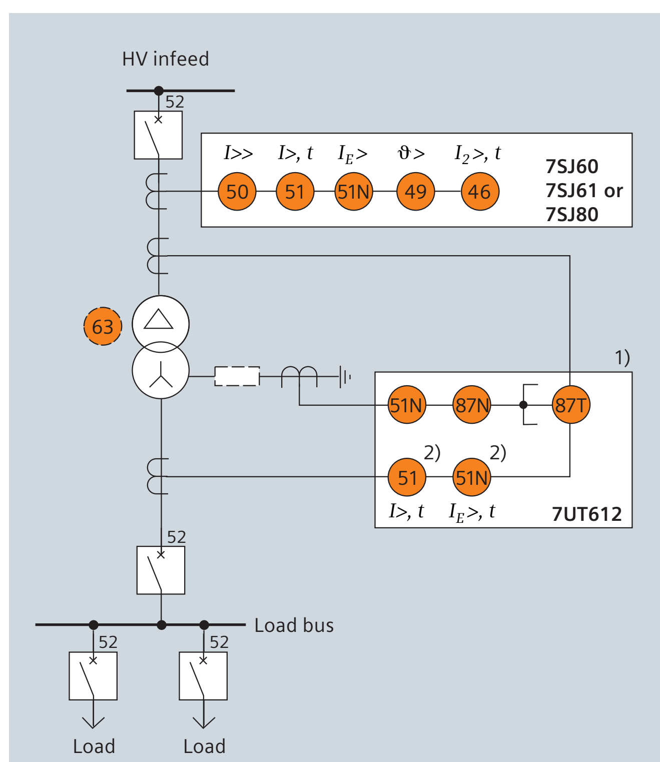


Fig. 6.2-49: **Large or important transformer infeed**

Dual infeed with single transformer

General notes:

- Line CTs are to be connected to separate stabilizing inputs of the differential relay 87T in order to ensure stability in the event of line through-fault currents.
- Relay 7UT613 provides numerical ratio and vector group adaptation. Matching transformers, as used with traditional relays, are therefore no longer applicable.

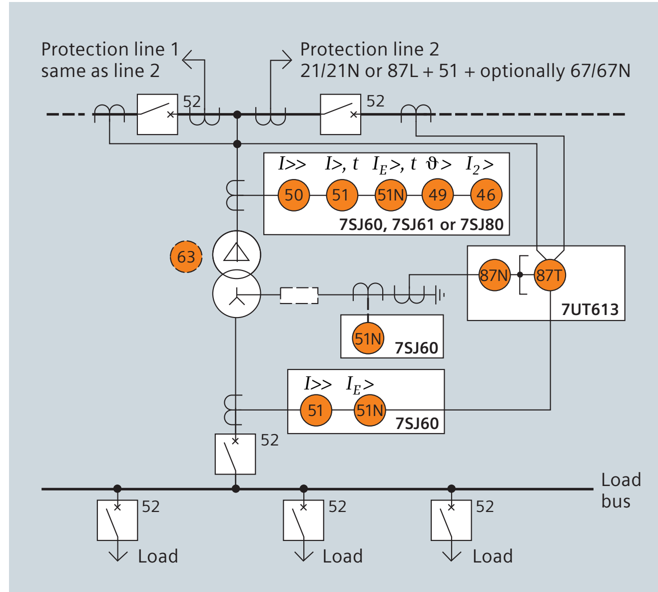


Fig. 6.2-50: **Dual infeed with single transformer**

Parallel incoming transformer feeders

Note:

The directional functions 67 and 67N do not apply for cases where the transformers are equipped with the transformer differential relays 87T.

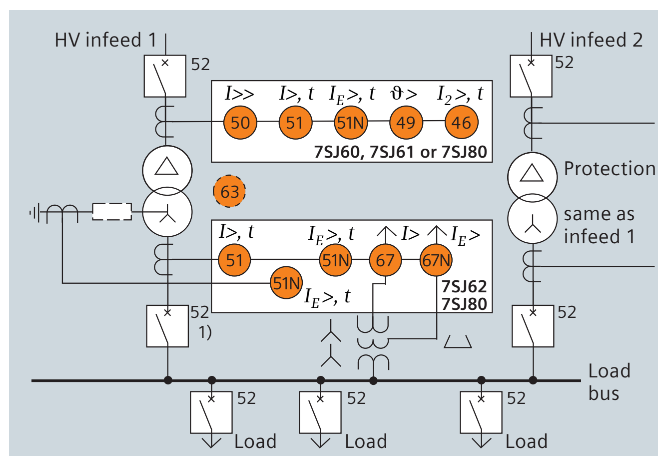


Fig. 6.2-51: **Parallel incoming transformer feeders**

Parallel incoming transformer feeders with bus tie

General notes:

- Overcurrent relay 51, 51N each connected as a partial differential scheme. This provides simple and fast busbar protection and saves one time-grading step.

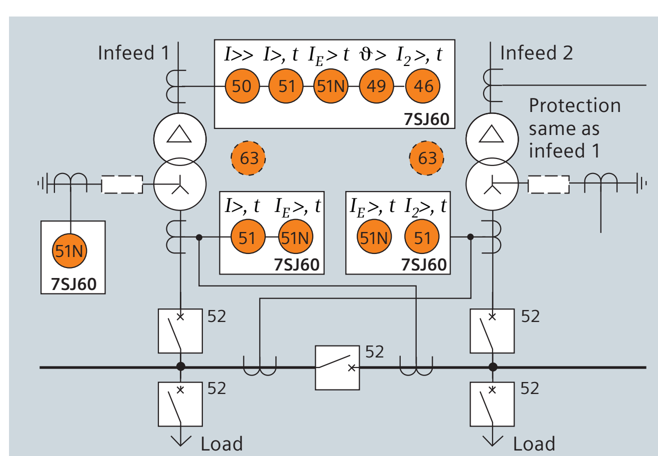


Fig. 6.2-52: **Parallel incoming transformer feeders with bus tie**

Three-winding transformer

Notes:

1) The zero-sequence current must be blocked before entering the differential relay with a delta winding in the CT connection on the transformer side with earthed starpoint. This is to avoid false operation during external earth faults (numerical relays provide this function by calculation). About 30 % sensitivity, however, is then lost in the event of internal faults. Optionally, the zero-sequence current can be regained by introducing the winding neutral current in the differential relay (87T). Relay type 7UT613 provides two current inputs for this purpose. By using this feature, the earth-fault sensitivity can be upgraded again to its original value. Restricted earth-fault protection (87T) is optional. It provides backup protection for earth faults and increased earth-fault sensitivity (about 10 % IN, compared to about 20 to 30 % IN of the transformer differential relay). Separate class X CT-cores with equal transmission ratio are also required for this protection.
2) High impedance and overcurrent in one 7SJ61.

General notes:

- In this example, the transformer feeds two different distribution networks with cogeneration. Restraining differential relay inputs are therefore provided at each transformer side.
- If both distribution networks only consume load and no through-feed is possible from one MV network to the other, parallel connection of the CTs of the two MV transformer windings is admissible, which allows the use of a two-winding differential relay (7UT612).

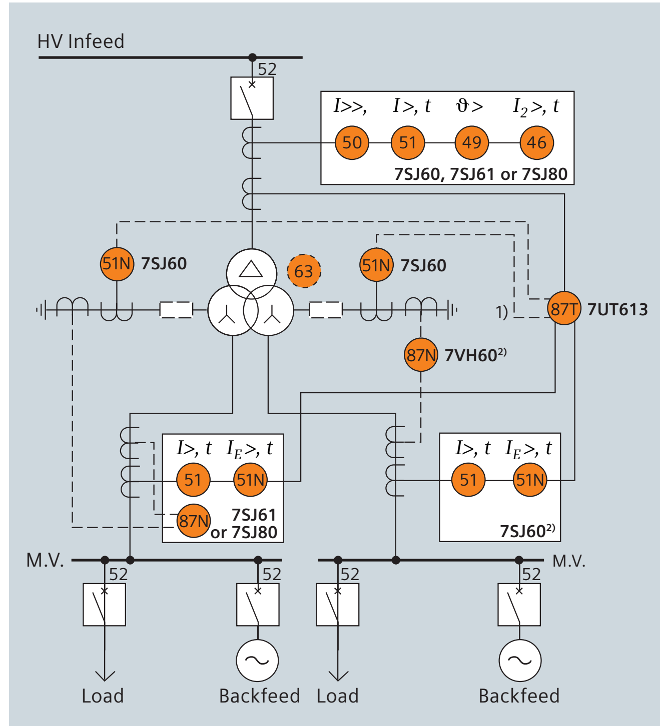


Fig. 6.2-53: **Three-winding transformer**

Autotransformer

Notes:

1) 87N high-impedance protection requires special class X current transformer cores with equal transformation ratios.
2) The 7SJ60 relay can alternatively be connected in series with the 7UT613 relay to save this CT core.

General note:

- Two different protection schemes are provided: 87T is chosen as the low-impedance three-winding version (7UT613). 87N is a 1-phase high-impedance relay (7VH60) connected as restricted earth-fault protection. (In this example, it is assumed that the phase ends of the transformer winding are not accessible on the neutral side, that is, there exists a CT only in the neutral earthing connection.)

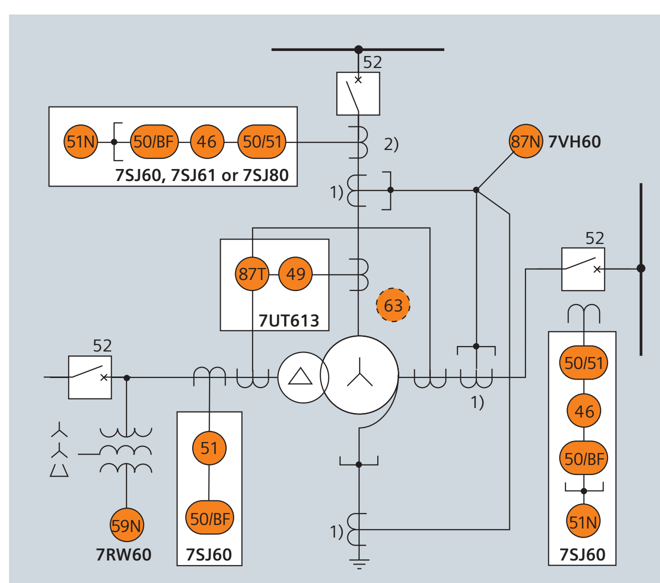


Fig. 6.2-54: **Autotransformer**

Large autotransformer bank

General notes:

- The transformer bank is connected in a breaker-and-a-half arrangement.
  Duplicated differential protection is proposed:
  Main 1: Low-impedance differential protection 87TL (7UT613) connected to the transformer bushing CTs.
  Main 2: High-impedance differential overall protection 87TL (7VH60). Separate class X cores and equal CT ratios are required for this type of protection.
- Backup protection is provided by distance protection relay (7SA52 and 7SA6), each “looking” with an instantaneous first zone about 80 % into the transformer and with a time-delayed zone beyond the transformer.
- The tertiary winding is assumed to feed a small station supply network with isolated neutral.

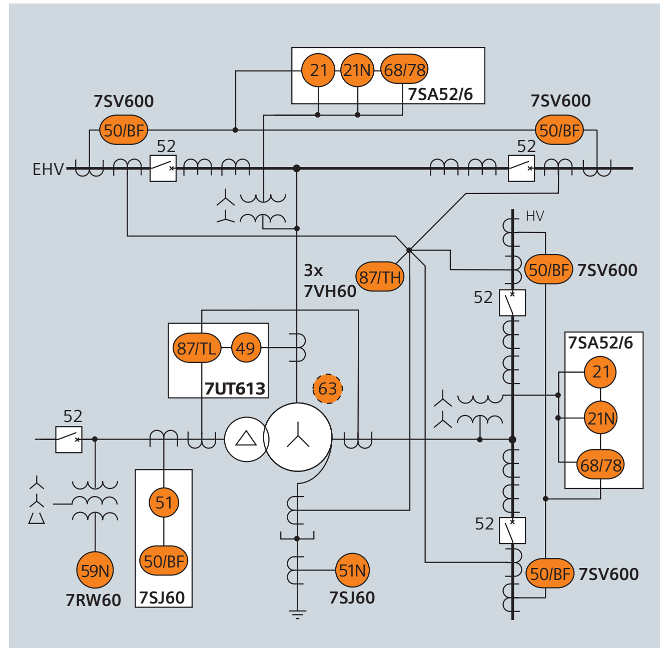


Fig. 6.2-55: **Large autotransformer bank**

3. Motors

Small and medium-sized motors < about 1 MW

a) With effective or low-resistance earthed infeed ($I_E \geq I_{N\,Motor}$)

General note:

- Applicable to low-voltage motors and high-voltage motors with low-resistance earthed infeed ($I_E \geq I_{N\,Motor}$)

b) With high-resistance earthed infeed ($I_E \leq I_{N\,Motor}$)

Notes:

1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed network (for dimensioning of the sensitive directional earth-fault protection, see also application circuit no. 30)
3) The 7SJ602 relay can be applied for isolated and compensated networks.

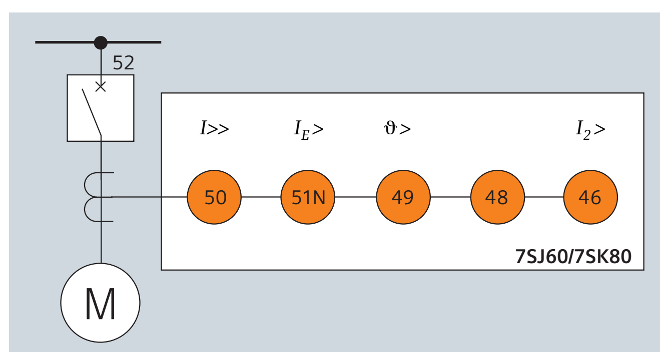


Fig. 6.2-56: **Motor protection with effective or low-resistance earthed infeed**

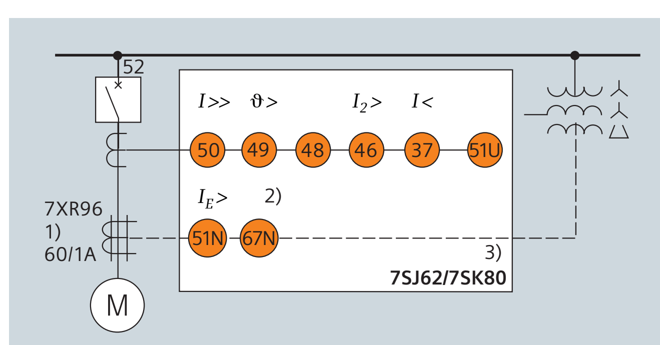


Fig. 6.2-57: **Motor protection with high-resistance earthed infeed**

Large HV motors > about 1 MW

Notes:
1) Core-balance CT.
2) Sensitive directional earth-fault protection (67N) only applicable with infeed from isolated or Petersen coil earthed network
3) This function is only needed for motors where the startup time is longer than the safe stall time tE. According to IEC 60079-7, the tE time is the time needed to heat up AC windings, when carrying the starting current I_A, from the temperature reached in rated service and at maximum ambient air temperature to the limiting temperature. A separate speed switch is used to supervise actual starting of the motor. The motor circuit-breaker is tripped if the motor does not reach speed in the preset time. The speed switch is part of the motor supply itself.
4) Pt100, Ni100, Ni120
5) 49T only available with external temperature monitoring device (7XV5662)

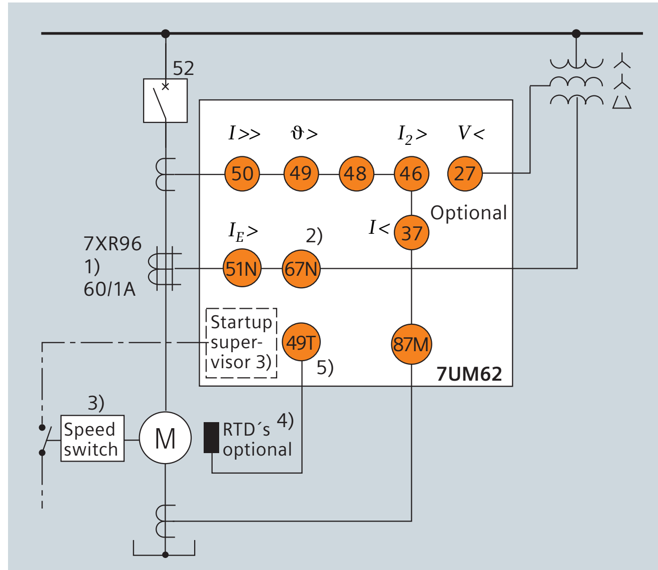


Fig. 6.2-58: **Protection of large HV motors > about 1 MW**

Cold load pickup

By means of a binary input that can be wired from a manual close contact, it is possible to switch the overcurrent pickup settings to less sensitive settings for a programmable amount of time. After the set time has expired, the pickup settings automatically return to their original setting. This can compensate for initial inrush when energizing a circuit without compromising the sensitivity of the overcurrent elements during steady-state conditions.

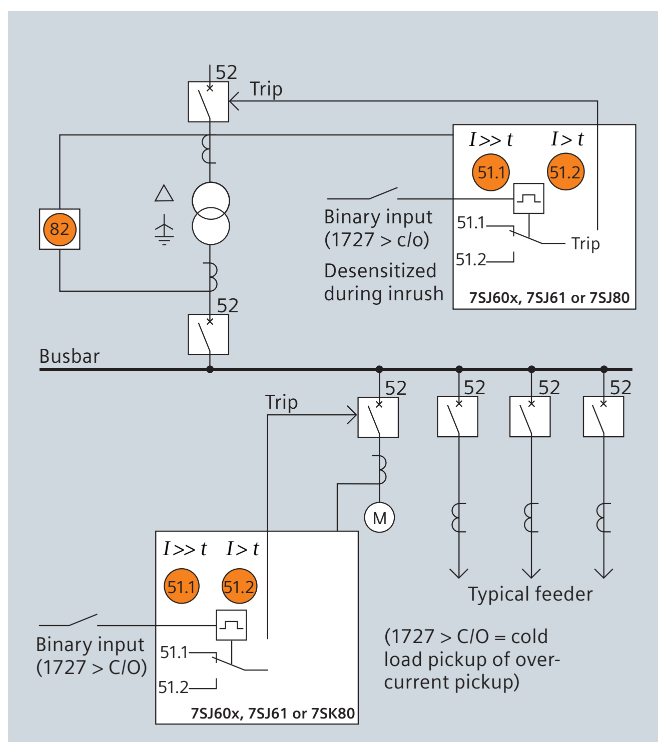


Fig. 6.2-59: **Cold load pickup**

4. Generators

Generators < 500 kW (fig. 6.2-60 and fig.6.2-61)

Note:
If a core-balance CT is provided for sensitive earth-fault protection, relay 7SJ602 with separate earth-current input can be used.

Generators, typically 1–3 MW
(fig. 6.2-62)

Note:
Two VTs in V connection are also sufficient.

Generators > 1–3 MW
(fig. 6.2-63)

Notes:
1) Functions 81 and 59 are required only where prime mover can assume excess speed and the voltage regulator may permit rise of output voltage above upper limit.
2) Differential relaying options:
   – Low-impedance differential protection 87.
   – Restricted earth-fault protection with low-resistance earthed neutral (fig. 6.2-62).

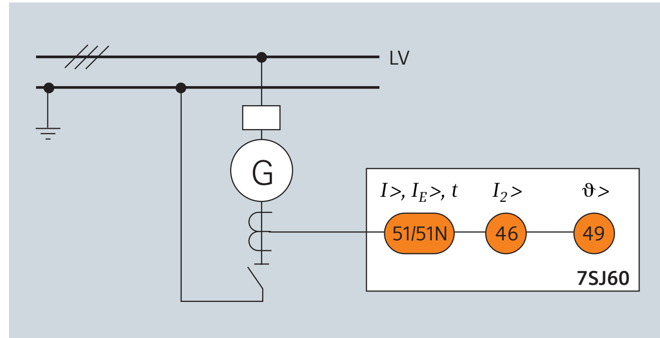


Fig. 6.2-60: **Generator with solidly earthed neutral**

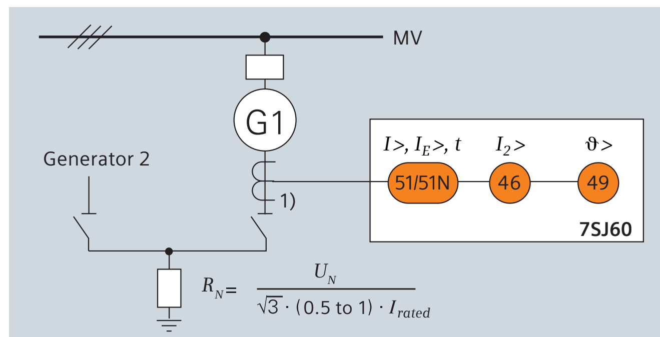


Fig. 6.2-61: **Generator with resistance-earthed neutral**

6

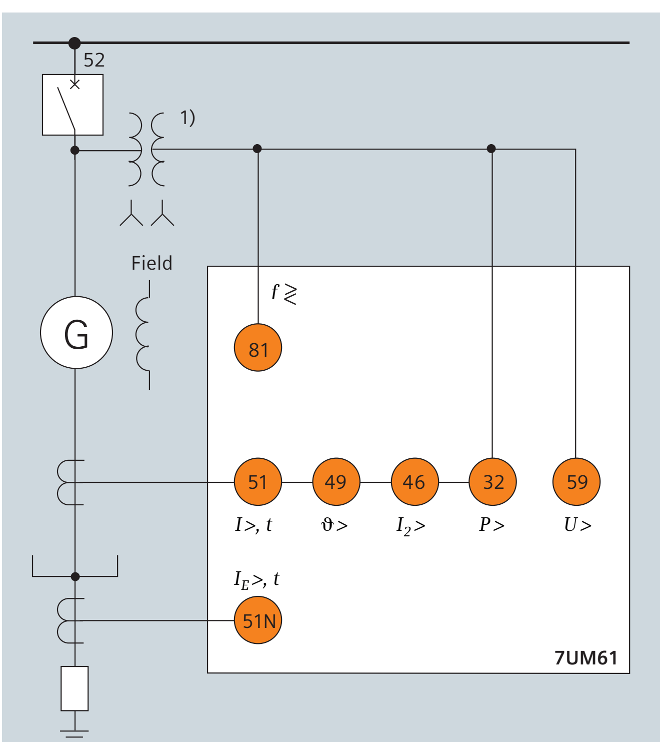


Fig. 6.2-62: **Protection for generators 1–3 MW**

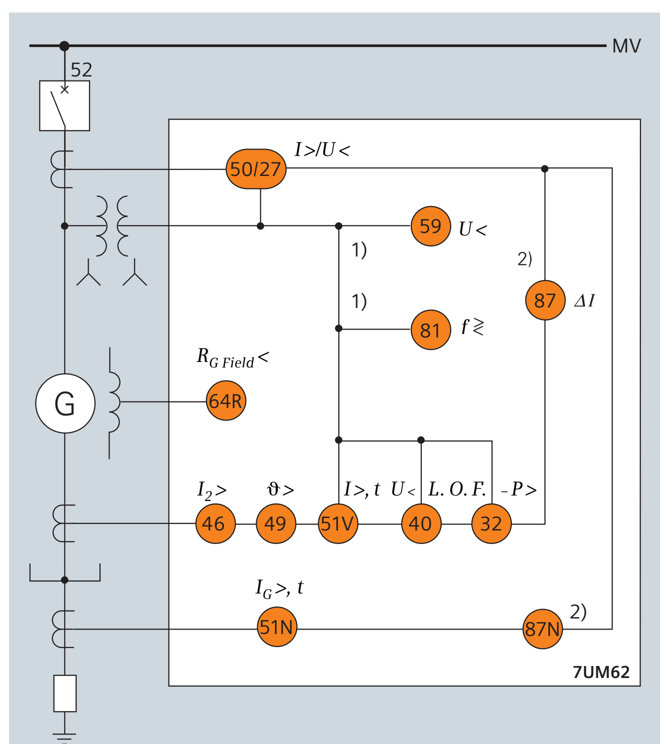


Fig. 6.2-63: **Protection for generators >1–3 MW**

Generators > 5 –10 MW feeding into a network with isolated neutral

(fig. 6.2-64)

General notes:

- The setting range of the directional earth-fault protection (67N) in the 7UM6 relay is 2–1,000 mA. Depending on the current transformer accuracy, a certain minimum setting is required to avoid false operation on load or transient currents.
- In practice, efforts are generally made to protect about 90 % of the machine winding, measured from the machine terminals. The full earth current for a terminal fault must then be ten times the setting value, which corresponds to the fault current of a fault at 10 % distance from the machine neutral.

Relay earth-current input connected to:	Minimum relay setting:	Comments:
Core-balance CT 60 / 1 A: 1 single CT 2 parallel CTs 3 parallel Cts 4 parallel CTs	 2 mA 5 mA 8 mA 12 mA	
Three-phase CTs in residual (Holmgreen) connection	1 A CT: 50 mA 5 A CT: 200 mA	In general not suitable for sensitive earth-fault protection
Three-phase CTs in residual (Holmgreen) connection with special factory calibration to minimum residual false currents (≤ 2 mA)	2–3 ‰ of secondary rated CT current $I_{n\ SEC}$ 10–15 mA with 5 A CTs	1 A CTs are not recommended in this case

For the most sensitive setting of 2 mA, we therefore need 20 mA secondary earth current, corresponding to (60/1) x 20 mA = 1.2 A primary.

If sufficient capacitive earth current is not available, an earthing transformer with resistive zero-sequence load can be installed as earth-current source at the station busbar. The smallest standard earthing transformer TGAG 3541 has a 20 s short-time rating of input connected to: S_G = 27 kVA

In a 5 kV network, it would deliver:

$$I_{G\ 20\ s} = \frac{\sqrt{3} \cdot S_G}{U_N} = \frac{\sqrt{3} \cdot 27{,}000 \text{ VA}}{5{,}000 \text{ V}} = 9.4 \text{ A}$$

corresponding to a relay input current of 9.4 A x 1/60 A = 156 mA. This would provide a 90 % protection range with a setting of about 15 mA, allowing the use of 4 parallel connected core-balance CTs. The resistance at the 500 V open-delta winding of the earthing transformer would then have to be designed for

$R_B = U^2_{SEC}/S_G$ = 500 U^2/27,000 VA = 9.26 Ω (27 kW, 20 s)

For a 5 MVA machine and 600/5 A CTs with special calibration for minimum residual false current, we would get a secondary current of $I_{G\ SEC}$ = 9.4 A/(600/5) = 78 mA.

With a relay setting of 12 mA, the protection range would in this case be $100\left(1-\frac{12}{78}\right)$ = 85 %.

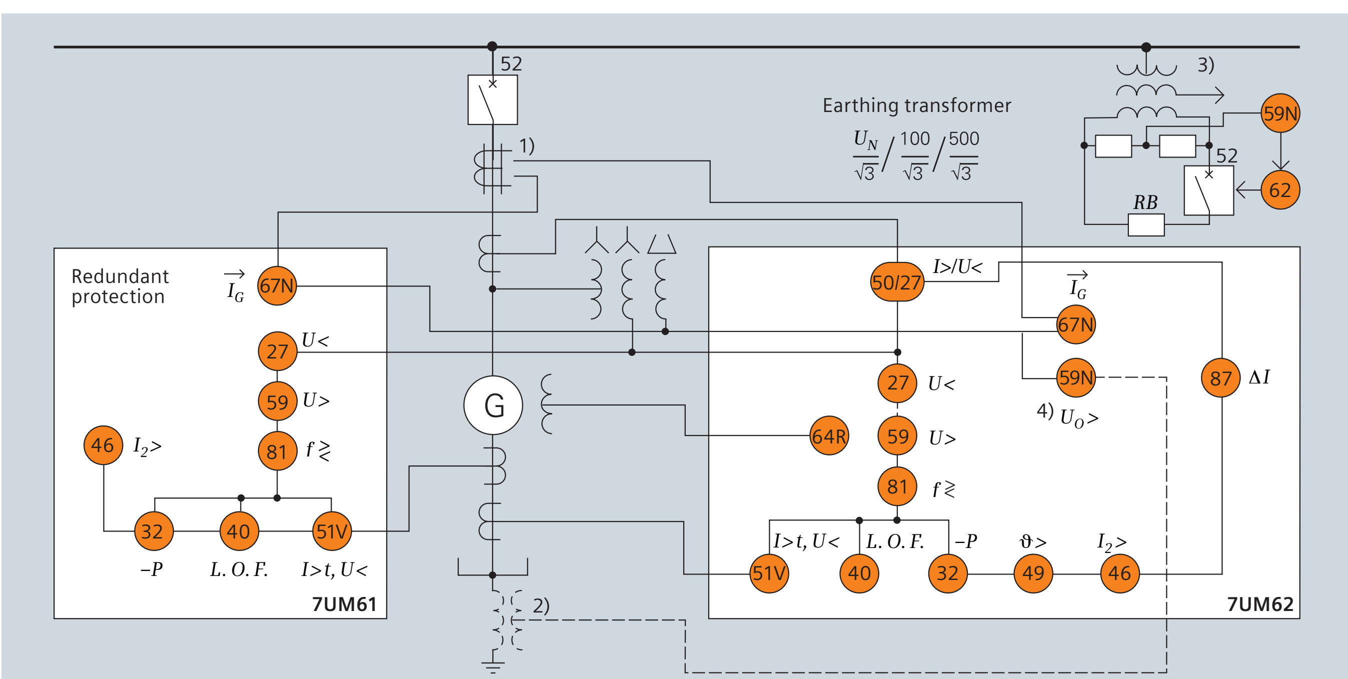


Fig. 6.2-64: **Protections for generators > 5–10 MW**

Notes (fig. 6.2-64):
1) The standard core-balance CT 7XR96 has a transformation ratio of 60/1 A.
2) Instead of an open-delta winding at the terminal VT, a 1-phase VT at the machine neutral could be used as zero-sequence polarizing voltage.
3) The earthing transformer is designed for a short-time rating of 20 s. To prevent overloading, the load resistor is automatically switched off by a time-delayed zero-sequence voltage relay (59N + 62) and a contactor (52).
4) During the startup time of the generator with the open circuit-breaker, the earthing source is not available. To ensure earth-fault protection during this time interval, an auxiliary contact of the circuit-breaker can be used to change over the directional earth-fault relay function (67N) to a zero-sequence voltage detection function via binary input.

Generators > 50 –100 MW in generator transformer unit connection
(fig. 6.2-65)

Notes:
1) 100 % stator earth-fault protection based on 20 Hz voltage injection
2) Sensitive rotor earth-fault protection based on 1–3 Hz voltage injection
3) Non-electrical signals can be incoupled in the protection via binary inputs (BI)
4) Only used functions shown; further integrated functions available in each relay type.

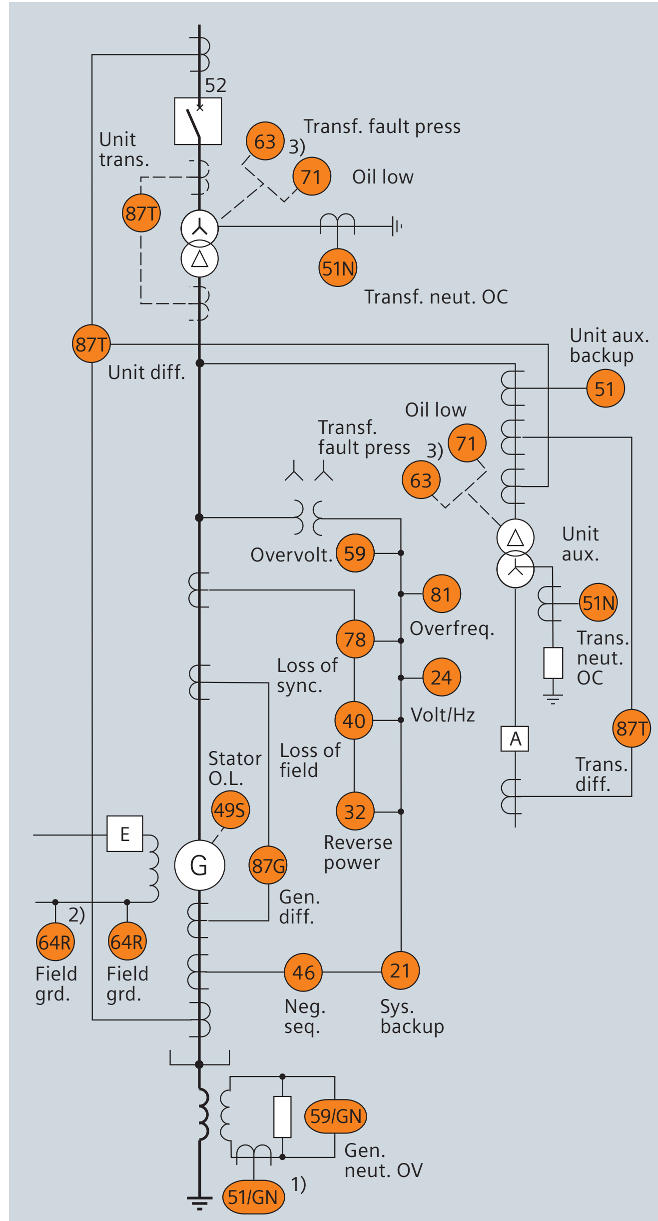


Fig. 6.2-65: **Protections for generators > 50 MW**

Relay type	Functions[4]	Number of relays required
7UM62	21, 24, 32, 40, 46, 49, 51GN 1), 59GN, 59, 64R, 64R 2), 78, 81, 87G, via BI: 71, 63	2
7UM61	51, 51N, optionally 21, 59, 81, via BI: 71, 63	1
7UT612	87T, 51N optionally	1 2
7UT613	87T	1

Fig. 6.2-66: **Assignment for functions to relay type**

Synchronization of a generator

Fig. 6.2-67 shows a typical connection for synchronizing a generator. Paralleling device 7VE6 acquires the line and generator voltage, and calculates the differential voltage, frequency and phase angle. If these values are within a permitted range, a CLOSE command is issued after a specified circuit-breaker make time. If these variables are out of range, the paralleling device automatically sends a command to the voltage and speed controller. For example, if the frequency is outside the range, an actuation command is sent to the speed controller. If the voltage is outside the range, the voltage controller is activated.

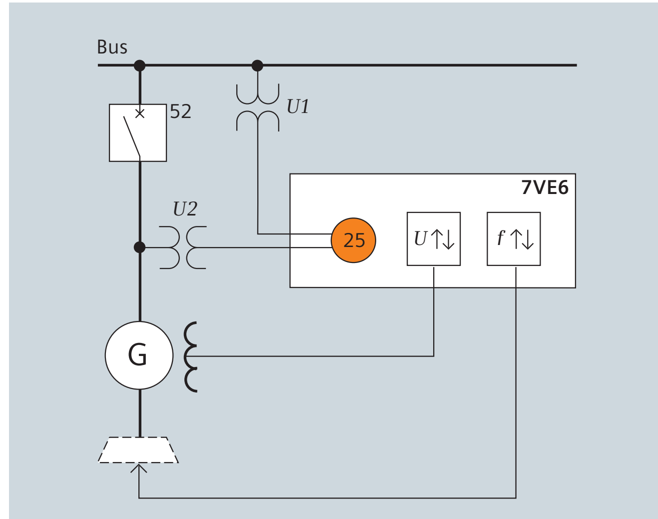


Fig. 6.2-67: **Synchronization of a generator**

5. Busbars

Busbar protection by overcurrent relays with reverse interlocking

General note:

- Applicable to distribution busbars without substantial (< 0.25 x I_N) backfeed from the outgoing feeders.

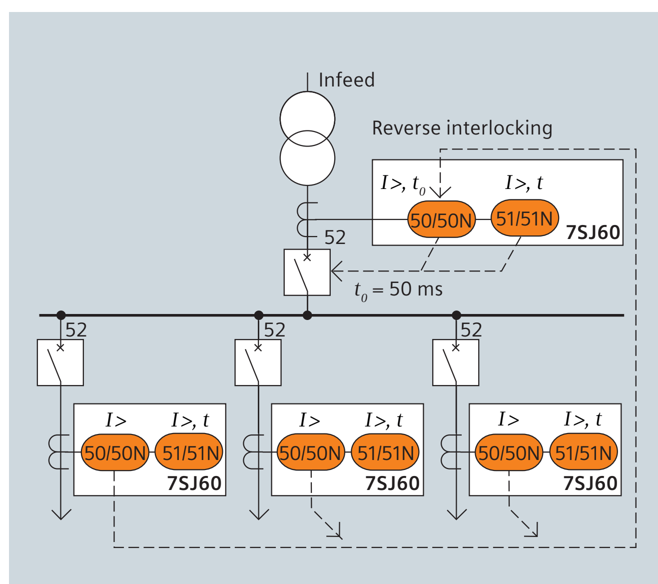


Fig. 6.2-68: **Busbar protection by O/C relays with reverse interlocking**

High-impedance busbar protection

General notes:

- Normally used with single busbar and one breaker-and-a-half schemes.
- Requires separate class X current transformer cores. All CTs must have the same transformation ratio.

Note:
A varistor is normally applied across the relay input terminals to limit the voltage to a value safely below the insulation voltage of the secondary circuits.

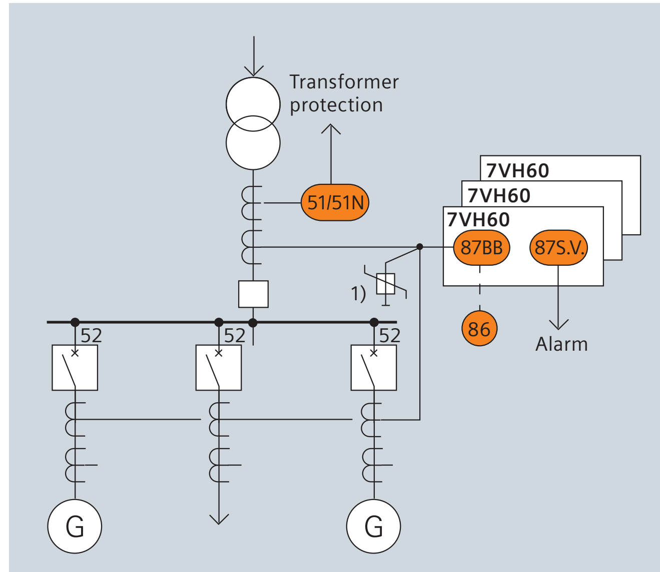


Fig. 6.2-69: **High-impedance busbar protection**

Low-impedance busbar protection 7SS60

General notes:

- Normally used with single busbar, one breaker-and-a-half and double busbar schemes.sformation ratios can be adapted by matching transformers.
- Unlimited number of feeders.
- Feeder protection can be connected to the same CT core.

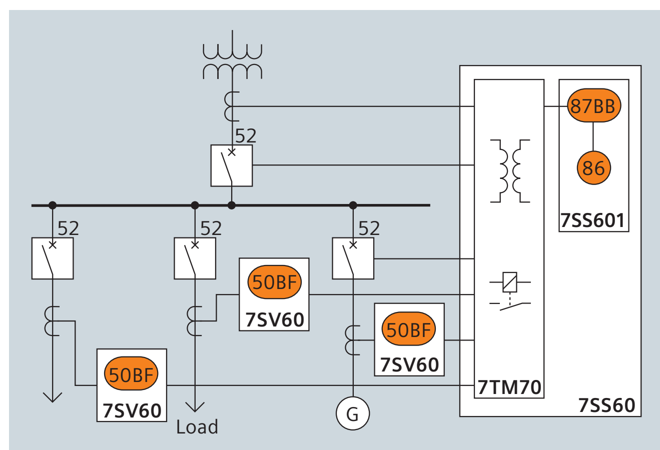


Fig. 6.2-70: **Low-impedance busbar protection 7SS60**

Distributed busbar protection 7SS52

General notes:

- Preferably used for multiple busbar schemes where a disconnector (isolator) replica is necessary.
- The numerical busbar protection 7SS5 provides additional breaker failure protection.
- CT transformation ratios can be different, e.g., 600/1 A in the feeders and 2000/1 A at the bus tie.
- The protection system and the disconnector (isolator) replica are continuously self-monitored by the 7SS52.
- Feeder protection can be connected to the same CT core.

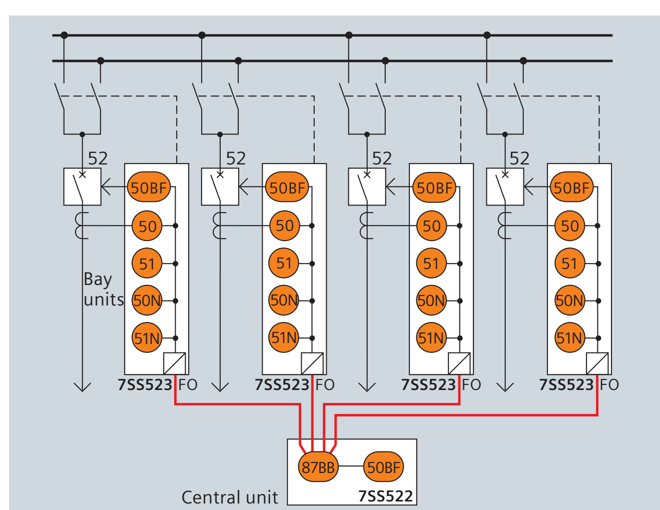


Fig. 6.2-71: **Distributed busbar protection 7SS52**

6. Networks

Load shedding

In unstable networks (e.g., solitary networks, emergency power supply in hospitals), it may be necessary to isolate selected loads from the network to prevent overload of the overall network.The overcurrent-time protection functions are effective only in the case of a short-circuit.
Overloading of the generator can be measured as a frequency or voltage drop.
(Protection functions 27 and 81 available in 7RW600, 7SJ6 and 7SJ8.)

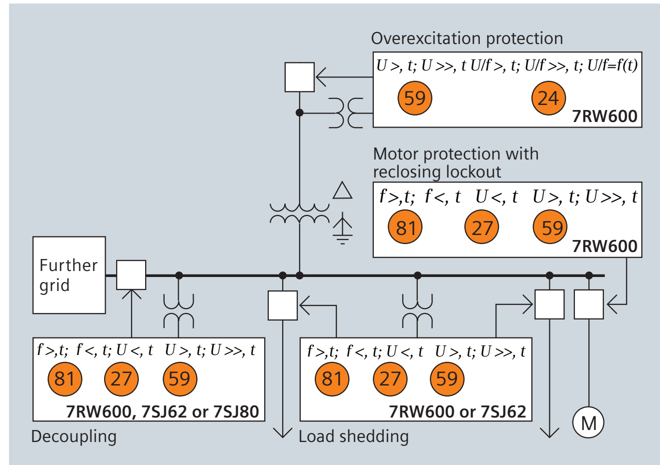


Fig. 6.2-72: **Load shedding**

Load shedding with rate-of-frequency-change protection

The rate-of-frequency-change protection calculates, from the measured frequency, the gradient or frequency change df/dt. It is thus possible to detect and record any major active power loss in the power system, to disconnect certain consumers accordingly and to restore the system to stability. Unlike frequency protection, rate-of-frequency-change protection reacts before the frequency threshold is undershot. To ensure effective protection settings, it is recommended to consider requirements throughout the power system as a whole. The rate-of-frequency-change protection function can also be used for the purposes of system decoupling.
Rate-of-frequency-change protection can also be enabled by an underfrequency state.

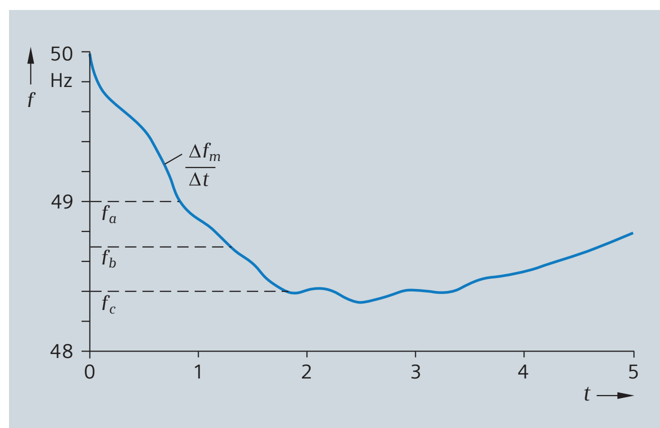


Fig. 6.2-73: **Load shedding with rate-of-frequency-change protection**

Trip circuit supervision (ANSI 74TC)

One or two binary inputs can be used for the trip circuit supervision.

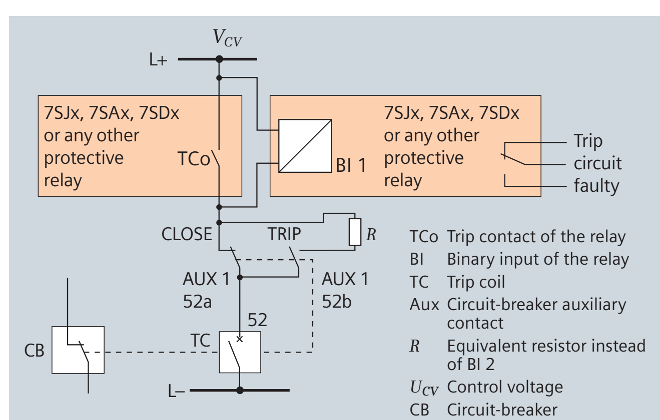


Fig. 6.2-74: **Trip circuit supervision (ANSI 74TC)**

Disconnecting facility with flexible protection function

General note:
The SIPROTEC protection relay 7SJ64 disconnects the switchgear from the utility power system if the generator feeds energy back into the power system (protection function P reverse>). This functionality is achieved by using flexible protection. Disconnection also takes place in the event of frequency or voltage fluctuations in the utility power system (protection functions $f<$, $f>$, $U<$, $U>$, $I_{dir}>$, $I_{Edir}>$/ 81, 27, 59, 67, 67N).

Notes:
1) The transformer is protected by differential protection and inverse or definite-time overcurrent protection functions for the phase currents. In the event of a fault, the circuit-breaker CB1 on the utility side is tripped by a remote link. Circuit-breaker CB2 is also tripped.
2) Overcurrent-time protection functions protect feeders 1 and 2 against short-circuits and overload caused by the connected loads. Both the phase currents and the zero currents of the feeders can be protected by inverse and definite-time overcurrent stages. The circuit-breakers CB4 and CB5 are tripped in the event of a fault.

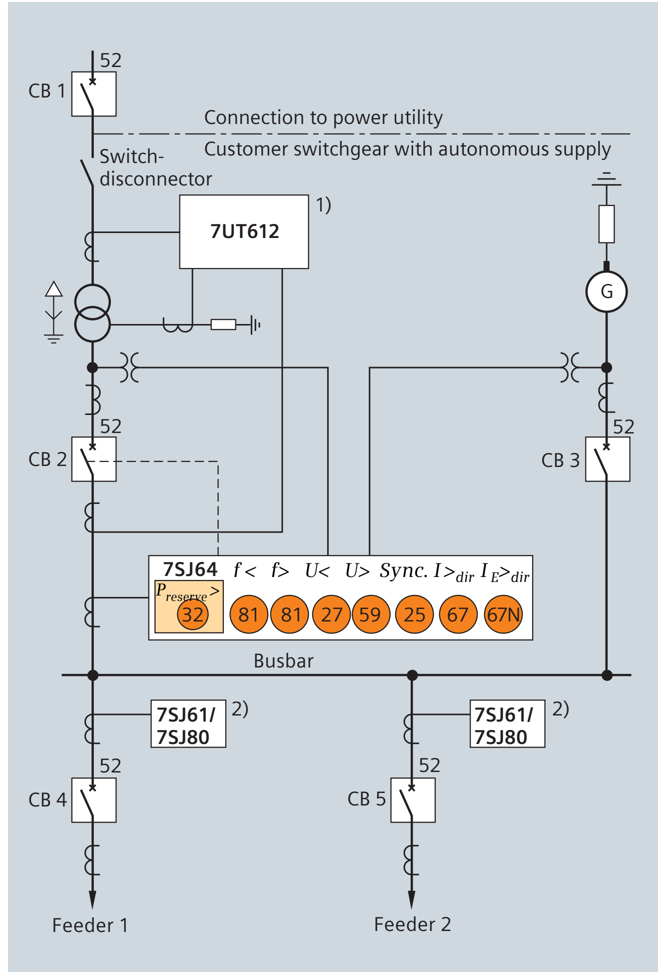


Fig. 6.2-75: **Example of a switchgear with autonomous generator supply**

6.2.4 Protection Coordination

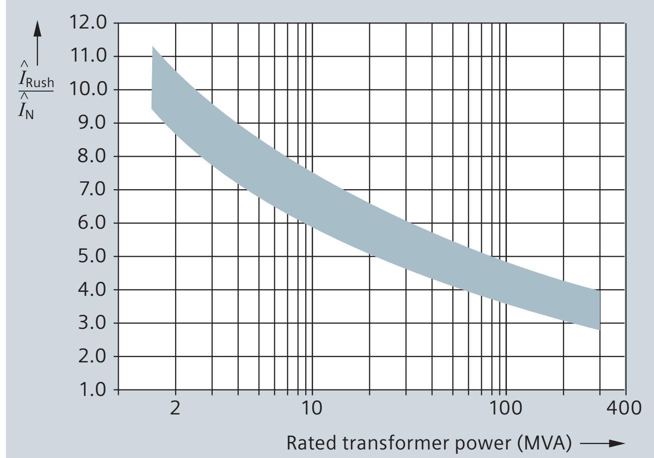
Typical applications and functions
Relay operating characteristics and their settings must be carefully coordinated in order to achieve selectivity. The aim is basically to switch off only the faulty component and to leave the rest of the power system in service in order to minimize supply interruptions and to ensure stability.

Sensitivity
Protection should be as sensitive as possible in order to detect faults at the lowest possible current level. At the same time, however, it should remain stable under all permissible load, overload and through-fault conditions. For more information: http://www.siemens.com/systemplanning. The Siemens engineering programs SINCAL and SIGRADE are especially designed for selective protection grading of protection relay systems. They provide short-circuit calculations, international standard characteristics of relays, fuses and circuit-breakers for easy protection grading with respect to motor starting, inrush phenomena, and equipment damage curves.

Phase-fault overcurrent relays
The pickup values of phase overcurrent relays are normally set 30 % above the maximum load current, provided that sufficient short-circuit current is available. This practice is recommended particularly for mechanical relays with reset ratios of 0.8 to 0.85. Numerical relays have high reset ratios near 0.95 and allow, therefore, about a10 % lower setting. Feeders with high transformer and/or motor load require special consideration.

Transformer feeders
The energizing of transformers causes inrush currents that may last for seconds, depending on their size (fig. 6.2-76). Selection of the pickup current and assigned time delay have to be coordinated so that the inrush current decreases below the relay overcurrent reset value before the set operating time has elapsed. The inrush current typically contains only about a 50 % fundamental frequency component. Numerical relays that filter out harmonics and the DC component of the inrush current can therefore be set to be more sensitive. The inrush current peak values of fig. 6.2-76 will be reduced to more than one half in this case. Some digital relay types have an inrush detection function that may block the trip of the overcurrent protection resulting from inrush currents.

Earth-fault protection relays
Earth-current relays enable a much more sensitive setting, because load currents do not have to be considered (except 4-wire circuits with 1-phase load). In solidly and low-resistance earthed systems, a setting of 10 to 20 % rated load current can generally be applied. High-resistance earthing requires a much more sensitive setting, on the order of some amperes primary. The earth-fault current of motors and generators, for example, should be limited to values below 10 A in order to avoid iron burning. In this case, residual-current relays in the start point connection of CTs cannot be used; in particular, with rated CT primary currents higher than 200 A. The pickup value of the zero-sequence relay would be on the order of the error currents of the CTs. A special core-balance CT is therefore used as the earth-current sensor. The core-balance CT 7XR96 is designed for a ratio of 60/1 A. The detection of 6 A primary would then require a relay pickup setting of 0.1 A secondary. An even more sensitive setting is applied in isolated or Petersen coil earthed networks where very low earth currents occur with 1-phase-to-earth faults. Settings of 20 mA and lower may then be required depending on the minimum earth-fault current. Sensitive directional earth-fault relays (integrated into the relays 7SJ62, 63, 64, 7SJ80, 7SK80, 7SA6) allow settings as low as 5 mA.



Time constant of inrush current			
Nominal power (MVA)	0.5 … 1.0	1.0 … 10	> 10
Time constant (s)	0.16 … 0.2	0.2 … 1.2	1.2 … 720

Fig. 6.2-76: **Peak value of inrush current**

Motor feeders
The energization of motors causes a starting current of initially 5 to 6 times the rated current (locked rotor current).

A typical time-current curve for an induction motor is shown in fig. 6.2-77.

In the first 100 ms, a fast-decaying asymmetrical inrush current also appears. With conventional relays, it was common practice to set the instantaneous overcurrent stage of the short-circuit protection 20 to 30 % above the locked rotor current with a short-time delay of 50 to 100 ms to override the asymmetrical inrush period.

Numerical relays are able to filter out the asymmetrical current component very rapidly so that the setting of an additional time delay is no longer applicable.

The overload protection characteristic should follow the thermal motor characteristic as closely as possible. The adaptation is made by setting the pickup value and the thermal time constant, using the data supplied by the motor manufacturer. Furthermore, the locked-rotor protection timer has to be set according to the characteristic motor value.

Time grading of overcurrent relays (51)
The selectivity of overcurrent protection is based on time grading of the relay operating characteristics. The relay closer to the infeed (upstream relay) is time-delayed against the relay further away from the infeed (downstream relay). The calculation of necessary grading times is shown in fig. 6.2-79 by an example for definite-time overcurrent relays.

The overshoot times take into account the fact that the measuring relay continues to operate due to its inertia, even if when the fault current is interrupted. This may be high for mechanical relays (about 0.1 s) and negligible for numerical relays (20 ms).

Inverse-time relays (51)
For the time grading of inverse-time relays, in principle the same rules apply as for the definite-time relays. The time grading is first calculated for the maximum fault level and then checked for lower current levels (fig. 6.2-78).

If the same characteristic is used for all relays, or if when the upstream relay has a steeper characteristic (e.g., very much over normal inverse), then selectivity is automatically fulfilled at lower currents.

Differential relay (87)
Transformer differential relays are normally set to pickup values between 20 and 30 % of the rated current. The higher value has to be chosen when the transformer is fitted with a tap changer.

Restricted earth-fault relays and high-resistance motor/generator differential relays are, as a rule, set to about 10 % of the rated current.

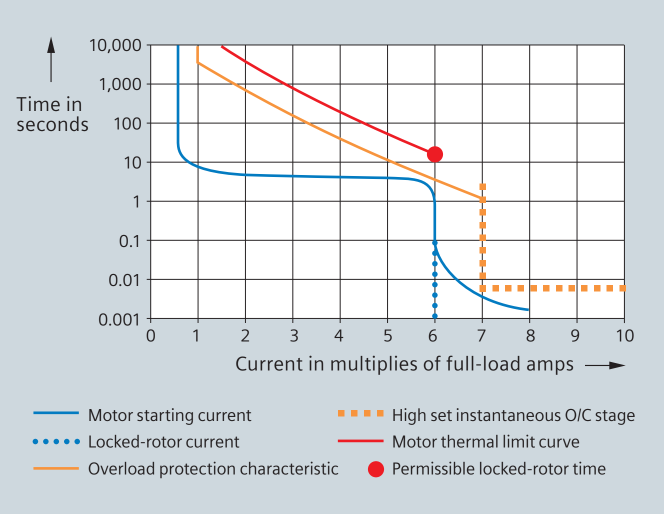


Fig. 6.2-77: **Typical motor current-time characteristics**

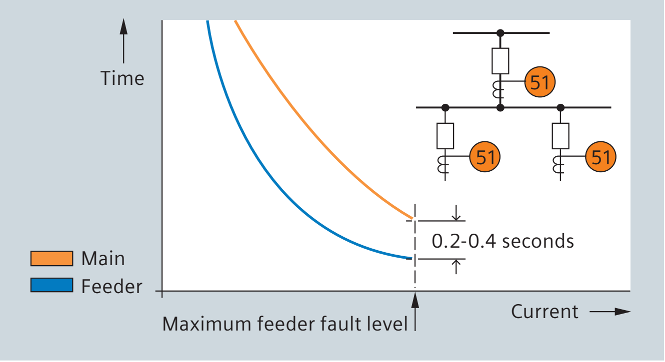


Fig. 6.2-78: **Coordination of inverse-time relays**

Instantaneous overcurrent protection (50)
This is typically applied on the final supply load or on any protection relay with sufficient circuit impedance between itself and the next downstream protection relay. The setting at transformers, for example, must be chosen about 20 to 30 % higher than the maximum through-fault current. The relay must remain stable during energization of the transformer.

Calculation example

The feeder configuration of fig. 6.2-80 and the associated load and short-circuit currents are given. Numerical overcurrent relays 7SJ60 with normal inverse-time characteristics are applied.

The relay operating times, depending on the current, can be derived from the diagram or calculated with the formula given in fig. 6.2-81.

The I_p/I_N settings shown in fig. 6.2-80 have been chosen to get pickup values safely above maximum load current.

This current setting should be lowest for the relay farthest downstream. The relays further upstream should each have equal or higher current settings.

The time multiplier settings can now be calculated as follows:

Station C:

- For coordination with the fuses, we consider the fault in location F1.
  The short-circuit current $I_{scc.}$ max. related to 13.8 kV is 523 A.
  This results in 7.47 for I/I_p at the overcurrent relay in location C.
- With this value and $T_p = 0.05$, an operating time of $t_A = 0.17$ s can be derived from fig 6.2-81.

This setting was selected for the overcurrent relay to get a safe grading time over the fuse on the transformer low-voltage side. Safety margin for the setting values for the relay at station C are therefore:

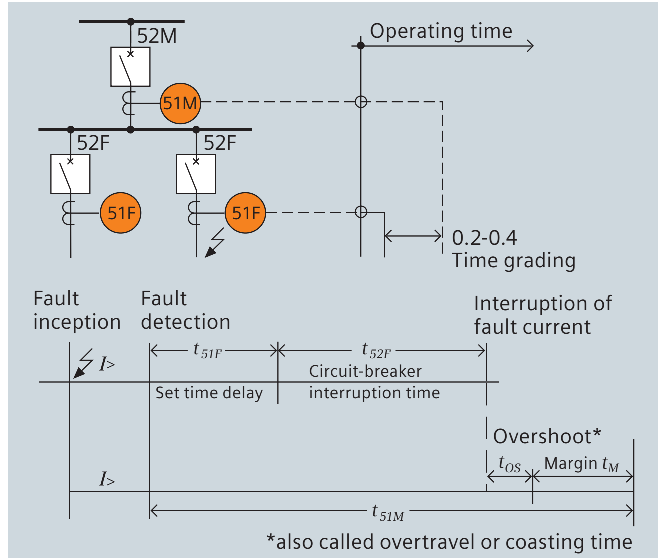
- Pickup current: $I_p/I_N = 0.7$
- Time multiplier: $T_p = 0.05$

Station B:

The relay in B has a primary protection function for line B-C and a backup function for the relay in C. The maximum through-fault current of 1.395 A becomes effective for a fault in location F2. For the relay in C, an operating time time of 0.11 s ($I/I_p = 19.93$) is obtained.

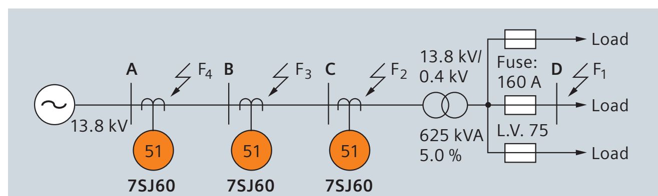
It is assumed that no special requirements for short operating times exist and therefore an average time grading interval of 0.3 s can be chosen. The operating time of the relay in B can then be calculated.

- $t_B = 0.11 + 0.3 = 0.41$ s
- Value of $I_p/I_N = \dfrac{1{,}395\ \text{A}}{220\ \text{A}} = 6.34$ (fig. 6.2-80)
- With the operating time 0.41 s and $I_p/I_N = 6.34$, $T_p = 0.11$ can be derived from fig. 6.2-81.



Time grading	
$t_{rs} = t_{51M} - t_{51F} = t_{52F} + t_{OS} + t_M$	
Example 1	t_{TG} =0.10 s + 0.15 s + 0.15 s = 0.40 s
Oil circuit-breaker	t_{52F} = 0.10 s
Mechanical relays	t_{OS} = 0.15 s
Safety margin for measuring errors, etc.	t_M = 0.15 s
Example 2	t_{TG} = 0.08 + 0.02 + 0.10 = 0.20 s
Vacuum circuit-breaker	t_{52F} = 0.08 s
Numerical relays	t_{OS} = 0.02 s
Safety margin	t_M = 0.10 s

Fig. 6.2-79: **Time grading of overcurrent-time relays**



Station	Max. load A	$I_{SCC.}$ max* A	CT ratio	I_p/I_N**	I_{prim}*** A	$I/I_p = \dfrac{I_{scc.\,max}}{I_{prim}}$
A	300	4,500	400/5	1.0	400	11.25
B	170	2,690	200/5	1.1	220	12.23
C	50	1,395	100/5	0.7	70	19.93
D	–	523	–	–	–	–

*) $I_{SCC.}$ max = Maximum short-circuit current
**) I_p/I_N = Relay current multiplier setting
***) I_{prim} = Primary setting current corresponding to I_p/I_N

Fig. 6.2-80: **Time grading of inverse-time relays for a radial feeder**

The setting values for the relay at station B are:

- Pickup current: $I_p/I_N = 1.1$
- Time multiplier $T_p = 0.11$

Given these settings, the operating time of the relay in B for a close fault in F3 can also be checked: The short-circuit current increases to 2,690 A in this case (fig. 6.2-80). The corresponding I/I_p value is 12.23.

- With this value and the set value of $T_p = 0.11$, an operating time of 0.3 s is obtained again (fig. 6.2-81).

Station A:

- Adding the time grading interval of 0.3 s, the desired operating itme is $t_A = 0.3 + 0.3 = 0.6$ s.

Following the same procedure as for the relay in station B, the following values are obtained for the relay in station A:

- Pickup current: $I_p/I_N = 1.0$
- Time multiplier $T_p = 0.17$
- For the close-in fault at location F4, an operating time of 0.48 s is obtained.

The normal way

To prove the selectivity over the whole range of possible short-circuit currents, it is normal practice to draw the set of operating curves in a common diagram with double log scales. These diagrams can be calculated manually and drawn point-by-point or constructed by using templates.

Today, computer programs are also available for this purpose. Fig. 6.2-82 shows the relay coordination diagram for the selected example, as calculated by the Siemens program SIGRADE (Siemens Grading Program). For further information: http://www.siemens.com/systemplanning.

Note:

To simplify calculations, only inverse-time characteristics have been used for this example. About 0.1 s shorter operating times could have been reached for high-current faults by additionally applying the instantaneous zones I>> of the 7SJ60 relays.

Coordination of overcurrent relays with fuses and low-voltage trip devices

The procedure is similar to the above-described grading of overcurrent relays. A time interval of between 0.1 and 0.2 s is usually sufficient for a safe time coordination.

Strong and extremely inverse characteristics are often more suitable than normal inverse characteristics in this case. Fig. 6.2-83 shows typical examples.

Simple distribution grid stations use a power fuse on the secondary side of the supply transformers (fig. 6.2-83a).

In this case, the operating characteristic of the overcurrent relay at the infeed has to be coordinated with the fuse curve.

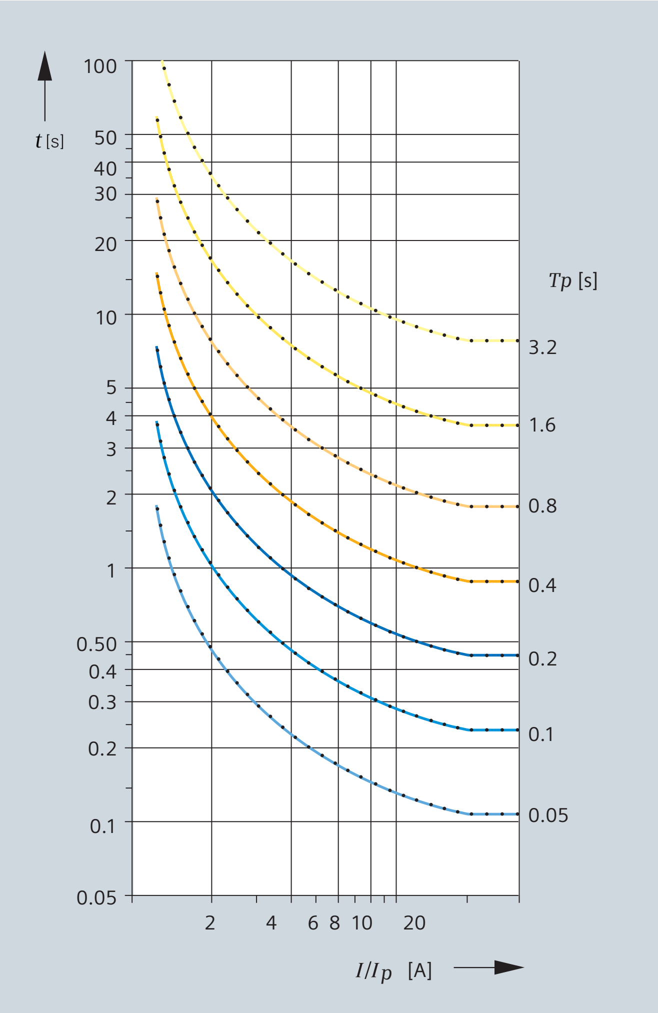


Fig. 6.2-81: **Normal inverse-time characteristic of the 7SJ60 relay**

Normalinverse

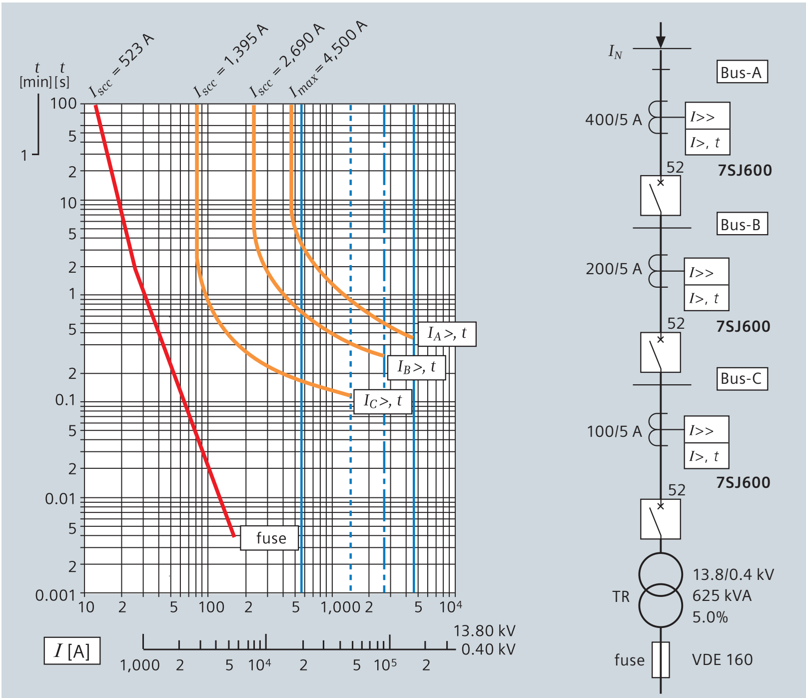
$$t = \frac{0.14}{(I/I_p)^{0.02} - 1} \cdot T_p (s)$$

Strong inverse characteristics may be used with expulsion-type fuses (fuse cutouts), while extremely inverse versions adapt better to current limiting fuses.

In any case, the final decision should be made by plotting the curves in the log-log coordination diagram.

Electronic trip devices of LV breakers have long-delay, short-delay and instantaneous zones. Numerical overcurrent relays with one inverse-time and two definite-time zones can closely be adapted to this (fig. 6.2-83b).

6



Setting range	setting
I_p = 0.10 – 4.00 I_N T_p = 0.05 – 3.2 s I>> = 0.1 – 25 I_N	I_p = 1.0 I_N T_p = 0.17 s I>> = ∞
I_p = 0.10 – 4.00 I_N T_p = 0.05 – 3.2 s I>> = 0.1 – 25 I_N	I_p = 1.0 I_N T_p = 0.11 s I>> = ∞
I_p = 0.10 – 4.00 I_N T_p = 0.05 – 3.2 s I>> = 0.1 – 25 I_N	I_p = 0.7 I_N T_p = 0.05 s I>> = ∞
HRC fuse 160 A	

Fig. 6.2-82: **Overcurrent-time grading diagram**

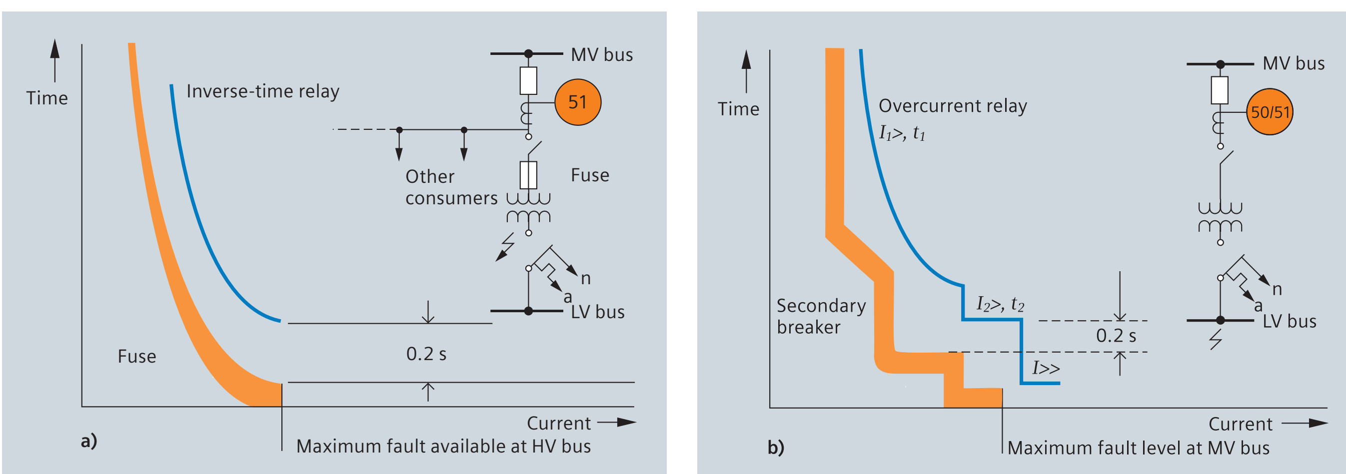


Fig. 6.2-83: **Coordination of an overcurrent relay with an MV fuse and low-voltage breaker trip device**

Coordination of distance relays

The distance relay setting must take into account the limited relay accuracy, including transient overreach (5 %, according to IEC 60255-6), the CT error (1 % for class 5P and 3 % for class 10P) and a security margin of about 5 %. Furthermore, the line parameters are often only calculated, not measured. This is a further source of errors. A setting of 80 to 85 % is therefore common practice; 80 % is used for mechanical relays, while 85 % can be used for the more accurate numerical relays.

Where measured line or cable impedances are available, the protected zone setting may be extended to 90 %. The second and third zones have to keep a safety margin of about 15 to 20 % to the corresponding zones of the following lines. The shortest following line always has to be considered (fig. 6.2-84).

As a general rule, the second zone should at least reach 20 % over the next station to ensure backup for busbar faults, and the third zone should cover the longest following line as backup for the line protection.

Grading of zone times

The first zone normally operates undelayed. For the grading of the time delays of the second and third zones, the same rules as for overcurrent relays apply (fig. 6.2-79, page 262). For the quadrilateral characteristics (relays 7SA6 and 7SA5), only the reactance values (X values) have to be considered for the protected zone setting. The setting of the R values should cover the line resistance and possible arc or fault resistances. The arc resistance can be roughly estimated as follows:

$$R_{Arc} = \frac{2.5 \cdot l_{arc}}{I_{SCC\,Min}}\ [\Omega]$$

l_{arc} = Arc length in mm

$I_{SCC\,Min}$ = Minimum short-circuit current in kA

- Typical settings of the ratio R/X are:
  – Short lines and cables (≤ 10 km): R/X =2 to 6
  – Medium line lengths < 25 km: R/X =2
  – Longer lines 25 to 50 km: R/X =1

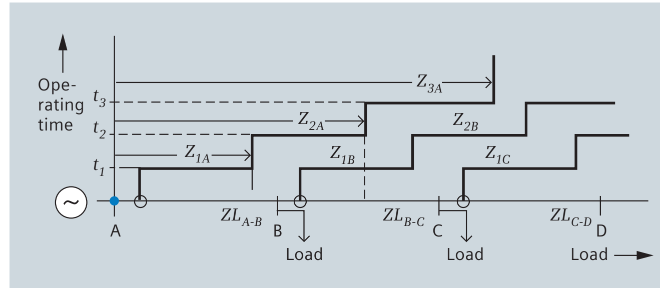
Shortest feeder protectable by distance relays

The shortest feeder that can be protected by underreaching distance zones without the need for signaling links depends on the shortest settable relay reactance.

$$X_{Prim\,Min} = X_{Relay\,Min} \cdot \frac{VT_{ratio}}{CT_{ratio}}$$

$$l_{min} = \frac{X_{Prim\,Min}}{X'_{Line}}$$

The shortest setting of the numerical Siemens relays is 0.05 Ω for 1 A relays, corresponding to 0.01 Ω for 5 A relays. This allows distance protection of distribution cables down to the range of some 500 meters.



$Z_{1A} = 0.85 \cdot ZL_{A-B}$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{1B})$

$Z_{2A} = 0.85 \cdot (ZL_{A-B} + Z_{2B})$

Fig. 6.2-84: **Grading of distance zones**

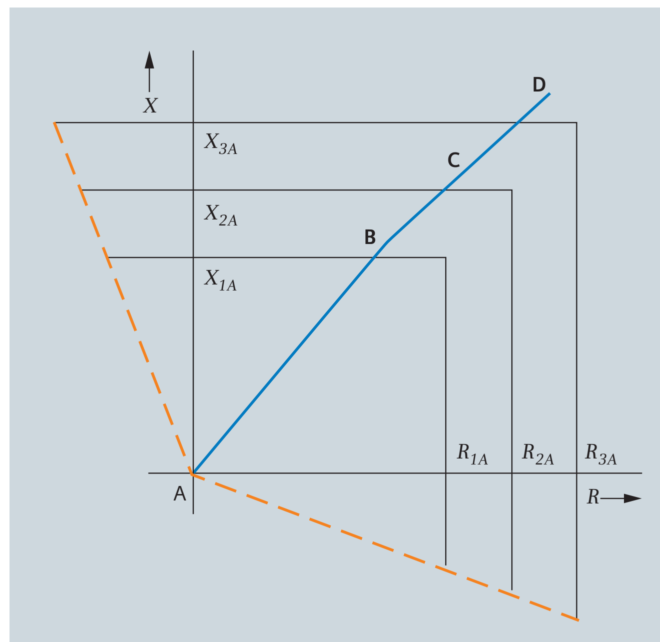


Fig. 6.2-85: **Operating characteristics of Siemens distance relays**

6

Breaker failure protection setting
Most numerical relays in this guide provide breaker failure (BF) protection as an integral function. The initiation of the BF protection by the internal protection functions then takes place via software logic. However, the BF protection function may also be initiated externally via binary inputs by an alternate protection. In this case, the operating time of intermediate relays (BFI time) may have to be considered. Finally, the tripping of the infeeding breakers requires auxiliary relays, which add a small time delay (BFI) to the overall fault clearing time. This is particularly the case with one-breaker-and-a-half or ring bus arrangements where a separate breaker failure relay (7SV600 or 7VK61) is used per breaker (fig. 6.2-46, fig. 6.2-47).

The decisive criterion of BF protection time coordination is the reset time of the current detector (50BF), which must not be exceeded under any condition during normal current interruption. The reset times specified in the Siemens numerical relay manuals are valid for the worst-case condition: interruption of a fully offset short-circuit current and low current pickup setting (0.1 to 0.2 times rated CT current).

The reset time is 1 cycle for EHV relays (7SA6/52, 7VK61) and 1.5 to 2 cycles for distribution type relays (7SJ**).

Fig. 6.2-86 shows the time chart for a typical breaker failure protection scheme. The stated times in parentheses apply for transmission system protection and the times in square brackets for distribution system protection

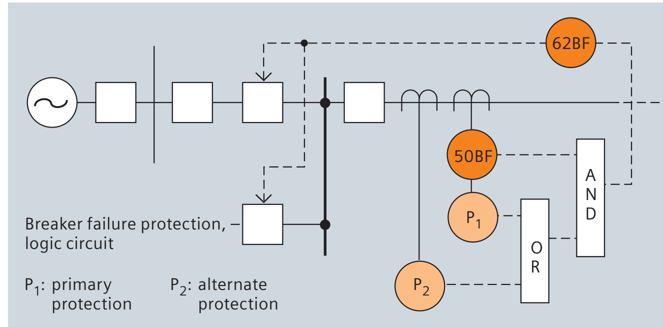


Fig. 6.2-86: **Time chart for breaker failure protection scheme**

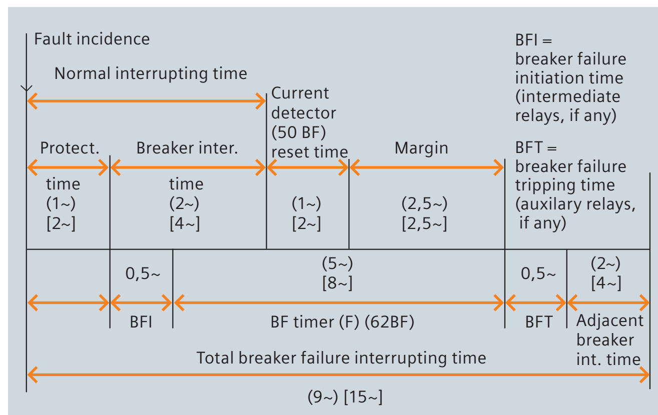


Fig. 6.2-87: **Time coordination of BF time setting**

High-impedance differential protection: Verification of design

The following design data must be established:
CT data
The CTs must all have the same ratio and should be of low leakage flux design according to Class TPS of IEC 60044-6 (Class X of BS 3938). The excitation characteristic and the secondary winding resistance are to be provided by the manufacturer. The knee-point voltage of the CT must be at least twice the relay pickup voltage to ensure dependable operation with internal faults.

Differential relay
The differential relay must be a high-impedance relay designed as a sensitive current relay (7VH60: 20 mA) with series resistor. If the series resistor is integrated into the relay, the setting values may be directly applied in volts, as with the relay 7VH60 (6 to 60 V or 24 to 240 V).

Sensitivity
For the relay to operate in the event of an internal fault, the primary current must reach a minimum value to supply the relay pickup current (IR), the varistor leakage current ($Ivar$) and the magnetizing currents of all parallel-connected CTs at the set pickup voltage. A low relay voltage setting and CTs with low magnetizing current therefore increase the protection sensitivity.

Stability during external faults
This check is made by assuming an external fault with maximum through-fault current and full saturation of the CT in the faulty feeder. The saturated CT is then substituted with its secondary winding resistance R_{CT}, and the appearing relay voltage VR corresponds to the voltage drop of the infeeding currents (through-fault current) across R_{CT} and R_{lead}. The current (voltage) at the relay must, under this condition, stay reliably below the relay pickup value.

In practice, the wiring resistances R_{lead} may not be equal. In this case, the worst condition with the highest relay voltage (corresponding to the highest through-fault current) must be sought by considering all possible external feeder faults.

Setting
The setting is always a trade-off between sensitivity and stability. A higher voltage setting leads not only to enhanced through-fault stability but also to higher CT magnetizing and varistor leakage currents, resulting consequently in a higher primary pickup current.

A higher voltage setting also requires a higher knee-point voltage of the CTs and therefore greater size of the CTs. A sensitivity of 10 to 20 % I_N is normal for motor and transformer differential protection, or for restricted earth-fault protection.

With busbar protection, a pickup value ≥ I_N is normally applied. An increased pickup current value can be achieved by connecting a shunt resistor (as an option) in parallel to the relay.

Varistor
Voltage limitation by a varistor is needed if peak voltages near or above the insulation voltage (2 kV) are expected. A limitation to U_{rms} = 1,500 V is then recommended.

This can be checked for the maximum internal fault current by applying the formula shown for U_{rmax}.

A restricted earth-fault protection may sometimes not require a varistor, but a busbar protection in general does. The electrical varistor characteristic can be expressed as $U = K\, I^B$ where K and B are the varistor constants.

CT requirements for protection relays

Relay setting U_{rms}	K	B	Varistor type
≤ 125	450	0.25	600 A /S1/S256
125 – 240	900	0.25	600 A /S1/S1088

Instrument transformers
Instrument transformers must comply with the applicable IEC recommendations IEC 60044 [formerly IEC 60185 (CT)] and 60186 (PT), ANSI/IEEE C57.13 or other comparable standards.

Voltage transformers (VT)
Voltage transformers (VT) in single or double-pole design for all primary voltages have typical single or dual secondary windings of 100, 110 or 115 V/√3 with output ratings between 10 and 300 VA, and accuracies of 0.2, 0.5 or 1 % to suit the particular application. Primary BIL values are selected to match those of the associated switchgear.

Current transformers
with output ratings between 10 and 300 VA, and accuracies of 0.2, 0.5 or 1 % to suit the particular application. Primary BIL values are selected to match those of the associated switchgear.

Current transformers
Current transformers (CT) are usually of the single-ratio type with wound or bar-type primaries of adequate thermal rating. Single, dual or triple secondary windings of 1 or 5 A are standard. 1 A rating should, however, be preferred, particularly in HV and EHV stations, to reduce the burden of the connected lines. Output power (rated burden in VA), accuracy and saturation characteristics (rated symmetrical short-circuit current limiting factor) of the cores and secondary windings must meet the requirements of the particular application.

The CT classification code of IEC is used in the following:

- Measuring cores
  These are normally specified with 0.5 % or 1.0 % accuracy (class 0.5 FS or 1.0 FS), and an rated symmetrical short-circuit current limiting factor of 5or 10.

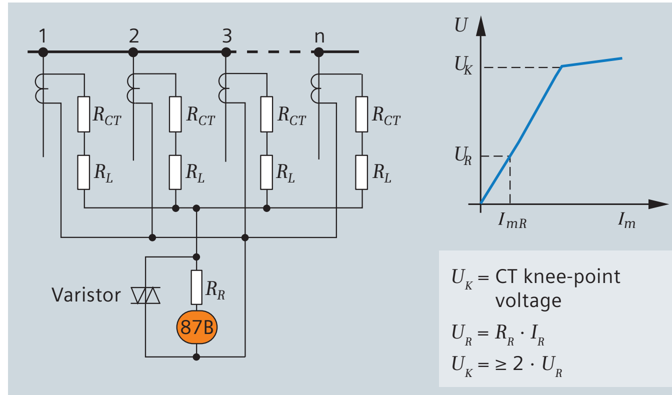


Fig. 6.2-88: **Principal connection diagram**

Sensitivity:

$I_{Fmin} = N\,(I_R + I_{Var} + n \cdot I_{mR})$

Stability:

$IF_{max.\ Through} < N \cdot \dfrac{R_R}{R_{lead} + R_{CT}} \cdot I_R$

N = CT ratio

I_R = Set relay pickup current

I_{Var} = Varistor spill current

I_{mR} = CT magnetizing current at relay pickup voltage

Voltage limitation by a varistor is required if:

$U_{rmax} = 2 \cdot \sqrt{2U_k(U_F - U_k)} > 1.5$ kV

with U_F $\dfrac{I_{Fmax.\ Through}}{N} R_{CT} + 2 \cdot R_{lead} + R_R)$

Calculation example:

Given:
n = 8 feeders
N = 600 /1 A
U_K = 500 V
R_{CT} = 4 Ω
I_{mR} = 30 mA (at relay setpoint)
R_{lead} = 3 Ω
I_R = 20 mA
R_R = 10 kΩ
I_{Var} = 11 mA (at relay setpoint)

Sensitivity:

$I_{Fmin} = N \cdot (I_R + I_{Var} + n \cdot I_{mR})$

$I_{Fmin} = \dfrac{600}{1} \cdot (0.02 + 0.05 + 8 \times 0.03)$

I_{Fmin} = 186 A (31% I_N)

Stability:

$I_{Fmax.\ Through} < N \cdot \dfrac{R_R}{R_{lead} + R_{CT}} \cdot I_R$

$I_{Fmax.\ Through} < \dfrac{600}{1} \cdot \dfrac{10{,}000}{3 + 4}$

$I_{Fmax.\ Through} <$ 17 kA (28 x I_s)

The required output power (rated burden) should be higher than the actually connected burden. Typical values are 5, 10, 15 VA. Higher values are normally not necessary when only electronic meters and recorders are connected.
A typical specification could be: 0.5 FS 10, 15 VA.

- Cores for billing values metering
  In this case, class 0.2 FS is normally required.
- Protection cores
  The size of the protection core depends mainly on the maximum short-circuit current and the total burden (internal CT burden, plus burden of connected lines plus relay burden) Furthermore, a transient dimensioning factor has to be considered to cover the influence of the DC component in the short-circuit current.

Glossary of used abbreviations (according to IEC 60044-6, as defined)		
K_{ssc}	=	Rated symmetrical short-circuit current factor (example: CT cl. 5P20 → K_{ssc} = 20)
K'_{ssc}	=	Effective symmetrical short-circuit current factor
K_{td}	=	Transient dimensioning factor
$I_{ssc\,max}$	=	Maximum symmetrical short-circuit current
I_{pn}	=	CT rated primary current
I_{sn}	=	CT rated secondary current
R_{ct}	=	Secondary winding d.c. resistance at 75°C (or other specified temperature)
R_b	=	Rated resistive burden
R'_b	=	$R_{lead} + R_{relay}$ = connected resistive burden
T_P	=	Primary time constant (net time constant)
U_K	=	Kneepoint voltage (r.m.s.)
R_{relay}	=	Relay burden
R_{lead}	=	$\frac{2 \cdot \rho \cdot l}{A}$
with		
l	=	Single conductor length from CT to relay in m
ρ	=	Specific resistance = 0.0175 Ωmm²/m (copper wires) at 20 °C (or other specified temperature)
A	=	Conductor cross-section in mm²

In general, an accuracy of 1 % in the range of 1 to 2 times nominal current (class 5 P) is specified. The rated symmetrical short-circuit current factor K_{SSC} should normally be selected so that at least the maximum short-circuit current can be transmitted without saturation (DC component is not considered).

This results, as a rule, in rated symmetrical short-circuit current factors of 10 or 20 depending on the rated burden of the CT in relation to the connected burden. A typical specification for protection cores for distribution feeders is 5P10, 10 VA or 5P20, 5 VA.

The requirements for protective current transformers for transient performance are specified in IEC 60044-6. In many practical cases, iron-core CTs cannot be designed to avoid saturation under all circumstances because of cost and space reasons, particularly with metal-enclosed switchgear.

The Siemens relays are therefore designed to tolerate CT saturation to a large extent. The numerical relays proposed in this guide are particularly stable in this case due to their integrated saturation detection function.

CT dimensioning formulae
$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ (effective)
with $K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\,max}}{I_{pn}}$ (required)

The effective symmetrical short-circuit current factor K'_{SSC} can be calculated as shown in the table above.

The rated transient dimensioning factor K_{td} depends on the type of relay and the primary DC time constant. For relays with a required saturation free time from w 0.4 cycle, the primary (DC) time constant TP has little influence.

CT design according to BS 3938/IEC 60044-1 (2000)
IEC Class P can be approximately transfered into the IEC Class PX (BS Class X) standard definition by following formula:
$U_k = \frac{(R_b + R_{ct}) \cdot I_n \cdot K_{ssc}}{1.3}$
Example: IEC 60044: 600/1, 5P10, 15 VA, R_{ct} = 4 Ω
IEP PX or BS: $U_K = \frac{(15 + 4) \cdot 1 \cdot 10}{1.3} = 146$ V, R_{ct} = 4 Ω
For *CT design according to ANSI/IEEE C 57.13*

The CT requirements mentioned in table 6.2-2 are simplified in order to allow fast CT calculations on the safe side. More accurate dimensioning can be done by more intensive calculation with Siemens's CTDIM (V 3.21) program. Results of CTDIM are released by the relay manufacturer.

Adaption factor for 7UT6, 7UM62 relays in fig. 6.2-89 (limited resolution of measurement)
(also 7SD52, 53, 610, when transformer inside protected zone)

$$F_{Adap} = \frac{I_{pn}}{I_{nO}} \cdot \frac{I_{Nrelay}}{I_{sn}} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}} \rightarrow \text{Request: } 1/8 \leq 8$$

with
I_{nO} = Rated current of the protected object
U_{nO} = Rated voltage of the protected object
I_{Nrelay} = Rated current of the relay
S_{Nmax} = Maximum load of the protected object (for transformers: winding with max. load)

Relay type	Transient dimensioning factor K_{td}	Min. required sym. short-circuit current factor K'_{ssc}	Min. required kneepoint voltage U_k
Overcurrent-time and motor protection 7SJ511, 512, 531 7SJ45, 46, 60 7SJ61, 62, 63, 64 7SJ80, 7SK80	–	$K'_{ssc} \geq \frac{I_{High\ set\ point}}{I_{pn}}$ at least: 20	$U_k \geq \frac{I_{High\ set\ point}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ at least: $\frac{20}{1.3} \cdot (R_{ct} + R'_b) \cdot I_{sn}$
Line differential protection (pilot wire) 7SD600	–	$K'_{ssc} \geq \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ and: $\frac{3}{4} \leq \frac{(K'_{ssc} \cdot I_{pn})_{end1}}{(K'_{ssc} \cdot I_{pn})_{end2}} \leq \frac{4}{3}$	$U_k \geq \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ and: $\frac{3}{4} \leq \frac{(U_k / (R_{ct} + R'_b) \cdot I_{pn} / I_{sn})_{end1}}{(U_k / (R_{ct} + R'_b) \cdot I_{pn} / I_{sn})_{end2}} \leq \frac{4}{3}$
Line differential protection (without distance function) 7SD52x, 53x, 610 (50/60 Hz)	Transformer: 1.2 Busbar/Line: 1.2 Gen./Motor: 1.2	$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$	$U_K \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$
Tranformer/generator differential protection 7UT612 7UT613, 633, 635 7UM62	Transformer / Busbar/Line / Gen./Motor: 4 / 4 / 5 3 / 3 / 5 4 / – / 5	and (only for 7SS): $K'_{ssc} \leq 100$ (measuring range)	and (only for 7SS): $U_k \geq \frac{100}{1.3} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ (measuring range)
Busbar protection 7SS5, 7SS600	for stabilizing factors k ≥ 0.5 0.5		
Distance protection 7SA522, 7SA6, 7SD5xx*)	primary DC time constant T_p [ms]: ≤ 30 / ≤ 50 / ≤ 100 / ≤ 200 K_{td} (a): 1 / 2 / 4 / 4 K_{td} (b): 4 / 5 / 5 / 5	$K'_{ssc} \geq$ $K_{td}\,(a) \cdot \frac{I_{scc\ max\ (close-in\ fault)}}{I_{pn}}$ and: $K_{td}\,(b) \cdot \frac{I_{scc\ max\ (zone\ 1-end\ fault)}}{I_{pn}}$	$U_K \geq$ $K_{td}\,(a) \cdot \frac{I_{scc\ max\ (close-in\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ and: $K_{td}\,(b) \cdot \frac{I_{scc\ max\ (zone\ 1-end\ fault)}}{I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$

Table 6.2-2: **CT requirements**

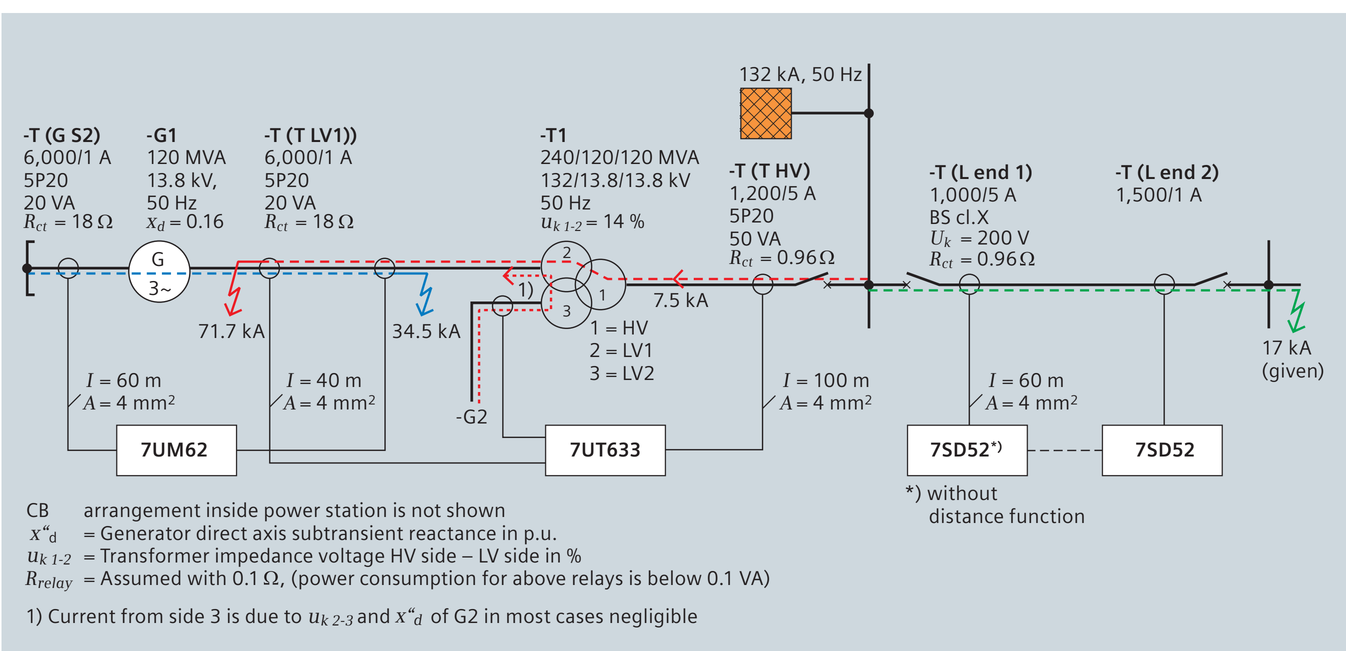


Fig. 6.2-89: **Example 1 – CT verification for 7UM62, 7UT6, 7SD52 (7SD53, 7SD610)**

-T (G S2), 7UM62	-T (T LV1), 7UT633	-T (T HV), 7UT633	-T (L end 1), 7SD52
$I_{scc\ max\ (ext.\ fault)} = \frac{c \cdot S_{NG}}{\sqrt{3} \cdot U_{NG}\ x''_{d}}$ $= \frac{1.1 \cdot 120{,}000\ \text{kVA}}{\sqrt{3} \cdot 13.8\ \text{kV} \cdot 0.16} = 34{,}516\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = \frac{S_{NT}}{\sqrt{3} \cdot U_{NT}\ u_{k}''}$ $= \frac{120{,}000\ \text{kVA}}{\sqrt{3} \cdot 13.8\ \text{kV} \cdot 0.14} = 35{,}860\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = \frac{S_{NT}}{\sqrt{3} \cdot U_{NT}\ u_{k}''}$ $= \frac{240{,}000\ \text{kVA}}{\sqrt{3} \cdot 132\ \text{kV} \cdot 0.14} = 35{,}860\ \text{A}$	$I_{scc\ max\ (ext.\ fault)} = 17\ \text{kA}$ (given)
$K_{td} = 5$ (from table 6.2-2)	$K_{td} = 3$ (from table 6.2-2)	$K_{td} = 3$ (from table 6.2-2)	$K_{td} = 1.2$ (from table 6.2-2)
$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 5 \cdot \frac{31{,}378\ \text{A}}{6{,}000\ \text{A}} = 28.8$	$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 3 \cdot \frac{35{,}860\ \text{A}}{6{,}000\ \text{A}} = 17.9$	$K'_{ssc} \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{I_{pn}}$ $= 5 \cdot \frac{7{,}498\ \text{A}}{1{,}200\ \text{A}} = 18{,}7$	
$R_b = \frac{S_{n)}}{1^2_{sn}} = \frac{20\ \text{VA}}{1\ \text{A}^2} = 20\ \Omega$	$R_b = \frac{S_{n)}}{1^2_{sn}} = \frac{20\ \text{VA}}{1\ \text{A}^2} = 20\ \Omega$	$R_b = \frac{S_{n)}}{1^2_{sn}} = \frac{50\ \text{VA}}{5\ \text{A}^2} = 2\ \Omega$	
$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot p \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 60\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.625\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot p \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 640\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.450\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot p \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 100\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.975\ \Omega$	$R'_b = R_{lead} + R_{relay}$ $R_b = \frac{2 \cdot p \cdot l}{A} + 0.1\ \Omega$ $= \frac{2 \cdot 0.0175 \frac{\Omega\ \text{mm}^2}{\text{m}} \cdot 60\ \text{m}}{4\ \text{mm}^2}$ $+ 0.1\ \Omega$ $= 0.625\ \Omega$
$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{18\ \Omega + 20\ \Omega}{18\ \Omega + 0.625\ \Omega} = 40.8$	$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{18\ \Omega + 20\ \Omega}{18\ \Omega + 0.450\ \Omega} = 41.2$	$K'_{ssc} = K_{ssc} \cdot \frac{R_{ct} + R_b}{R_{ct} + R'_b}$ $= 20 \cdot \frac{0.96\ \Omega + 2\ \Omega}{0.96\ \Omega + 0.975\ \Omega} = 30.6$	$U_K \geq K_{td} \cdot \frac{I_{scc\ max\ (ext.\ fault)}}{1.3 \cdot I_{pn}} \cdot (R_{ct} + R'_b) \cdot I_{sn}$ $= 1.2 \cdot \frac{17{,}000\ \text{A}}{1.3 \cdot 1{,}000\ \text{A}} \cdot (0.8\ \Omega + 0.625\ \Omega) \cdot 5\ \text{A}$ $= 111.8\ \text{V}$
K'_{ssc} required = 28.8, K_{ssc} effective = 40.8 28.8 < 40.8 → CT dimensioning is ok	K'_{ssc} required = 17.9, K_{ssc} effective = 41.2 17.9 < 41.2 → CT dimensioning is ok	K'_{ssc} required = 18.7, K_{ssc} effective = 30.6 18.7 < 30.6 → CT dimensioning is ok	U_K required = 111.8 V, U_K effective = 200 V 111.8 V < 200 V → CT dimensioning is ok
$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{6{,}000\ \text{A} \cdot \sqrt{3} \cdot 13.8\ \text{kV}}{120{,}000\ \text{kVA}} \cdot \frac{1\ \text{A}}{1\ \text{A}}$ $= 1.195$ $1/8 \leq 1.195 \leq 8$ → ok!	$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{6{,}000\ \text{A} \cdot \sqrt{3} \cdot 13.8\ \text{kV}}{240{,}000\ \text{kVA}} \cdot \frac{1\ \text{A}}{1\ \text{A}}$ $= 0.598$ $1/8 \leq 0.598 \leq 8$ → ok!	$F_{Adap} = \frac{I_{pn} \cdot \sqrt{3} \cdot U_{nO}}{S_{Nmax}} \cdot \frac{I_{Nrelay}}{I_{sn}}$ $= \frac{1{,}200\ \text{A} \cdot \sqrt{3} \cdot 132\ \text{kV}}{240{,}000\ \text{kVA}} \cdot \frac{5\ \text{A}}{5\ \text{A}}$ $= 1.143$ $1/8 \leq 1.143 \leq 8$ → ok!	$\frac{I_{pn\ max}}{I_{pn\ min}} \leq 8$ $\frac{1{,}500\ \text{A}}{1{,}000\ \text{A}} = 1.5 \leq 8$ → ok!

Fig. 6.2-90: **Example 1 (continued) – verfication of the numerical differential protection**

Attention: When low-impedance REF is used, the request for the REF side (3-phase) is:
$^1/_4 \leq F_{Adap} \leq 4$, (for the neutral CT: $^1/_8 \leq F_{Adap} \leq 8$

Further condition for 7SD52x, 53x, 610 relays (when used as line differential protection without transformer inside protected zone): Maximum ratio between primary currents of CTs at the end of the protected line:

$$\frac{I_{pn\ max}}{I_{pn\ min}} \leq 8$$

Example 2: Stability verification of the numerical busbar protection relay 7SS52

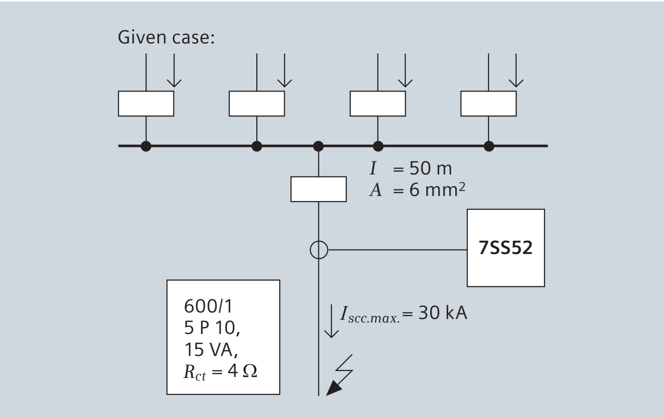


Fig. 6.2-90: **Example 2**

$\frac{I_{scc\,max}}{I_{pn}} = \frac{30{,}000\text{ A}}{600\text{ A}} = 50$

According to table 6.2-2, page 269 $K_{td} = {}^1/_2$

$K'_{ssc} \geq \frac{1}{2} \cdot 50 = 25$

$R_b = \frac{15\text{ VA}}{1\text{ A}^2} = 15\ \Omega$

$R_{relay} = 0.1\ \Omega$

$R_{lead} = \frac{2 \cdot 0.0175 \cdot 50}{6} = 0.3\ \Omega$

$R'_b = R_{lead} + R_{relay} = 0.3\ \Omega + 0.1\ \Omega = 0.4\ \Omega$

$K'_{ssc} = \frac{R_{ct} + R_b}{R_{ct} + R'_b} \cdot K_{ssc} = \frac{4\ \Omega + 15\ \Omega}{4\ \Omega + 15\ \Omega} \cdot 10 = 43.2$

Result:
The effective K'_{ssc} is 43.2, the required K'_{ssc} is 25. Therefore the stability criterion is fulfilled.

Relay burden
The CT burdens of the numerical relays of Siemens are below 0.1 VA and can therefore be neglected for a practical estimation. Exceptions are the busbar protection 7SS60 and the pilot-wire relays 7SD600.

Intermediate CTs are normally no longer necessary, because the ratio adaptation for busbar and transformer protection is numerically performed in the relay.

Analog static relays in general have burdens below about 1 VA.

Mechanical relays, however, have a much higher burden, up to the order of 10 VA. This has to be considered when older relays are connected to the same CT circuit.

In any case, the relevant relay manuals should always be consulted for the actual burden values.

Burden of the connection leads
The resistance of the current loop from the CT to the relay has to be considered:

$R_{lead} = \frac{2 \cdot \rho \cdot l}{A}$

l = single conductor length from the CT to the relay in m

Specific resistance:

$\rho = 0.0175 \frac{\Omega \cdot \text{mm}^2}{\text{m}}$ (copper wires) at 20 °C

A = Conductor cross-section in mm²

CT design according to ANSI/IEEE C 57.13

Class C of this standard defines the CT by ist secondary terminal voltage at 20 times rated current, for which the ratio error shall not exceed 10 %. Standard classes are C100, C200, C400 and C800 for 5 A rated secondary current.

This terminal voltage can be approximately calculated from the IEC data as follows:

ANSI CT definition

$U_{s.t.max} = 20 \cdot 5\text{ A} \cdot R_b \cdot \frac{K_{ssc}}{20}$

with

$R_b = \frac{P_b}{I_{sn}^2}$ and $I_{Nsn} = 5$ A, the result is

$U_{s.t.max} = \frac{P_b \cdot K_{ssc}}{5\text{ A}}$

Example:
IEC 60044: 600/5, 5P20, 25 VA,

ANSI C57.13: $U_{s.t.max} = \frac{(25\text{ VA} \cdot 20)}{5\text{ A}} = 100$ V, acc. to class C100

6.2.5 Relay Selection Guide

Protection functions	Type	Distance		Pilot-wire differential	Line differential		Overcurrent									Motor protection	Differential					
ANSI No.*	Description	7SA522	7SA6	7SD600	7SD5	7SD610	7SJ45	7SJ46	7SJ600	7SJ602	7SJ80	7SJ61	7SJ62	7SJ63	7SJ64	7SK80	7VH60	7UT612	7UT613	7UT63	7SS60	7SS52
14	Locked-rotor protection	–	–	–	–	–	–	–	–	–	–	●	●	●	●	■	–	–	–	–	–	–
21	Distance protection, phase	■	■	–	●	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
21N	Distance protection, earth (ground)	■	■	–	●	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
21FL	Fault locator	■	■	–	●	–	–	–	–	–	●	–	●	●	●	–	–	–	–	–	–	–
24	Overfluxing (V/f protection)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	●	●	–	–
25	Synchronizing, synchronism check	●	●	–	●	–	–	–	–	–	●	–	–	–	●	–	–	–	–	–	–	–
27	Undervoltage	●	●	–	●	●	–	–	–	–	●	–	●	●	●	●	–	–	●	–	–	–
27/34	Stator earth-fault 3rd harmonic	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
32	Directional power	–	–	–	–	–	–	–	–	–	●	–	–	–	●	●	–	–	●	–	–	–
32F	Forward power	–	–	–	–	–	–	–	–	–	●	–	–	–	●	●	–	–	●	–	–	–
32R	Reverse power	–	–	–	–	–	–	–	–	–	●	–	–	–	●	●	–	–	●	–	–	–
37	Undercurrent or underpower	–	–	–	–	–	–	–	–	●	■	■	■	■	■	■	–	–	–	–	–	–
40	Loss of field	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
46	Load unbalance, negative phase-sequence overcurrent	–	–	–	–	–	–	–	■	■	■	■	■	■	■	■	–	●	–	●	–	–
47	Phase-sequence voltage	■	■	–	■	–	–	–	–	–	●	–	■	■	■	●	–	–	–	–	–	–
48	Motor starting protection	–	–	–	–	–	–	–	■	●	–	●	●	●	●	■	–	–	–	–	–	–
49	Thermal overload	–	●	–	■	■	–	–	■	■	■	■	■	■	■	■	–	■	■	■	–	–
49R	Rotor thermal protection	–	–	–	–	–	–	–	■	■	–	■	■	■	■	■	–	–	–	–	–	–
49S	Stator thermal protection	–	–	–	–	–	–	–	■	■	–	■	■	■	■	■	–	–	–	–	–	–
50	Instantaneous overcurrent	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■	■	■	–	●
50N	Instantaneous earth-fault overcurrent	■	■	–	■	■	–	–	■	■	■	■	■	■	■	■	–	■	■	■	–	●
50BF	Breaker failure	●	●	–	■	●	–	–	–	■	■	■	■	■	■	■	–	●	●	●	–	■
51GN	Zero speed and underspeed device	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
51	Overcurrent-time relay, phase	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	–	■	■	■	–	●
51M	Load jam protection	–	–	–	–	–	–	–	–	–	●	●	●	●	●	■	–	–	–	–	–	–
51N	Overcurrent-time relay, earth	■	■	–	■	■	■	■	■	■	■	■	■	■	■	■	–	■	■	■	–	●
51V	Overcurrent-time relay, voltage controlled	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
59	Overvoltage	●	●	–	●	–	–	–	–	–	●	–	●	●	●	●	–	–	–	●	–	–
59N	Residual voltage earth-fault protection	●	●	–	●	●	–	–	–	■	●	–	■	■	■	●	–	–	–	–	–	–
59GN	Stator earth-fault protection	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
64	100 % stator earth-fault protection (20 Hz)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
64R	Rotor earth fault	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–

■ Standard function ● Option * ANSI/IEEE C 37.2: IEEE Standard Electrical Power System Device Function Numbers

6

Protection functions ANSI No.*	Type Description	7UM61 Generator and	7UM62 motor protection	7VK61 Breaker management	7VE6 Synchronizing	7SV600 Breaker failure	7RW600 Voltage, frequency
14	Locked-rotor protection	■	■	–	–	–	–
21	Distance protection, phase	■	■	–	–	–	–
21N	Distance protection, earth (ground)	–	–	–	–	–	–
21FL	Fault locator	–	–	–	–	–	–
24	Overfluxing (V/f protection)	■	■	–	–	–	■
25	Synchronizing, synchronism check	–	–	■	■	–	–
27	Undervoltage	■	■	●	●	–	■
27/34	Stator earth-fault 3rd harmonic	■	■	–	–	–	–
32	Directional power	–	■	–	–	–	–
32F	Forward power	●	■	–	–	–	–
32R	Reverse power	■	■	–	–	–	–
37	Undercurrent or underpower	–	■	–	–	–	–
40	Loss of field	●	■	–	–	–	–
46	Load unbalance, negative phase-sequence overcurrent	●	●	–	–	–	–
47	Phase-sequence voltage	■	■	–	–	–	–
48	Motor starting protection	●	●	–	–	–	–
49	Thermal overload	■	■	–	–	–	–
49R	Rotor thermal protection	–	■	–	–	–	–
49S	Stator thermal protection	■	■	–	–	–	–
50	Instantaneous overcurrent	■	■	■	–	–	–
50N	Instantaneous earth-fault overcurrent	■	■	–	–	–	–
50BF	Breaker failure	■	■	■	–	■	–
51GN	Zero speed and underspeed device	–	■	–	–	–	–
51	Overcurrent-time relay, phase	■	■	–	–	–	–
51N	Overcurrent-time relay, earth	■	■	–	–	–	–
51V	Overcurrent-time relay, voltage controlled	■	■	–	–	–	–
59	Overvoltage	■	■	●	●	–	■
59N	Residual voltage earth-fault protection	■	■	–	–	–	–
59GN	Stator earth-fault protection	■	■	–	–	–	–
64	100 % stator earth-fault protection (20 Hz)	–	●	–	–	–	–
64R	Rotor earth fault	■	■	–	–	–	–

■ Standard function ● Option

* ANSI/EEE C 37.2: IEEE Standard Electrical Power System Device Function Numbers

6

Protection functions	Type	Distance		Pilot-wire differential	Line differential		Overcurrent									Motor protection	Differential					
		7SA522	7SA6	7SD600	7SD5	7SD610	7SJ45	7SJ46	7SJ600	7SJ602	7SJ80	7SJ61	7SJ62	7SJ63	7SJ64	7SK80	7VH60	7UT612	7UT613	7UT63	7SS60	7SS52
ANSI No.*	Description																					
67	Directional overcurrent	–	–	–	–	–	–	–	–	–	●	–	■	■	■	–	–	–	–	–	–	–
67N	Directional earth-fault overcurrent	●	●	–	●	●	–	–	–	■	●	–	■	■	■	●	–	–	–	–	–	–
67G	Stator earth-fault directional overcurrent	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
68	Out-of-step protection	●	●	–	●	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
74TC	Trip circuit supervision	■	■	–	■	■	–	–	■	■	■	■	■	■	■	■	–	●	●	●	–	–
78	Out-of-step protection	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
79	Auto-reclosure	●	●	–	●	●	–	–	●	●	●	●	●	●	●	–	–	–	–	–	–	–
81	Frequency protection	■	■	–	●	–	–	–	–	–	●	–	●	●	●	●	–	–	–	●	–	–
81R	Rate-of-frequency-change protection	–	–	–	–	–	–	–	–	–	●	–	–	–	–	●	–	–	–	–	–	–
	Vector jump supervision	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
85	Carrier interface/remote trip	■	■	●	■	■	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■
86	Lockout function	■	■	■	■	■	–	–	–	–	■	■	■	■	■	■	–	■	■	■	■	–
87G	Differential protection generator	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■	■	■	–	–
87T	Differential protection transformer	–	–	■	●	●	–	–	–	–	–	–	–	–	–	–	■	■	■	■	–	–
87BB	Differential protection busbar	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■	■	■	■	■
87M	Differential protection motor	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	■	■	■	–	–
87L	Differential protection line	–	–	■	■	■	–	–	–	–	–	–	–	–	–	–	–	■	■	■	–	–
87N	Restricted earth-fault protection	–	–	–	–	–	–	–	–	–	■	■	■	■	■	–	■	●	●	●	–	–

■ Standard function ● Option * ANSI/IEEE C 37.2: IEEE Standard Electrical Power System Device Function Numbers

6

Protection functions	Type	7UM61 Generator and	7UM62 motor protection	7VK61 Breaker management	7VE6 Synchronizing	7SV600 Breaker failure	7RW600 Voltage, frequency
ANSI No.*	Description						
67	Directional overcurrent	■	■	–	–	–	–
67N	Directional earth-fault overcurrent	■	■	–	–	–	–
67G	Stator earth-fault directional overcurrent	■	■	–	–	–	–
68	Power swing detection	–	●	–	–	–	–
74TC	Trip circuit supervision	■	■	■	–	–	–
78	Out-of-step protection	–	■	–	–	–	–
79	Auto-reclosure	–	–	■	–	–	–
81	Frequency protection	■	■	–	●	–	■
81R	Rate-of-frequency-change protection	●	●	–	●	–	●
	Vector jump supervision	●	●	–	●	–	–
85	Carrier interface/remote trip	–	–	–	–	–	–
86	Lockout function	■	■	■	●	–	–
87G	Differential protection generator	–	■	–	–	–	–
87T	Differential protection transformer	–	■	–	–	–	–
87BB	Differential protection busbar	–	–	–	–	–	–
87M	Differential protection motor	–	■	–	–	–	–
87L	Differential protection line	–	–	–	–	–	–
87N	Restricted earth-fault protection	–	●	–	–	–	–

■ Standard function ● Option

* ANSI/EEE C 37.2: IEEE Standard Electrical Power System Device Function Numbers

6

6.3 Substation Automation

6.3.1 Overview and Solutions

During the last years, the influences on the business of the power supply companies have changed a lot. The approach to power grid operation has changed from a static quasi-stable interpretation to a dynamic operational management of the electric power grid. Enhanced requirements regarding the economy of lifetime for all assets in the grid are gaining importance.

As a result, the significance of automation systems has increased a lot, and the requirements for control, protection and remote control have undergone severe changes of paradigm:

- Flexible and tailor-made solutions for manifold applications,
- Secure and reliable operation management
- Cost-effective investment and economic operation
- Efficient project management
- Long-term concepts, future-proof and open for new requirements.

Siemens energy automation solutions offer an answer to all current issues of today's utilities. Based on a versatile product portfolio and many years of experience, Siemens plans and delivers solutions for all voltage levels and all kinds of substations (fig. 6.3-1).

Siemens energy automation solutions are available both for refurbishment and new turnkey substations, and can be used in classic centralized or distributed concepts. All automation functions can be performed where they are needed.

Flexible and tailor-made solutions for manifold applications

Siemens energy automation solutions offer a variety of standardized default configurations and functions for many typical tasks. Whereas these defaults facilitate the use of the flexible products, they are open for more sophisticated and tailor-made applications. Acquisition of all kinds of data, calculation and automation functions, as well as versatile communication can be combined in a very flexible way to form specific solutions, and fit into the existing surrounding system environment.

The classical interface to the primary equipment is centralized with many parallel cables sorted by a marshalling rack. In such an environment, central protection panels and centralized RTUs are standard. Data interfaces can make use of high density I/O – elements in the rack, or of intelligent terminal modules, which are even available with 220 V DC for digital inputs and direct CT/VT interfaces.

Even in such configurations, the user can benefit from full automation and communication capabilities. This means that classical RTU solution, interfaces to other IEDs are included, and HMIs for station operation and supervision can be added as an option. Also, the protection relays are connected to the RTU, so that data from the relays are available both at the station operation terminal and in the control centers.

Typically, these solutions are either based on the large system component AK 1703 ACP (19" rack design) or on the compact TM 1703 ACP (DIN-rail mounted). Like all members of the SICAM 1703 family, they can be equipped with different combinations of communication, both serial and Ethernet (TCP/IP). Different protocols are available, mainly IEC standards, e.g., IEC 60870-5-101/103/104 IEC 61850, IEC 62056-21, but also a lot of other well-known protocols from different vendors (product description section 6.3-2).

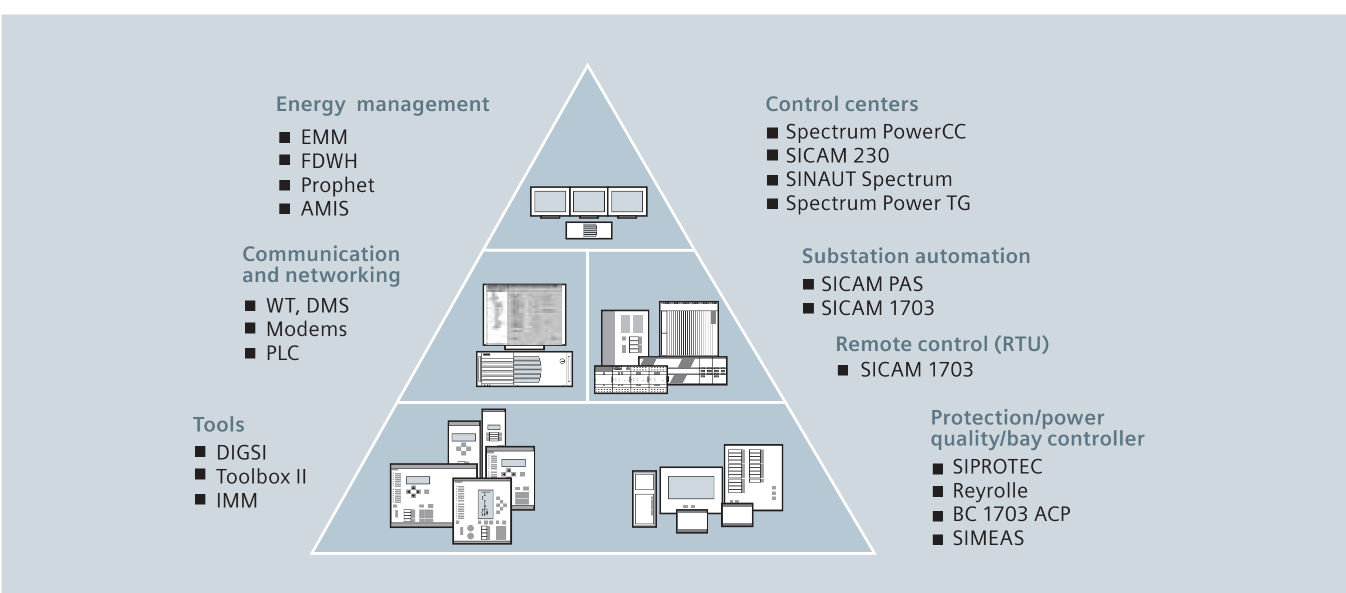


Fig. 6.3-1: **Siemens energy automation solutions**

Fig. 6.3-2 shows an example of refurbishment and centralized data acquisition in an MV substation. The interface to the primary equipment is connected via a marshalling rack, but can use any peripheral voltage (24–220 V DC). The electronic terminal blocks are designed to substitute conventional terminal blocks, thereby realizing a very economic design. Existing protection relays can be connected either by IEC 60870-5-103 or by the more enhanced IEC 61850.

In new substations, the amount of cabling can be reduced by decentralizing the automation system. Both protection relays and bay controllers are situated as near as possible to the primary switchgear. Typically they are located in relay houses (EHV) or in control cabinets directly beneath HV GIS feeders. The rugged design with maximum EMC provides high security and availability.

For station control, two different products are available: SICAM PAS is a software-oriented product based on standard industrial hardware, whereas SICAM 1703 represents the modular hardware-oriented design which bridges the gap between remote terminal units (RTUs) and substation automation (SAS) (fig. 6.3-3).

The flexible Siemens solutions are available for every kind of substation:

- For different voltage levels, from ring main unit to transmission substation
- For new substations or refurbishment
- For gas-insulated or air-insulated switchgear
- For indoor or outdoor design
- For manned or unmanned substations

Communication is the backbone of every automation system. Therefore, Siemens solutions are designed to collect the data from the high-voltage equipment and present them to the

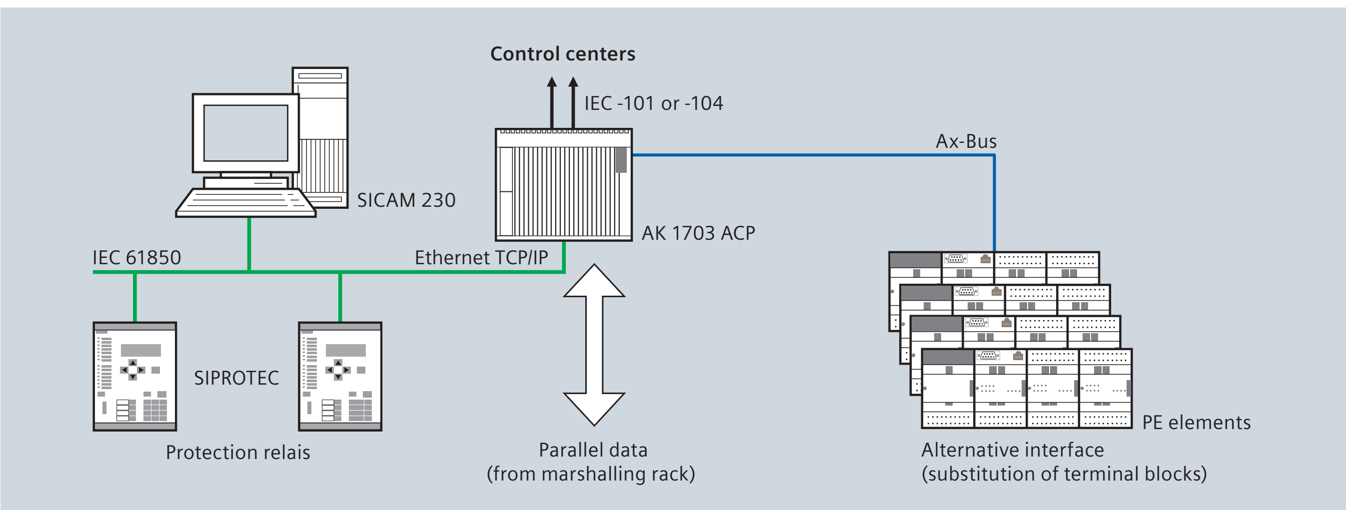


Fig. 6.3-2: **Example of refurbishment and centralized data acquisition in an MV substation**

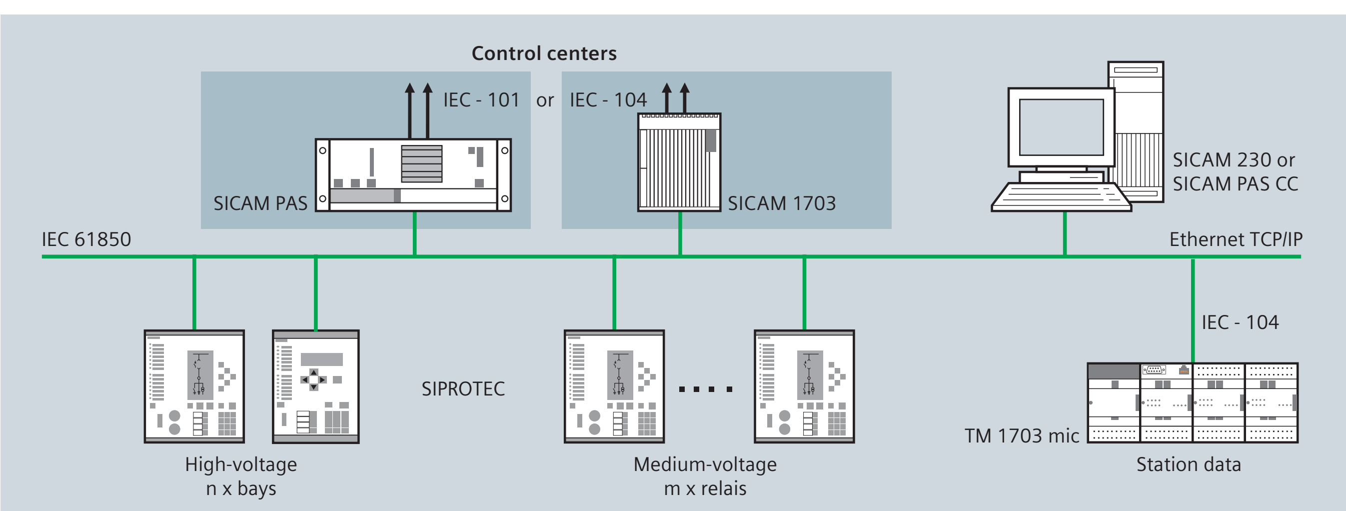


Fig. 6.3-3: **Basic principle of a SICAM station automation solution with alternative station controllers**

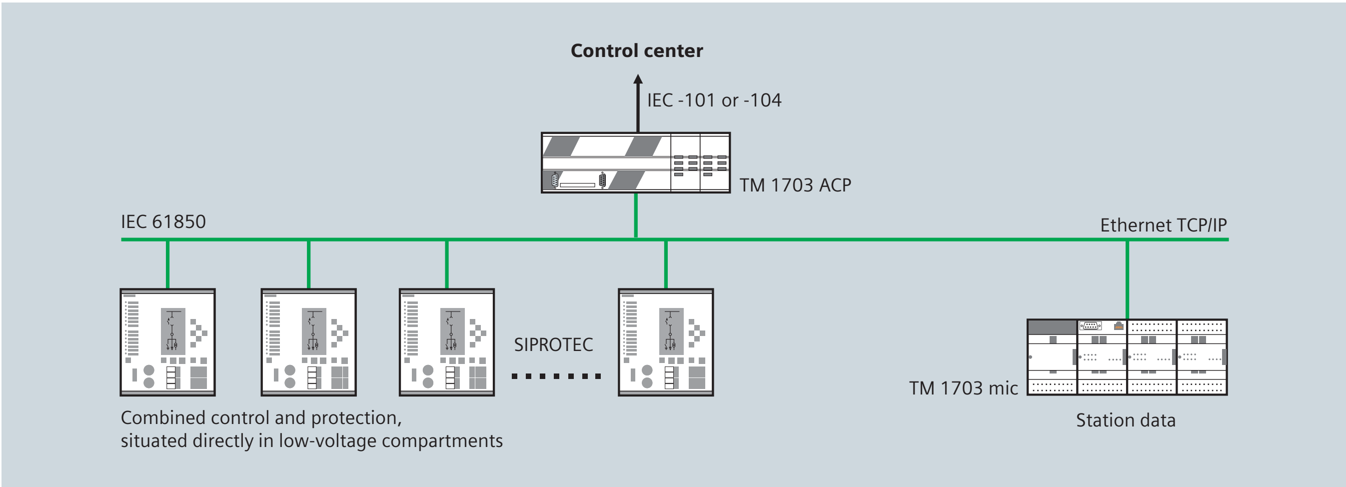


Fig. 6.3-4: **Combined control and protection, situated directly in low-voltage compartments**

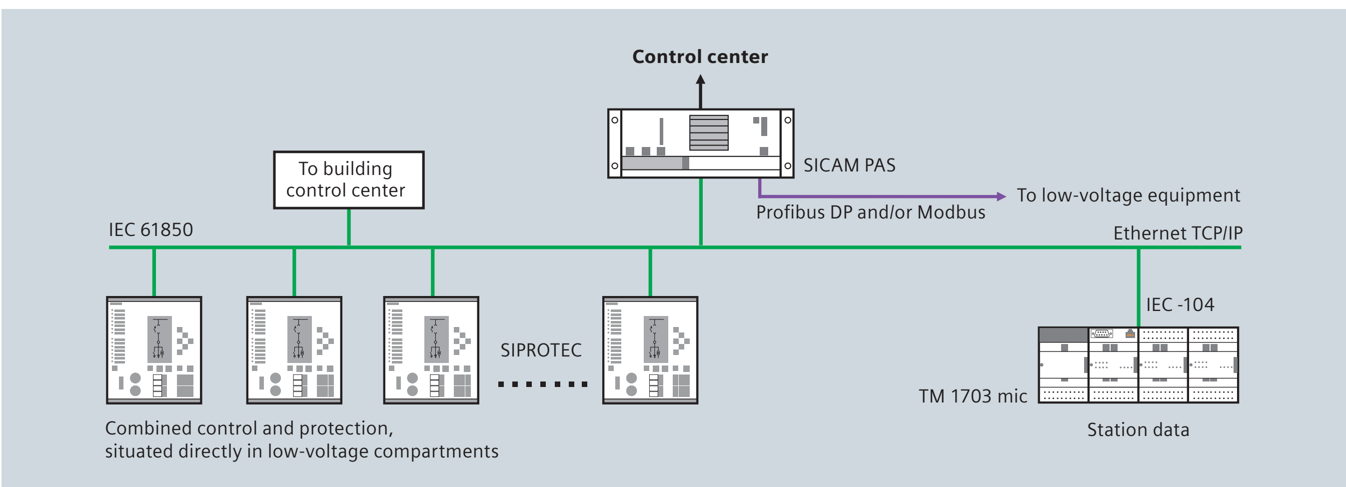


Fig. 6.3-5: **Example of a distribution substation in industry supply**

different users: the right information for the right users at the right place and time with the required quality and security.

Here are some default examples for typical configurations. They are like elements which can be combined according to the respective requirements. The products, which are the bricks of the configurations, are an integral part of the harmonized system behavior, and support according to the principle of single-point data input. This means that multiple data input is avoided. Even if different engineering tools are necessary for certain configurations, these tools exchange their data for more efficient engineering.

Example of a small medium-voltage substation: Typically it consists of 4 to 16 MV feeders and is unmanned. In most cases, combined bay control and protection devices are located directly in the low-voltage compartments of the switchgear panels.

A station operation terminal is usually not required, because such substations are normally remote-controlled, and in case of local service/maintenance they are easy to control at the front side of the switchgear panels (fig. 6.3-4).

Example of a distribution substation in industry supply: In principle they are similar to the configuration above, but they are often connected to a control center via local area network (LAN). A distinctive feature is the interface to low-voltage distribution boards and sometimes even to the industrial automation system for data exchange. Here, the compatibility with SIMATIC products simplifies system integration (fig. 6.3-5).

A subtransmission substation requires even more complexity: 2 or 3 voltage levels have to be equipped; a station operation terminal is usually required; more communication interfaces to external locations, separated control and protection devices on HV level, powerful LAN based on IEC 61850, and remote maintenance access are typical features of such applications (fig. 6.3-6).

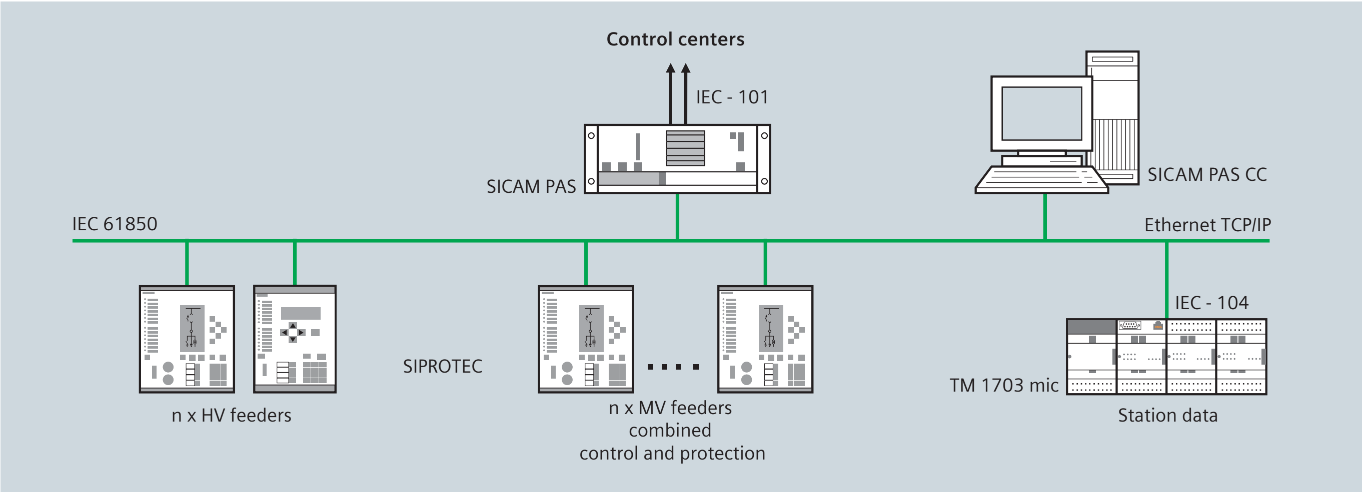


Fig. 6.3-6: **Example for subtransmission**

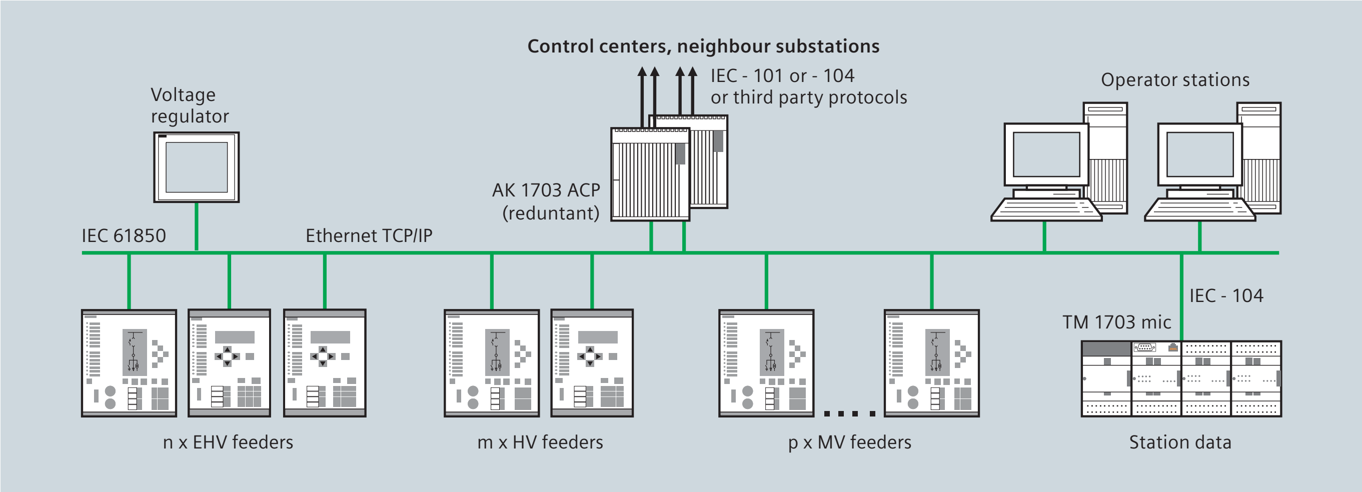


Fig. 6.3-7: **Example for a transmission substation**

In transmission substations, typically two to four voltage levels are to be automated. According to the high importance of such substations, availability is of the highest priority. Therefore, redundancy at substation level is generally required, both for station control units and station operation. Multiple operator stations are often required, multiple communication links to different control centers or neighboring substations are standard. Although most standard applications are IEC protocols, specific protocols also have to be offered for interfacing existing third-party devices. Complex automation functions support the operation and maintenance of such substations, such as voltage regulation by controlling on-load tap changers, synchrocheck, automatic command sequences, etc. (fig. 6.3-7).

The devices are as flexible as the configurations: bay controllers, protection relays, station control units, station operation units and RTUs can be configured from small to very large. The well-known products of the SICAM, SIMEAS and SIPROTEC series are a well proven base for the Siemens solutions.

Secure and reliable operation

Siemens solutions provide human machine interfaces (HMI) for every control level and support the operators with reliable information and secure, easy-to-use control features.

At feeder level:

- Conventional panels with pushbuttons and instruments for refurbishment
- Electronic front panels combined with bay control units (default)
- Access points for remote terminals connected to the station operation units
- Portable touch panels with wireless access in defined areas

At substation level:

- Single or redundant HMI
- Distributed server/client architectures with multiple and/or remote terminals
- Interface to office automation

All images and pictures of the HMIs are designed according to ergonomic requirements, so as to give the operators clear information that is easy to use. Control commands are only accepted if access rights are met, the local/remote switches are in the right position and the multi-step command sequence is actively handled. Care is taken that only commands which are intended and explicitly given are processed and sent to the switchgear.

Automation functions support operation:

- Interlocking
- Feeder or remote blocking (option)
- Command sequences (option)
- Automatic recloser (option)
- Automatic switchover (option)
- etc.

All images and pictures of the HMI are organized hierarchically and, for easy access, they guide the user to the required information and to fast alarm recognition. In addition, alarm and event logs, measurement curves, fault records, archives and flexible reports support the analysis of any situation in the power grid (fig. 6.3-8).

For security reasons only specially authorized personnel is granted access to operation and engineering tools. Flexible access rights are defined for operators, design engineers and service personnel, and differentiate between engineering access and operation rights.

Security of data transmission is catered for by secure protocols and secure network design. Especially, easy remote access to substations creates the need for such complex measures. The experienced Siemens engineers provide all the necessary knowledge for network security concepts.

Cost-effective investment and economic operation

The customized solutions from Siemens cater for effective investment. Tailor-made configurations and functions make sure that only required items are offered. The efficient tools cater for fast and easy engineering and support all project phases of an automation system, from collection of the substation data to deployment of all needed functions, and finally to reporting and archiving. The long lifetime of the involved future-proof products extend the time period between investments into automation systems.

Siemens solutions ensure low cost of ownership, thus taking into account all costs during lifetime. The automation systems are maintenance free and easy to expand at a later date. Last but not least, the powerful services for remote maintenance (diagnosis, settings, updates, test, etc.) provide a very economic way to keep any substation up-to-date and running.

Simple handling of the solutions is provided by:

- Same look and feel of all HMI on different levels
- Vertical and horizontal interoperability of the involved products
- Plug and play for spare parts by simple exchange of flash cards

Reduction of engineering effort by

- Seamless data management, only single data input for whole project
- Easy up and downloads, even remote
- Integrated test tools

Reduction of service expenses during lifetime by

- Integrated self-supervision in all components
- Powerful diagnosis in clear text
- Remote access for diagnosis, settings, test, expansions, etc.

Reduction of complexity by seamless communication

- Worldwide standard IEC 61850 promoted by Siemens
- Integrated IT security concepts
- Latest technology integrated

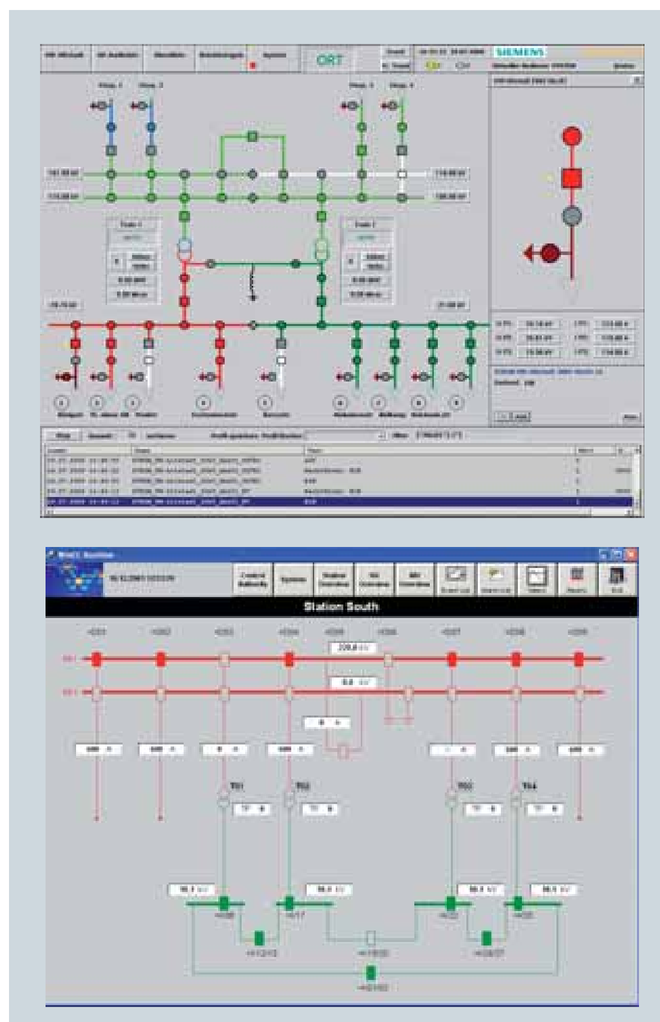


Fig. 6.3-8: **Human machine interface for every control level**

Efficient and state-of-the-art projects
The solutions for energy automation are part of the extensive programme, "Siemens One". This means that energy automation solutions are integrated in different applications of the vast activity and expertise of Siemens:

- Power grids in transmission and distribution
- Complete building automation
- Solutions for pipelines and infrastructure
- Turnkey railway systems

They all make use of the energy automation solutions and the associated transfer of expertise for efficient project and order execution. Our worldwide engineering centers are always close to the system operators (fig. 6.3-9).

Long-term stability and trendsetting features for new requirements
With Siemens energy automation systems every user benefits from more than 70 years of experience in remote control and substation automation. The energy automation systems are designed for a long lifetime. Innovation is based on existing products, and compatibility of different product generations is part of the Siemens development philosophy.

The extensive use of available IEC standards strongly supports long-term stability and expandability. Examples are communication protocols like IEC 61850 in the substation, IEC 61970 for control centers, and IEC 60870-5 for remote communication. They form the strong backbone for the seamless solutions in energy automation. Additionally, the systems are tested in rugged environmental conditions and certified according to applicable IEC standards.

Investments in our solutions are secured by the "evergreen concept", which defines migration methods when a new generation of products is introduced to the markets, e.g., the migration solution for SICAM LSA 678 from the early 90ies: By substituting the station control device with today's SICAM PAS, it is possible to retain the installed feeder devices and import the existing database with the settings into the new tool SICAM PAS UI. This method reduces the refurbishment work significantly and adds new features to the system: In the next years the substation can be expanded with new feeder devices through the use of IEC 61850, even though some parts of the system might already be older than 15 years (fig. 6.3-10).

Fig. 6.3-9: **The worldwide engineering centers of Siemens**

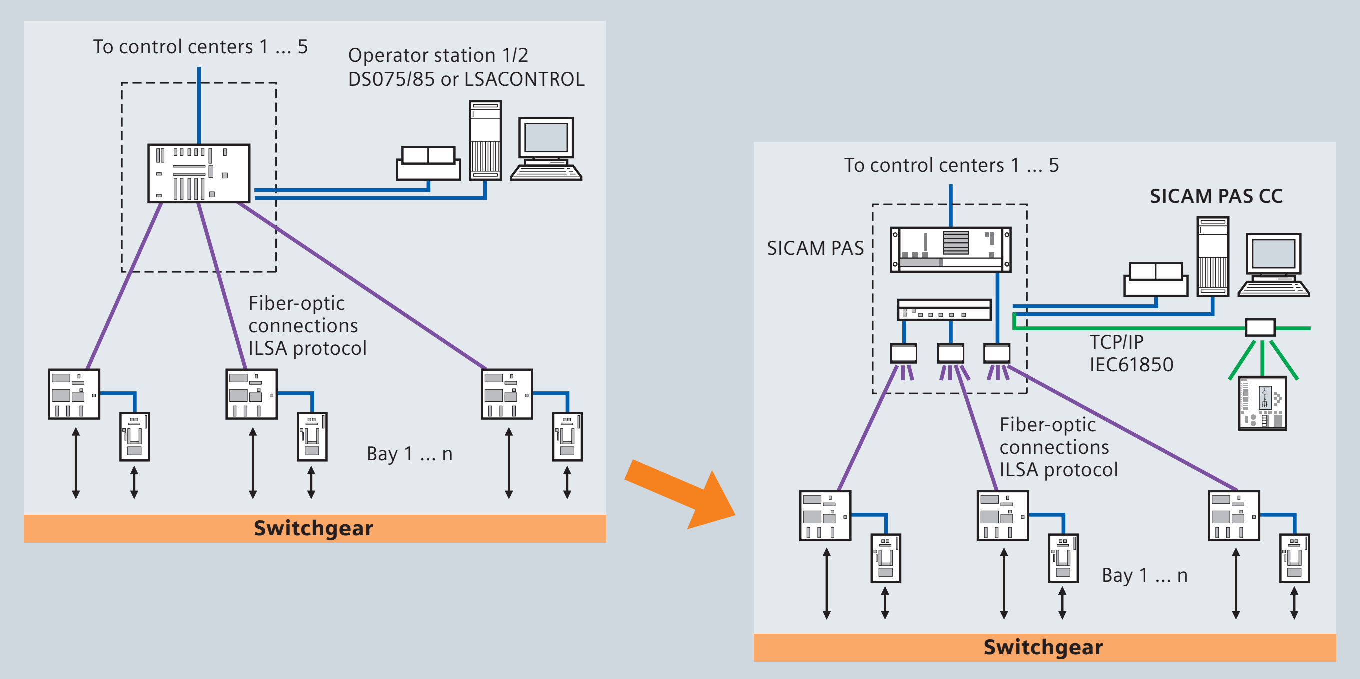


Fig. 6.3-10: **Migration from LSA to PAS**

Our solutions are not only compatible with older devices, they are also very innovative.

The Frost&Sullivan Technology Leadership Award 2006 was presented to Siemens for pioneering in the development of an innovative technology, the IEC 61850.

With Siemens energy automation solutions, every user is on the safe side: the combination of long-term experience and the newest innovation supplies safety for many years to come.

6.3.2 SICAM PAS

SICAM PAS (Power Automation System) meets all the demands made of a distributed substation control system – both now and in the future. Amongst many other standardized communication protocols, SICAM PAS supports the new IEC 61850 substation standard for communication with feeder devices. SICAM PAS is an open system and – in addition to standardized data transfer processes – it features user interfaces for the integration of system-specific tasks and offers multiple automation options. SICAM PAS can thus be integrated with ease in existing systems and can be used for system integration, too. With modern diagnostics, it optimally supports commissioning and maintenance. SICAM PAS is clearly structured and reliable, thanks to its open, fully documented and tested system (fig. 6.3-11).

System overview, application and functionality of SICAM PAS
SICAM PAS is an energy automation solution; its system architecture makes it scalable.

SICAM PAS is suitable for operating a substation not only from one single station computer (station unit), but also in combination with other SICAM PAS systems or station control units. Communication in this network is based on a powerful Ethernet LAN.

SICAM PAS for safe substation automation is based on robust hardware components (non-rotating components) and an embedded operating system. With its features and its modular expandability, SICAM PAS covers a broad range of applications and supports distributed system configurations. A distributed SICAM PAS system operates simultaneously on several computers. SICAM PAS can use existing hardware components and communication standards as well as their connections. SICAM PAS controls and registers the process data for all devices of a substation, within the scope of the data transfer protocols supported. SICAM PAS is a communication gateway. This is why only one single data connection to a higher-level system control center is required.

SICAM PAS enables integration of a fully graphical process visualization system directly in the substation. SICAM PAS simplifies installation and parameterization of new devices, thanks to its intuitive user interface. SICAM PAS is notable for its online parameter setting features, particularly when the system has to be expanded. There are no generation times, and there is no need for loading into a target system (unless configuration is performed on a separate engineering PC).

SICAM PAS features integrated testing and diagnostic functions. Its user-friendliness, its operator control logic, its orientation to the Windows world and its open structure ideally suit the users' requirements. SICAM PAS is developed in accordance with selected security standards.

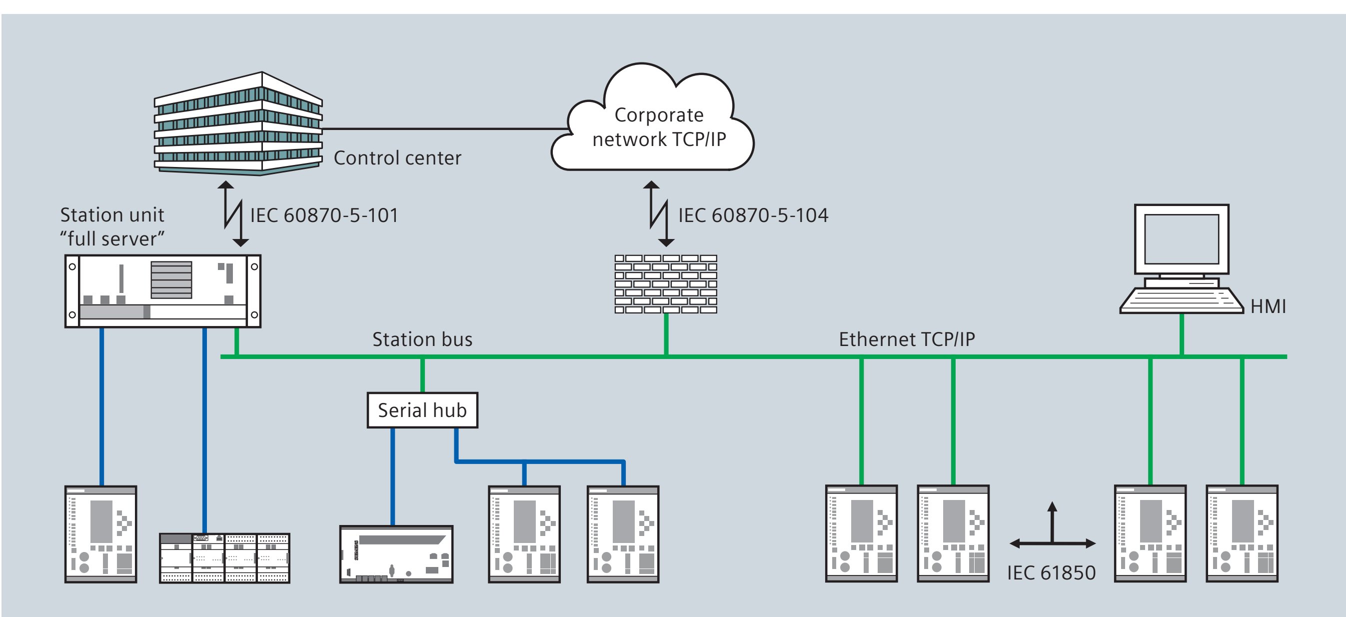


Fig. 6.3-11: **Typical SICAM PAS configuration; IEDs are connected to the station unit with IEC 61850 and various other protocols (IEC 60870-5-103,DNPV3.00, etc.). The station unit communicates with the higher-level system control center by means of IEC 60870-5-101 and/or 104**

System architecture
SICAM PAS works on PC-compatible hardware with the Microsoft Windows 2000, Windows XP Professional, Windows XP Embedded and Windows 2003 Server operating systems. The advantages of this platform are low hardware and software costs, ease of operation, scalability, flexibility and constantly available support. With the powerful real-time data distribution system, applications can be allocated among several computers, thus boosting performance, connectivity and availability. A system stores and organizes the database (e.g., configuration data, administrative status data, etc.). The device master function for communication with Intelligent Electronic Devices (IEDs) supports a large number of well-established protocols.

The SICAM PAS data normalization function allows such conversions as measurement filtering, threshold calculation and linear characteristics. SICAM PAS CC is used for process visualization. Specifically designed for energy automation, it assists in optimization of operations management, providing a quick introduction to the subject matter and a clearly arranged display of the system's operating states. SICAM PAS CC is based on SIMATIC WinCC, well-known in industrial automation worldwide. To facilitate incident analysis, the fault records from protection units are retrieved and archived automatically during operation.

This is supported by the IEC 61850 and PROFIBUS FMS (SIPROTEC 4) protocols, or the IEC 60870-5-103 protection units protocol. SICAM Recpro is used for archiving and navigation in the fault recording archive. Fault records are visualized with Comtrade View (included with SICAM Recpro). Alternatively, SIGRA 4 can also be used (fig. 6.3-12).

Communication
Device interfaces and communication protocols in a substation are configured and operated with SICAM PAS. The user can employ various types of protection units, IEDs, bay control units, measured-value recorders and telecontrol units from a wide range of manufacturers. SICAM PAS offers a large number of commercially available communication protocols for recording data from various devices and through differing communication channels. Subsequent expansion is easy.

Available protocols:
These communication protocols and device drivers can be obtained as optional additions to the standard scope of SICAM PAS.

IEC 61850:
IEC 61850 is the communication standard for interconnecting the devices at the feeder and station control levels on the basis of Ethernet. IEC 61850 supports the direct exchange of data between IEDs, thus enabling switching interlocks across feeders independently of the station control unit, for example.

PROFIBUS FMS:
Most SIPROTEC 4 bay controllers and protection units (fig. 6.3-12, fig. 6.2-13) can be connected to the SICAM PAS station unit with PROFIBUS FMS. Many of the functional aspects standardized in IEC 61850 have been anticipated in this communication platform (fig. 6.3-13).

Fig. 6.3-12: **SIPROTEC 4 bay controllers and protection devices**

Fig. 6.3-13: **SIPROTEC 4 bay controllers with local control**

- IEC 60870-5-103: Protection units, IEDs, bay control units, measured value recorders and transformer controllers from many manufacturers support the IEC 60870-5-103 protocol and can therefore be connected directly to SICAM PAS.
- IEC 60870-5-101 (Master): The IEC 60870-5-101 protocol is generally used to connect telecontrol units. The "balanced" and "unbalanced" traffic modes are supported.
  Automatic dialing is also supported for the connection of substations with this protocol. SICAM PAS can establish the dial-up connection to the substation either cyclically or as required (e.g., for command output). By contrast, the substation can also establish a connection cyclically or in

event-triggered mode. Analog or ISDN modems can be used. A GSM modem can also be used in the substation. Several modems are supported for communication with substations. Even if the "standard modem" is already in use, other substations remain accessible.
- IEC 60870-5-104 (Master): Furthermore, connection of substations is also supported by the TCP/IP-based IEC 60870-5-104 protocol.
- PROFIBUS DP: PROFIBUS DP is a highly powerful field bus protocol based on the token passing method. For example, it is used for industrial automation and for automating the supply of electricity and gas. PROFIBUS DP serves to interface multifunctional measuring instruments such as SIMEAS P or, for example, to connect ET200 components for gathering messages and for simple commands. Messages, for example, can be derived from the signaling contacts of a fuse switch. For simple applications that do not need functions like time synchronization and fault recording transfer, etc., SIPROTEC 4 units can also be interfaced via PROFIBUS DP. IEDs and substations can also be connected with DNP V3.00 (serial and "over IP") and MODBUS.
- ILSA Protocol Communication via the ILSA protocol is a highlight of SICAM PAS system. Existing LSA central devices can be used without changing of configuration at feeder level. A future-proof extension with IEC 61850 is possible. System control center connections, distributed process connection and process visualization.

SICAM PAS operates on the basis of Windows 2000, Windows XP Professional and Windows XP Embedded. This means that the extensive support which 2000/XP offers for modern communication protocols is also available with SICAM PAS.

SICAM PAS was conceived for easy and fast integration of conventional protocols. Questions about integration of user-specific protocols will be answered by Siemens on request. The standardized telecontrol protocols IEC 60870-5-101 IEC 60870-5-104, DNP V3.00 (which is also used throughout the world) as well as TG 8979 and CDT are supported for the purpose of linking up to higher-level system control centers. Asymmetric encryption enables tap-proof DNP V3.00 communication via TCP/IP connection to higher-level control centers. Distributed process connection in the substation is possible thanks to the SICAM PAS Device Interface Processor (DIP).

SICAM PAS can also be set up on computers networked with TCP/IP. Here, one computer performs the task of the so-called full server. Up to six other computers can be used as DIPs. With this architecture, the system can be adapted to the topological situation and its performance also boosted. SICAM PAS allows use of the SICAM PAS CC process visualization system for central process control and monitoring. For industrial applications, it is easy to configure an interface to process visualization systems via OPC (Object Linking and Embedding for Process Control).

SICAM PAS can be configured as an OPC server or as an OPC client. The SICAM PAS process variables – available with the OPC server – can be read and written with OPC clients working either on the same device or on one networked by TCP/IP. This mechanism enables, for example, communication with another process visualization system. The OPC server is included in the basic system. Typical applications are data exchange with another SICAM PAS station unit, and the connection of SIMATIC programmable controllers. The OPC client is available as an optional package.

SICAM Diamond

SICAM Diamond can be used to monitor the system interfaces, to indicate switching device states (and up-to-date measured values), and also for further diagnostic purposes. SICAM Diamond features an event list and enables the issue of switching commands. SICAM Diamond allows access to data with a Web browser (Microsoft Internet Explorer), either on the same computer or from a Web client. In other words: SICAM PAS permits data access with Web-based programs (fig. 6.3-14).

Further station control aspects

SICAM PAS features feeder blocking and telecontrol blocking functions. The telecontrol blocking function can also be configured for specific channels so as to prevent the transfer of information to one particular control center during operation, while transfer continues with other control centers. The feeder blocking and telecontrol blocking functions act in both the signaling and the command directions. Channel-specific switching authority also makes it possible to distinguish between local control (SICAM PAS CC) and remote control for the switching direction, but also between control center connections. Circuit-breakers can be controlled in synchronized/unsynchronized mode. Automation tasks can be configured in SICAM PAS with the CFC (Continuous Function Chart), which conforms to IEC 61131. In this editor, tasks are configured graphically by wiring function blocks. SICAM PAS comes with an extensive library of CFC function blocks, developed and system-tested specially for energy automation. Applications range from generation of simple group indications through switching interlocks to complex switching sequences. Namely the creation of switching sequences is supported by the SFC Editor (Sequential Function Chart).

Protocols

SICAM PAS supports the following communication protocols (optionally available):
- Control center connection IEC 60870-5-101, IEC 60870-5-104, DNP V3.00 (serial and "over IP"), TG 8979, CDT
- Open data exchange, OPC server, OPC client
- IED and substation connection IEC 61850, IEC 60870-5-101, IEC 60870-5-103, IEC 60870-5-104, DNP V3.00 (serial and "over IP"), PROFIBUS FMS, PROFIBUS DP, MODBUS, SINAUT LSA-ILSA

Fig. 6.3-14: **Versatile communication with SICAM PAS**

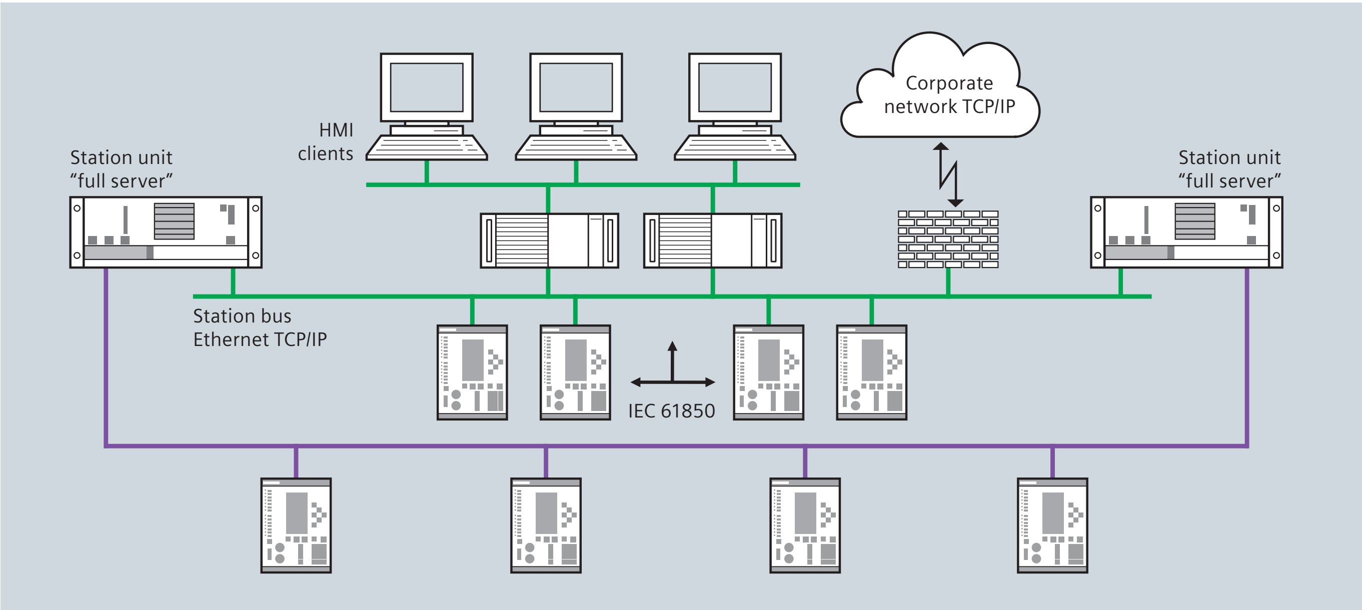


Fig. 6.3-15: **Typical redundant configuration: The station unit and the HMI server are based on a redundant structure to boost availiability**

Redundancy

The SICAM PAS station unit can be used in a duplicate configuration to further boost the availability of the station control level (fig. 6.3-15). This duplication is possible with IEDs or substation devices that support simultaneous communication with two masters (PROFIBUS FMS, IEC 60870-5-101) or clients (IEC 61850). A redundant structure is also possible for process visualisation with SICAM PAS CC and fault-record archiving with SICAM Recpro as shown in fig. 6.3-15.

Scope of information

The amount of information to be processed by SICAM PAS is essentially determined by the following factors:

- Computer network concept (multiple-computer network or single-station system)
- Performance data of the hardware used
- Performance data of the network
- Size of the database (RDBMS)
- Rate of change of values

A maximum of 250 IEDs and 20,000 data points can be processed.

Process visualization with SICAM PAS CC

In the operation of a substation, SICAM PAS is used for configuration purposes and as a powerful data concentrator. SICAM PAS CC serves as the process visualization system. SICAM PAS CC can be connected both to a SICAM PAS full server and to a SICAM PAS-DIP. Several independent SICAM PAS CC servers can be connected to one SICAM PAS. Connection of redundant servers is also possible. SICAM PAS CC supports the connection of several SICAM PAS systems. In the signal lists, the original time stamps are logged in ms resolution as they occur in the devices. With every signal, a series of additional data is also presented to provide information about causes (spontaneous, command), event sources (close range, local, remote), etc. Besides process signals, command signals are also logged. IndustrialX controls are used to control and monitor switchgear. These switching-device objects support four different forms of presentation (IEC, DIN, SINAUT LSA, SICAM) for circuit-breakers and disconnectors. It is also possible to create bitmaps (defined for a specific project) to represent switching devices, and to link them to the objects. For informative visualization, not only nominal and spontaneous flashing are supported, but also the display of various device and communication states (e.g., up-to-date/not up-to-date, feeder and telecontrol blocking, etc.). Measured values and switching device states that are not continuously updated due to, e.g., device or communication failure or feeder blocking, may be updated directly via the operation panel with SICAM PAS CC (fig. 6.3-16).

In conjunction with the SICAM PAS station unit, the switching devices can be controlled either directly or with "select before operate". When visualizing the process by single-line images, topological coloring can be used. The WinCC Add-on SIMATIC Web navigator can be used for control and monitoring via the Internet. SICAM Valpro can be used to evaluate measured and metered values. It not only allows a graphical and a tabular display of archived values, but also enables subsequent evaluation functions such as minimum, maximum and averages values (on an hourly or daily basis). SICAM Recpro supports automatic retrieval and archiving of fault records from protection units connected with IEC 60870-5-103, PROFIBUS FMS and IEC 61850.

SICAM PAS CC is based on SIMATIC WinCC, which has advanced to become both the industrial standard and the market leader in Europe. It features: multilingual capability. All operation and monitoring functions are on-board. These include not only the graphics system for plant displays as well as the signaling and

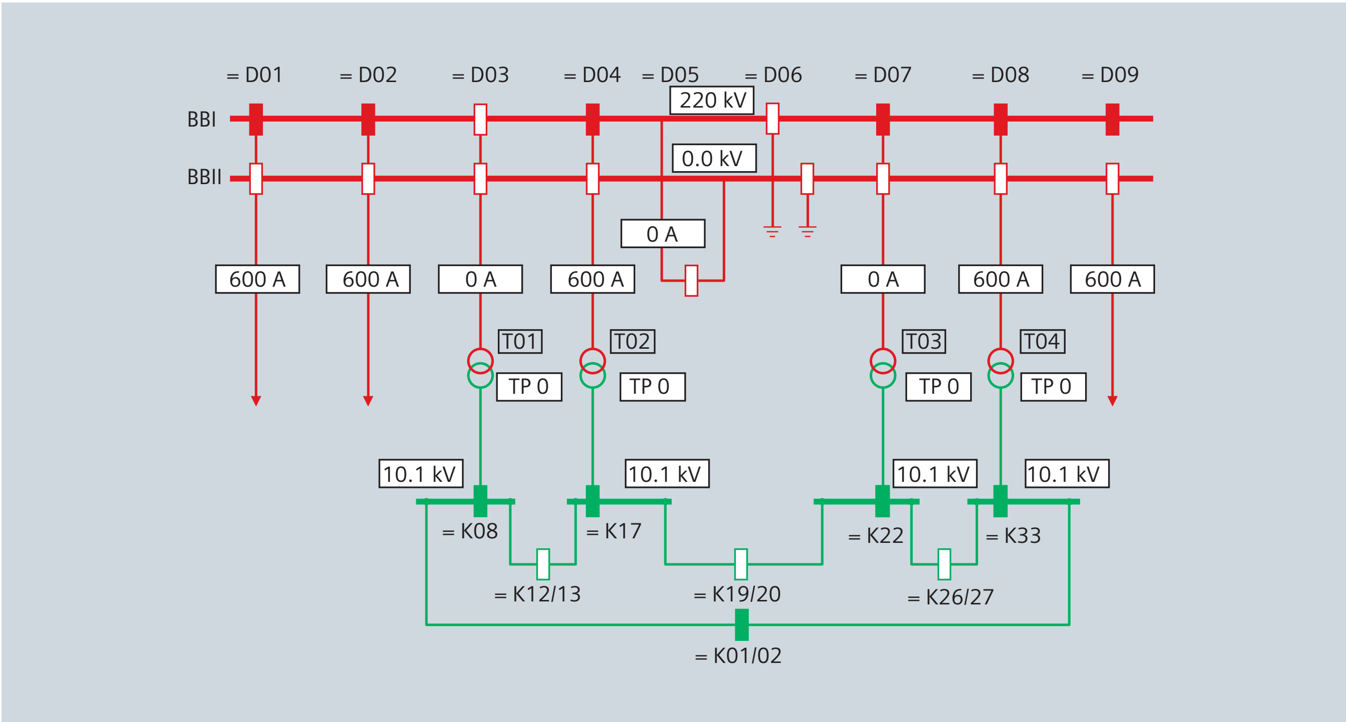


Fig. 6.3-16: **Process visualization with SICAM PAS CC**

archiving system for alarms and measured values, but also a reporting and logging system. Further advantages are integrated user administration, along with the granting and checking of access rights for configuration and runtime operations.

Easy and efficient configuration
Configuration is assisted by dialogs, wizards and extensive libraries.

Consistently scalable, even via the Web, in conformity with requirements, the bandwidth ranges from simple single-user station through to distributed multi-user systems with redundant servers and multi-site solutions with Web clients. Open standards for easy integration

- Using any external tools, archived data can be accessed through a series of open interfaces (such as SQL and ODBC) for further editing.
- Manufacturer-independent communication with lowerlevel controllers (or with applications such as MS Excel) is supported with OPC (OLE for Process Control).
- Visual Basic for Applications (VBA), VBScript or ANSI-C create an ideal scope for project-specific solutions. Expandable with options and add-ons
- WinCC/Dat@Monitor serves to display and evaluate current process states and historical data on office PCs, using standard tools such as the Microsoft Internet Explorer or Microsoft Excel
- WinCC/Web Navigator is an option with SIMATIC WinCC for controlling and monitoring systems over the Internet, a company Intranet or a LAN
- WinCC/Connectivity Pack ensures the functions of the two OPC servers HDA and A&E, and of the WinCC OLE-DB provider are ensured by the WinCC/Connectivity Pack.

FunkServerPro helps to forward messages from the WinCC signaling system automatically to radio call receivers (fig. 6.3-17).

Overview of the operator control philosophy and user interface
The SICAM PAS user interface is based on customary Windows technology, which allows to navigate in the familiar Windows environment both when configuring the system and during ongoing operation. The system distinguishes between configuration and operation of a substation. In SICAM PAS, these two tasks are firmly separated by two independent programs.

The SICAM PAS UI – configuration program (fig. 6.3-18) is used to create and edit a project-specific configuration. To enhance clarity, four views are distinguished:

- Configuration
- Mapping
- System topology
- Device templates

A common feature of all views is that they have an Explorer window that shows the system configuration in a clearly arranged tree structure. As in the Windows Explorer, it is possible to open individual levels of this tree structure to work in them. Meanwhile, other levels can be closed to improve clarity. Depending on the current navigation level and the chosen component, in the context menu (right mouse button) SICAM PAS offers precisely those program functions that are currently

Fig. 6.3-17: **SICAM PAS UI – Configuration**

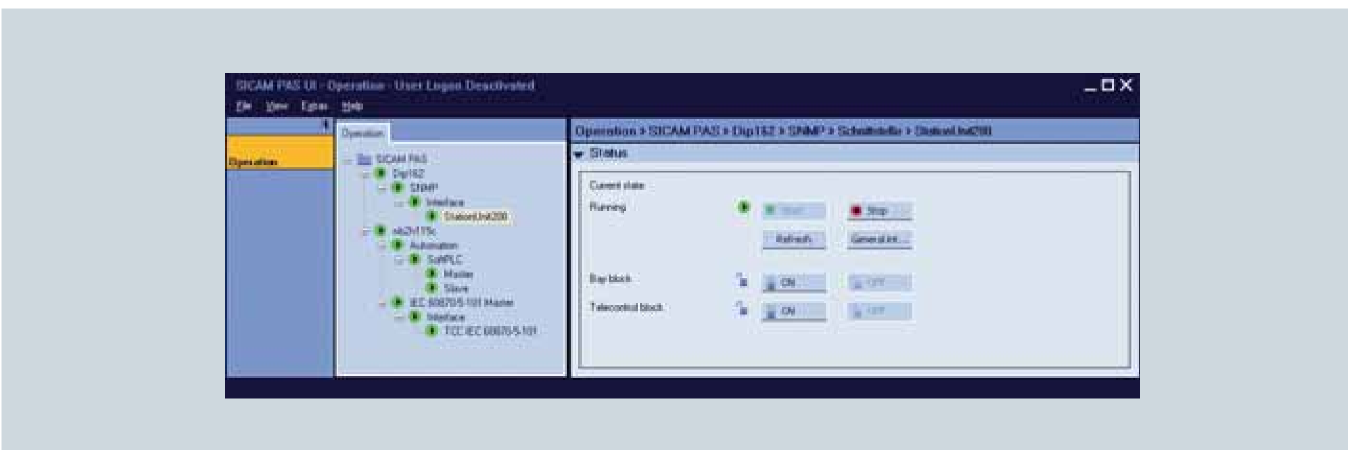


Fig. 6.3-18: **SICAM PAS UI – Operation**

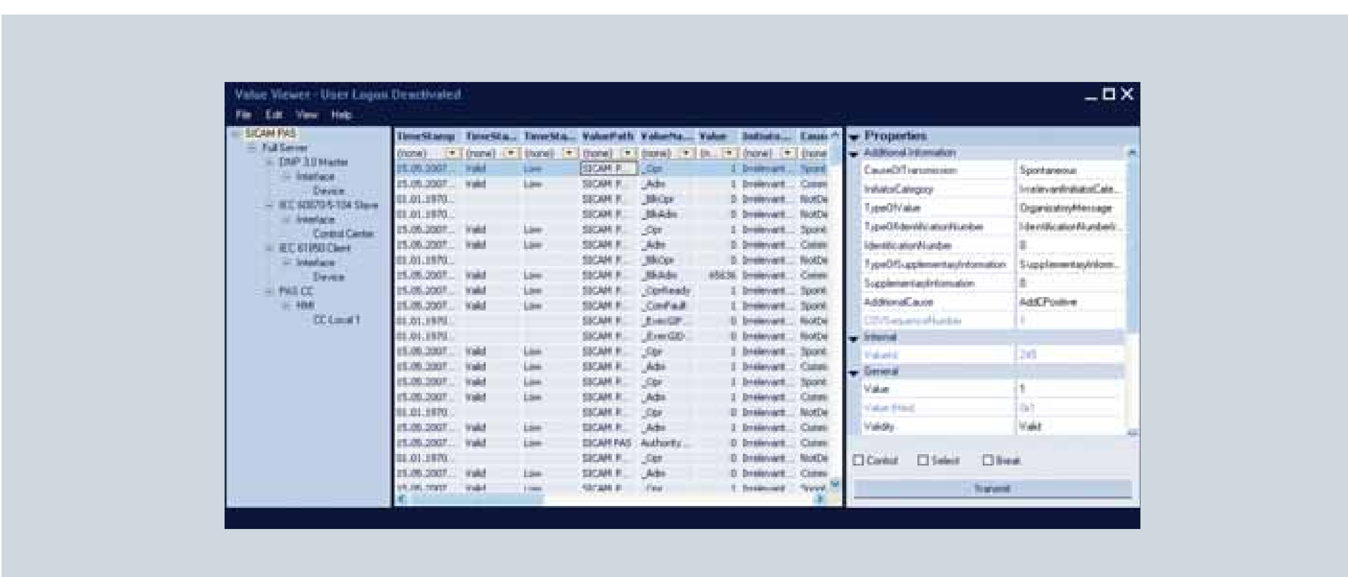


Fig. 6.3-19: **SICAM PAS Value Viewer**

Software [1]

SICAM PAS

Basic system includes:
SICAM PAS UI – Operation
SICAM PAS UI – Configuration (depending on the variant ordered)
SCADA Value Viewer
OPC Server
SNMP Manager
SNTP for time synchronization
Real-time data distribution system
Sybase SQL database

The following variants of the basic system are available:

"Full Server" (Runtime & Configuration) basic component
as a single-user system or as the central component in a distributed system

"Full Server" (Runtime) basic component

"Full Server" (Configuration) basic component

Configuration Upgrade for one "Full Server" (Runtime)

Device Interface Processor (DIP) basic component for use as a subordinate component in a distributed PAS system (Runtime & Configuration)

Device Interface Processor (DIP; Runtime) basic component

Basic packages available
with dongle for parallel printer-interface
with dongle for USB-interface

The following option packages are available for SICAM PAS Full Server and DIP:
For connecting SIPROTEC 4 IEDs
IEC 61850 (Client)
Driver for PROFIBUS FMS

For connecting devices
(e.g. SIPROTEC 4, SIMEAS P, S7-300, ET 200, etc.)
Driver for PROFIBUS DP

For connecting IEDs or substations
IEC 60870-5-103 Master
IEC 60870-5-101 Master
IEC 60870-5-104 Master
DNP V3.00 Master (serial and "over IP")
MODBUS Master
SINAUT LSA-ILSA

For connection to higher-level control centers
IEC 60870-5-101 Slave
IEC 60870-5-104 Slave
DNP V3.00 Slave (serial and "over IP")
CDT
TG8979

Further option packages
Automation SoftPLC (CFC, SFC)
OPC Client

SICAM PAS CC
Human Machine Interface
Process visualization

Runtime
Runtime incl. evaluation applications SICAM Valpro, SICAM Recpro
Runtime & Configuration
Runtime & Configuration incl. evaluation applications
SICAM Valpro, SICAM Recpro
128 tags
256 tags
1024 tags
8000 tags
64000 tags

[1] Positions 13 and 16 of the software Order No. indicate the version. Version 6.0 is the current version

Fig. 6.3-20: **Overview of deliverable software packages for SICAM PAS** appropriate. The necessary steps in the data window are worked through on the right. Here, parameters are set, information is selected and assignments to a user-specific, process-oriented system topology are defined. The user interface is uncomplicated and structured according to the task definition, so as to enable intuitive working and to simplify changes. The user interface assists the editing process by displaying parameter descriptions and messages when incorrect parameters are entered. In the tabular views for information assignment and allocation to the system topology, configuration is made easy by extensive sorting and filtering mechanisms, multiple choices, as well as drag and drop. To ensure data consistency and to avoid redundant data input, SICAM PAS UI provides extensive import and export functions for the exchange of configuration data, e.g., with the bay control level and with process visualization.

The SICAM PAS UI – operation program features a series of editing and diagnostics views for monitoring and controlling a substation. In the Operation Manager, you check and control the states of individual data connections. In the SCADA Value Viewer you can see incoming values in a clearly arranged form and perform operator control actions for test purposes. Security can be boosted by applying "user administration" for the SICAM PAS UI Configuration (fig. 6.3-17), UI – Operation (fig. 6.3-18) and Value Viewer (fig. 6.3-19) programs. User administration supports user-rights contexts with pre-defined rights and password protection (fig. 6.3-18, fig. 6.3-19, fig. 6.3-20).

Hardware components of the SICAM station unit

The industrial standard SICAM station unit represents the robust, embedded hardware platform for the SICAM PAS software product. It is based on the 19" rack technology. The SICAM Station Unit (fig. 6.3-22) consists of the following hardware components:

- Optional extensions must be ordered separately
- Power supply modules as ordered
- Power supply control unit
- 2 USB interfaces (V2.0) on the rear panel (for dongle and memory stick)
- CPU module with mobile Intel processor M440, 1.86 MHz
- SDRAM, DDR2, 2 GB, 533 MHz
- 2 flash cards, 2 GB each
- Graphic feature: 1280 pixels x 1024 pixels, 16.7 million colors
- VGA interface for monitor
- 4 USB interfaces (V2.0) e.g., for keyboard/mouse
- 2 RJ45 interfaces for LAN (10/100/1000BaseT Gigabit Ethernet)
- 2 COM interfaces
- Connection unit with connections for power supply and ON/OFF switch

6

SICAM PAS station unit

SICAM PAS station unit V2 based on industrial mobile processor 19" rack system,
fanless operation, without moving components.
CPU: Yonah M processor, 1.87 GHz
2 GB RAM, 2 x 2 GB Flash, 4 external USB, 2 internal USB,
2 x Gbit Ethernet RJ45, 1 serial port, status LEDs.
Redundant power supplies, switchover without reboot.
Monitored by SNMP, HW Watchdog,
Temperature/voltage monitoring, live contact
Windows XP Embedded service pack 2
SICAM PAS software pre-installed, without license / dongle
SICAM PAS license / dongle (USB-version) must be ordered separately.

Power supply

Primary power supply
24 – 60 V DC
110 – 230 V AC / DC

Secondary power supply
without
24 – 60 V DC
110 – 230 V AC / DC

Storage medium / operating system

2 x 2 GB compact flash cards with Windows XP Embedded

Language of operating system and SICAM PAS software

German
English

Function

Full server
Device interface processor

PCI adapter

without PCI adapter
with PCI adapter

Guarantee extension

2 years guarantee
3 years guarantee

Fig. 6.3-21: **Overview of available packages for the Station Unit**

Optional extensions:
- External USB-DVD drive for image DVD
- External USB hard disk for backup
- USB memory stick
- PCI adapter for up to 4 PCI cards
- COM-port extension cards
- PROFIBUS card
- GPS/DCF 77 time signal receiver manufactured by Hopf

Configuration for small to medium-sized applications
If the system comprises up to 150 feeder devices, SICAM PAS is installed just as one station unit, the full server. The process visualization with SICAM PAS CC runs on a separate PC. Both applications are available as runtime versions, or as runtime and

Fig. 6.3-22: **SICAM PAS station unit: industrial hardware for high reliability**

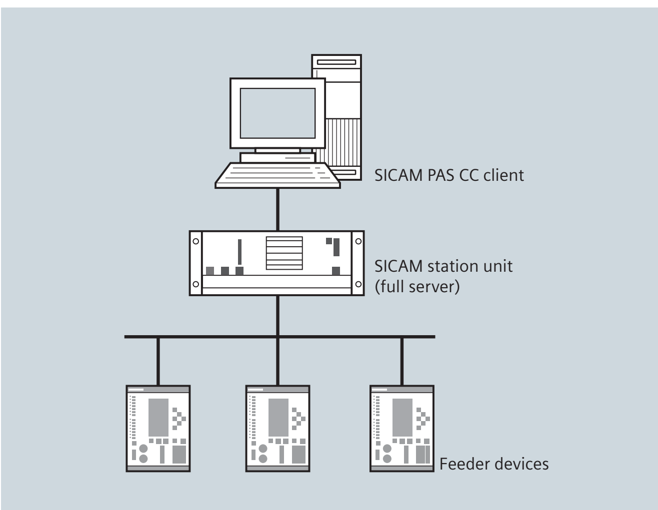


Fig. 6.3-23: **Connection of feeder devices to a SICAM station unit**

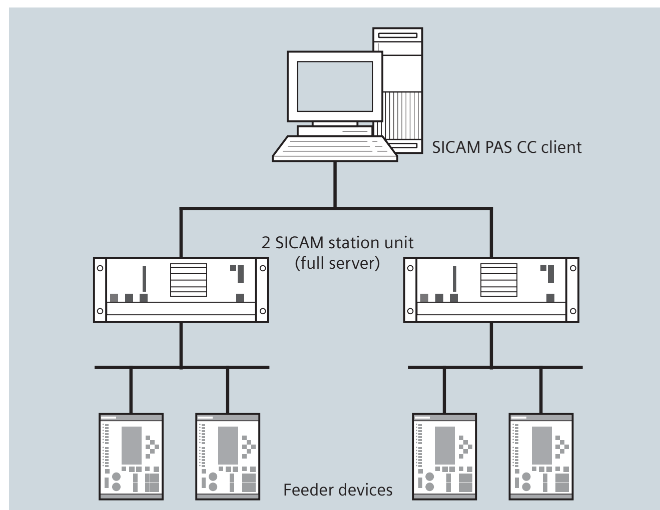


Fig. 6.3-25: **SICAM PAS CC with several SICAM station units**

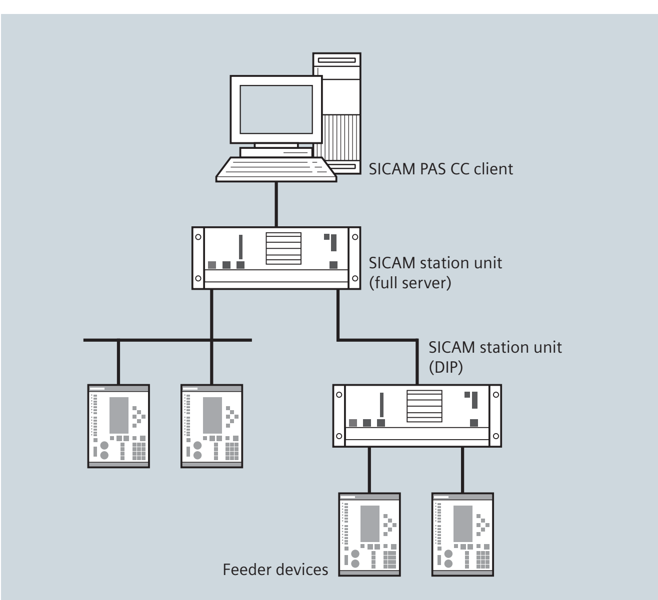


Fig. 6.3-24: **Connection of feeder devices in a distributed system**

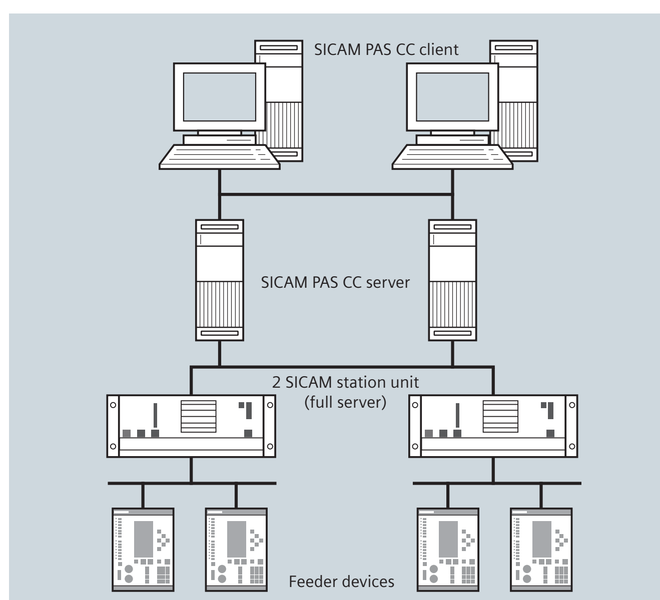


Fig. 6.3-26: **Redundant SICAM PAS in client/server configuration**

configuration versions. The SICAM PAS UI configuration tool can also be used on the PC on which SICAM PAS CC is installed (fig. 6.3-23).

Configuration for medium to large-sized applications
In medium-sized to extremely large-sized applications with up to 350 feeder devices, SICAM PAS is implemented as a distributed system with a full server and up to six DIPs (Distributed Interface Processors).

SICAM station units can be equipped with runtime versions, or with runtime and configuration versions (fig. 6.3-24).

One single HMI for several station units
In distributed systems, several stations or independent system components can be monitored and operated through one single SICAM PAS CC HMI.

For the example configuration illustrated below, a separate SICAM station unit (full server) is used for each station or system component (fig. 6.3-25).

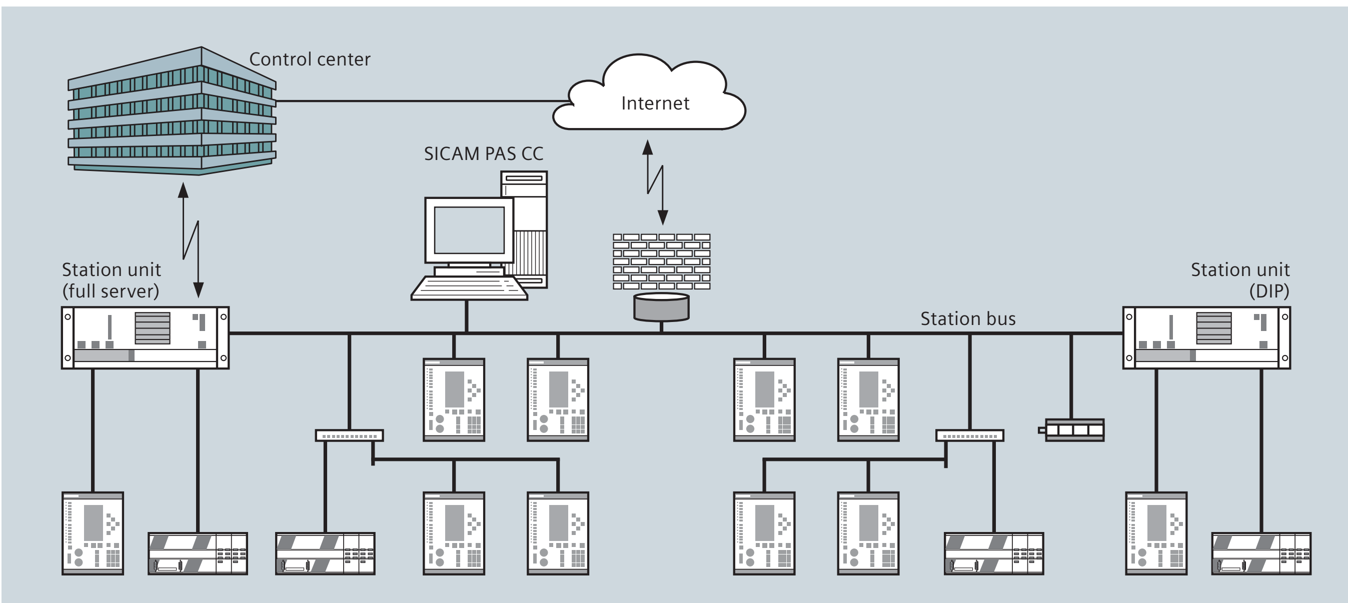


Fig. 6.3-27: **Example of a distributed SICAM PAS system with full server and DIPs**

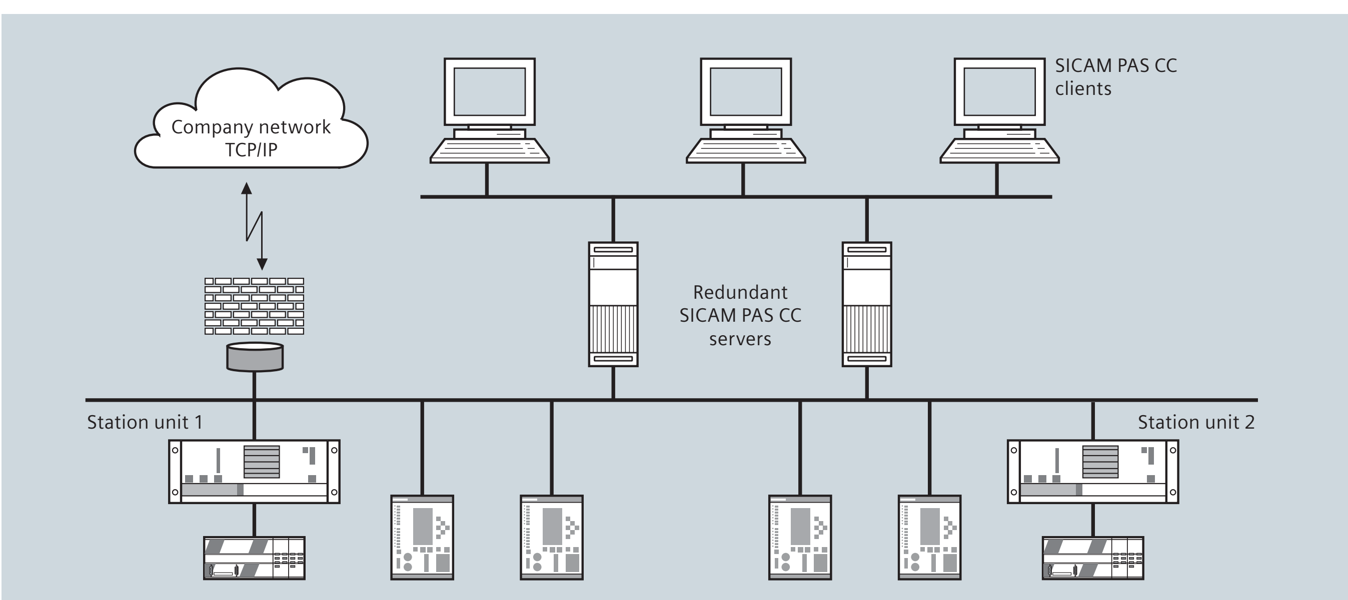


Fig. 6.3-28: **SICAM PAS station bus configuration with redundant connection of the feeder devices and the redundant SICAM PAS CC station controller**

Redundant HMI
The redundant version of the SICAM PAS CC HMI is another configuration option (fig. 6.3-26).

Distributed SICAM PAS system with full server and DIP
The example below illustrates a distributed SICAM PAS system with a full server and DIPs. The feeder devices are connected to it via serial interfaces and Ethernet (fig. 6.3-27).

In this example, the SICAM station unit is used as station controller and/or as gateway.

Furthermore, the SICAM station unit is also suitable for use in redundant systems.

Redundant SICAM PAS system
Feeder devices/substations can be connected to the SICAM PAS in redundant configuration. Read the related protocol and restrictions with regard to the devices used.

Feeder devices communicating via the IEC 61850 protocol can be simultaneously connected to two SICAM station units. This is also possible for substations equipped with two telecontrol interfaces based on the IEC 60870-5-101 protocol.

The HMI of the SICAM PAS CC can be implemented in redundant configuration (fig. 6.3-28).

6.3.3 SICAM 1703

Versatile functionality and high flexibility are fundamental for a modern remote control system. SICAM 1703 adds comprehensive options for communication, automation and process interfaces. The different components of SICAM 1703 offer optimal scalability regarding the number of interfaces and signals. Nevertheless these components are all based on the same system architecture, the same technology, and are handled with the same engineering tool (Toolbox II).

- AK 1703 ACP is the large automation component for a flexible mix of communication, automation and I/O. It offers optimal support as master controller or RTU, gateway or front-end, with local or distributed I/O. Versatile redundancy concepts are another asset of these components.
- TM 1703 ACP is the solution for compact applications. This component offers up to 4 communication interfaces plus automation function and process interface per distributed terminal modules. All modules are easily mounted to standard DIN rails. The terminal modules can be distributed up to 200 m with fiber-optic cables.
- BC 1703 ACP is the ruggedized component for highest EMC and direct process interface up to 220 V DC. High switching capacity and direct interface for measurement transformers, plus expandability with TM modules provide flexible application in centralized and distributed configurations. Up to 3 communication interfaces and automation functions are integrated.
- TM 1703 mic is a small RTU and offers either a serial interface according to IEC 60870-5-101 or an Ethernet interface with IEC 60870-5-104. Up to 8 terminal modules for I/O can be connected. A simplified automation function and a web server for easy engineering are integrated.

All components of the ACP family are using the same communication modules, and therefore they can use all available protocols. In addition to standards like IEC 60870-5-101/103/104 and IEC 61850 (client and/or server), also DNP 3.0 and Modbus are available in addition to a lot of legacy and third-party protocols for connecting third-party devices.

Another joint feature of all components is the integrated flash memory card, where all parameters and firmwares are stored. A simple exchange of a component is now possible, just by changing the memory card.

The Toolbox II offers all functions for an integrated, seamless engineering of complete projects, and works with all components of SICAM 1703. It supports all phases of an RTU or station automation project. Data exchange with DIGSI and PAS UI means a single entry point for data engineering avoiding multiple manual data inputs for a mixed configuration.

With SICAM 1703 there is always enough performance at hand: The modular multiprocessor concept grows with every enhancement of the system. The distributed architecture and the principle of "evolutionary development" cater for a future proof system with long lifetime expectation and high security of investment. SICAM 1703 carries the experience of more than 30 years of remote control and automation; many references are proving the flexible ways of application.

Automation component AK 1703 ACP

Longevity through continuity and innovation
AK 1703 ACP features high functionality and flexibility through the implementation of innovative and reliable technologies, on the stable basis of a reliable product platform.

For this, the system concept ACP (Automation, Control and Protection) creates the technological preconditions. Balanced functionality permits the flexible combination of automation, telecontrol and communication tasks. Complemented with the scalable performance and various redundancy configurations, an optimal adaptation to the respective requirements of the process is achieved (fig. 6.3-29).

AK 1703 ACP is thus perfectly suitable for automation with integrated telecontrol technology as:
- Telecontrol substation or central device
- Automation unit with autonomous functional groups
- Data node, station control device, front-end or gateway
- With local or remote peripherals
- For rear panel installation or 19 inch assembly

AK 1703 ACP – the forward-looking product
Versatile communication:
- Up to 66 serial interfaces according to IEC 60870-5-101/103
- LAN/WAN communication according to IEC 60870-5-104
- LAN communication according to IEC 61850
- Various third-party protocols possible

Easy engineering with TOOLBOX II:
- Object-oriented data model
- Creation of open-loop and closed-loop control application programs according to IEC 61131-3
- All engineering tasks can also be carried out remotely

Plug and play for spare parts:
- Storage of parameters and firmware on a flash card
- Spare part exchange does not require additional loading with TOOLBOX II

Open system architecture:
- Modular, open and technology-independent system structure
- System-consistent further development and therefore an innovative and future-proof product

Scalable redundancy:
- Component redundancy
- Doubling of processing/communication elements

The intelligent terminal – TM 1703:
- Direct connection of actuators and sensors with wire cross-sections up to 2.5 mm^2
- Can be located remotely up to 200 m
- Binary input/output also for 110/220 V DC
- Assembly on 35 mm DIN rail

Versatile communication capability
With AK 1703 ACP, a variety of media can be utilized for local and remote communication. (wire connections, FO, radio, dial-up traffic, GSM, GPRS, WAN, LAN, field bus etc.)

Through the simple installation of serial interface modules, in total up to 66 communication interfaces are possible in one AK 1703 ACP, whereby a different individual protocol can be used for each interface.

For standard communication protocols according to IEC 60870-5-101/103/104 and IEC 61850 are implemented.

Besides the standard protocols there are also a variety of third-party protocols available (DNP 3.0, Modbus etc.).

Simple process interfacing
In addition to the central acquisition and output of process signals within an AK 1703 ACP mounting rack, it is possible to use TM 1703 peripheral elements (fig. 6.3-30).

Fig. 6.3-29: **AK 1703 ACP**

Fig. 6.3-30: **TM 1703 peripheral elements**

An essential feature of the TM 1703 peripheral elements is the efficient and simple interfacing possibility of the process signals. This takes place on so-called I/O modules, which are distinguished through a robust casing, a secure contact as well as solid electronics. The I/O modules are lined up in rows. The contact takes place during the process of latching together, without any further manipulation. Thereby each module remains individually exchangeable.

A clearly arranged connection front with LEDs for the status display ensures clarity locally. The structure of the terminals enables a direct sensor/actuator wiring without using intermediate terminal blocks with wire cross-sections up to 2.5 mm^2. Modules for binary inputs and outputs up to 220 V DC open further saving potentials at the interface level.

Depending on the requirements, the I/O modules can be fitted with either an electrical bus or an optical bus, through which the peripheral signals can be acquired as close as possible to the point of origin. In this way, broad cabling can be reduced to a minimum.

Easy engineering

An essential aspect in the overall economical consideration are the costs that occur for the creation, maintenance and service. For this, the reliable TOOLBOX II is used.

- Object orientation:
  The object orientation makes it possible to also utilize the same characteristics of same-type primary-technology units and operational equipment (e.g., disconnectors, circuit-breakers, feeders etc.) for the configuration. The close coupling with the design tool ensures the consistent, uniform documentation of the entire plant through to circuit diagram. Through this, considerable rationalization results with engineering.
- Open-loop and closed-loop control according to IEC 61131-3:
  Open-loop and closed-loop control application programs are created by means of CAEx plus according to IEC 61131-3, a standard that is generally accepted and recognized in the market. As a result, the training periods are reduced considerably.
- All engineering tasks can also be carried out remotely:
  All engineering tasks, from the system diagnostic through to the online test, can also be performed remotely with the TOOLBOX II. For this, a separate communication link between TOOLBOX II and AK 1703 ACP is not necessary: Every available communication interface can be used. Using further automation units of the ACP 1703 product family, the TOOLBOX II can be remotely positioned over an arbitrary number of hierarchies.

The access to the engineering data is fundamentally protected by a password.

Plug and play for spare parts

All data of an automation unit – such as firmware and parameters – are stored non-volatile centrally on an exchangeable flash card. With a restart of the automation unit, and also with a restart of individual modules, all necessary data are automatically transferred from the flash card to all CPUs and modules.

Consequently, with the exchange of modules, new loading is no longer required, since new modules obtain all data from the memory card. With the replacement of spare parts, plug and play becomes a reality: No special tool is required, even loading is no longer necessary.

Thereby, work during a service operation is reduced to a minimum.

Open system architecture

The basis for this automation concept is a modular, open and consequently technology-independent system architecture for processing, communication and peripherals (multi-processor system, firmware).

Standardized interfaces between the individual elements again permit, even with further developments, the latest state of technology to be implemented, without having to modify the existing elements. In this way, a longevity of the product and consequently investment security and continuity can be ensured (fig. 6.3-31).

Every board and every module on which a firmware can run, forms, together with the function-determining firmware, one system element.

The adaptation to the specific requirements of the application is achieved through the individual configuration and through the loading of standard firmware and parameters. Within their defined limits, the parameters thereby not only influence the behavior of the firmware functions, but also that of the hardware functions. With that, for all module types, all mechanical parameter settings are omitted, such as e.g., the changing of jumpers or loads, thus enabling not only the online change, but also a consistent documentation of the set parameters by the TOOLBOX II as well as a simplified storage.

System overview

Mechanics

Fig. 6.2-33 and fig. 6.2-34 show two types of basic mounting racks: module CM-2832 with 9 slots and Module CM-2635 with 17 slots.

Module CM-2833 (not pictured here) is the expansion mounting rack for up to 16 peripheral elements outside the basic mounting rack.

With the mechanics, value has been placed on flexibility and easy handling. Consequently, the mounting rack is available for rear panel installation or for 19“ (swing) frame installation.

Almost all necessary external connectors (e.g., communication, peripherals, external periphery bus) can be connected with the help of standard cables or prefabricated cables without any additional tools (fig. 6.3-34, fig. 6.3-35, fig. 6.3-36).

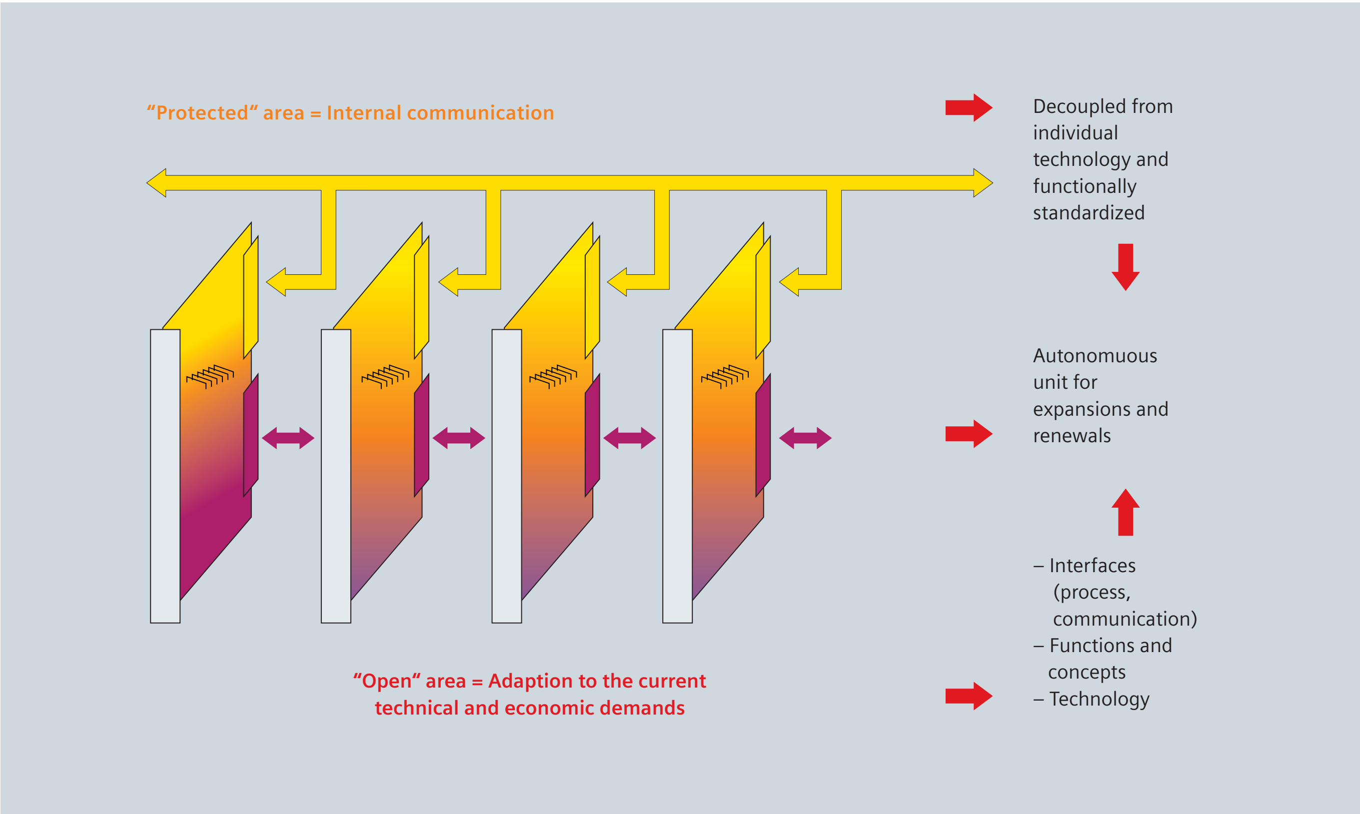


Fig. 6.3-31: **Open system architcture**

Fig. 6.3-32: **CM-2832 – AK 1703 ACP mounting rack with 9 slots**

Fig. 6.3-33: **CM-2835 – AK 1703 ACP mounting rack with 17 slots**

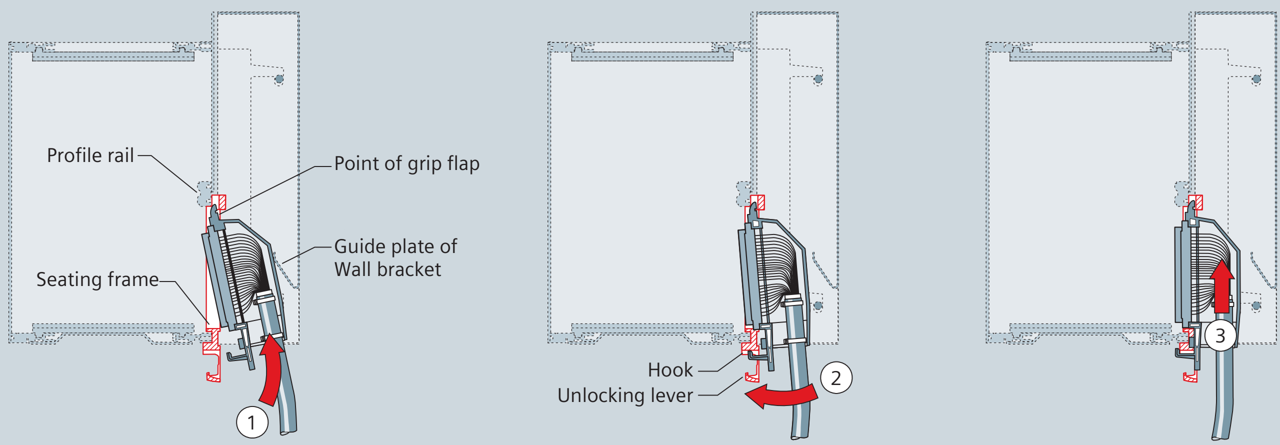


Fig. 6.3-34: **Connection technique for peripheral signals**

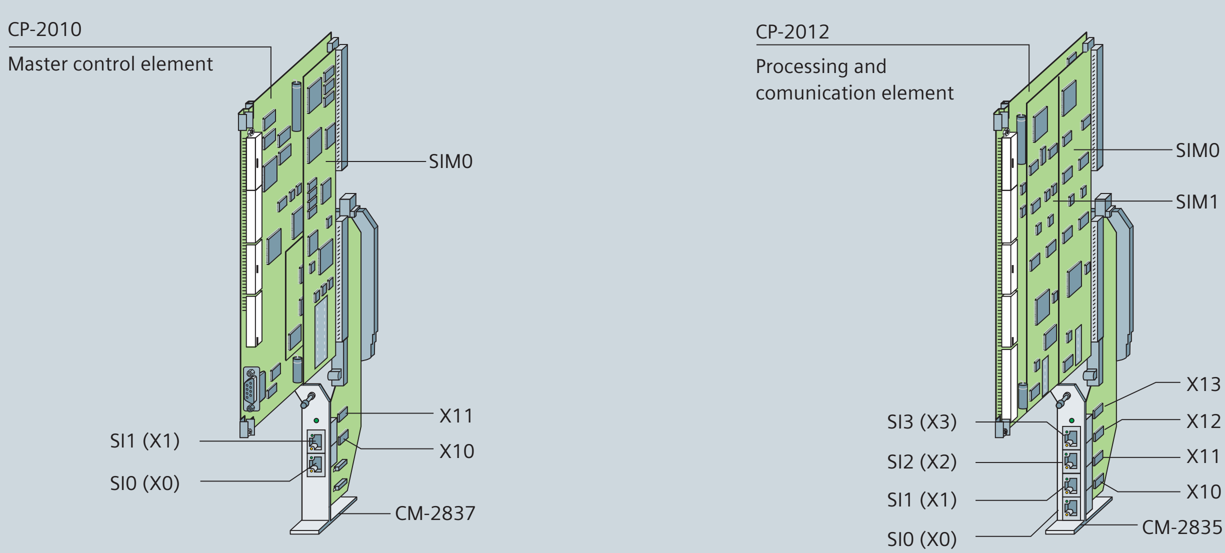


Fig. 6.3-35: **RJ45 connection technique for communication**

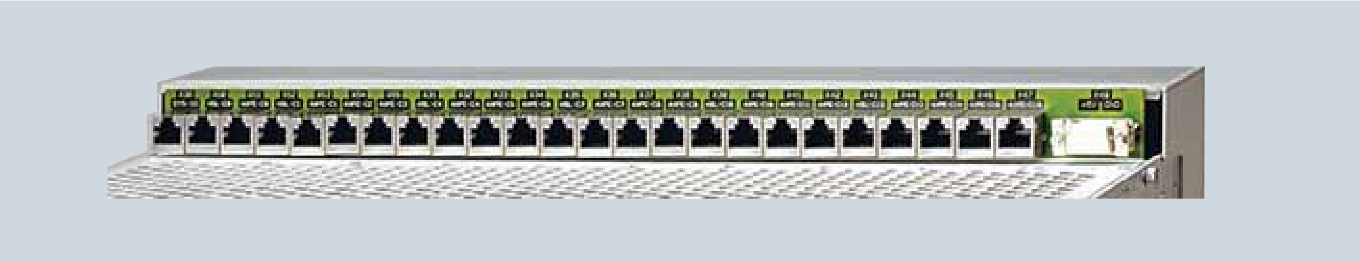


Fig. 6.3-36: **RJ45 connection technique for external Ax 1703 peripheral bus**

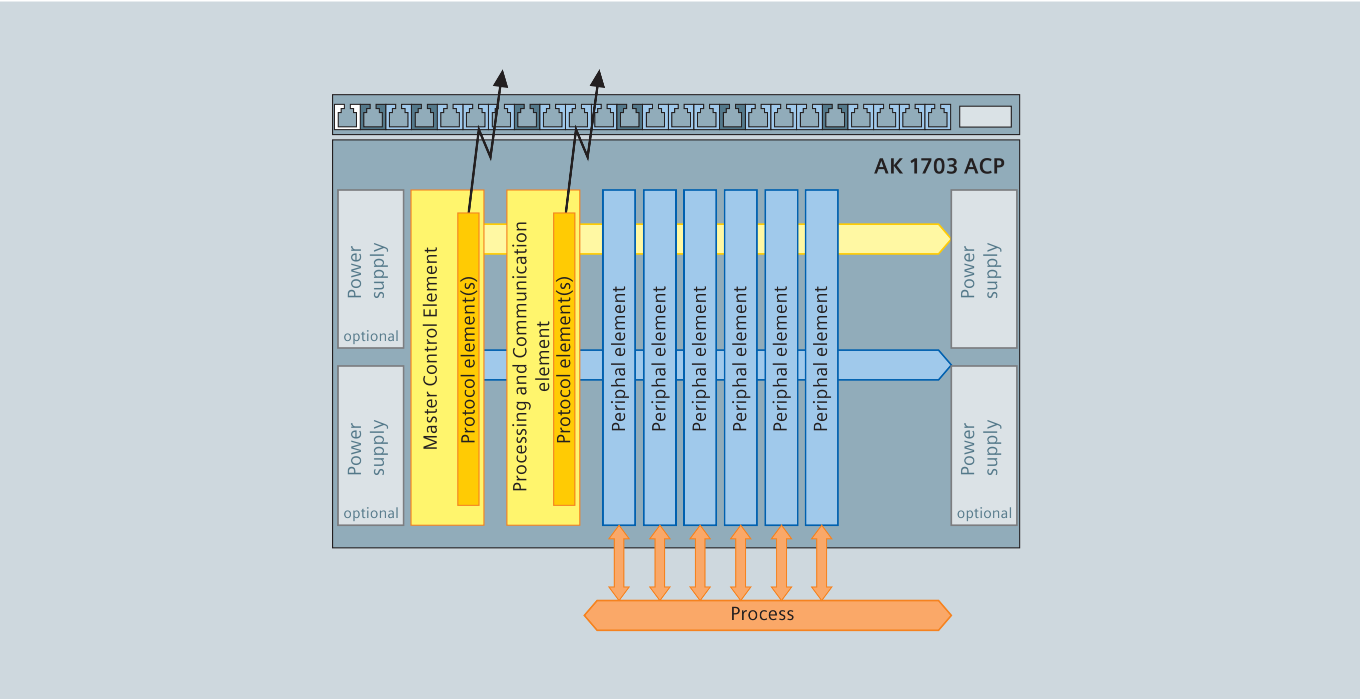


Fig. 6.3-37: **Basic mounting rack AK 1703 ACP peripheral bus**

System architecture
The system architecture is shown in fig. 6.3-37.

Configuration
An AK 1703 ACP forms an automation unit of the system family SAT 1703 and is structured from the following elements:
- Master control element (*)
- Processing and communication element(s) (*)
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Mounting rack with one to four power supplies

Parts that are marked with (*) are.

Peripheral elements can also be installed outside of the basic mounting rack.

Configuration
The configuration of an automation unit AK 1703 ACP is shown in fig. 6.3-38, next page.

Configuration
- 1 master control element
  - Forms the independent Ax 1703 peripheral bus AXPE-C0, on which up to 16 peripheral elements can be installed
- Up to 16 processing and communication elements
  - Each processing and communication element forms an independent Ax 1703 peripheral bus AXPE-Cn (n = 1…16), on which up to 16 peripheral elements can be installed
- Up to 272 peripheral elements
- Up to 66 protocol elements (interfaces with individual communication protocol)
  - Up to 2 protocol elements on the master control unit
  - Up to 4 protocol elements for each processing and communication element

Ax 1703 peripheral bus
The AXPE-Cn buses (n = 1...16) are available on connectors, in order to be able to connect peripheral elements outside the basic mounting rack. One of the buses can be selected, in order to also supply those peripheral elements in the basic mounting rack.

Peripheral elements outside the basic mounting rack
Peripheral elements may be
- installed in the basic mounting rack (as shown above), and/or
- installed in an expansion mounting rack and connected electrically, and/or
- installed at remote locations and connected electrically or optically.

System elements
A system element is a functional unit and consists of hardware and firmware. The firmware gives the hardware the necessary functionality.

Master control element
The master control element (fig. 6.3-39) forms the heart of the automation unit.

6

Functions of the master control element:
- Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
- Open/closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
- Communication with other automation units via protocol elements installable on the master control element (up to 2 interfaces)
- Central coordinating element for all system services and all internal and overlapping concepts, such as e.g.,
  - Data flow control
  - Monitoring functions
  - Diagnostic
  - Time management and time synchronization via minute pulse, serial time signal (DCF77/GPS-receiver), serial communication link, NTP – Server over LAN/WAN
  - Local TOOLBOX II connection
  - Storage of parameters and firmware on a flash card

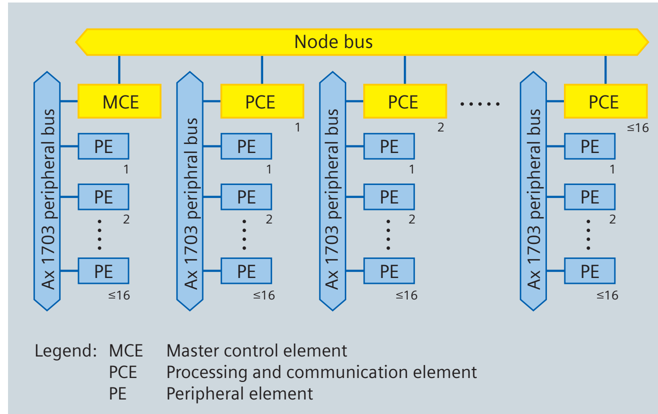


Fig. 6.3-38: **Configuration of an automation unit AK 1703 ACP**

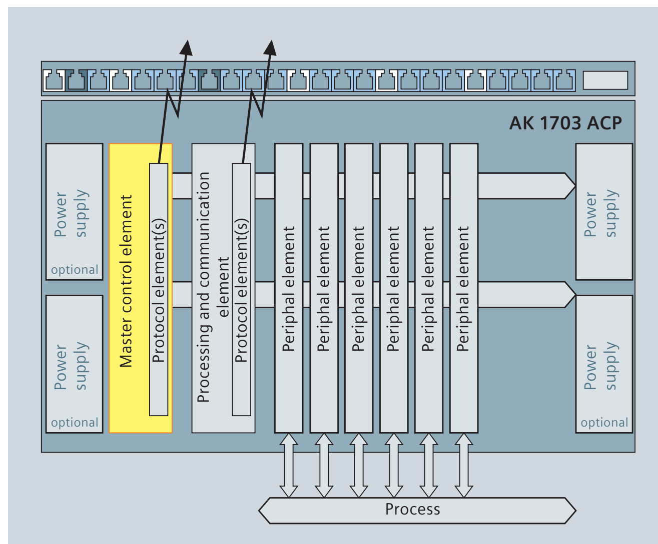


Fig. 6.3-39: **Master control element**

Processing and communication element

Functions of the processing and communication elements (fig. 6.3-40):

- Communication with installed peripheral elements via the serial Ax 1703 peripheral bus
- Open/closed-loop control function with a freely programmable user program according to IEC 61131-3, e.g., in function diagram technology
- Communication with other automation units via protocol elements installable on the processing and communication element (up to 4 interfaces)

Peripheral element

Peripheral elements, as shown in fig. 6.3-41, are used for acquisition or output of process information and perform process-oriented adaption, monitoring and processing of the process signals at each point where the signals enter or leave an automation unit. Processing is performed to some degree by

- hardware (e.g., filter, ADC, DAC) and by
- firmware (e.g., smoothing of measured values, time tagging)

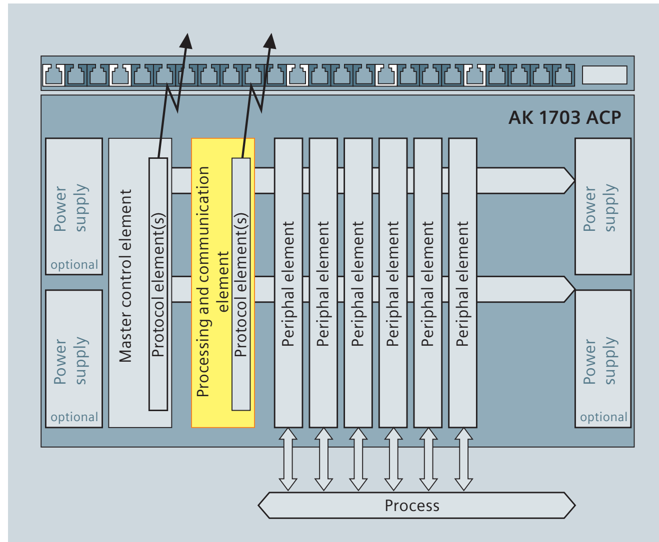


Fig. 6.3-40: **Processing and communication element**

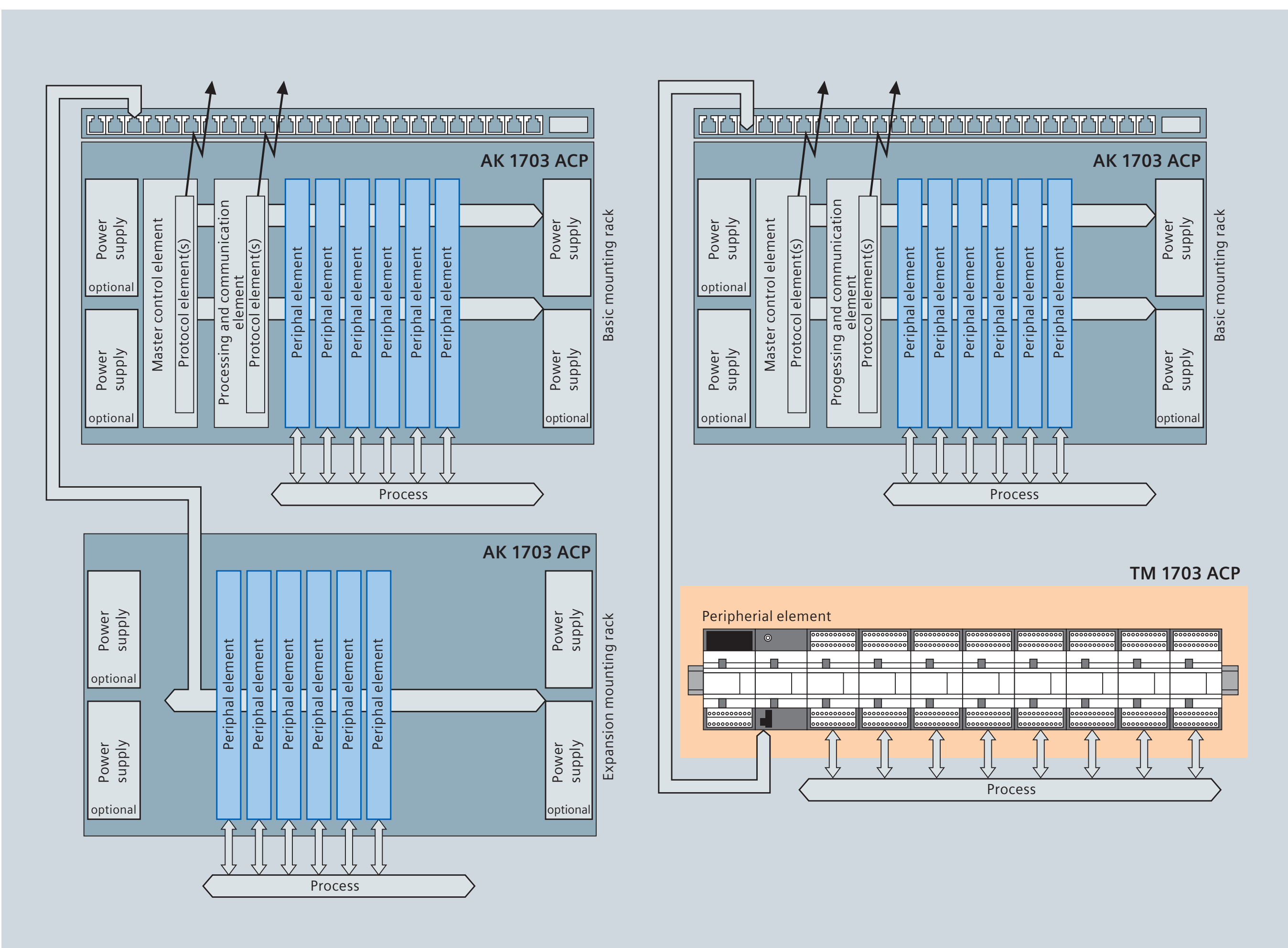


Fig. 6.3-41: **Peripheral elements**

6

The peripheral elements deliver over the Ax 1703 peripheral bus
- periodical information,
- messages with process information, and
- messages with system information (e.g., diagnostic information)

and receive
- messages with process information,
- periodical information, and
- messages with system information (e.g., parameters)

Protocol element

A protocol element (fig. 6.3-42) is used for the exchange of data – and thereby for the transmission of messages – over a communication interface to other automation units or devices of third-party manufacturers, e.g., control systems.

The hardware of a protocol element is a communication interface which – dependent on system and interface – can be available in different ways:
- Integrated on a basic system element
- On a serial interface module (SIM), which is installed – directly or cascaded (SIM on SIM) – on the basic system element

On every interface provided by the SIM, a communication protocol available for the interface can be loaded with the TOOLBOX II.

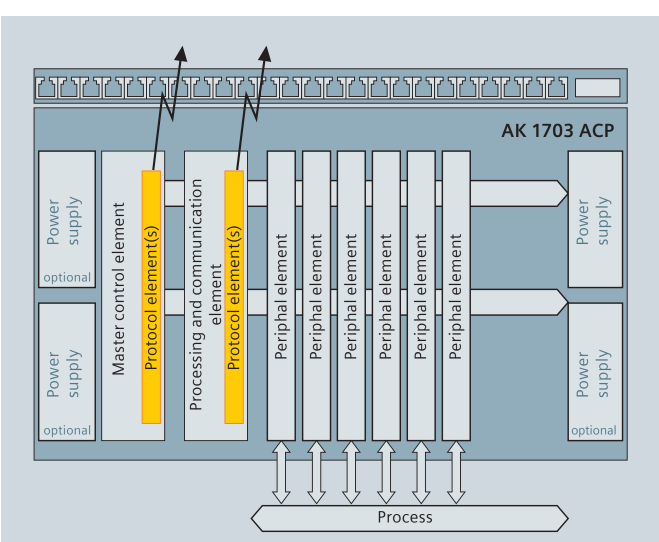


Fig. 6.3-42: **Protocol element**

System elements in AK 1703 ACP

Master control element

Module	Designation
CP-2010/ CPC25	System functions, processing and communication

Processing and Communication Element

Module	Designation
CP-2012/ PCCE25	Processing and communication

Peripheral elements AK 1703 ACP

Module	Designation
DI-2100/ BISI25	Binary signal input (8 x 8, 24 – 60 V DC)
DI-2110/ BISI26	Binary signal input (8 x 8, 24 – 60 V DC)
DI-2111/ BISI26	Binary signal input (8 x 8, 110 / 220 V DC)
DO-2201/ BISO25	Binary output (Transistor, 40 x 1, 24 – 60 V DC)
AI-2300/ PASI25	Analog input/output (16 x ± 20 mA + 4 x 2 opt. expans.)
DO-2210/ PCCO2X	Checked command output (64 x 24 – 60 V DC)
DO-2211/ PCCO2X	Checked command output (64 x 60 – 125 V DC)
MX-2400/ USIO2X	Signal input/output (24 – 60 V DC, ± 20 mA, opt. exp.)

Supported peripheral elements TM 1703 ACP

Module	Designation
PE-6400/ USIO65	Peripheral controller (Ax-PE bus el)
PE-6401/ USIO65	Peripheral controller (1x Ax-PE bus opt)

Power supply

The mounting racks CM-2832, CM-2835 and CM-2833 are to be equipped with 80W power supplies of the following types:

Designation	
PS-5620	Power supply (24 – 60 V DC)
PS-5622	Power supply (110 – 220 V DC, 230 V AC)

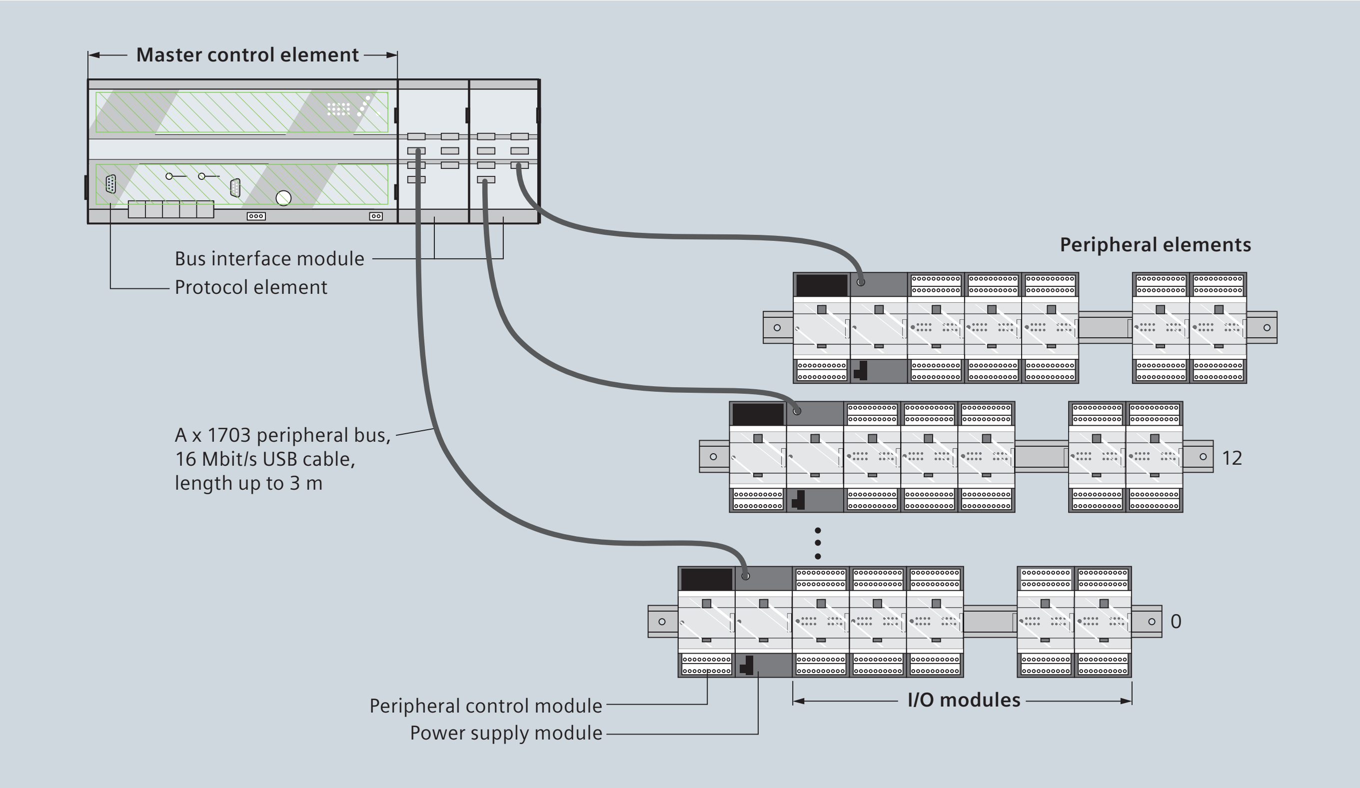


Fig. 6.3-43: **TM 1703 ACP system architecture**

Function packages

Telecontrol

The function package "Telecontrol" includes the following functions:

- Process input and output on peripheral elements
- Communication with other automation units
- Protocol elements
- Automatic data flow routing
- Data storage
- Priority control
- Redundant communication routes
- Communication within the automation unit
- Protocol element control and return information

Automation

The function package "Automation" includes the following functions:

- Process input and output on peripheral elements
- Telecontrol functions
  – Treatment for commands according to IEC 60870-5-101/104
  – Change monitoring and generation of messages with time tag
- Open/Closed-loop control function

System services

„System Services" is a function package providing general functions and basic services in an automation unit, which are required by other function packages:

- Communication with the engineering system
- Data flow control
- Addressing
- Time management
- General interrogation
- Self-test
- Failure
- Diagnostic and signaling
- Autonomy

System concept TM 1703 ACP

TM 1703 ACP, as a part of SICAM 1703, is designed especially for easy installation and powerful application. Due to consequent development it fits optimally both for automation and telecontrol systems (fig. 6.3-43).

An essential feature of TM 1703 ACP is its efficient and simple way of interfacing to the process signals. This is accomplished by so-called I/O modules boasting a robust housing, reliable contacting, and sound electronics. The I/O modules are arranged side-by-side. Contact between them is established as soon as they engage with one another, without requiring any further manual intervention. Even so, it is still possible to replace every single module separately.

A clearly structured connection front featuring status indicator LEDs makes sure that things at the site remain clear and transparent. The structure of the terminals permits direct sensor/actuator wiring without requiring the use of intermediate terminals.

The I/O modules may, depending on the requirements, be equipped with either an electrical or an optical bus, whereby the peripheral signals can be acquired very close to their point of origin. Consequently, wide cabling can be reduced to a minimum.

TM 1703 ACP is highlighted by the following future-oriented features:

- Modular, open and technology-independent system structure
- Direct periphery coupling without intermediate terminals
- Software parameter setting (hardware and software)
- Online parameter modification
- LED's for process and operating conditions
- Simplified connection handling by "intelligent terminals"
- 35 mm international standard profile rails
- Secured internal communication over all bus systems
- Little training needed
- Data storage via multi media card (plug and play for spares)
- Periodical processing and creation of automation functions carried out with the tool CAEx.plus
- Spontaneous processing supports the processing- and communication-orientated telecontrol functions and includes:
- Parameterizable telecontrol processing of the periphery
- Change monitoring, signal creation and time-stamping of the event data of the periodical processing
- Timely decoupling of the signal and prioritized transfer with the aid of a deterministic priority algorithm
- Prioritization of messages
- Energy metering value collection
- Extended temperature range (–25 °C to +65 °C)
- High EMC (electromagnetic compatibility)
- Increased electric strength (class 2)

System architecture

A TM 1703 ACP forms an automation unit of the SICAM 1703 system family and is constituted of the following components:

- Master control element,
- Modular, expandable and detachable peripheral elements,
- Protocol elements for communications, mountable on the master control element (fig. 6.3-44).

Master control unit

The master control element forms the heart of the TM 1703 ACP automation module. Process input and output is connected externally via peripheral elements. The communication interfaces can be fitted directly onto the master control element.

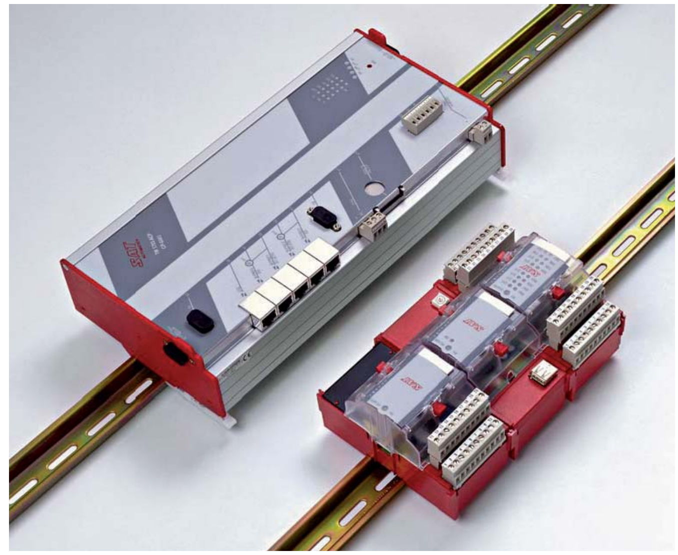


Fig. 6.3-44: **TM 1703 ACP mounted on 35 mm DIN rails**

Functions of the master control element:

- Communication with peripheral elements via the serial Ax 1703 peripheral bus
- Open/closed-loop control functions with a user program created freely according to IEC 61131-3, e.g., in function diagram technology
- Parameterizable telecontrol functions
- Time management and time synchronization via minute pulse, serial time signal (DCF77/GPS-receiver), serial communication link, NTP server via LAN/WAN
- Communication via the mountable protocol elements
- Engineering by means of TOOLBOX II
- Storage of parameters and firmware on a flash card

The master control element provides the open-/closed-loop functions and/or the parameterizable telecontrol function, as well as the node function for the communication via serial interfaces and LAN/WAN. Therefore, it also serves as a centrally coordinating element for all system functions and all internal and integral concepts.

This architecture ensures

- deterministic behavior of the open/closed-loop control function with guaranteed reaction times,
- autonomous behavior (e.g., in the case of communication failure), and
- integration of the telecontrol functionality (spontaneous processing and spontaneous communication) as well as the open/closed-loop control functions (periodical processing and periodical communication with the periphery) into one common automation device.

To connect peripheral elements to the master control element, a bus interface module must be arranged side by side with the master control element.

For this purpose,
- the master control element has a 9-pin D-SUB socket on its right side, and the
- bus interface module has a 9-pin D-SUB connector on its left side.

Up to 2 bus interface modules can be attached to one master control element.

Up to 14 peripheral elements can be connected to a master control element.

Peripherals
A peripheral element is constituted of
- 1 power supply module,
- 1 peripheral control module, and
- up to 8 I/O modules (fig. 6.3-45)

The respective data sheets document how many I/O modules may actually be used per peripheral element and in what order they can be used.

A key feature of TM 1703 ACP is that it provides for the efficient and simple connection of the process signals. This is done at the I/O modules standing out for a robust housing, reliable contacting, and sound electronics.

The I/O modules are added side by side to the peripheral control module. Contact is established as soon as they engage with one another, without requiring any further manual intervention. Even so, every single I/O module can still be exchanged separately and mounted on a DIN rail. It may be installed horizontally or vertically.

Removable terminals (I/O connectors) are used for the simple handling of modules when they are to be mounted or exchanged. Since the terminals carry the wiring, no connections need to be disconnected when devices are exchanged.

To interface peripheral elements to the master control element, a bus interface module must be fitted on the side of the master control element. Using simple, standardized USB cables, the peripheral control modules are connected to the bus interface module, thereby reducing the assembly effort required for their connection to a minimum.

The Ax 1703 peripheral bus permits the secured, serial, in-system communication between the master control element and the peripheral elements. Serial communication also renders it possible to detach individual or all peripheral elements via optical links up to 200 m from the master, with full system functionality remaining intact.

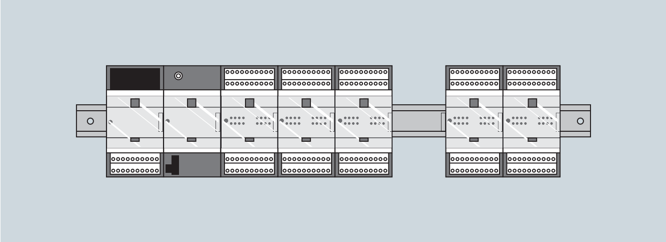


Fig. 6.3-45: **Peripheral element**

Functions of the peripheral control module:
- Secured data exchange with the master control element
- Secured data exchange with the connected I/O modules via the TM bus (Terminal Module Bus)
- Monitoring of the connected I/O modules
- Preprocessing of the input and output signals

Functions of the I/O modules:
- Acquisition and output of binary and analog process signals,
- Secured data exchange with the peripheral control element via the TM bus

The communication between the I/O modules and the peripheral control module takes place via the TM bus according to the master/slave method, with the I/O modules being the slaves.

By arranging the various modules side by side, contact will be established automatically throughout the TM bus so that no additional wiring is required.

Communication
The communication function is used for the exchange of data – and thus for the transmission of messages – via protocol elements to other automation units or control systems.

The hardware for the protocol elements is serial interface modules (SIMs), which can be mounted on the master control element. On one master control element, up to 2 SIMs can be mounted.

A serial interface module features:
- Two serial communication interfaces, or
- one LAN communication interface (Ethernet) plus optional serial interface, or
- one Profibus interface (DP master)

Since a communication interface corresponds to one protocol element, a total of up to 4 protocol elements can be used for each TM 1703 ACP. This way, a multitude of communication options is available.

Product overview

Master control unit

Module	Designation
CP-6003/ CPC65	Processing and communication

Bus Interface Module

Module	Designation
CM-6830	Bus interfacemodule (7 x USB-Connector)

Peripherals

Module	Designation
PS-6620	Power supply module (24-60 V DC)
PS-6630	Power supply module (24-60 V DC (EMC+))
PS-6632	Power supply module (110 / 220 V DC (EMC+))
PE-6400/ TCIO65	Peripheral controller for TC 1703 (Ax-PE bus el)
PE-6401/ TCIO65	Peripheral controller for TC 1703 (Ax-PE bus opt.)
DI-6100	Binary input (2 x 8, 24-60 V DC)
DI-6101	Binary input (2 x 8, 110 / 220 V DC)
DO-6200	Binary output transistor (2 x 8, 24-60 V DC)
DO-6212	Binary output relays (8 x 24-220 V DC / 230 V AC)
DO-6220	Command output basic module (4 x 24 – 110 V DC)
DO-6221	Command output basic module measure (4 x 24 – 110 V DC)
DO-6230	Command output relais module (16 x 24 – 110 V DC)
AI-6300	Analog input (2 x 2 ± 20 mA / ± 10 mA / ± 10 V)
AI-6307	Analog input (2 x 2 ± 5 mA)
AI-6310	Analog input (2 x 2 Pt100 / Ni100)
AO-6380	Analog output (4 x ± 20 mA / ± 10 mA / ± 10 V)

Compact RTU TM 1703 mic

TM 1703 mic, as a part of SICAM 1703, is designed for application of compact telecontrol systems.

Installation takes place on a 35 mm rail. It must be considered that the modules are mountedhorizontally or vertically on a vertically standing rack.

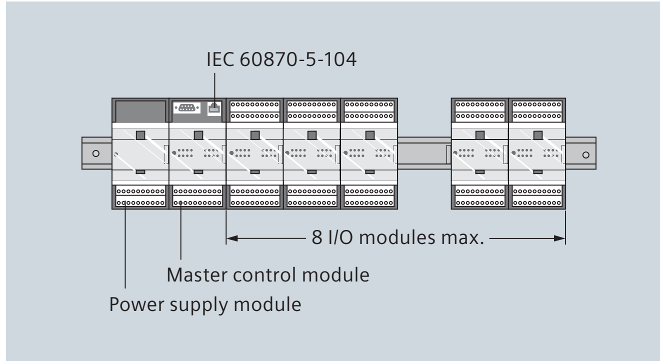


Fig. 6.3-46: **TM 1703 mic system architecture**

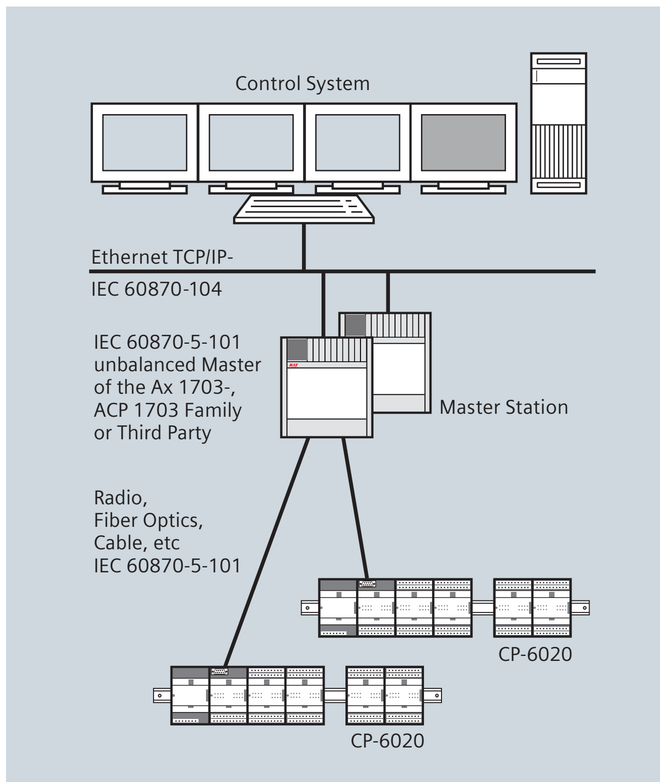


Fig. 6.3-47: TM 1703 mic configuration – multi-point traffic

The sequence of modules from left to right or from top to bottom is prescribed as follows:

- Power supply module
- Master control module
- Up to 8 I/O modules in arbitrary order (fig. 6.3-46)

The power supply and TM bus are electrically connected during the process of latching together, wherein each module can be individually replaced.

The master control modules are:

- CP-6020 master control module (V.28 / 8 modules)
- CP-6040 master control module (ET10TX/V.28 / 8 modules)

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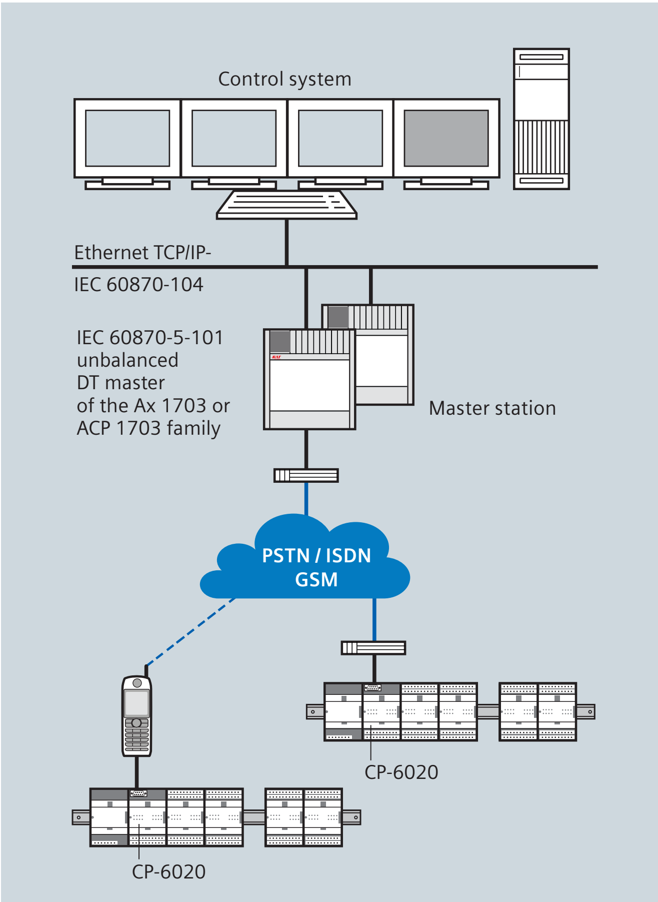

Fig. 6.3-48: **TM 1703 mic configuration – simple dial-up traffic**

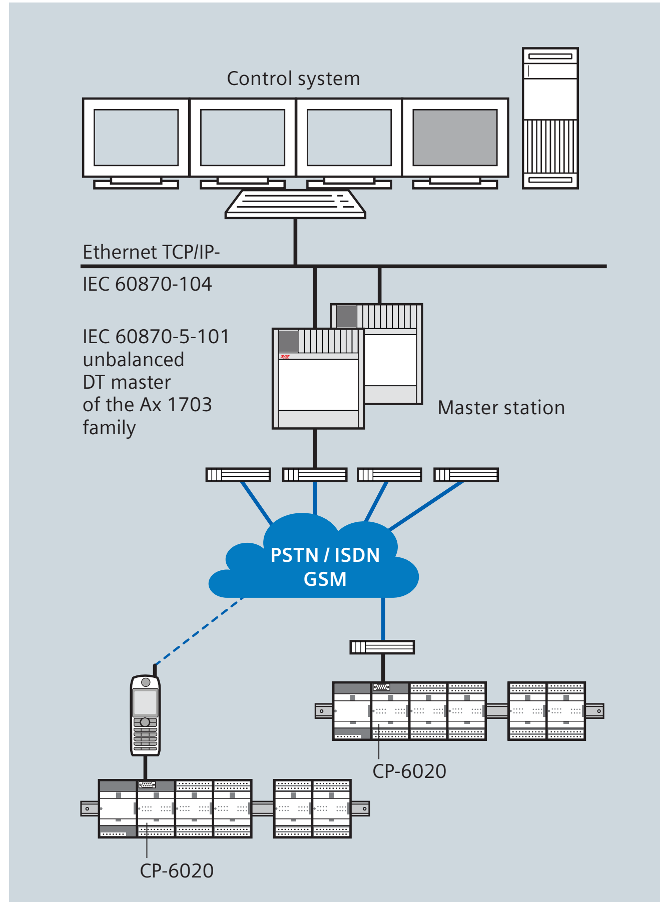

Fig. 6.3-49: **TM 1703 mic configuration – multi-master dial-up traffic**

Configuration
The following figures show the configurations of multi-point traffic (fig. 6.3-47), of dial-up traffic (fig. 6.3-48), of multimaster dial-up traffic (fig. 6.3-49), of LAN/WAN (fig. 6.3-50) and of GPRS (fig. 6.3-51).

Bay control units
The Bay Control Unit (BCU) is the linking member between the station control level and the primary system, and is integrated in the feeder-related local control cubicle.

It is therefore designed for rough electric and thermal ambient conditions and is based on the BC 1703 ACP bay controller.

The bay control unit acquires all feeder-relevant process data and time tags them at a resolution of 1 ms. All feeder related functions are executed autonomous in the bay control unit:
- Interlocking
- Synchrocheck
- Automatic voltage regulation by control of transformer onload tap changer (option)
- Closed-loop control for arc suppression coils (option)
- Operation cycle counter
- Calculation of rms values of currents and voltages, active and reactive power

Local control panel for feeder operation
The bay control unit comes in two mechanical sizes (fig. 6.3-53): BC 1703 ACP/C is designed for compact feeders (typical in distribution); BC 1703 ACP/M is the modular version for larger amounts of I/O (typical in transmission).

Both versions are based on the same system architecture and use the same modules. They are ruggedised for use as near as possible to the primary equipment featuring the highest EMC and a broad temperature range, and the I/O-modules are designed for direct interfacing of all signals from the process without any interposing level (e.g., interposing relays, measuring transducers, etc.). This means a peripheral voltage of up to 220 V DC or direct interfacing of transformers with 1 A to 6 A or 110/220 V AC.

Architecture of BC 1703 ACP
A BC 1703 ACP forms an automation unit of the SICAM 1703 system family and consists of the following elements:
- Master control element (control) (*)
- Processing element (protection) (*)
- Protocol element(s) (*)
- Peripheral element(s) (*)
- Operation and display panel
- Mounting rack with one or two power supplies

Parts that are marked with (*) are system elements

The mounting rack is available in two sizes:
- The compact BC 1703 ACP/C can host up to 2 peripheral elements
- The modular BC 1703 ACP/M can host up to 15 peripheral elements.

Seamless communication
BC 1703 ACP offers a complete solution based on IEC standards (IEC 60870-5-101/103/104 and IEC 61850).

A serial interface is included in the control master CPU based on IEC60870-5-103 SLAVE via fiber-optic for communication with upper levels. Local communication to the maintenance notebook for the engineering tool is done via a 9-terminal connector on the front side of the device. In addition, a SIP (Serial Interface Processor) with two serial interfaces or a NIP (Network Interface Processor) with one Ethernet interface, or a combined SIP+NIP with one serial and one Ethernet interface can be equipped for enhanced communication capability.

Plug and play for spare parts by flash card
Parameters and firmware are stored directly on flash card. That means that no tool for device exchange is necessary. This facilities the maintenance and service tasks. Additionally the flash card can be written by the engineering tool.

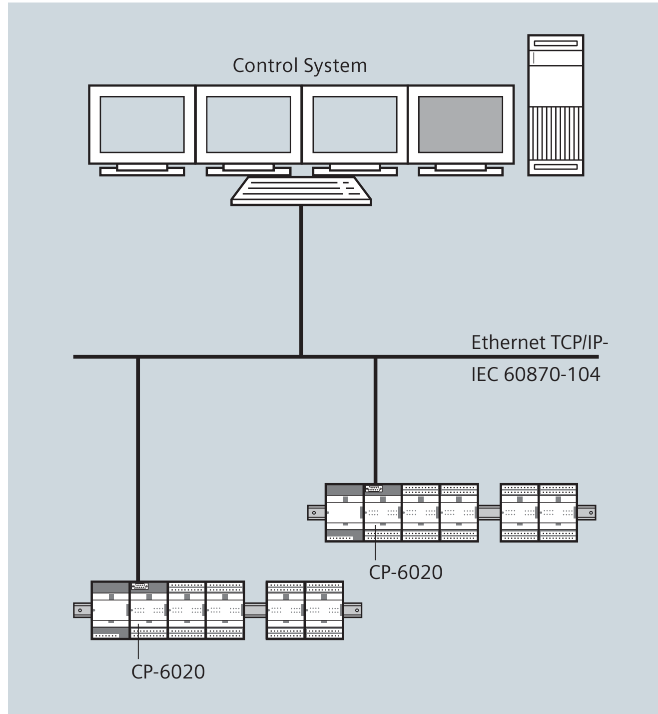

Fig. 6.3-50: **TM 1703 mic configuration – LAN/WAN**

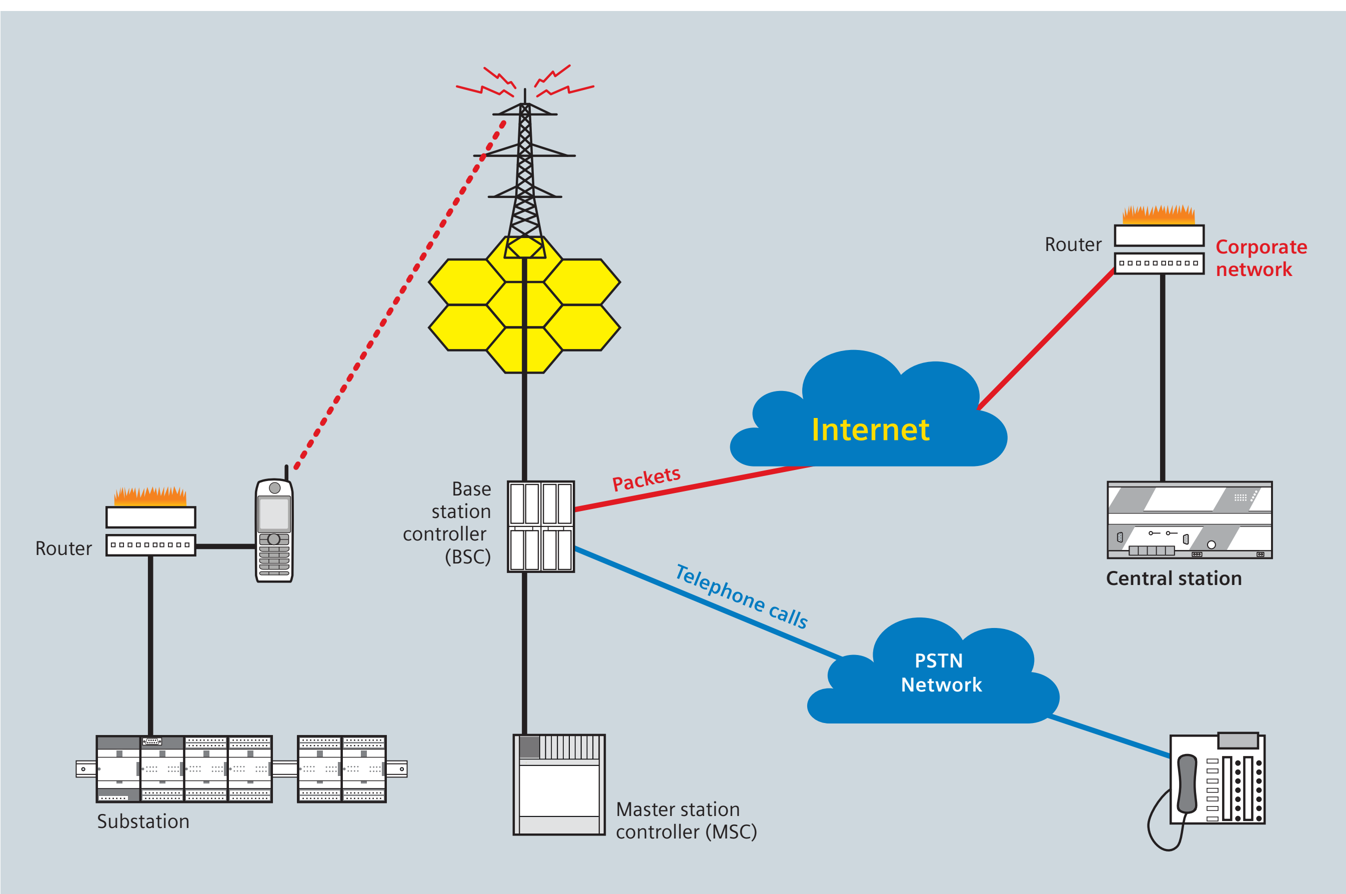

Fig. 6.3-51: **TM 1703 mic configuration – GPRS**

General features
- Power supply is available in 110–220 V DC / 230 V AC (80 W) or 24–60 V DC (80 W) and a second power supply can be added for redundancy
- The signal acquisition has a 1 ms resolution of real-time stamping.

As shown in the picture, the bay control devices are designed for rough electric and thermal environments.

The operating temperature ranges from – 25 °C to + 70 °C. Installation in outdoor cabinets is intended.

Bay control unit HMI
In order to make it easier for the system operator's staff to perform operation and maintenance tasks from the local bay control cubicle, the BC 1703 ACP bay control unit can be operated through a display panel (fig. 6.3-52).

The local operation panel is designed as a dedicated solution to show all necessary information about the status of a feeder in a clear and simple way, and to support easy and secure local operation directly at the feeder. It is designed for use in the door of local bay control cubicles at all voltage levels of a substation. Therefore it complies with highest EMC and a wide temperature range.

It provides an interface to be used with the BC 1703 ACP, and can be combined both with the compact and the modular version of the bay controller. It can be directly attached to the BC 1703 ACP/C, or be used separated with only two connecting cables (up to 3 m). The integrated and divided frame allows for either surface mounting, without the need for a big cut-out in the door, or for flush mounting. Operation and display have been arranged in accordance with ergonomic principles, and are compatible with similar sequences on the station operation terminal. The display shows the status of the dynamic single-line diagram of the feeder, plus selected measurement information. By changing to other images, the operator gets information about all accessible measurements, statistical data, important alarms, etc. Additional LEDs indicate important status and alarms beside the display, so that any unusual condition can be recognized immediately. The associated description is provided with a slide-in strip, so that image and status are shown simultaneously. Two key locks give access to the operation mode: one for local/remote/test, and the other one for interlocked/non-interlocked operation. Command initiation is done securely in multiple steps. In this way, inadvertent input is definitely avoided.

Temperature range: – 25 °C to + 70 °C. The display has a limited readability below – 10 °C. External dimensions (H x W x D) are 280 mm x 220 mm x 37 mm.

Fig. 6.3-52: **Bay control units (BCU)**

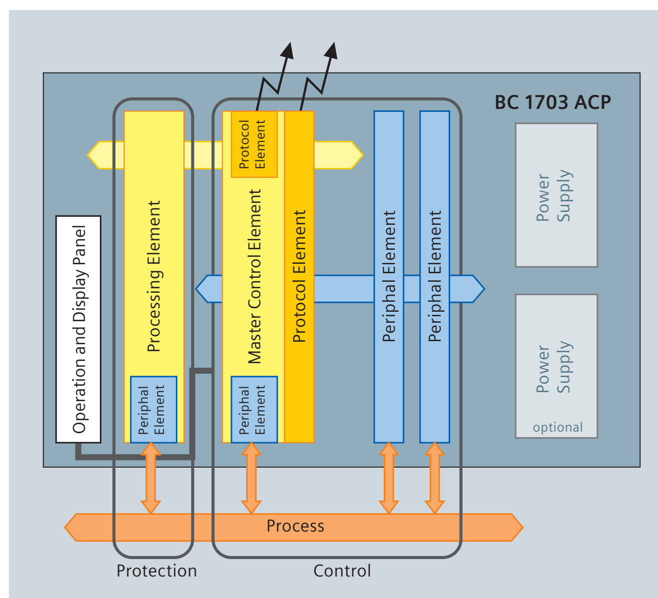

Fig. 6.3-53: **BC 1703 ACP**

6

6.4 Power Quality – Measuring, Recording and Analyzing

6.4.1 Introduction

Modern developed societies are totally dependent on the supply of electricity. With businesses operating almost totally via electronic communication and our hospitals and factories being unable to operate without electricity, the impact of dips or interruptions in the supply voltage can be catastrophic.

Social changes in recent years have lead to increasing pressure on the electricity suppliers. In some countries civil unrest has resulted in significant damage to the infrastructure. In more peaceful countries a different pressure has occurred in that commercial or environmental concerns have delayed the construction of new generation and distribution plants. This has resulted in the reduction or even elimination of redundant capacity leading to some network breakdowns.

Changes have also occurred on the consumer side. There has been a rapid increase in the use of electronic controls for high power loads such as electric motors and heaters, both in the industrial and domestic sector. These electronic controls can reflect voltage spikes and harmonics back into the power supply if they are not well designed. These spikes and harmonics can travel through the network to neighboring consumers, and this at the same time as there has been a rapid growth in the use of computers, digital TV and other equipment which can be damaged by supply line spikes and harmonics.

Power quality

For power supply companies, aiming to maintain a continuous supply within the specified voltage range is not enough. They must also minimize the effect of harmonics and unbalanced loads which increase energy losses in the distribution network and could potentially damage consumer's equipment. Major consumers take a serious view of electrical quality and in many cases insist on quality standards being written into supply contracts with penalties for non-compliance. The basis for delivering a reliable power supply and ensuring compliance to contractual commitments is the continuous measuring and recording of power quality.

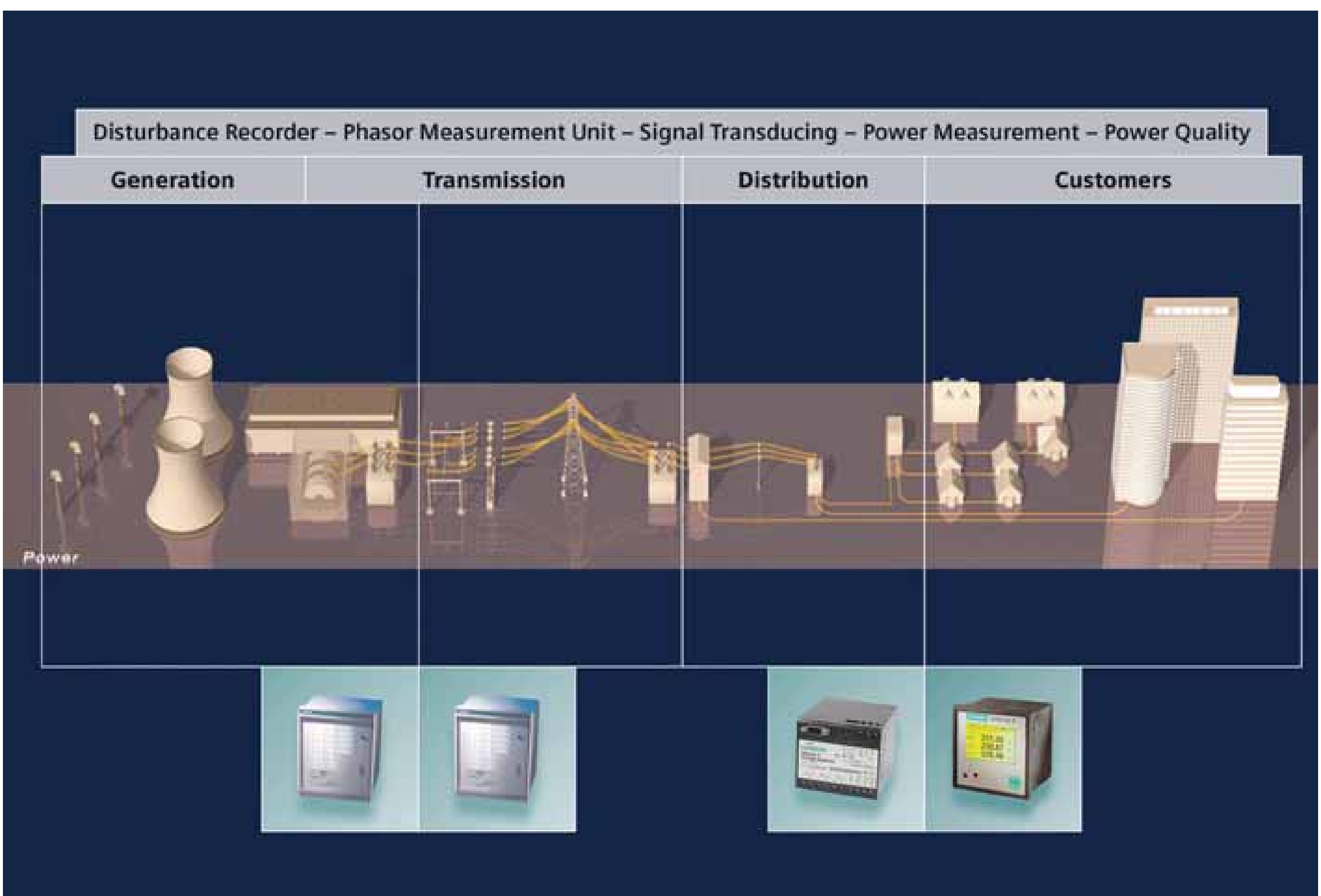

Fig. 6.4-1: **Siemens covers the complete power chain**

The two major factors in power quality are the supply reliability and the voltage quality. The most common causes of supply interruptions are external events impacting on the distribution network. These can include lightning strikes, toppled trees, landslips or unusually large snowfalls.

Voltage quality is influenced by both network events and load-dependent events. Network events can result in short interruptions, voltage dips, or voltage surges. Load-dependent events can generate transients, harmonics, imbalances and voltage fluctuations. It is common for neighboring networks to supply electricity from one to the other to accommodate peak load demands. In this case, if one network has problems with its supply quality this can 'pollute' the receiving network with harmonics and distortion.

Measurement and analysis
Siemens power quality measurement and analysis systems enable the network operator to manage and control the issues of quality and reliability within its network. Data is continuously collected at multiple points through generation and network distribution using SIMEAS power meters and recorders (SIMEAS R for generation and transmission, SIMEAS P and Q for distribution and customer premises). The information is analyzed for conformance to quality standards using OSCOP and SICARO analysis tools. The results are collated into quality reports and archived into a database. The quality reports provide the network operator with critical information on performance trends and help pinpoint any problem areas. Then, the operator can apply the appropriate action to optimize the power quality in a continuous improvement cycle.

System integration
Many power supply systems have been built up over time using autonomous equipment, each unit having its own incompatible protection and fault recording facilities. Often the result is that when network problems occur the operators are faced with an "information overload" of difficult to interpret data. Expert personnel then have to be called in to decipher the situation. This can lead to delay in correcting problems and even result in supply interruptions that should really have been avoided.

SIMEAS SAFIR provides the solution. SIMEAS SAFIR gathers real-time data from the configured network topology, clustering records to events, and identifying the key information points. It then automatically generates a fault report in plain language, highlighting the optimum corrective action. SIMEAS SAFIR enables the operators in the control room to deal with problems on the spot before they potentially escalate and propagate through the power supply system.

SIMEAS SAFIR provides vendor-independent device integration from generation and transmission to distribution. Its web-based network quality and analysis system enables the network operator to optimize system efficiency, and to meet and exceed its commitment on power quality.

6.4.2 SIMEAS SAFIR

Network quality is of increasing importance as a competitive factor in deregulated energy markets. One of the fundamental issues in this context is minimizing network outages. The quicker a fault can be analyzed and the more clearly faults can be identified, the shorter the downtime and, as a result, the more likely contractual penalties can be limited.

The best option, however is to prevent faults from occurring in the first place. A precondition for this is consequent condition monitoring, i.e., continuous monitoring and documentation of network states. From this, the preventive maintenance work can be derived and planned.

Fully integrated system
In today's electrical networks, digital devices are increasingly being used. In addition to their core functionality, the devices are capable of data registration.

Therefore, ensuring compatibility and seamless data exchange is becoming more and more important. Compatibility problems due to manufacturer-specific software products have to be overcome and international standards are of increasing importance.

All of this means that the network operator is able to document seamlessly faults states in his network, as well as the quality of the electrical energy supplied (fig. 6.4-2).

SIMEAS SAFIR is a system that integrates all device types and therefore enables consistent, standardized network monitoring.

With SIMEAS SAFIR, analyses are completely automated and documented.

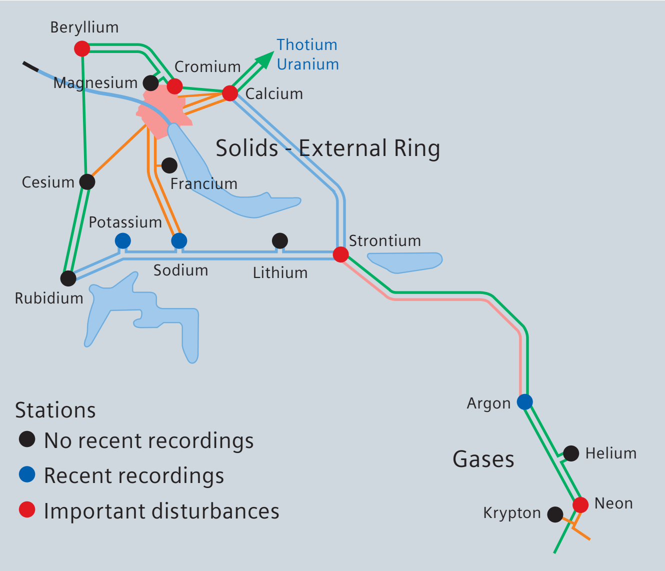

Fig. 6.4-2: **Example of an electrical network (Switzerland)**

An overview of the options:

- Fully automated distance to fault location in high-voltage networks encompassing all data relating to the network event.
- Fully automated distance to fault location in medium-voltage networks encompassing all data relating to the network event.
- Fully automated generation of power quality reports in accordance with applicable PQ standards
- (EN 50160; IEC 61000) – monitoring functionality (fig. 6.4-3, fig. 6.4-4).

Benefits

- Information on network states is compared with the best diagnosis and assigned to a best result report, independently of which device the information originates. Deviations are quickly seen, i.e., you have a decisive analysis origin for rapid fault clarification.
- Ad-hoc actions for fault clarification can be replaced with planned maintenance, drastically reducing outage time after a fault.
- Condition monitoring of your network equipment allows preventative maintenance – hence faults might not even occur.

Fault identification redefined
Without network quality systems, the process (data transfer, analysis, start of fault clearance, information distribution, reporting and archiving) must be carried out manually. Fault susceptibility and time used are high, particularly where the data originates from different, non-compatible systems.

Network topology
Faults that occur are firstly recorded by the relevant devices. SIMEAS SAFIR enables their automatic transfer and analysis. Diagnosis results are also distributed across the information system in the same automatic way.

Overview
An overview is created in SIMEAS SAFIR, which informs those in charge a few minutes later. The results are classified automatically.

Diagnosis results
Within just a few minutes, SIMEAS SAFIR supplies reliable diagnosis results. This is thus the basis for the rapid and targeted implementation of measures, because every minute counts for network outages and their troubleshooting.

Grouping
SIMEAS SAFIR groups all affected data sets according to the system concerned. In this way a rapid and reliable overall picture is attained of which faults have occurred in which part of the network. The results are automatically archived in order to ensure seamless documentation and to be able to access the fault history at any time.

Analysis

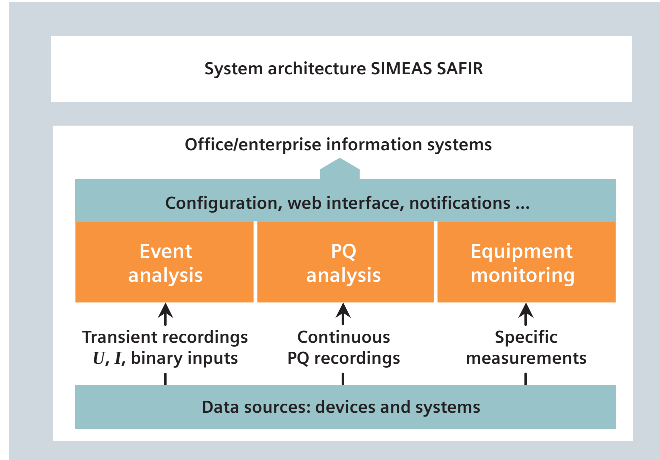

Fig. 6.4-3: **System architecture SIMEAS SAFIR**

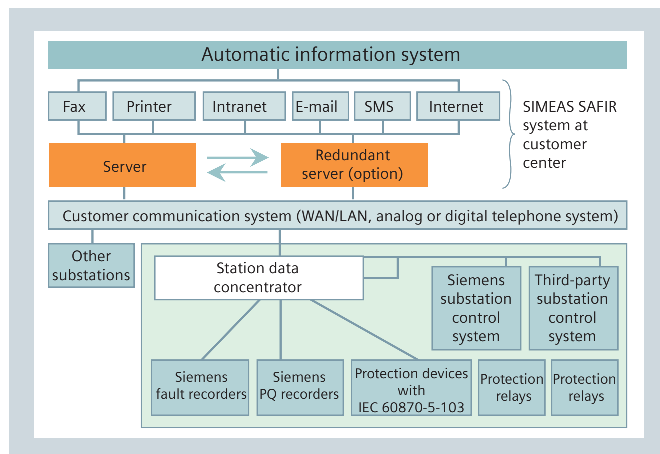

Fig. 6.4-4: **Overview of a network quality system configuration with SIMEAS SAFIR**

Detailed analysis also takes place automatically with SIMEAS SAFIR, whereby the results are compared with the best diagnosis. In this way, the cause of a fault can be quickly identified.

Information on all relevant channels
When it comes to network quality, it is speed and transparency which count. SIMEAS SAFIR distributes all relevant information on a network event in the fastest way to whom that need to know. In this way, the correct recipients get the information within minutes, and can implement the necessary reactions in a prompt and coordinated way.

Transparency at all times: Websites on the network operator's Intranet
At a click of the relevant site, operators can see automatically generated information from SIMEAS SAFIR on their Intranet. To do this they do not need to know the devices from which the data originates in any detail – what counts is the evaluation. The personnel should be provided with all means of online analyses and reporting.

Direct to recipients: e-mail
A further quick and direct way is notification by e-mail. This is to be recommended in particular where selected individuals should be informed about a faulty feeder or substation within their area of responsibility. This information service provides clearly comprehensible results in short form.

Information in short form: SMS
The alternative to e-mail: One mobile phone message, and the relevant individuals are quickly informed. The SIMEAS SAFIR administrator can assign priorities. This avoids a flood of SMS in which truly relevant information may get lost. For less can often mean more.

Black and white: in paper form
The classical printout of the fault should not be omitted, so that the information is conveniently available in black and white.

Complexity can also be transmitted: fax
If there are graphical overviews that cannot be transmitted by SMS, fax machines can also be incorporated into the information chain.

More individuals, more services: Internet applications
Is it recommendable to provide selected individuals from other companies with access to agreed information? Then a secure Internet connection is the fastest and most economical way.

Of course, you can also use these Internet applications as a platform for services for other power supply companies.

6.4.3 SIMEAS P Power Meter

Today, currents, voltages and performance values in power distribution systems are routinely measured in order to determine the load. It is important to ensure that no overloading occurs. However, the possibilities for measuring currents, voltages and performance values for the purpose of increasing system availability are nowhere near exhausted. This can be achieved when the measurement results are used to better distribute the load. There is tremendous potential here, provided suitable meters, measuring transducers and transformers are available. This solution is also cost-effective when all measurements are performed with a multi-function measuring device.

SIMEAS P is a power meter for panel or standard rail mounting that is used for acquiring and/or displaying measured values in electrical power supply systems. More than 100 values can be measured, including phase voltages and currents, active power, reactive power, apparent power, symmetry factor, voltage and current harmonics, energy output, as well as external signals and states. SIMEAS P shows this data on the graphic display and transfers it to a central computer system for further processing via either PROFIBUS DP or Modbus RTU/ASCII and IEC 60870-5-103 (for P50 and P55 options).

Fig. 6.4-5: **Power meter P610 and P50**

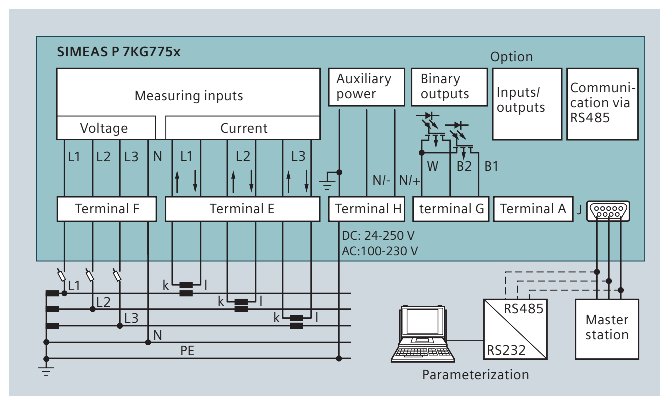

Fig. 6.4-6: **SIMEAS P50 block diagram**

Functionality
Input voltages and currents are sampled in order to calculate the corresponding r.m.s. values. All the measured variables thus derived are then calculated by a processor, and can be displayed on the screens and transmitted via the serial interface. With SIMEAS P, it is also possible to define several limit values for the measured variables. These can be combined with the logical elements AND/OR, and their violations be displayed on counters or made available at the binary outputs (fig. 6.4-7).

Application as a measured-value recorder
All the measured variables recorded can be displayed along with their units on the device, and/or be transferred to a central control system for further processing. As with standard devices, transmission is via the PROFIBUS DP V1 and MODBUS RTU/ASCII communication protocols IEC 60870-5-103.

In addition, external measured values, including time information, can be stored in the memory. This information can be read out with the SIMEAS P PAR parameterization software, displayed, evaluated, and stored in the COMTRADE format.

The SIMEAS P input modules can be used to acquire, display and further process external measured variables (DC 0 to 20/4 to 20 mA). The output modules can be used for conversion of electrical variables to a DC 0 to 20/4 to 20 mA output signal, for power metering, for generating messages, and for switching operations. The SIMEAS P is available with mounting dimensions of 144 mm x 144 mm (P610 with display and P660 without display) and 96 mm x 96 mm (P50 with display and P55 without display). The SIMEAS P610/P660 can be fitted with 4 additional analog input and output modules (fig. 6.4-5, fig. 6.4-6)

Module assignment
The assignment of different input and output modules to the SIMEAS P must be specified when the unit is ordered. It is not possible to change or retrofit modules.

Operation
Clear designations and texts, as well as simple menu-driven parameterization guarantee the simple and straightforward operation of the SIMEAS P.

Parameterization
The SIMEAS P PAR parameterization software makes configuring SIMEAS P devices even faster. Users can set and store parameters even when no device is present. Thus, a number of SIMEAS P units can also be configured within a minimum time span. The stored set of parameters is simply reloaded when a unit has to be replaced. Additional options include loading communication protocols and firmware updates (fig. 6.4-7, fig. 6.4-8).

6.4.4 SIMEAS T Universal Measuring Transducer

With the SIMEAS T universal measuring transducer (fig. 6.4-9), it is possible to measure all variables in any high-voltage system with a single unit. Measuring transducers are required for the galvanic isolation and further processing of electrical signals, especially in power station and switchgear areas. Any measured value (current, voltage, active power, reactive power, frequency, etc.), as well as any measuring range, can be assigned to each of the 3 analog outputs. Additional software products are also available (SIMEAS T PAR, SIMEAS EVAL) to take care of all your parameterization and evaluation needs.

The transducer has 3 galvanically isolated analog outputs and one binary output, as well as an RS232 serial interface.

The output signal (for example, –10 to 10 mA, ± 20 mA, 4 to 20 A, 0 to 10 V, etc.) can be freely parameterized for each output. The binary output can be used as a meter to register the energy, or as a limit monitor. Input currents up to max. 10 A or input voltages up to 600 V with rated frequencies of 50, 60 or 16 ⅔ Hz can be connected. Depending on the measuring requirements, any unnecessary input terminals remain free. The measurement is a true r.m.s. value measurement that can also precisely measure distorted waveforms up to the 32nd harmonic (fig. 6.4-10, fig. 6.4-11).

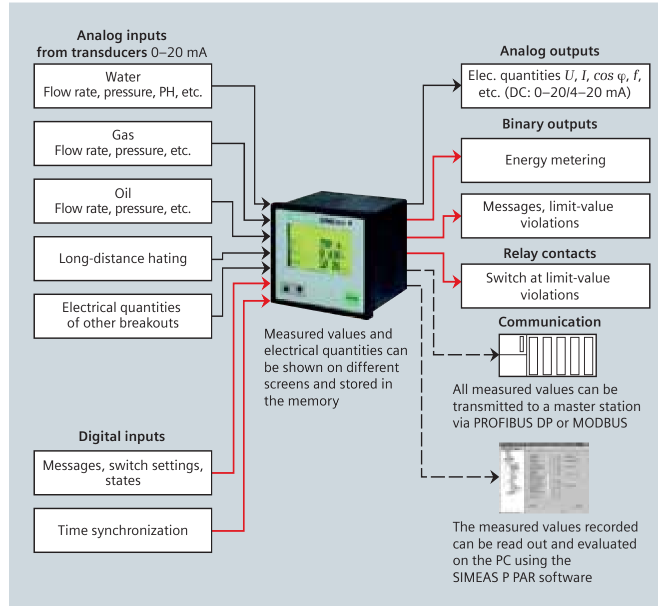

Fig. 6.4-7: **SIMEAS P sample applications**

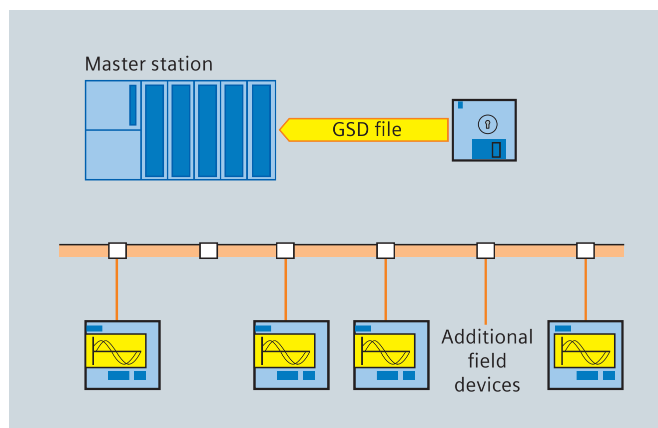

Fig. 6.4-8: **SIMEAS P connected to PROFIBUS DB**

Interface to IEC 60870-5-103
In terms of design, method of connection and technical data, the transducers are identical to the standard units featuring an RS232 interface. Instead of the RS232 interface, however, an interface conforming to EAI RS485 is installed for operation on an IEC 60870-5-103 bus. Thus, the transducers are bus-compatible and, as shown in the example, can be networked. Bus operation has no adverse effect on the output of analog measured variables via the analog outputs. The units are parameterized with the SIMEAS T PAR software.

Note:
A new SIMEAS T based on Ethernet communication with many other improved features will be available in 2009. Information is available at the Siemens representatives in the regions.

Fig. 6.4-9: **SIMEAS T universal measuring transducer**

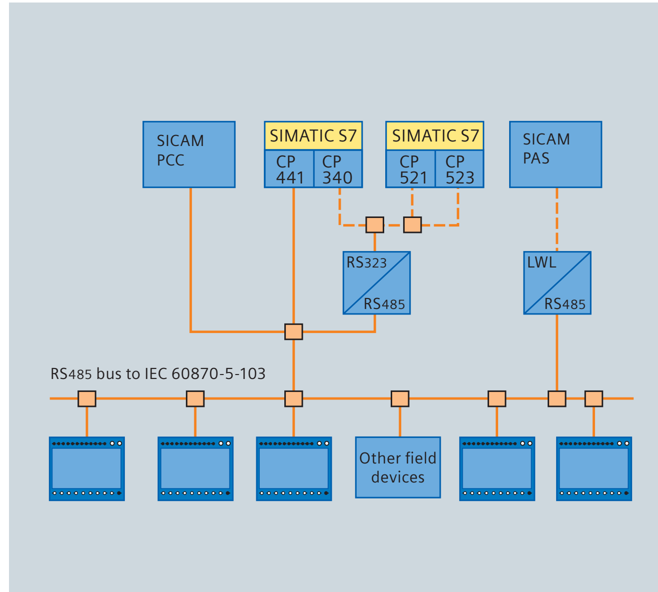

Fig. 6.4-10: **Connection example: user programs for SIMATIC for linking transducers with an RS485 interface (on request)**

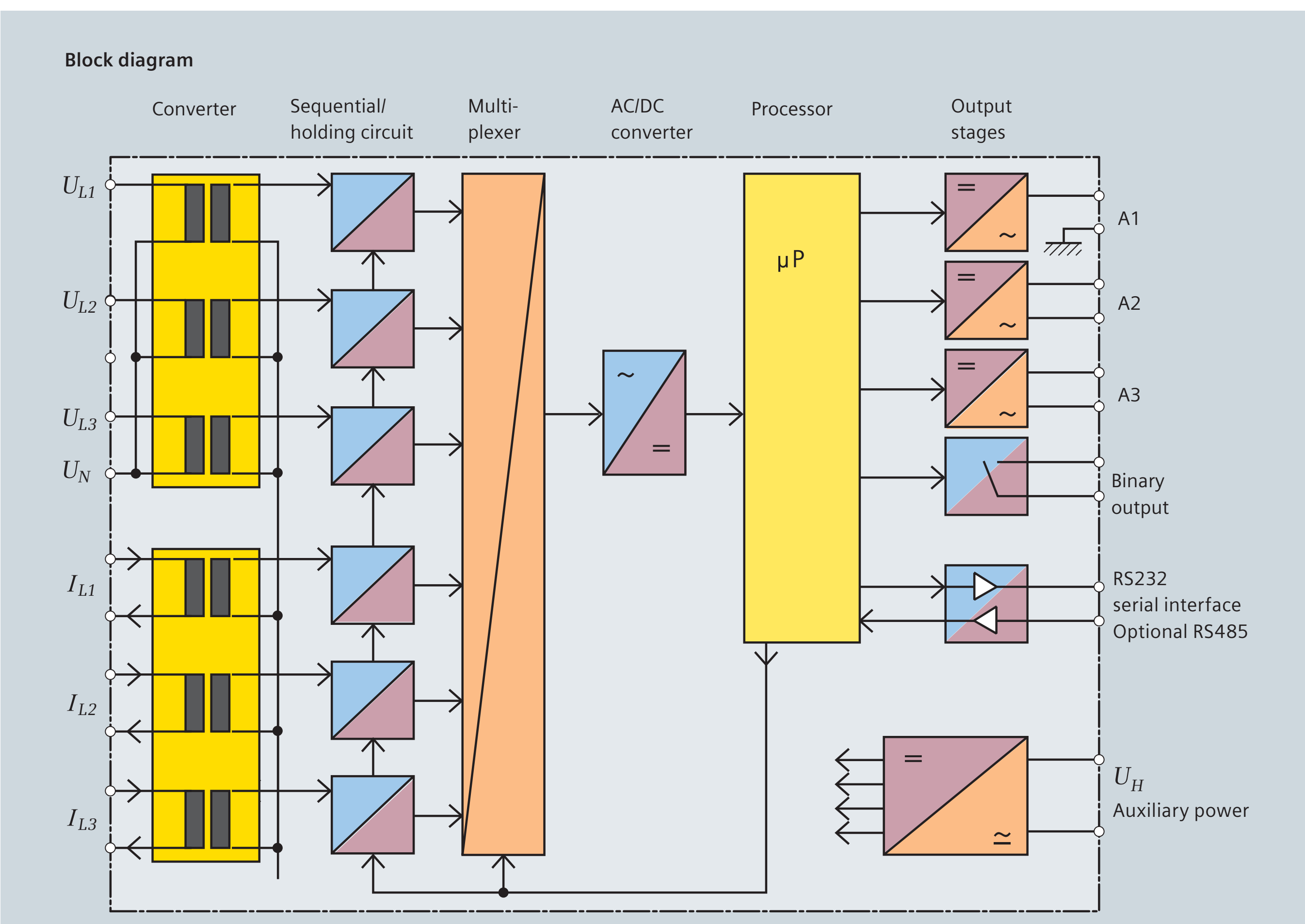

Fig. 6.4-11: **Block diagram of the SIMEAS T**

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6.4.5 SIMEAS Q Quality Recorder

SIMEAS Q is a measuring and recording device which enables monitoring of all characteristics related to the voltage quality in 3-phase systems according to the specifications defined in the standards EN 50160 and IEC 61000 (fig. 6.4-12, fig. 6.4-14). It is mounted on a standard rail with the help of a snap-on mechanism.

Application
Medium and low-voltage systems. The device requires only little space and can be easily installed for stationary use.

Functions
Instrument for network quality measurement. All relevant measurands and operands are continuously recorded at freely definable intervals or, if a limit value is violated, the values are averaged. This enables the registration of all characteristics of voltage quality according to the relevant standards. The measured values can be automatically transferred to a central computer system at freely definable intervals via a standardized PROFIBUS DP interface, and at a transmission rate of up to 1.5 Mbit/s (fig. 6.4-13).

Special features
- Cost-effective solution
- Comprehensive measuring functions which can also be used in the field of automatic control engineering
- Minimum dimensions
- Integrated PROFIBUS DP
- The integrated clock can be synchronized via the PROFIBUS. Configuration and data output via PROFIBUS DP.

Measuring inputs
- 3 voltage inputs, 0–280 V
- 3 current inputs, 0–6 A.

Communication
- 2 optorelays as signaling output, available either for:
  - Device in operation
  - Energy pulse
  - Signaling the direction of energy flow (import, export)
  - Value below min. limit for cos φ
- Pulse indicating a voltage dip
- 3 LEDs indicating the operating status and PROFIBUS activity
- 1 RS 485 serial interface for connection to the PROFIBUS.

Auxiliary power
Two versions: 24 to 60 V DC and 110 to 250 V DC, as well as 100 to 230 V AC.

Measured and calculated quantities
- R.m.s. values of the phase-to-earth or phase-to-phase voltages
- R.m.s. values of the pahse-to-phase currents
- Phase frequency (from the first voltage input)
- Active, reactive and apparent power, separately for each phase and as a whole

Fig. 6.4-12: **The SIMEAS Q quality recorder**

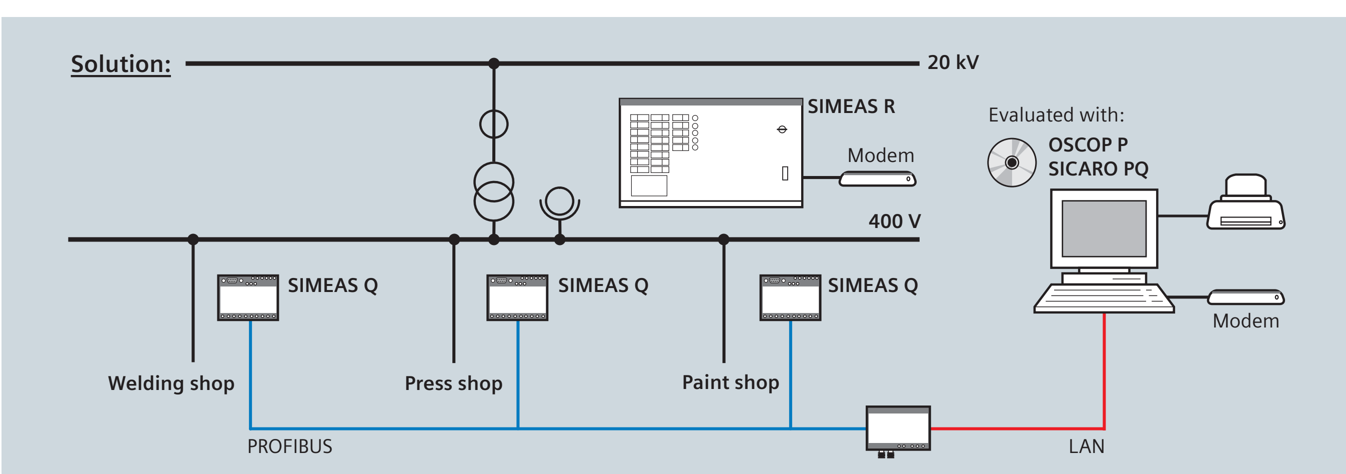

Fig. 6.4-13: **The SIMEAS Q quality recorder, network configuration example**

- Harmonics for voltages and currents up to the 40th order
- Total harmonic distortion (THD), voltages and currents of each phase
- Unbalanced voltage and current in the 3-phase system,
- Flicker irritability factor

Averaging intervals
- Voltages and currents: from 10 ms to 60 min
- Other quantities: from 1 s to 60 min

Operating modes
- Continuous measurement with definable averaging intervals
- Event-controlled measurement with definable averaging intervals

Storage capacity
Up to 20,000 measured and calculated values. Parameters for the measuring points can be freely defined. PROFIBUS DP enables quick loading of the measured values, so that the apparently small storage capacity is absolutely sufficient. Assuming a usual parameter setting with regard to the measuring points and averaging intervals for quality monitoring, the storage capacity will last for seven days in case of a PROFIBUS failure.

Basic functions
In the course of continuous measurement, the selected measuring data are stored in the memory or transferred directly via the PROFIBUS. The averaging interval can be selected separately for the different measurands. In the event-controlled mode of operation, the data will be stored only if a limit value has been violated within an averaging interval.

Apart from the mean-values, the maximum number and minimum values within an averaging interval can be stored, with the exception of flicker irritability factors and the values from energy measurement. Parameter assignment and adjustment of the device are performed via the Profibus interface.

Information for SIMEAS Q project planning
Up to 400 V (L-L), the device is connected directly, or, if higher voltages are applied, via a external transformer. The rated current values are 1 and 5 A (max. 6 A can be measured) without switchover. Communication with the device is effected via PROFIBUS DP or, as an option, via modem (telephone network).

Auxiliary voltage is available in two variants: 24 to 60 V DC and 110 to 250 V DC or 100 to 230 V AC.

Note:
A new development in SIMEAS Q family will improve the available features. A new release is planned in 2009. Information is available at the Siemens representatives in the regions.

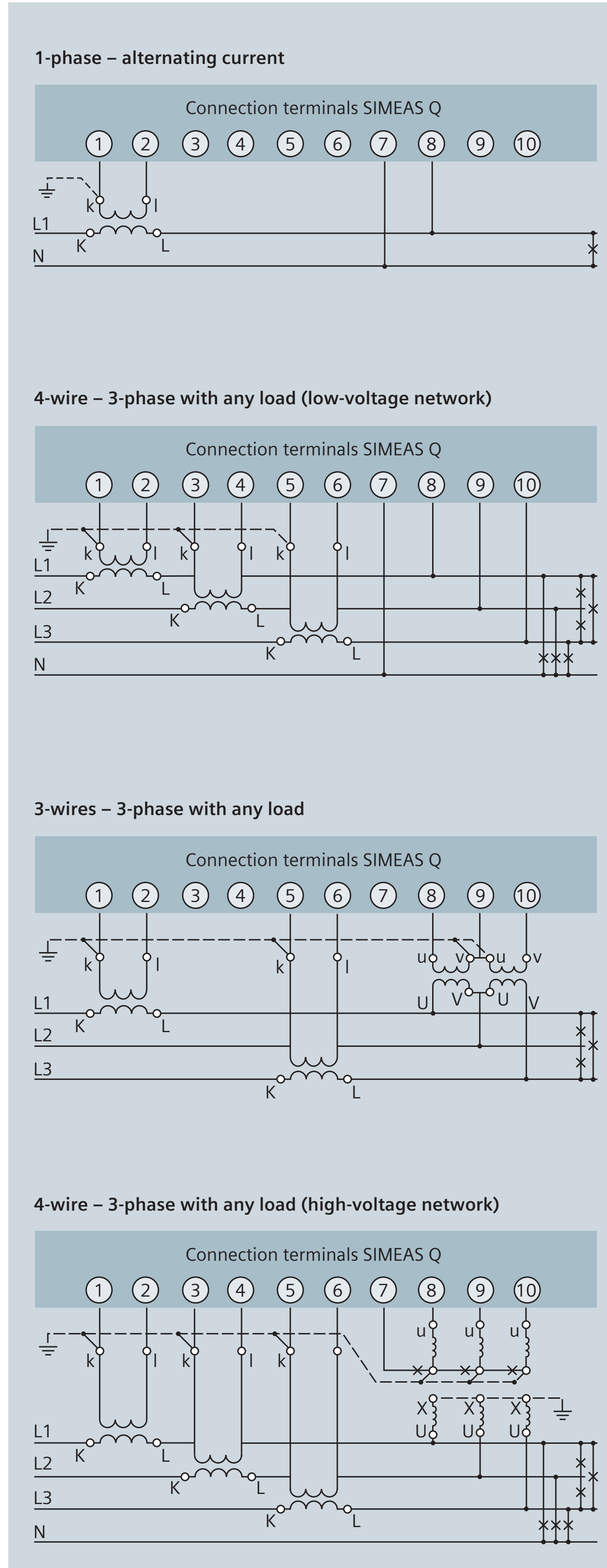

Fig. 6.4-14: **Connection terminales SIMEAS Q**

6.4.6 SIMEAS R – DigitalFaultRecorder with Power Quality (PQ) or Phasor Measurement Unit (PMU)

Application

- Stand-alone stationary recorder for extra-high, high and medium-voltage systems
- Component of secondary equipment of power plants and substations or industrial plants

Function overview

- Disturbance recorder for applications in substations atMV/HV/EHV level and in power plants
- Power and frequency recorder for applications in power plants
- Power quality recorder for analysis and recording/archiving of power quality problems of all power applications
- Event recorder for binary signals for observation of the status of various primary components like circuit-breakers, disconnectors, etc.
- Transient recorder for DC signals
- Test recorder for commissioning and system test
- PMU according to IEEE C37.118. Measurement of vector quantities of voltages and currents with high accuracy in regard to amplitude, phase angle and time synchronization
- According to IEEE C37.118, internal recording of phasors via Transient and Continuous Phasor Recorder and parallel disposition of the measured phasors to a Phasor Data Concentrator (PDC)

Dynamic fault recorder for analog and binary channels

The “fault recorder” function includes recording of analog and digital signals. These signals are continuously recorded and simultaneously compared with the parameterized trigger criteria. On triggering, all channels are recorded concurrently and with a pre-fault, variable fault progression and post-fault, depending on the parameter settings for recording.

Recording alternating current and voltage

Three different Data Acquisition Units (DAU) are available for recording currents and voltages:

- VCDAU with 4 voltage and 4 current inputs
- CDAU with 8 current inputs or
- VDAU with 8 voltage inputs

SIMEAS R V3.0: The sampling rate is 256 x system frequency. For a system frequency of 50 Hz, the sampling rate is therefore 12.8 kHz (for 60 Hz, 15.36 kHz per channel).

SIMEAS R-PMU: The sampling rate is constant at 192 samples. For a system frequency of 50 Hz (frequency range 25 to 60 Hz) the sampling rate is constant at 9,600 Hz and for 60 Hz (frequency range 30 to 70 Hz) the sampling rate is constant at 11,520 Hz.

Fig. 6.4-15: **SIMEAS R, compact housing**

Fig. 6.4-16: **SIMEAS R, front view – a DAU can be seen in the middle slot**

Fig. 6.4-17: **DAUs**

6

Recording of the process variables
DC signals are measured via the DDAU data acquisition unit, which has 8 signal inputs. The DDAU can be ordered for an input range of –1 V to +1 V, –10 V to +10 V or –20 mA to +20 mA. These inputs can be assigned to one process signal each, e.g., display of temperature in K, speed of rotation in rpm, voltage in kV, current in kA.

Recording of binary signals
The recording of binary channels is fully synchronized with the recording of analog channels. The sampling rate is 2 kHz. A group of 16 binary inputs can record up to 250 state changes per second.

SIMEAS R-PMU: Phasor measurement unit (PMU)
The SIMEAS R-PMU is equipped with an integrated Phasor Measurement Unit (PMU) according to IEEE C37.118 – 2005. Among other things, this standard defines PMU quality criteria and the data formats.

At absolute instants of time, which are defined by the reporting rate, the PMU determines the phasors from the measured values and sends them to a Phasor Data Concentrator (PDC).

The phasor measurement requires a highly precise time synchronization (< 5 µs) of the SIMEAS R-PMU device; especially if phasors of different locations are to be compared to each other.

Phasor data concentrator (PDC)
A Phasor Data Concentrator (PDC) continuously receives data from one or several PMU devices. The phasor data concentrator can switch the PMU on or off, and read out its configurations and channel descriptions. The data received by the PDC is visualized and may be stored in a database if necessary.

Complex phasors
A phasor $\underline{v}(t) = \underline{V}e^{j\,t}$ can be displayed as a pointer that rotates counter-clockwise with the angular velocity ω in the complex plane. The voltage $v(t) = Re\{v(t)\}$ is a result of the projection of the phasor $v(t)$ on the real axis.

Data recording
The phase angle of signal X_m is calculated in relation to a cosine function with the nominal frequency that has been synchronized with the UTC time reference (UTC = Universal Coordinated Time).

The reporting rate defines the number of phasors transferred per second. If the defined sampling interval T_0 is unequal to the integer multiple of the measuring signal cycle duration T_m, the phasors length remains constant, however, the phase angle is changed.

If the sampling interval T_0 corresponds to the integer multiple of the measuring signal X_m cycle duration, a constant phasor is determined during every sampling instant.

Reporting rate
The parameterizable reporting rate of the SIMEAS R-PMU defines the number of telegrams that are created and transferred to the PDC per second. It can be set depending on the nominal frequency, and equally applies to all data acquisition units (DAU) in the SIMEAS R-PMU. When selecting the reporting rate, the available bandwidth of the data connection to the PDC should always be considered (table 6.4-1).

Name	Description								
Nominal frequency	f_n = 50 Hz			f_n = 60 Hz					
Reporting rate in telegrams/s	10	25	50[1]	10	12	15	20	30	60[1]
Recording values	VDAU, VCDAU, CDAU:			Phasors U, I or positive-sequence Phasors, binary data					
	DDAU:			Process values, binary data					
	BDAU:			Binary data					

[1] The reporting rates of 50 or 60 telegrams/second are not prescribed by the standard but are supported by the SIMEAS R-PMU.

Table 6.4-1: **Technical data PMU**

Fig. 6.4-18: **SIMEAS R systems are used in power plants ...**

Fig. 6.4-19: **... and to monitor transmission lines**

Transient Phasor Recorder (TPR)
The Transient Phasor Recorder (TPR) records the voltage and current curves, the derived values (e.g., active and reactive power) of the fundamental component, binary signals and process values in cycles when a fault occurs. For this purpose, the user defines trigger limits and recording times using the OSCOP P parameterization software. The input signals are analyzed according to the preset trigger conditions, and recorded if the limit values are exceeded or not reached. The essential difference to the transient analog recorder is the cycle-based determination of the measured and derived values, as well as a longer recording time. The fault record contains the pre-fault time, the trigger time and the recorded fault. The trigger cause is also stored.

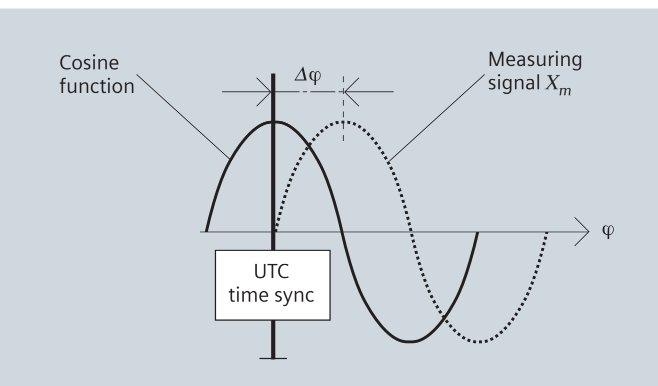

Fig. 6.4-20: **Determination of the phase angle φ of the measuring signal X_m with regard to the cosine function**

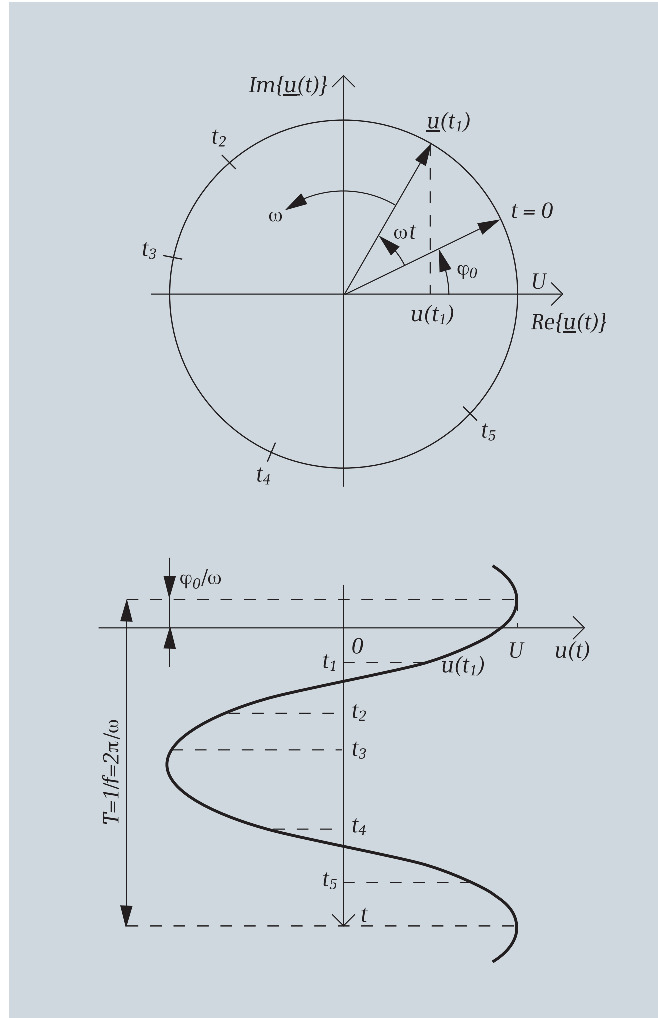

Fig. 6.4-21: **Geometrical illustration of a phasor**

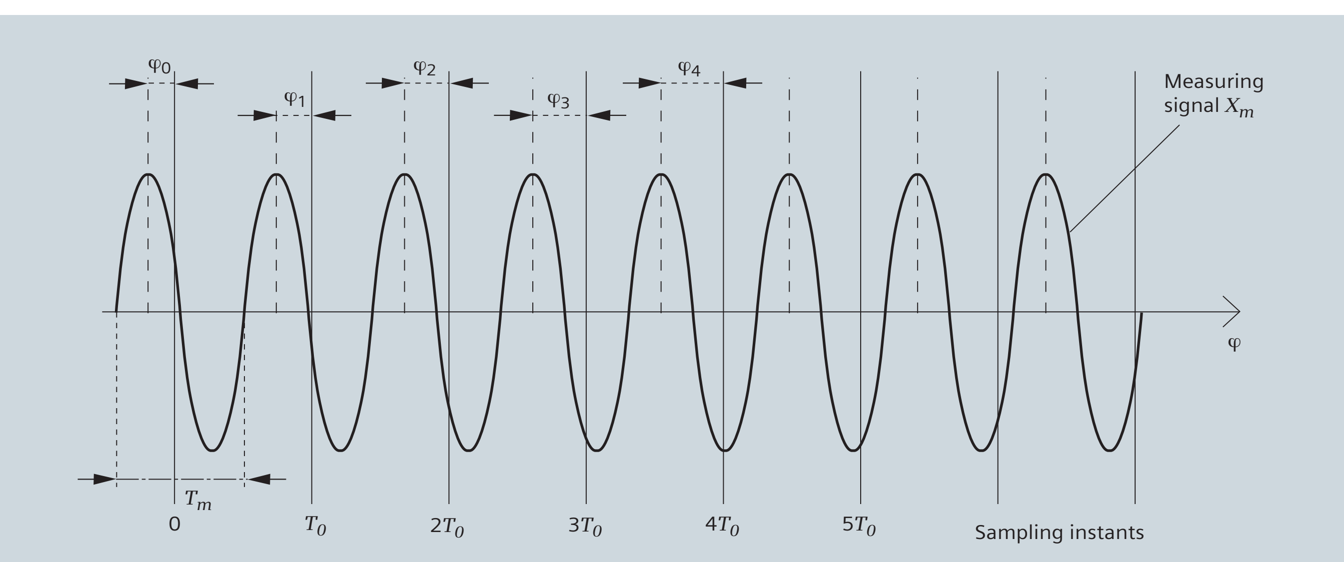

Fig. 6.4-22: **Sampling of the signal X_m; T_m unequal T_0**

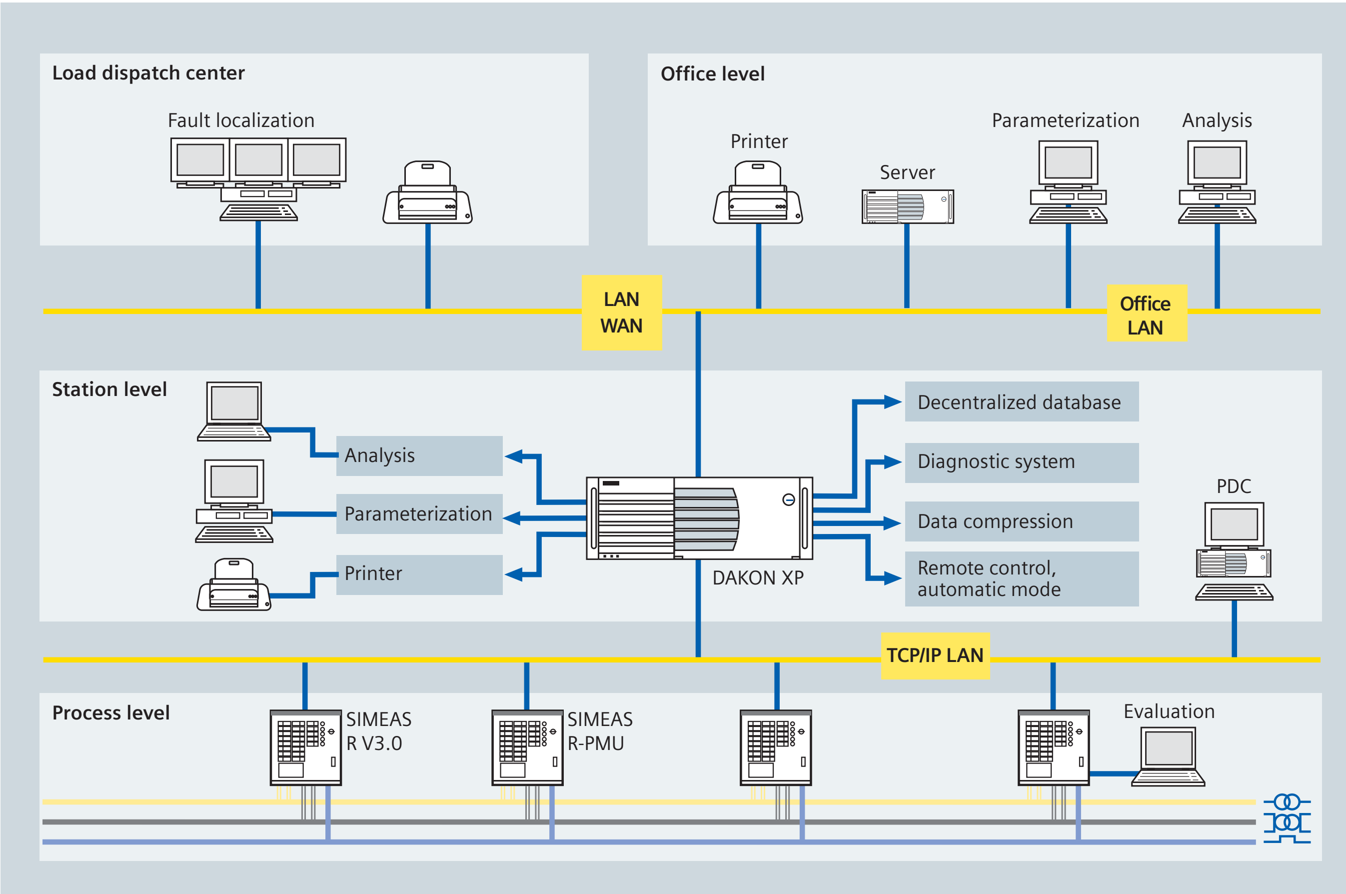

Fig. 6.4-23: **Example of a distributed recording system implemented with SIMEAS R recorders and data central unit DAKON**

The following trigger functions can be parameterized for the transient phasor recorder:

- Level trigger min/max
- Gradient trigger
- Binary trigger
- Cross trigger
- Manual trigger
- External trigger
- Network trigger.

SIMEAS R V3.0: Power and frequency recorder

The frequency and power recorder SIMEAS R V3.0 calculates and stores the active and reactive power and the power factor plus the frequency (P, Q, PF, $cos\ \varphi$ and f). This function is used, for example, to record the load conditions before, during and after a fault in a power plant. Power swings in the power system and the frequency curve over a long time can be recorded.

One special application is recording of the properties of primary control in a power plant. For example, if a power plant unit is shut down at another location in a grid, the frequency of the power system will drop. This causes a considerable change in the power output of the power plant in which recording is taking place. Because all channels are recorded simultaneously, the user can establish a power balance, e.g., at the infeed points in substations.

Recording principle SIMEAS R V3.0

The variables active power, reactive power, power factor and frequency (P, Q, PF, $cos\ \varphi$ and f)are continuously calculated at intervals of one system cycle and stored in a buffer. If the parameter "averaging time" is set to 1, the calculation interval of the frequency and power recorder is one system cycle. The values in the fault recording therefore correspond to the values in the buffer. Other settings of the "averaging time" parameter can reduce the recorder's calculation interval. For example, if the "averaging time" parameter is set to 4, a mean-value is formed over the 4 last calculated values of the variables (P, Q, PF, $cos\ \varphi$ and f), and written to the buffer after 4 system cycles have elapsed. This means that the calculation interval of the fault recording is 4 system cycles. The "averaging time" parameter can be set in the range 1 to 250. The number of calculated values before the trigger point (pre-fault) can be selected in the range of 0 to 500.

The system frequency is measured via a voltage channel if the unit is equipped with an appropriate module (VDAU, VCDAU); if not, the frequency is measured via a current channel of a CDAU by automatic determination of the current signal with the highest amplitude and the lowest harmonic distortion.

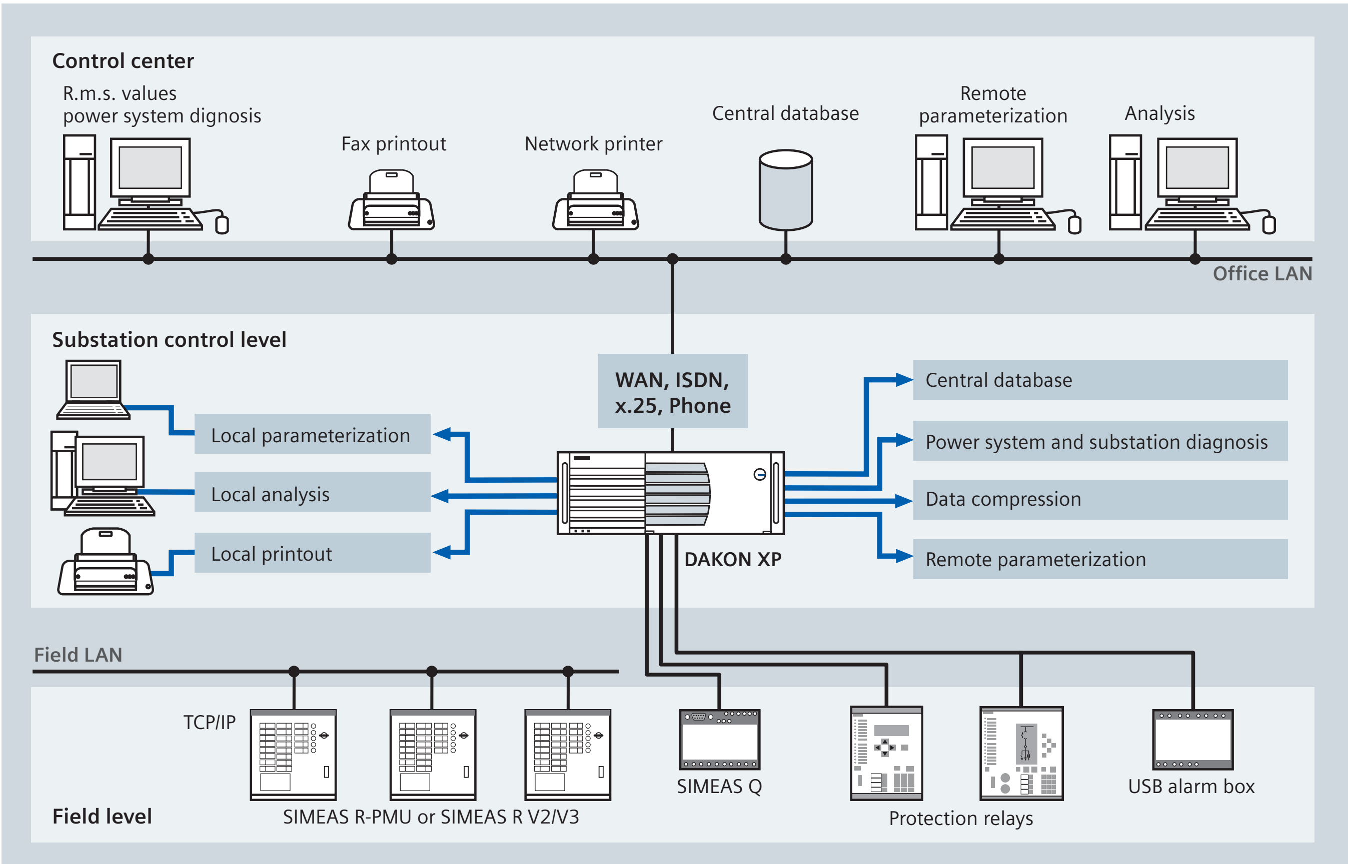

Fig. 6.4-24: **Rear view of a SIMEAS R unit with terminals for the signals and interfaces for data transmission**

Power quality recorder and mean-value recorder (SIMEAS R V3.0)

The mean-value recorder and power quality recorder functions store the signals continuously. The averaging time for the groups listed below can be freely parameterized in the range of 10 s to one hour. The following electrical quantities are measured, stored and displayed in the evaluation program:

- Voltage and current
- Active and reactive power
- Frequency, positive and negative sequence system
- Weighted and unweighted THD
- Current and voltage harmonic
- Process variables
- Voltage dips
- Flicker

With this function it is possible to monitor a substation or part of a substation (e.g., feeder) continuously and to evaluate its power quality. The measurement is used for monitoring the rms current progression as well as the active and reactive power. This enables the energy requirement of a feeder to be averaged over a long period. Moreover, an analysis of the r.m.s. voltage, the current harmonic progression, the THD, the progression of voltage dips and flicker effects (P_{st} and P_{lt} value) provides information about the quality of the power supply on a feeder. Existing fault sources can thus be located and countermeasures taken.

Use of the interface modules		
DAU Type	Measurands	Application
VCDAU	4 AC voltages, 4 AC currents, 16 binary signals	Monitoring of voltages and currents of 3-phase feeders or transformers including the signals from protective equipment. All recorder functions can be run simultaneously.
VDAU	8 AC voltages, 16 binary signals	Monitoring of busbar voltages
CDAU	8 AC currents, 16 binary signals	Monitoring of feeder and transformer currents or currents at the infeeds and coupling of busbars
DDAU	8 DC currents or 16 binary signals	For monitoring of quantities received from measuring transducers and telecontrol units, 20 mA or 1 and 10 V
BDAU	16 binary signals	Event recording of alarm signals, disconnector status signals, circuit-breaker monitoring

Table 6.4-2: **Use of the data acquisition units**

Event recorder
With the independent "event recorder" function, SIMEAS R continuously records the status of the binary inputs and stores them in an event memory. This permits analysis of the state changes of the binary inputs over a long time, for example, several months. This is relevant, e.g., for example, for examining faults that occur on switching.

The described independent recording functions "analog and binary recorder, frequency and power recorder, mean-value and power quality recorder and event recorder" can run in parallel depending on the parameter settings.

Bulk storage
SIMEAS R features a bulk storage in flash technology to ensure the required high degree of reliability. During commissioning, it is possible to allocate separate areas to the various recorder functions, depending on the importance of the individual functions for the application.

The unit automatically reserves the memory range required for the operating system and firmware. Each memory range for recordings (a to d) is organized as a circulating memory. As soon as a memory range is 90 % full after several recordings, the procedure is as follows: The latest fault record is written to memory first, then the oldest recordings are deleted until the free capacity in this range reaches 80 % of the allotted memory size.

Data compression
Even if you are using fast modem cards or a LAN/WAN connection, data compression is essential in a fault recorder in order to achieve:
- Efficient use of the device's internal bulk storage as a distributed data archive
- Fast transmission of the fault records to a DAKON (data concentrator) or a valuation PC to enable a fault analysis to be performed immediately after the fault
- Acceptable transmission times when using slow transmission media, e.g., an analog modem
- Coping with LAN/WAN bottlenecks, which are particularly frequent in large-scale networks.

Flexible triggering
With its numerous settable trigger conditions, SIMEAS R can be precisely adapted to the specific requirements of an application:
- Triggering on the rms value of an analog channel (min./max. triggering)
- Triggering on a change in the rms value of an analog channel (dM/dt triggering)
- Triggering on the rms value of the positive or negative sequence system (min./max. triggering)
- Triggering on the limit of a DC channel (min./max. triggering)
- Triggering on the gradient of a DC channel (gradient triggering)
- Triggering on binary channels
- Logic gating of trigger conditions

Analog and binary trigger conditions can be ANDed.
- Triggering via the front panel (manual trigger)

Triggering via PC
This triggering is activated from the PC via the OSCOP P software.

Network trigger
This triggering applies to devices communicating via an Ethernet network.

External trigger
For the SIMEAS R-PMU the Transient Analog Recorder (TAR) starts recording of the transient phasor recorder (TPR) (and converse).

Cross trigger
For the SIMEAS R-PMU the Transient Analog Recorder (TAR) starts recording of the Transient Phasor Recorder (TPR) (and converse).

Examples of logic gating
- Voltage min. trigger threshold, recording reached, and current max.
- Binary contact channel 1 high recording and current max. trigger reached
- Binary contact 1, 3, 4 high and 6, 7, 9 low recording

OSCOP P software

The OSCOP P software package is suitable for use in personal computers provided with the operating systems MS WINDOWS XP. It is used for remote transmission, evaluation and archiving (database system) of the data received from a SIMEAS R or OSCILLOSTORE and from digital protection devices. The program includes a parameterization function for remote configuration of SIMEAS R and OSCILLOSTORE units.

The program enables fully-automated data transmission of all recorded events from the acquisition units to one or more evaluation stations via dedicated line, switched line or a network; the received data can then be immediately displayed on a monitor and/or printed (fig. 6.4-23).

The OSCOP P program is provided with a very convenient graphical evaluation program for the creation of a time diagram with the curve profiles, diagrams of the 5 r.m.s. values or vector diagrams.

The individual diagrams can, of course, be adjusted to individual requirements with the help of variable scaling and zoom functions. Records from different devices can be combined in one diagram. The different quantities measured can be immediately calculated by marking a specific point in a diagram with the cursor (impedance, reactance, active and reactive power, harmonics, peak value, r.m.s. value, symmetry, etc.).

Additional diagnosis modules can be used to perform an automatic analysis of fault events and to identify the fault location. The program also supports server/client structures.

Information for project planning with SIMEAS R

The secondary components of high or medium-voltage systems can either be accommodated in a central relay room or in the feeder-related low-voltage compartments of switchgear panels. For this reason, the SIMEAS R system has been designed in such a way as to allow both centralized or decentralized installation.

The acquisition unit can be delivered in two different widths, either ½ 19″ or 19″ (full width). The first version is favorable if measurands of only one feeder are to be considered (8 analog and 16 binary signals). This often applies to high-voltage plants where each feeder is provided with an extra relay kiosk for the secondary equipment. In all other cases, the full-width version of 19″ is more economical, since it enables the processing of up to 32 analog and 64 binary signals. The modular structure with a variety of interface modules (DAUs) provides a maximum of flexibility. The number of DAUs which can be integrated in the acquisition system is unlimited (fig. 6.4-23).

With the help of a DAKON, several devices can be interlinked and automatically controlled. In addition, digital protection devices of different makes can be connected to the DAKON. The voltage inputs are designed for direct connection to low-voltage networks or to low-voltage transformers. Current inputs are suitable for direct connection to current transformers (I_N = 1 or 5 A). All inputs comply with the relevant requirements for protection devices according to IEC 60255. The binary inputs are connected to floating contacts.

Data transmission is preferably effected via telephone network or WAN (Wide Area Network). If more than one SIMEAS R is installed, we recommend the use of a DAKON. The DAKON creates connection with the OSCOP P evaluation program, e.g., via the telephone network. Moreover, the DAKON automatically collects all information registered by the devices connected and stores these data on a decentralized basis, e.g., in the substation. The DAKON performs a great variety of different functions, e.g., it supports the automatic fax transmission of the data. A database management system distributes the recorded data to different stations either automatically or on special command (fig. 6.4-24, table 6.4-1).

Typical applications of SIMEAS R

- Monitoring the power feed
  Monitoring the infeed from a high-voltage network via 2 transformers on two busbars of the medium-voltage network. This application is relevant for the infeeds of municipal utilities companies and medium to large industrial enterprises (fig. 6.4-25).
- Monitoring the infeed (fig. 6.4-26)

Fault monitoring and power quality in power distribution networks

Power supply companies with distribution networks are not only suppliers but also consumers, particularly of renewable energy. Therefore, it is important to monitor power quality both at the transfer points of critical industrial enterprises and at the power supply points of the suppliers (fig. 6.4-27).

Monitoring power quality in an industrial enterprise

All industrial enterprises with sensitive productions need to document the power quality at the transfer point, and thus document any claims for damages against the suppliers. For internal control, it is important to monitor individual breakouts with regard to cost-center accounting and specific quality features (fig. 6.4-28).

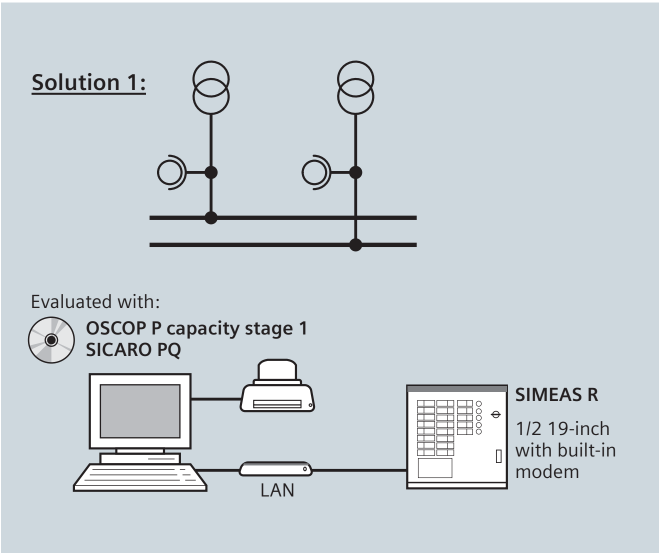

Fig. 6.4-25: **Monitoring the power feed**

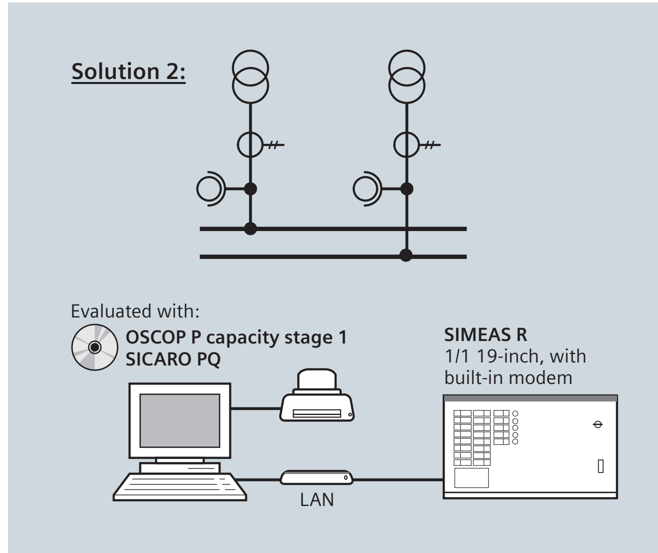

Fig. 6.4-26: **Monitoring the infeed**

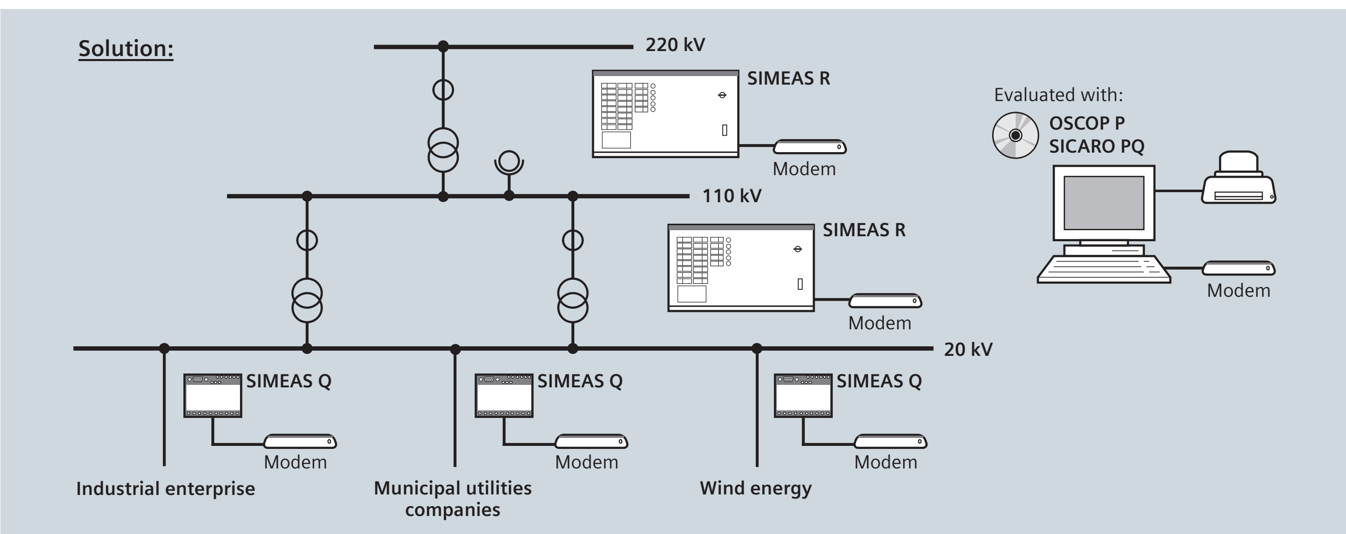

Fig. 6.4-27: **Monitoring the quality in power distribution networks**

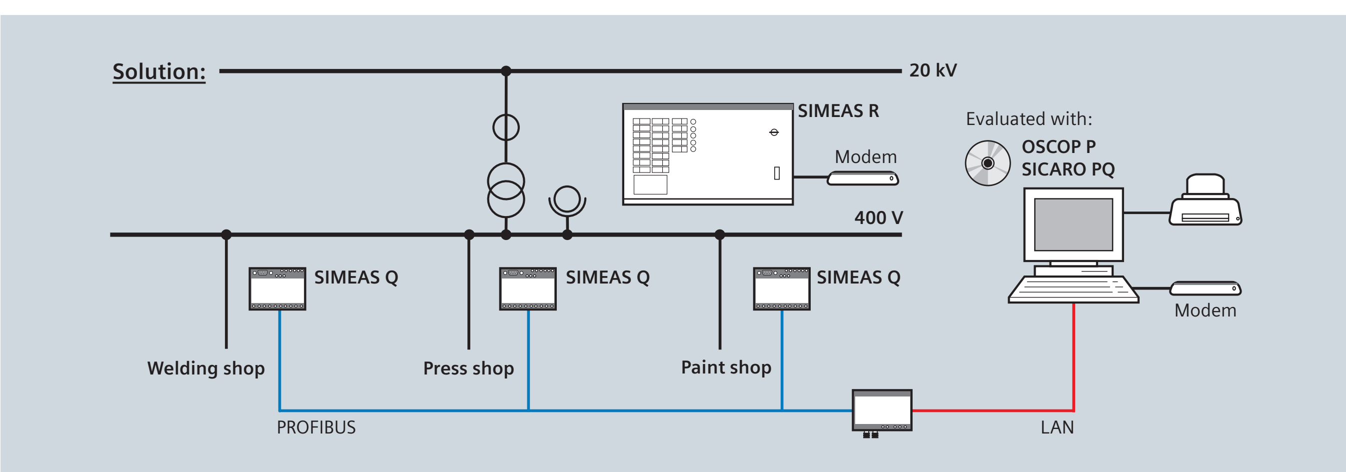

Fig. 6.4-28: **Monitoring the power quality in an industrial enterprise**

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7

Energy Management

7 Energy Management

7.1 Principles of Energy Management

The provision of an adequate supply of electrical power to consumers is a highly complex process, especially because individual components of the process can be spread over a wide geographic area. The purpose of power system control is to monitor and control this process from central points (Energy Management). The basic functionality of power system control is also termed the Supervisory Control and Data Acquisition (SCADA) function, and comprises the supervision and control of the final controlling elements in a power supply system as well as the recording of the measured values and status data transmitted from the system.

7.1.1 The Role of the Network Control System in Power System Management

History

The control and information technology used in electrical power supply has its origins in the automation of power plants. The primary objective was originally to improve operational reliability; another, though secondary, objective of automation was to reduce personnel.

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Later, with the increasing networking of power plants, frequency control grew in importance as a function of power system control. In order to coordinate power generation and later also the exchange of power with other companies, control functions were increasingly concentrated in centrally located control centers.

Before the introduction of the transistor in 1947, the vast majority of protection and control devices used in power system control were of electromechanical design. In the early days, information was transmitted by means of relays and pulse techniques, but with the introduction of electronics it became possible to implement increasingly efficient transmission routes. At the end of the 1960s, with the introduction of the first process control computer, the first computer-assisted power and frequency control systems became possible.

As computers became more efficient in the 1970s, the switchgear in transmission networks was also gradually monitored and automated with the aid of power system control technology. In response to the growing demand for network control systems, a number of companies began developing standardized systems for these applications. The systems of that period can be called the first generation of network control systems.

Because of the inadequate graphics capability of computer terminals at that time, the master computers were used mainly for remote monitoring of unmanned stations or for performing calculations to support operations. The network state was displayed visually on large switch panels or mosaic walls that were also used to control the switchgear. Only as the performance of graphical displays improved were operation management functions gradually transferred to VDU-based workstations.

As computing power continued to increase in the 1980s, it also became possible to use computers for optimization processes. With the aid of optimization programs run initially as batch jobs and later online as well, it was possible, for instance, to determine the most economical use of hydroelectric and thermal power plants. These programs also provided a method of economically assessing the exchange of energy, a basic requirement for energy trading later on. Increasing computer power was, however, also harnessed to further develop man-machine communication towards greater user friendliness.

In the 1990s, power system control, which had until then been restricted to transmission networks, was increasingly used in the distribution network area as well. Apart from pure network supervision, additional functions such as work or material administration were integrated into control systems during the ongoing automation of the distribution network.

Functions of a network control system

With the aid of network control systems, network operators can obtain information from the network, usually in real time, which they can then use as the basis for optimizing supervision and control of the power supply system.

The information transmitted by the station automation systems via telecontrol must be collected and processed at a central point. This function is performed by network control systems that are installed at central locations, which are also known as system control centers or control rooms.

A distinction is made between Energy Management Systems (EMS) and Distribution Management Systems (DMS) depending on the type of network being monitored (transmission or distribution). In the wake of the deregulation of the energy market and the resulting unbundling of the generation and transmission functions, there are now also control systems that are designed exclusively for the central control of power plants (GMS = Generation Management System).

All types of network control systems use the so-called SCADA system platform. Other applications operate on this platform also, depending on the function. The most important application components of a network control system and their application areas are listed in the table 7.1-1.

Real-time processing

SCADA applications are basic functions of the network control system and provide a means of supervising and controlling the power supply system. For this purpose, all information transmitted from the network is collected, preprocessed and visually displayed in order to keep the operator constantly informed about the current operating state of the power supply system. The operator can also store additional information in the system or enter corrections for incorrectly reported information or information reported by phone into the system in order to complete the current operational network display.

The main objective of preprocessing is to relieve the operator of routine work and to supply the operator with essential information. The most important preprocessing steps to mention are limit value monitoring and alarm processing. These are absolutely essential, especially in the case of a fault incident, in order to enable the operator to identify the cause of the fault quickly and precisely and to take suitable countermeasures. The supply state of the network elements is shown in color (topological network coloring) in the process images used for network monitoring in order to provide better visualization of the current network state. As a result, the operator can see at a glance which network sections are supplied and can identify any interruption in the supply at that particular moment.

Another important function performed by the SCADA applications is the so-called operational logbook, in which the process history is shown chronologically in plain text. Entries in the operational logbook can be triggered by events in the power supply system as well as by operator actions.

Switching measures in the power supply system, such as disconnecting and earthing a cable so that maintenance can be carried out without danger, generally require a sequence of individual commands. Because disconnection processes of this type have to be checked for plausibility in advance, a switching sequence management system in a control system can assist the operator in drawing up and testing the required switching sequences. During this process, the switching actions carried out in a simulation environment are recorded and can then be carried out partly or fully automatically after positive testing and in the real-time environment.

Process data and control center communication

Process data from operational equipment is transferred and recorded directly from the process. There is often also an exchange of process data with other control centers. This exchange of information also has the purpose of enabling processes in the directly adjacent section of the network to be included in the network supervision and control process.

Today, the standardized IEC 870-5-101 and 104 protocols are increasingly used alongside old proprietary transmission protocols for transferring information from the local network. The OPC (OLE for Process Control) standard also offers a method of process communication and a means of communicating with the world of automation. The Inter-Control Center Communication Protocol (ICCP), also known as TASE2, has now become the established form of data exchange between control centers and is compliant with IEC standard 870-6.

Application	EMS	DMS	GMS
Real time processing (SCADA)	x	x	x
Process communication	x	x	x
Archiving	x	x	x
Load forecast	x	x	(x)
Power plant deployment planning	(x)	–	x
Power/frequency control	(x)	–	x
Transmission system management	x	(x)	(x)
Distribution system management	(x)	x	(x)
Load control	(x)	x	-
Training simulator	x	(x)	(x)

Table 7.1-1: **Typical control system applications and their areas of application**

Archiving

Another basic function of a control system is the processing of archive data. Archive data processing is responsible for cyclical collection, storage and aggregation. The archive allows different functions for data collection that group together and further process the data received from the real-time database. The resulting values are stored in turn in the archive. However, archives often also provide additional functions such as generating a sliding average or determining maximum and minimum values in order to process the real-time values before they are stored.

The calculation functions of an archive usually also comprise functions for implementing recurring calculations for time-dependent data. For example, the four fundamental operations can be used on measurement values. These calculations can be carried out at several levels, with the calculations at the lowest level being completed before the calculations at the next higher level are started. A typical application is the totaling of power generation in its entirety and per power plant type, or the balancing of energy consumption according to regions under different customer groups.

Load forecasting

In order to ensure a reliable power supply, a forecast of the development of energy consumption over time (load) is required. Forecasting methods working on the basis of a regression approach or Kalman filtering are used for medium-term planning in the range of up to one week (load planning). Some promising trials based on neural networks have already been conducted in isolated research. For the short term, directly acting functions for optimizing operation that influence the consumption trend in the current accounting interval (procurement interval) and special methods of determining trends are used that either employ continuously operating filters or are based on characteristic consumption trend patterns.

Power plant deployment planning

A power supply company generally has a portfolio of different power plants available for generating electrical power. Power plant deployment planning is a matter of economically optimizing the generation of the power needed according to the load forecast, taking into account the characteristics of the different power plants in the portfolio (fuel costs, start-up and shutdown times and costs, and rate of power change) and calculating a generation timetable for all power plants. These timetables are then used as the target for power plant management.

Power plant management and frequency regulation
The advantage that electric power has of being universally usable is offset by the disadvantage that it is difficult to store. For this reason, the generation of electrical power must take place more or less simultaneously with consumption. The frequency is used as an indirect means of measuring whether generation and consumption are balanced. As long as generation and consumption are in equilibrium, the network frequency corresponds to the rated frequency. If consumption exceeds the power infeed, the difference is covered from the kinetic energy of the rotating generator or turbine masses. This drawing of energy, however, causes a reduction in the rotational speed and hence a drop in the frequency. In the reverse situation, in other words, in overgeneration, the difference is converted into kinetic energy, and the speed of rotation increases and so too does the frequency.

Because the system frequency is equal at all points in the system, it can be easily used as the input quantity for controlling the frequency of load distribution systems. New setpoint values for the individual generators are determined there from the measured frequency deviation on the basis of technical and economic factors, and transmitted to the decentralized generator control systems by means of telecontrol. If a power supply system is linked to adjacent systems, the frequency as well as the power exchange with the adjoining systems must be monitored and controlled. Because the number of interconnecting cables is limited, the interchange power can be measured directly in this case. The individual measurements of the interconnected powers in the load distribution system are added up to form the boundary integral of the system to be controlled. If no agreement is made to the contrary, the boundary integral should be zero, that is, there should be no exchange of power. In the case of an agreed exchange of power, the boundary integral must correspond to the agreed power. If the boundary integral varies from its nominal value, the generated power must be reduced in the network that is exporting too much energy, while the generated power must be increased accordingly in the network that is importing too much energy.

Applications for transmission network management
Transmission networks characteristically have less operational equipment than do distribution networks, although they are better equipped for carrying out measurements. Transmission networks are of meshed structure and are generally also mesh-operated. Because they are equipped for obtaining a large number of measurement values, transmission networks are able to determine the current load flow situation by means of estimation algorithms. In an estimate, the algorithm uses a numerical network model to try to find a load flow solution in which the root mean square value of the difference between the load flow solution and measurement values is minimal. Roughly incorrect measurement values are detected and excluded from the calculation. The estimation of the network state supplies the operator with a complete load flow solution for supervising the network, including those sections of the network for which no measurement values are transmitted to the control system.

The network state estimation is generally followed by a limit value monitoring process that compares the result of the estimation with the operating limits of the individual operational equipment in order to inform the operator about overloads or other limit value infringements in a timely fashion. The load flow solution of the network state estimation is then used for ongoing functions such as outage analysis, short-circuit analysis or optimizing load flow as a basic solution for further calculations.

The outage analysis carries out "What if?" studies in which the failure of one or more items of operational equipment is simulated. The results of these load flow calculations are then compared with the operational equipment limits in order to be able to detect secondary faults resulting from an operational equipment failure. If such violations of the so-called (n-1) security are detected, an attempt can be made by, for example, using a bottleneck management application to define measures with which (n-1) security can be reestablished.

The short-circuit analysis simulates short-circuit situations for all kinds of different network nodes on the basis of numerical model calculations. It checks whether the ensuing short-circuit currents are within the operational equipment limits. The quantities to be checked are the breaking power of the circuit-breakers and the peak short-circuit current strength of the systems. Here again, the operator is informed about any limit violations so that suitable remedial action can be taken in a timely fashion.

The optimizing load flow attempts to determine an optimum network state by varying the controlled variables in the power supply system. The following target functions for "optimum" are possible:

- The voltage/reactive power optimization attempts to minimize the reactive power flow in the network in order to reduce transmission losses. In particular, the reactive power generation of the generators or compensation equipment and the setting levels of the in-phase regulator act as controlled variables.
- The active power optimization system tries to minimize the transmission losses by redispatching the incoming supplies from the generator. Any available quadrature or phase-angle regulators can also be used for optimization.
- If system reliability has been selected as the target function of the optimization, the optimizing load flow tries to find a system state in which the capacity of all operational equipment is utilized as evenly as possible. The purpose of this is to avoid further secondary failures in the event of failure of heavily utilized resources.

The network calculation functions just described usually also have a simulation mode in which the calculations can be carried out for a network state different from the current situation. This mode is used, for example, for checking a planned switching operation.

Applications for distribution system management
In the past, it was not usual to apply network calculation functions for distribution systems, because such systems were equipped for only a small number of measurements. This fact ruled out the use of estimation algorithms. The size of medium-voltage supply systems also posed resource problems as far as computing power and computing time were concerned.

Today there are distribution system analysis software packages available that have been developed specifically for large power distribution systems. These software applications comprise functions for monitoring and optimizing system operation and apply so-called load calibration techniques instead of estimation algorithms. The missing dynamic measurement value information is replaced by corresponding statistical information that, for example, enables load profiles to be defined for the loads. In a multistage process, the statistical information is then compared (calibrated) with the few available measured values so that a complete load flow solution can subsequently be found for the distribution system with the aid of a load flow calculation.

This load flow solution can then be used in the same way as in transmission network applications as the basic case for further applications. However, the high proportion of radial sections in a distribution network makes applications such as outage analysis rather pointless, because failure in a radial section of the system leads to an immediate interruption of the power supply.

On the other hand, fault management plays a greater role in the operation of distribution systems than it plays in transmission systems. The lower selectivity of the protection in the distribution network means that larger sections of the network are disconnected in the event of a fault than is the case in a transmission network, where usually only the operational equipment affected by the fault is isolated from the grid.

For this reason, it is imperative to localize faults in the distribution network as precisely as possible in order to be able to restore power as quickly as possible to those sections of the network that have been de-energized although they are not faulty. For this purpose, there are applications designed for distribution system operation that narrow down the fault location as far as possible by analyzing the fault messages received in the control system. On this basis, they then propose ways of isolating the operational equipment that is suspected of being faulty. After that equipment has been isolated, switching proposals are then formulated whereby the voltage can be restored to the fault-free but de-energized sections of the system without causing overload situations.

There are special programs that allow the automatic or semi-automatic implementation of these corrective switching operations and that also support the preparation and implementation of all other switching measures in the network. Fault and outage management combined with applications for call centers and deployment management for field service personnel enable planned and unscheduled interruptions of the supply to be implemented quickly and efficiently in order to maximize the supply quality.

Load control – load management and load optimization for electricity and gas supply networks
Distribution companies frequently have multi-energy network management in one control center, that is, management for electricity, gas and water networks are centrally located. The main function of demand management is the supervision and control of the exchange of energy in the electricity/gas distribution system using a dual optimization strategy:

- Maximum utilization of existing contracts for energy purchasing and exchange
- Avoiding violations of contractually agreed-upon limits for energy purchasing and exchange

This dual optimization strategy is implemented in part by online functions such as load shedding, increasing power generation or voltage reduction, and by pressure management and use of storage. In water management, the water supply network is supervised in the same way that electricity and gas consumption is controlled. Inflows and outflows are recorded and balanced, and any losses from the pipeline are determined (leak monitoring). Apart from monitoring the flows in the pipelines, the levels of reservoirs and inflows and outflows are monitored in order to assure a continuous supply of water.

Training simulator
The growing complexity of existing power supply systems places increasing demands on operating personnel. Efficient training simulators are available for carrying out the necessary comprehensive hands-on training at low cost. The following application areas can be covered with training simulators:

- Familiarization of operating personnel with the control system and the existing network
- Training for experienced personnel when new functions are added
- Training of personnel to deal with exceptional situations
- Analyzing fault incidents (simulation of scenarios)
- Testing of network expansions (simulation)

For the training of personnel, training simulators are needed that can simulate network behavior precisely in specific scenarios. The training simulator is based on the same efficient network analysis processes and calculation methods used in the other network control system applications. Consequently, the network behavior can be described comprehensively. A training simulator provides the environment for the operator (trainee), and also provides an independent environment so that the instructor can influence the process and thereby force the trainee to react to situations.

Training simulators are typically divided into the following subfunctions, as shown in fig. 7.1-1:

- Control center functions (identical to the control center system)
- Training simulator administration functions (for the instructor)
- Network simulator (for displaying the network)
- Telecontrol model (linking of network simulator and the control center system)

7.1.2 Network Control Centers in a Deregulated Energy Market

As a result of the movement towards deregulation and liberalization of business, the electricity industry has undergone dramatic changes since the beginning of the 1990s. This process has been marked by the following characteristics:

- Competition wherever possible – electrical energy is traded as a commodity. This initially affects power generation, but other services can also be offered on a competitive basis.
- Commercial separation of the natural network monopolies from the competitive elements. This impacts numerous areas, such as planning, operation and maintenance of formerly integrated systems.
- Access to the networks by third parties. This is an essential precondition for open trading in electrical energy via the natural network monopoly.
- Regulation of the network monopolies by a public agency. Because the network is the basis for competition in the electrical energy market, considerable importance is attached to reliable, economical and neutral network operation. In order to ensure such operation, a new regulatory element must be introduced at the same time that other sections of the electricity business are deregulated.

Restructuring models

In a deregulated environment of the type just described, the power supply companies that traditionally have a vertically integrated structure start to split up into companies responsible for power generation (GENeration COmpanies), transmission (TRANSmission COmpanies) and distribution (DIStribution COmpanies). Totally new market players can also come into being (fig. 7.1-2), such as electricity traders and brokers who purchase energy from GenCos, independent power producers (IPPs) or other sources and resell it. On the load side, the energy business, including load management, is operated by a power supply company quite separately from the actual power distribution function.

The technically critical part of deregulation concerns the operation of the overall system. Because there is no longer integrated operation of generation, transmission and distribution in one business unit, a special institution must take over responsibility for observing specific electrical energy quality standards such as frequency control, the voltage level and provision of adequate generation and transmission reserves for emergencies. In the United States, this institution is called an independent system operator (ISO). The ISO is not concerned with the financial aspects of the energy market and acts for the benefit of all market players. An ISO is established for a section of the grid to deal with the technical aspects. This section may be, for instance, the supply area of a former integrated power supply company or that of several power supply companies (former grid).

The functions of the ISO can be combined with those of a TransCo for the operation and maintenance of the network, or they can remain separate. The ISO normally does not have its

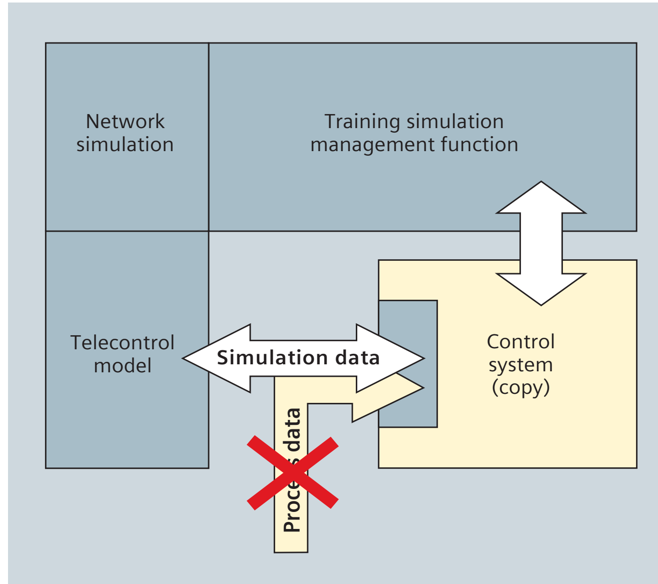


Fig. 7.1-1: **Block diagram of training simulator**

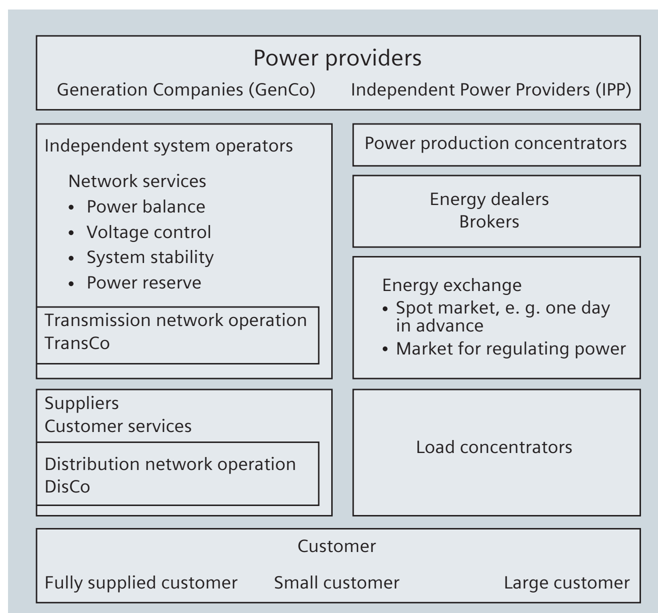


Fig. 7.1-2: **Players in the deregulated energy market**

own generation capability. Instead, it purchases regulating energy (active and reactive power) from the power producers. The final touch is added to an open energy market by power exchanges, also known internationally as “pools”. This institution organizes energy trading. There can be several markets for different time horizons, such as two days in advance, one day in advance, the next hour and so on. The proportion of energy traded on the spot market compared with what is fixed by bilateral agreements can vary from one country to another.

New requirements for network control centers

The deregulation models just described represent only some of the many existing or developing models to be found in various regions of the world, but they are useful in developing general conclusions about new requirements. Communication options will need to increase drastically in order to enable the complex collection of market players to interoperate successfully. There is growing uncertainty in many aspects of planning and operation because the influence of the largely unknown price and marketing strategies of many buyers and sellers now add to the familiar uncertainties, for example, with regard to load behavior or the availability or unavailability of generation capacity.

For the purposes of granting access to the network and for network operation, an ISO needs large archiving resources and special methods to enable it to verify compliance with the stipulated rules and standards at any time. Resources must be available to record, calculate and bill the different services of the many independent market operators, such as services for voltage stabilization by a GenCo. Far more than the traditional market, the deregulated market needs close coordination between business planning and network operation. This coordination also requires a number of adjustments to what are known as the classic functions of a network control system.

Effects on existing control center functions

Even if the effects of a restructured market environment on the required functions of a network control center are dependent in their specifics on the individual restructuring model, process-related functions are not, as a general rule, affected by the changes. However, a number of further processing functions must be adapted to the changed situation, and totally new application requirements will doubtless appear.

Communication

Communication between the control center and various different partners such as power producers, independent power producers, distribution companies, exchanges and traders will increase greatly. Communication media such as public networks, special communication links and the Internet are already used in control centers today. Trading on the open market will require procedures that make the same information available to all interested parties simultaneously. The OASIS system (Open Access Same-Time Information System) for reserving transmission capacity in the United States is an example of an existing system of this kind. Absolutely confidential handling of the data of competing market operators during transmission and processing at the control centers will be vital.

Fundamental changes to the properties of network control systems

The need for greater communication has already been highlighted. Whereas communication today usually takes place between a small number of selected partners via point-to-point links, such as between neighboring control centers, in the future there will be additional communication using, for example, public information nodes where sellers of electrical energy or transmission capacity can post their offers and other communications with dozens or even hundreds of market operators with whom bilateral agreements are made. It follows from this that a control system must be capable of connecting to high-speed networks and operating several different protocols and activities in parallel.

Intensified communication will not only take place with external partners but will also occur internally. Control centers will exchange information with the sales, purchasing and finance departments, which will become heavily involved in the electricity business. These departments need easy access to information from the control center, such as meter readings, measurement values, state and loading of transmission routes, contracts, history of energy transactions. For this reason, company-wide database structures must be put in place that can be updated and corrected easily.

The deregulated energy business is still new in most regions. The rules of the game in the market will therefore change over time, and it is still necessary to gather more experience with the deregulated energy business. The software tools will have to change quickly, together with the marketing strategies or with the market itself. It is therefore absolutely necessary for the control system to have the flexibility and openness to be able to integrate new tools of this type at a reasonable cost. Functions that have nothing directly to do with process control but are required for maximizing profit in the energy business will be encountered increasingly frequently in control centers.

These functions overlap with the functions of the sales, purchasing and finance departments. Joint tools that are frequently based on commercial products from the office world, e.g., spreadsheet programs or databases, will therefore find application here. The new generation of control centers will have to support the simple integration of these products. Because the control system is closely interlinked with internal and external systems, and because it will always contain standard products, it will be necessary to update to new versions of operating systems, communication protocols and databases far more frequently than presently required.

Network calculations

The basic functions, such as state estimator and functions for analyzing the current network reliability, that is, load flow calculation, short-circuit calculation and outage analysis, will not normally be influenced by the restructuring. The target function will have to be expanded in functions for voltage/reactive power planning in order to include the costs for purchasing reactive power from a power provider. Most changes or expansions can be expected in the optimum load flow calculation for the reactive power, which is concerned with the uncertainties in the behavior of the energy market and has to supply the energy trading functions with information with regard to network restrictions. A new function is the calculation of the available transmission capacity when providing access to the network for a planned energy transaction. This calculation tool must take network load forecasts, availabilities and power limits of generating units as well as planned shutdowns of transmission resources into account in the calculation of available transmission capacity.

Power plant deployment planning and energy trading
The role of an power supply company in a regulated market is to cover the (specified) load in a protected supply area reliably. The object of optimizing operation is to minimize the costs for covering the load while at the same time complying with other marginal conditions such as holding of reserves or management of storage facilities. In a deregulated market, on the other hand, an open market is created for the product "electricity". The person using a planning program is no longer the technical coordinator of production but an energy trader. The object of planning now is to maximize profit on the electricity market, taking all technical marginal conditions into account. Therefore, the focus is no longer on the technical, but rather on the commercial aspect. The function of a planning instrument is now not merely to minimize the costs of the process but to supply the (energy) trader with the information from the process area that is needed for the conduct of the work of trading.

Techniques for forecasting the energy price and for analyzing the behavior of the different market operators, statistics on volumes of energy traded and tools of the type commonly used in the stock market are applied with the object of planning the deployment of power-generating resources as effectively as possible. The numerous transactions conducted with different partners need to be tracked and billed.

Power plant management
In order to be able to perform these functions in a master role upon instruction by the system operator, large power producers will install the necessary tools for power frequency control, the keeping of reserves and instantaneous optimization, as they did before. This is subject to the proviso that they can provide energy resources, for example, that they can control power generating plants and low-cost standby generating units at competitive prices.

7.1.3 Common Information Model

In order to survive in the deregulated energy market, power supply companies today face the urgent task of optimizing their core processes. This is the only way that they can survive in this competitive environment. The vital step here is to combine the large number of autonomous IT systems into a homogeneous IT landscape. However, conventional network control systems can only be integrated with considerable effort because they do not use uniform data standards. Network control systems with a standardized data format for source data based on the standardized data model Common Information Model (CIM), in accordance with IEC 61970, offer the best basis for IT integration.

CIM – key to interoperability and openness
The Common Information Model (CIM) defines a common language and data modeling with the object of simplifying the exchange of information between the participating systems and applications via direct interfaces. The CIM was adopted by IECTC 57 and fast-tracked for international standardization. In the United States, CIM is already stipulated by the North American Reliability Council (NERC) for the exchange of data between electricity supply companies. The standardized CIM data model offers a very large number of advantages for power suppliers and manufacturers:

- Simple data exchange for companies that are near each other
- Standardized CIM data remains stable, and data model expansions are simple to implement
- As a result, simpler, faster and less risky upgrading of energy management systems, and if necessary, also migration to systems of other manufacturers
- The CIM application program interface creates an open application interface. The aim is to use this to interconnect the application packages of all kinds of different suppliers per "Plug and Play" to create an EMS.

CIM forms the basis for the definition of important standard interfaces to other IT systems. Siemens is an active member of the standardization bodies and the working group in IEC TC 57, playing a leading role in the further development and international standardization of EC 61970 and the Common Information Model. Working group WG14 (IEC 61968 Standards) in the TC57 is responsible for standardization of interfaces between systems, especially for the power distribution area.

Standardization in the outstation area is defined in IEC 61850. With the extension of document 61850 for communication to the control center, there are overlaps in the object model between 61970 and 61850. In order to accelerate harmonization between documents 61970 and 61850, TC57 has set up a working group (ad hoc WG07).

CIM data model and packages
The CIM data model describes the electrical network, the connected electrical components, the additional elements and the data needed for network operation as well as the relations between these elements. The Unified Modeling Language (UML), a standardized, object-oriented method that is supported by various software tools, is used as the descriptive language. CIM is used primarily to define a common language for exchanging information via direct interfaces or an integration bus and for accessing data from various sources.

The CIM model is subdivided into packages such as basic elements, topology, generation, load model, measurement values and protection. The sole purpose of these packages is to make the model more transparent. Relations between classes may extend beyond the boundaries of packages.

Topology model

The electrically conductive connections between the elements are defined via terminals and nodes (connectivity nodes). Every conductive element has one or more terminals. A terminal connects the element, such as a generator, or one side of, for example, a circuit-breaker, to a node. A node can hold any number of terminals and provides an impedance-free connection linking all elements connected to it. A topology processor can determine the current network topology via these relations and with the current states of the circuit-breakers. This topology model can also be used to describe gas, water, district heating and other networks for tasks such as modeling interconnected control rooms.

Measurement value model

The dynamic states of an electric network are displayed in the form of measurement values. Measurement values can contain numerical values, such as active/reactive power, current and voltage, or discrete states such as a 1-switch position. Measurement values always belong to a measurement. A measurement always measures a single physical quantity or a state of the relevant object. It is either allocated directly to the object or to a terminal of the object if it is significant at which end of the object the measurement is made, such as a measurement at the beginning of a high-voltage line. A measurement contains one or more measurement values, e.g., the value transmitted by SCADA, or the value determined by the state estimator or by the voltage/reactive power optimizer. Whether the current value comes from the expected source or is a substitute value can also be indicated if, for example, the connection to the process is interrupted (fig. 7.1-3).

Interoperability tests and model data exchange

Since September 2001, NERC has prescribed the CIM/XML/RDF format for the exchange of electrical network data between network security coordinators. With funding from the Electric Power Research Institute (EPRI), leading manufacturers of complete EMSs or partial components (ABB, Alstom, CIM-Logic, Langdale, PsyCor, Siemens and Cisco) have started planning interoperability tests and developing the tools necessary for this, and have also begun carrying out the tests. Three highly successful test series were completed in the period between December 2000 and September 2001. In the first test (with seven participants), the main object was to verify that the CIM data model is suitable for the exchange of data that NERC has set as its target. Another aspect of this test was the development of tools by the different manufacturers in order to be able to import, manipulate and re-export the data.

The principle of the test can be seen in fig. 7.1-4. Participant A imports the test data using the tool, modifies the data and exports it for further use by participant B. Participant B imports the data, processes it and amends it and exports it for participant C, and so on. The data structures, the variety of different types and the scope of data were kept deliberately small in this first test. In the second interoperability test (with six participants), more complicated test data models, which are similar to those that will be encountered in practice later, have been agreed upon and tested. For this, it was important that the manufacturers had already implemented large parts of the CIM standard. In the third interoperability test (with five participants), complete load flow model data records were exchanged, and the correctness of the imported data was verified by means of a load flow calculation. For this purpose, every participant provided a load flow data model with a maximum of 100 nodes. The interoperability tests have shown clearly that the CIM data model is suitable for standardized data exchange.

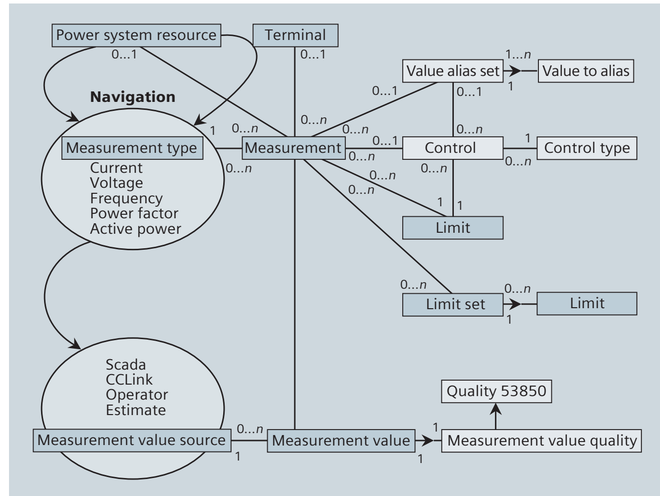


Fig. 7.1-3: **Measurement value model**

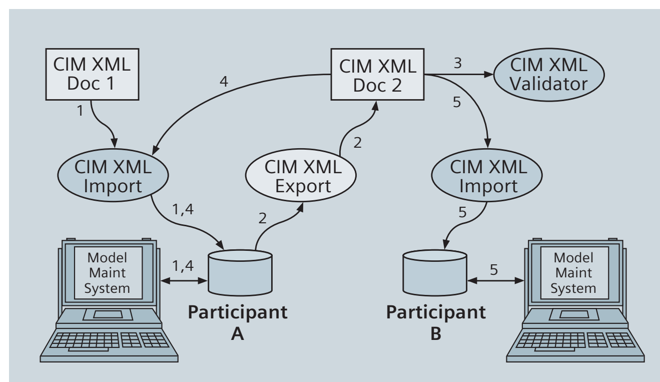


Fig. 7.1-4: **Principle of the interoperability test**

7.1.4 IT Integration and Service-Oriented Architecture

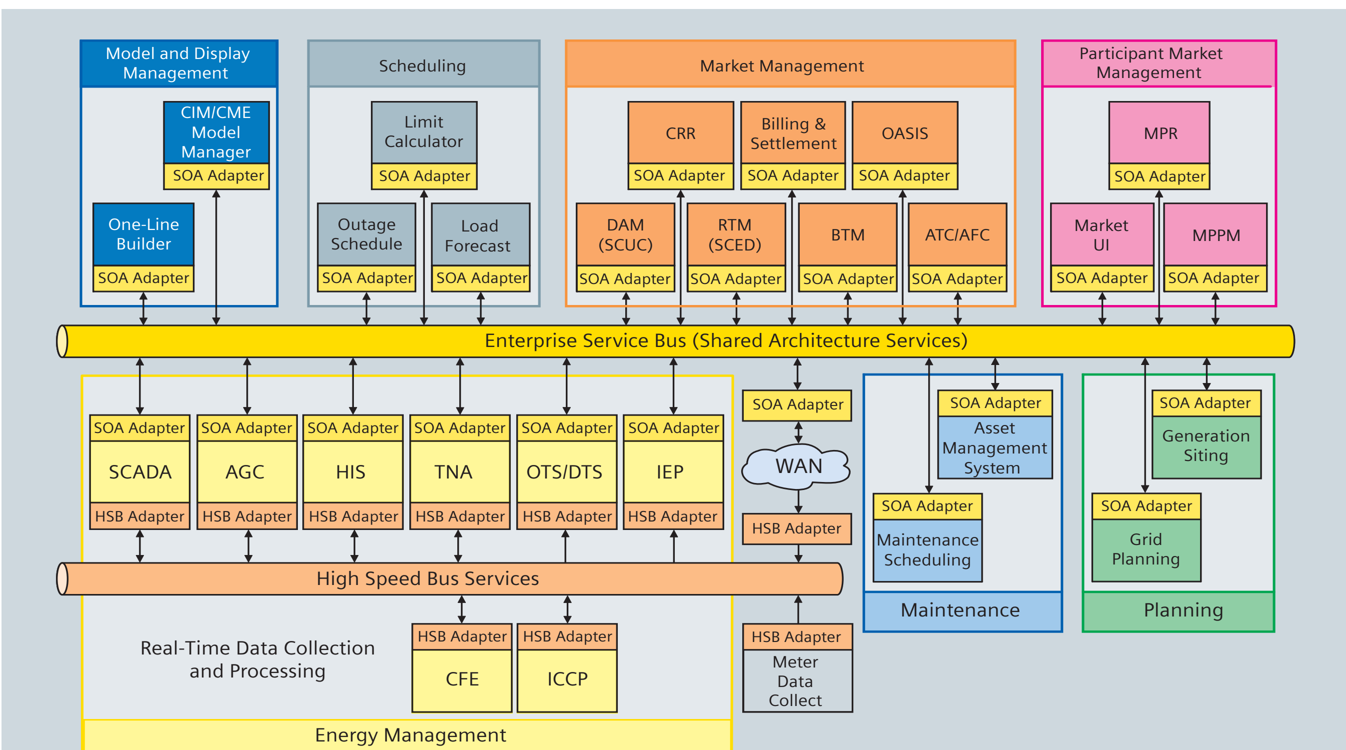
In order to survive in the deregulated energy market, power supply companies today face the urgent task of optimizing their core processes. This is the only way that they can survive in this competitive environment. The requirements in the energy market have undergone permanent change. Modern network control systems are optimized to meet these requirements. The high degree of scalability with regard to hardware configuration and software functionality allows flexible matching to changing requirements over the entire life cycle of the system and beyond.

The aim is to make the system architecture modular and component-based so that a flexible configuration and IT integration can be implemented in a cost-efficient manner. The crucial step here is to combine the large number of autonomous IT systems into one homogeneous IT landscape. However, conventional network control systems can only be integrated with considerable effort.

Open systems through the use of standards and de facto standards

A modern network control system provides the basis for integration of an energy management system in the existing system landscape of the power supply company through the use of standards and de facto standards.

- IEC 61970 Common Information Model (CIM) defines the standard for data models in electrical networks. It supports the import and export of formats such as XDF, RDF and SVG, which are based on the XML standard
- Windows and Web technology
- Standardized PC hardware instead of proprietary hardware
- Client/server configuration based on standard LANs and protocols (TCP/IP)
- Open interfaces (OBCD, OLE, OPC, etc.)
- RDBMS basis with open interfaces
- Nationally and internationally standardized transmission protocols (IEC 60870-5, IEC 60870-6)



AFC	Available Flow Gate Calculation	**HIS**	Historical Information System
AGC	Automatic Generation Control	**IEP**	Intelligent Event Processor
ATC	Available Transmission Capacity Calculation	**ICCP**	Inter Control-Center Communication Protocol
BTM	Bilateral Transmission Capacity	**MPR**	Market Participant Registration
CFE	Communications Front End (RTUCS)	**MPPM**	Market Participant Prudential Management
CIM	Common Information Model	**OASIS**	Transmission Reservation
CME	CIM Market Extension	**OTS**	Operator Training Simulator (DTS)
CRR	Congestion Revenue Right	**RTM**	Real-Time Market
DAM	Day-Ahead Market	**SCUC**	Security-Constrained Unit-Commitment
FEP	Front End Processor	**TNA**	Transmission Network Applications

Fig. 7.1-5: **Spectrum Power SOA (Service-Oriented Architecture) vision: Integration of the network control system in the enterprise service environment of the power supply company**

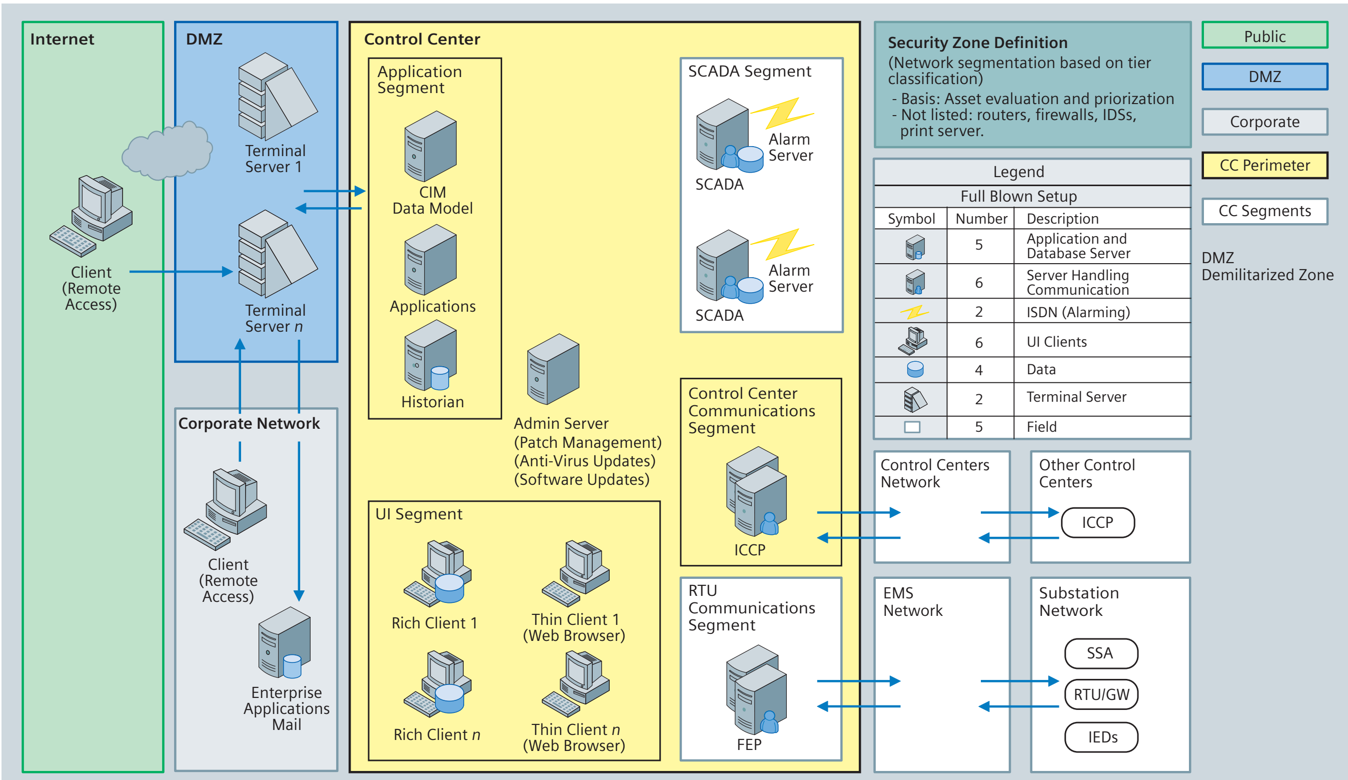


Fig. 7.1-6: **Integration of the network control system in the IT network of the power supply company**

Service-oriented architecture

A modern network control system provides a service-oriented architecture with standardized process, interface and communication specifications based on standards IEC 61968 and IEC 61970. They form the basis for integrating the network control system in the enterprise service environment of the power supply company.

The services of a control system comprise:

- Data services with which, for example, the databases of the core applications can be accessed, e.g., readout of the operational equipment affected by a fault incident in the power supply system
- Functional logic services, e.g., for starting a computing program for calculating the load flow in the power supply system
- Business logic services that coordinate the business logic for specific energy management work processes of the participating systems, e.g., fault management in the network control system within the customer information system at the power supply company.

The network control system is one of many systems in the IT network of the power supply company that interacts with other systems and that offers and uses services such as:

- Services forming part of the offered scope of functions of the network control system
- Services that are used by the network control system and are provided by other systems and applications

Fig. 7.1-5 shows a typical example of the incorporation of the network control system in the enterprise service environment of the power supply company. Further planning with respect to the required work processes and integration in the heterogeneous system landscape of the power supply company are based on this incorporation.

Integration into IT networks

A modern network control system acting as an energy management system fits harmoniously into the IT networks and the existing IT landscape of the power supply company. The network control system is one of many systems in the IT network of the power supply company that interacts with other systems. The following are some of the points defined for the IT integration process:

- Access to the system by intranet users, e.g., from the back office
- Configuration for the DMZ (Demilitarized Zone)
- Integration of the corporate network, such as for e-mail notification
- Protected area for the application and SCADA servers
- TCP/IP-based communication to substations or to adjoining control centers
- Configuration of switches/routers
- Password protection and requirements

Fig. 7.1-6 shows an example of the integration of the network control system in the IT network of the power supply company. It forms the basis for further planning with respect to the tasks required during IT integration in the heterogeneous system landscapes of the power supply company.

7.2 Energy Management Products and Solutions

7.2.1 Spectrum Power Control Systems

Siemens has supplied more than 1,600 computer-based control systems for power systems worldwide. The result of these many years of experience is the development of the product family Spectrum Power® – control systems for electric power systems as well as for gas, water and district heating networks (fig. 7.2-1).

A Spectrum Power control system is divided into various subsystems. On the basis of a minimum configuration for operation, it is possible to add subsystems to meet the requirements in terms of size, tasks and structure of the system. With the modular structure, the system can be expanded with little effort, even subsequently. Modules can be replaced or new modules can be added to implement the required modifications. On the basis of the standard system, open programming interfaces permit individual adaptations and subsequent expansions for new or existing customer-specific components.

In a basic configuration, a Spectrum Power control system encompasses the following components, which are described in greater detail later in this section:

- SCADA applications
  For implementing the functions required for systems operation for signaling, measuring, controlling and monitoring
- Basic system services
  To ensure that the basic functions are provided, such as data exchange and coordination of computers involved in the control center
- Information model management
  For data entry and data maintenance for network data, online diagrams and data exchange with other IT systems
- User interface providing powerful and graphically oriented interfaces between the operator and the system
- Communication front end
  For interfacing to the process via remote terminal units (RTU)

In addition to these components, the following subsystems are available for expanding the functionality. They are used and configured to match the tasks and size of the control systems:

- Historical information system
  For storing, archiving and subsequent reconstruction of the process data
- Multi-site operation of control centers
  For configuring flexible and dynamic system management in multi-site systems
- Power applications
  For cost-optimized control of the power plants on the network (optimal distribution of generator power)
- Scheduling applications
  For optimizing the resource planning and the unit commitment of power plants

Fig. 7.2-1: **Spectrum Power control system**

- Network applications
  For fast and comprehensive analysis and optimization of the transmission network state
- Training simulator
  For practical training with realistic network behavior using specific scenarios
- Distribution management applications
  For efficient and economic operation of the distribution networks
- Distribution network applications
  For fast and comprehensive analysis and optimization of the distribution network state
- Expert system applications
  Supporting the operator in critical and complex tasks in the field of network operations and disturbance analysis
- ICCP and ELCOM
  For real-time information exchange with other control centers

Details of the components described earlier are presented in the remainder of this section.

SCADA applications

The SCADA applications group together all Spectrum Power functions that are the minimum required to operate a network control center. SCADA contains all functions for signaling, measuring, controlling and monitoring.

The basic data processing uses preprocessed data of the communication front end for further processing. Value changes are monitored, and data are distributed to other subsystems and written to the operational database. Moreover, calculations, logic operations and special processing functions for special data types (e.g., metered values) are performed.

Spectrum Power control systems use a mature network control concept that reduces the execution time and increases operational reliability. Network control can be performed for any elements of the energy distribution network from any operator station that is set up to perform that task. Individual switching operations and switching sequences can be implemented. Online adaptations of interlock conditions and safety features permit network expansion without interrupting operation (using a preliminary test in study mode). Complex switching operations such as busbar changeover and line switching permit reduced switching times and therefore fast execution of the switching operations. To ensure operational reliability, the network control concept of Spectrum Power contains various additional safety features such as checking the various interlock conditions, network reliability monitoring of planned switching operations, and monitoring of network changes during switching operations.

Spectrum Power control systems allow the user to freely position temporary network modifications such as temporary jumpers, earth connections and isolating points online or to remove them without having to resort to source data management. Temporary network modifications become active in the topology immediately (interlocking, path tracing, etc.). They remain active in topology until they are removed again. The set temporary network modifications can be parameterized.

Switching procedure management provides the control room personnel of a dispatch center with powerful tools for creating, checking and executing switching operations in the network (in the process and study mode). Up to 1,000 switching procedures can be managed; each switching procedure can contain up to 100 actions.

Acoustic alarms and blinking display elements on the screen inform the user about alarms and deviations from the normal state of the power supply system. Logs are used to record alarms and indications. Several logs can be kept. Each log can be assigned to a certain output unit. By using fault data acquisition, the dispatch center personnel and system engineers can analyze the states prevailing in the power supply system before and after a fault. Snapshots, trend data and state changes are stored in this analysis.

Interactive topological path tracing allows the operator to determine paths between electrically connected equipment in the distribution network. The network coloring function controls the color display of equipment depending on various properties of individual items of equipment. Partial networks, network groups (e.g., voltage levels) and operating states of equipment (e.g., dead, earthed, undefined) can be highlighted in different colors.

The report generator is an easy-to-use tool for simple and fast creation, management and output of reports. An SQL interface permits direct access to the database of the system. The layout can be configured individually by the operator using the graphic editor (in the format world view). The user can define variables for dynamic values that are updated automatically when a report is created. Moreover, data views (tables and station diagrams) can be linked in, and their dynamic elements are updated automatically.

Basic system services

The Spectrum Power contains various basic functions (services and systems) that govern the fundamental functions required to operate a network management system. Based on the operating systems and relational databases, these functions are used to organize data management, data exchange and communication between the modules installed on distributed computers.

The multi-computer system is a subsystem that manages communication between distributed computers and various services for hardware and software redundancy, multi-computer coordination and system state monitoring. Bidirectional communication between individual programs of the system is possible. The following functions are implemented:

- Management of the operating contexts
- Process operation (normal state of the system)
- Study context (to perform “What if?” studies)
- Test context (system test after data or program modifications)
- Training (context for training simulator)
- Management of computer states
- Redundancy
- Monitoring
- Error detection and automatic recovery
- Data consistency
- Start-up coordination and switchover
- Updating and synchronization of date and time

The high-speed data bus is a communication system that organizes the link between the user programs and the basic system via standardized interfaces. This communication is provided between individual program modules within a computer. Communication between several computers is conducted via the local area network (via TCP/IP). The high-speed data bus is also used as the link between the modules and the database. Further features are:

- Integrated time processing
- Support of redundant LANs
- Support of the test and simulation mode
- Performance of immediate program activation after delay or cyclically

The database system of Spectrum Power consists of an operational database for real-time operation (process and application data) and a relational database that is used by the information model management. Features of the database system are:
- Standard model for all process and application data
- Incremental data changes
- Import and export of data

Information model management
The Spectrum Power information model management (IMM) is specially designed for online operation and use within the power system control centers (fig. 7.2-2). It is based on the international standard for a common information model, IEC 61970. This standard describes the data that is required in a power control system and allows easy data exchange with other applications or control centers.

With IMM, changes to the network configuration, data optimization and restructuring of displays can be performed interactively at any connected operator station. For the use of IMM by the operator, no specific knowledge of the software of the control center system is necessary. The task of IMM is to manage the input of the data of the electric power system into the database of the power control system, both during commissioning of the system and afterwards for subsequent modifications and extensions of the network (new substations, changes to the network, etc.).

The IMM uses a relational database system as a database for data input. Database validation is done in the source database. When entering and altering any data, all the testing, writing and reading processes are performed within the source database. The input of new or changed data into the original operational database is performed by data activation within the IMM. All activities within IMM for data validation and data activation are controlled and supervised by the IMM job management function.

For frequently recurring parts of the power system (substations, feeders, transformers, etc.) standard model features can be used together with well-known operations, such as copy, move, cut, paste and others, to enter data into the source database. This capability greatly reduces the number of interactive operation steps for description, thus minimizing the sources of error when entering data.

IMM enables simultaneous multiuser sessions. Entry can be done from several operator consoles at once, which can be used to simultaneously display and modify data. Data inputs and modifications that have to be activated in the operational database within one transaction must be assembled into a job. Any number of such jobs can be handled at the same time. A job can be set up, handled and activated. Interlocks control job handling. For example, the same display segment can only be handled by one job.

Input and validation of the data is performed in the source database, so that current online data and online system operations remain unaffected. Once entered, prepared and checked, the set of data within a job can then be activated in the operational database at a time convenient to the operator. Activation means the takeover of modified data from the source database via the database copy to the operational database, without interruption of system operation and without losing any manually entered data. Data activation is coordinated automatically with all other subsystems or activities of a Spectrum Power control system.

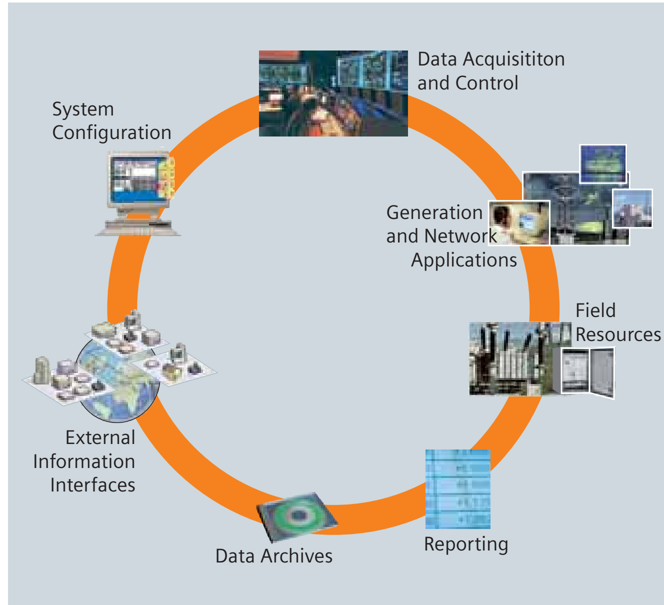


Fig. 7.2-2: **The Spectrum PowerCC information model management provides the functionality to enter and maintain all power-system-related data**

As an example, it is impossible for an operator using IMM to activate a data modification for a circuit-breaker while a supervisory control action is active for that device. Activation includes an updating of all servers of the Spectrum Power control system that is precisely coordinated with online system operation. After activation, newly entered data (e.g., status information, analog values, station feeders, entire stations) can immediately be called up and displayed by the operator for test purposes. IMM sessions leading to modification of the database (copy and original) are listed in a job-oriented log. Within this log, both the modification actions (DO actions) and actions for restoring the previous state (UNDO actions) are listed. Activating a job means that all DO actions are carried out in the original distributed database. After this operation, the copy and the original have the same status with regard to the data of the job concerned. After all jobs have been activated, the database copy and the database original are identical.

Modifications that are recognized later as erroneous by the operator can be corrected by an UNDO function, because all modifications carried out in the database within a job are automatically recorded in a built-in database change log. Several levels of security-checking functions provide an audit trail for all data changes in the database and guarantee data consistency throughout the entire system.

When editing source data (interactively via data editors or during data import), the entered data is checked immediately to ensure correctness. This is done by, for example, checking input data formats and checking input data range of values. When detecting data errors, the affected data cannot be activated in the operational database before it is corrected.

After completely entering the data of a data object, the whole object is checked for data consistency. Items to be checked here include external references. Global validations are performed when the source data input is completed, e.g., within a job. This can also be done on operator demand. It always has to be done before data activation. Within global validation, it is checked whether the data for both sides of a transmission line is described, and whether the data already exists in the database. IMM provides a very large number of global validation routines to ensure data model correctness within the database. All data inputs and data changes via IMM are logged in a database change log. This log consists of separate log items that describe the performed data modifications, date and time of modification and identification of the operator. For example, data logs can be used for supervision of the number of data changes in the database in a certain time frame, and can also be used to track all changes to a data object within a time interval.

An integral part of the user interface is the graphics editor. This editor is used as a tool to build and maintain the graphic displays used in the system. It eliminates the need to code and assemble or compile display presentations. Current displays may be changed, edited or deleted. New displays may be added without software modifications. The graphic editor operates in the real-time mode of the system at a low priority. Modifications and editing can therefore be accomplished with minimal effect on the operation of the real-time system. A comprehensive set of functions permits the user to specify what the presentation is to look like, and the information it will contain. The main features of the graphics editor and the graphics constructed by this tool are:

- "What you see is what you get" representation
- Functionality of a well-known graphics environment, e.g., basic graphic elements (line, polygon, circle, etc.) and their handling (selection, dragging, cut, paste, insert, text strings, coloring). Predefined graphic elements can also be used. Graphics variables are linked to the operational database via technological addresses.
- The graphics editor is also included into the job management of information model management (IMM). That means that all graphical changes are performed and tested in a copy of the operational database before activation in the operational database. Time stamps are applied to changes for database logging purposes.

All displays of the Spectrum Power control systems are worldmaps. A worldmap is a two-dimensional (2-D) graphical representation of a part of the real world. Each point in a worldmap is defined by a pair of unique X, Y coordinates (world coordinates). A worldmap is divided into a set of planes. Each plane covers the complete 2-D area including the whole range of the unique

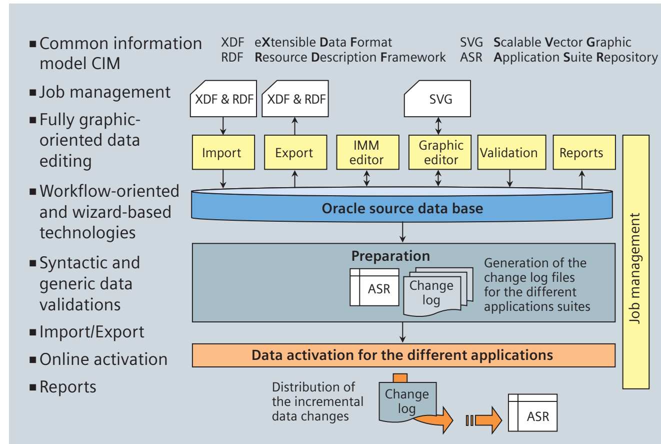


Fig. 7.2-3: **Functional overview of IMM**

world coordinates. Each worldmap consists of a minimum of one plane. The first plane is visible over the entire worldmap magnification range. Any other plane is visible within a certain magnification range only, and contains different graphic representations of the technological (real) objects (e.g., plane 2 shows the substation state, plane 3 shows the summary state of the main feeders, plane 4 shows the single-switching states and so on). Planes can overlap magnification ranges of other planes.

The point P has the same world coordinates (X, Y) in all planes. A plane is visible within a certain magnification range only. Each plane consists of at least one segment. The first segment covers the complete 2-D area with the whole range of the unique world coordinates (segment 0). The plane is additionally divided into segments, each of which covers a part of the total 2-D area. The coordinate range of a segment is a subrange of the world coordinates.

For data entry, modification or deletion within one or more worldmap segments, the Spectrum Power control system provides a very helpful function, the Dynamic Segment Locking. With this function, data changes within one worldmap but within several segments can be performed by different users at the same time. In this way, several segments can be handled within one job. An element that is already being modified or used by a job will be locked. If an already-used element is selected, an alert box displays a message telling the user that the segment is not available. Additionally, locked segments are indicated by a different frame color.

In Spectrum Power control systems, displays are built through a graphic editor. Each graphic editor supports the user in the display building process by means of on-screen messages.

IMM provides standardized interfaces for import and export of source data (fig. 7.2-3). Network data and facility data, as well as graphic data, can be imported or exported via these interfaces. The ability to import large or small amounts of data is supported for the purpose of major or minor system updates and the initial loading of the database (bulk loading). This data is transmitted to the system via a generic file transfer facility, for example, FTP, and consists of graphic data (lines, symbols, static text), non-graphic attribute data relating to the graphic elements and even raster data for presenting pictures at workstations.

Initially, the entire attribute data for the network is extracted from the external database and encapsulated in an attribute import data file. It is then validated and loaded into the Spectrum Power database. Using the attribute input data, technological addresses are also composed and stored for the database elements along with associated data (e.g., line impedance data, nominal transformer rating data) needed for support of other functions such as, for example, the distribution power flow. Finally, using normal switching states stored as attribute data or graphic data, the entire topology of the power system can be determined. After the initial load of the entire database, changes can be introduced incrementally. For example, changes are made in the AM/FM/GIS system and then transferred to the Spectrum Power database. The import and bulk loading of data is an automated process that can be started by the operator through IMM. The graphic data import from AM/FM and GIS systems supports multiple input data, such as Intergraph, Siemens SICAD, ARC/INFO and AutoCAD systems. The native formats for these systems can also be used.

User interface

The user interface of the Spectrum Power control system provides powerful functions to ensure an overview at all times and to permit fast and easy switching between views across all worldmaps. The user interface allows the user to operate the networks and power plant efficiently and permits the administrator to maintain the database and system parameters. The system uses static and dynamic display elements to display the network structure and network state. The user interface provides means for guiding the operator to the workflows, e.g., by checking the plausibility of switching actions after each operating step. Multi-screen operation using drag and drop supports the operator in having a good overview of the power system and in accessing the required equipment in a fast and comfortable manner.

Communication front end

The remote terminal interface of Spectrum Power is the Communication Front End (CFE). It is part of the control center system and communicates with the other subsystems of a Spectrum Power control system via the local area network (LAN). CFE has direct access to the remote terminal units (RTU) of various manufacturers. The control center system is connected to the substations or power stations through these RTUs, which transmit process data of the power supply system. The data is preprocessed by the CFE, which exchanges data with the RTU, preprocesses data in real time and monitors and controls the system, including redundant components.

CFE supports different connections of remote terminal units as point-to-point, multiple point-to-point and multi-point. The transmission can be spontaneous, cyclic, periodic or scanned. The process interface is able to process several protocols such as IEC 870-5-101 or the metered value protocol IEC 870-5-102. Substation equipment (RTUs, submasters) having a TCP/IP interface according to the standard IEC 60870-5-104 may be connected via a WAN link directly to the CFE-LAN. Both dual channel connections and multi-channel connections are possible.

The following data are implemented in the process data preprocessing:

- Detection of state changes with image maintenance (old/new comparison of status messages; forwarding only on change)
- Intermediate position suppression (parameterizable monitoring time)
- Plausibility check of all numeric values (error message on invalid data or limit violations)
- Threshold value monitoring of analog values (passed on only if a parameterized threshold value is exceeded)
- Measured value smoothing (parameterizable filtering function)
- Resultant value formation from raw values using specific characteristics
- Renewal check of cyclically transmitted values
- Information type conversion for raised/cleared indication and transient indications
- Time processing and time synchronization
  The CFE server regularly receives the absolute time. The substations are synchronized via time signal transmitters or by protocol-specific synchronization telegrams. All information is kept internally with a resolution of 1 ms.
- Monitoring of remote terminal units, communication connections and system components

Historical information system

Storage of process data and processing of historical data is an important basis for advanced energy management system functions. Load forecasting, for example, is based on a consistent set of historical data. The results are stored as future data in the archives and used by other applications. Another important application for the historical data function is the restoration of a historical network topology and corresponding power flow solution in order to provide the basic input data for subsequent power flow studies. Historical logs can be recovered by again logging the retrieved historical data. Archives can contain analog values or counter values with time stamp, calculated values (for example, state estimator results), status indications and alarms. They can also contain network topology data, forecast values, trend data or disturbance data (including status data).

Archive duration and a storage period can be configured for each archive containing values. Typical storage periods are from a few minutes to several months. For trend data archives, typical storage periods are from a few seconds to one minute. For status indication and alarm archives, the number of entries can be defined. Archives can be initialized and removed online by the source data management function, where a display shows the status and parameters of every archive. Stored values can be modified by manual entry and will be marked as 'manual'. The stored information can be retrieved via technological addresses in value or time sequence. Every stored state estimator result can be retrieved together with associated network topology.

Multi-site operation of control centers
With the multi-site operation subsystem in Spectrum Power, the operator is provided with a powerful tool for optimizing operation management. It is possible to transfer network management partially or wholly from one control center to another. Emergency concepts can thus be designed and implemented effectively. Such a capability provides for greater reliability of the system (emergency strategies) and makes a considerable contribution to cost reduction. The multi-site control centers can be configured from two or more control centers and permit a very flexible and dynamic system. In the event of failures, each system continues to work autonomously. After recovery of the communication link, the data is automatically updated.

Power applications
The aim of power applications (PA) is to distribute the power over several generators in such a way that the costs are kept as low as possible after taking operational and safety rules into account. In process operation, power applications require comprehensive collaboration between load dispatchers and individual power plants. Different factors can be matched in an optimum fashion, which leads to considerable cost reduction. Several input parameters have to be considered, such as the degree of efficiency of the generating units and the transmission system, fuel costs and the availability of fuels, price and availability of interchange powers. Within the overall system of Spectrum Power, the generation control subsystem is used for cost-optimized management of power plants in the network. Operation and safety-related restrictions are taken into account. The power applications provide several functions:

Load/Frequency Control (LFC)
provides control mechanisms with which generating units under the control of a dispatch center can be controlled. This allows the operator to provide the required generation while controlling the system frequency and the interchange with neighboring utilities. By varying the reference frequency and/or the agreed-upon interchange power, it is also possible to control the control time error and/or unforeseen energy interchange. The monitor for recording the load/frequency control performance (LFC Performance Monitor, LPM) provides information about the performance of the power supply system during automatic control. To achieve the required overall performance, the power/frequency control can be readjusted using LFC internal adjustment parameters.

Reserve Monitoring (RM)
supports network management with preparation for sudden drops in power generation. These can be caused by the failure of a generating unit or an intertie with an external network. Reserve monitoring considers generation, pump operation in pumped storage plants, interchange power, reactive power compensation and sheddable load reserves.

Economic Dispatch (ED)
is the optimum distribution of the load over the available generating units. Production Costing (PC) examines the current costs of generation, determines the source of these costs and compares current costs with optimal costs.

Interchange Transaction Scheduling (ITS)
allows a utility to define and revise interchange contracts with other networks in the grid. ITS provides the operator with summarized information and interchange information for power frequency control and for reserve monitoring in process mode.

Interchange Transaction Evaluation Economy A (ITA, Economy A)
optimizes energy exchange with neighboring systems with respect to the use and assignment of system resources that are already working on the network. This gives the operator a way of assessing the economic advantages of an interchange.

Energy Accounting (EA)
provides the user with all information of current and past energy interchange (for generation and consumption). In assessing interchange work (part of the energy accounting function), those tariffs are taken into account that are agreed upon in interchange contracts.

Load Shedding (LS)
automatically performs load rejection or disconnection of parts of the network in the event of certain faults and emergencies in order to maintain system stability. It analyzes the state of the network, detects significant events, defines the load to be shed and prepares the required switching actions. The emergency strategies can be configured individually. Depending on the customer requirements, a configuration can be selected from a simple manual solution to a fully automatic system for dealing with faults and emergencies. The following emergency strategies are possible:

Scheduling applications
The aim of scheduling applications (SA) is to optimize the use of individual power plants (thermal, hydro) in such a way that the sum of the operating costs incurred is minimized after taking all operational and safety rules into account. To ensure optimum scheduling, close cooperation is required between the load dispatcher and the individual power plants. Generation scheduling is used for predicting the system load, optimizing the schedules for the power plants on the network, calculating of evaluation factors, optimizing of resources and planning and optimizing interchange powers.

Within the overall system of Spectrum Power, the generation scheduling subsystem is used for predicting the system load and for scheduling. Various methods and tools are provided to the operator for this purpose. The forecast network load forms the basis for generation scheduling so that sufficient quantities of power can be generated and sufficient spinning and standby reserves can be planned. Generation scheduling can be processed both in process mode and in study mode.

Short-Term Load Forecast (STLF)
supports the user in forecasting loads for the whole system or for individual sub-areas of the system. The load forecast supports several prediction algorithms (up to 14 days in advance) and provides the operator with tools to enter or edit the forecast manually.

Short-Term Load Forecast based on Artificial Neural Networks (STLF-ANN)
performs a load forecast using neural networks. It is assumed that the network load mainly depends on weather data and types of day. Load forecast can be created for any day of the year, including public and religious holidays.

Unit Commitment (UC)
One main aspect of operation of a power supply system is scheduling the use of thermal power plants after taking operating costs into account. The function of unit commitment is to plan the use of thermal power plants in such a way that minimum operating costs are incurred to generate the required load. This minimum is achieved by determining the most economical start-up and shutdown times for the thermal power plants in conjunction with generation and, if necessary, interchange transactions.

Hydro Scheduling (HYS)
calculates the optimum schedule for units of the hydro power plant system. For existing interchange transactions, the optimum schedule is determined at which the real costs from the interchange transactions are minimized. If no interchange transactions are planned, the requirement for potential energy is minimized. In both cases, storage management and pump operation are implemented.

Hydro-Thermal Coordination (HTC)
distributes the available hydro and thermal stored resources and energy interchange in order to achieve the system load with a minimum overall production cost.

Interchange Transaction Evaluation B (ITB)
is a tool for the operator to evaluate the cost-effectiveness and feasibility of a future interchange transaction with another utility. In this case, the entire automatic planning is started several times to check various planning scenarios for minimization of costs in the plant energy interchange.

Short-Term Inflow Forecast (STIF)
calculates future inflows into a hydrological system. On the basis of this data, the planning function (e.g., hydro scheduling) can calculate the schedule for hydro plant units. In this way, available resources (water) are used.

Network applications
Within a Spectrum Power control system, the network applications (NA) subsystem supports the user in fast and comprehensive assessment of the current state of the network. This considerably increases operational reliability and supports economic network management. It is possible to calculate optimum control options by simulating network situations. Different objectives and changing conditions are taken into account.

Network Reduction (NR)
is a tool that reduces the dimensions of a large external network into an equivalent network for a computationally economical solution of NA functions. Network equivalents are used to model the influence of the external (unobservable) network on the internal (observable) network. Network reduction deals with passive network data and the topological status of the external network to obtain a conductivity model that reflects the current operating status of the network. The computation is based on the sparse nodal admittance matrix. Sparse matrix techniques are applied. Equivalents for several partial networks can be computed simultaneously. Because high-impedance equivalent branches are of low influence on the results of the functions of the network applications subsystem, there is the possibility to enter an impedance threshold value such that equivalent branches with higher impedances are omitted. In addition, as results, either equivalent branches with complex impedances or equivalent branches with reactances only can be selected.

Bus Scheduler (BS)
This function provides active and reactive power values for injections as well as voltage magnitudes for individual generators. In addition, distribution factor sets are calculated. In the real-time mode, BS-derived values are needed for non-observable network parts. In study mode, BS-derived values can be used for setting up study situations for general NA purposes.

State Estimator (SE)
The purpose of this function is to provide a reliable and complete network solution from the real-time measurements, pseudo-measurements from bus scheduler (BS) and operator entries. The real-time measurements are imperfect but redundant. This redundancy permits the state estimator to determine an estimate for the complex voltage solution for the observable portion of the network model that best matches the information given by the measurements. For the portion of the network model that is unobservable, load and generation is forecasted and bus voltage is scheduled by the BS function. These pseudo-measurements, along with scattered telemetry and any operator entries, are used by the state estimator to determine a complex voltage estimate for the unobservable portion of the network model. Although the state estimator's essential task is to process real-time data, the SE can optionally also be executed in study mode.

Dispatcher Power Flow (DPF)
This function calculates power flows, currents and voltages in a specific study network situation and checks them for limit violations.

Optimal Power Flow (OPF)
The purpose of this function is to generate a network configuration that optimizes a performance criterion while satisfying all operating constraint limits. Depending on the optimization objectives, the OPF applications can be defined as a reactive power optimization or as an active power optimization:

Voltage/Var Scheduling (VVS)
is an application of the OPF method. It determines the optimum use of Var resources and the optimum voltage profile that should be maintained in order to achieve a favorable voltage/reactive power situation. For that purpose, optimal settings of reactive power controls are determined such that active power transmission losses are minimized. Optimal control settings are computed and displayed for operator information.

Voltage/Var Dispatch (VVD)
is a constrained dispatch of reactive sources and other controls as a form of preventive control action used to prevent the system from getting into severe abnormal voltage conditions and to keep the voltage/Var situation as close as possible to a specified optimal situation (target optimal state). Usually, optimal setpoints determined by the VVS function are used as target optimal values. The objective of VVD is to alleviate voltage violations by minimum shifting of controls from specified setpoints (least-squares shift). For that purpose, VVD minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. Each such "cost" curve penalizes its related control variable for a shift away from the target value. Weighting of the "cost" curves is performed by a factor specified for each control variable.

Reactive Power Remedial Action (RRA)
is a constrained dispatch of reactive sources and other controls as a form of corrective control action (remedial strategy) used to alleviate an existing severe abnormal voltage condition. The primary objective of RRA is correcting the system state with minimum control moves, thus driving the system back into a feasible state as fast as possible. The objective of RRA is to alleviate voltage violations by minimum shifting of controls from initial values (least-squares shift). For that purpose, RRA minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. Each such "cost" curve penalizes its related control variable for a shift away from the initial value. Weighting of the "cost" curves is performed by a factor specified for each control variable. By appropriate setting of the factors, the operator can ensure that control shifts are penalized according to the time needed to move the control.

Emergency Constrained Dispatch (ECD)
is an application of the OPF method. It is a form of constrained economic dispatch of MW generation and other controls as a preventive control action. The objective is to avoid driving the system into overloading conditions while maintaining economic operation as far as possible. If overloads already exist in the current system, ECD calculates adjustments of generators such that the system is driven back into a feasible state with minimal cost increase. Basically, ECD is an optimal dispatch like conventional economic dispatch (ED). Compared to ED, however, it is extended to also taking into account network loading constraints . This is particularly useful in usually highly loaded systems as well as during exceptional load situations, e.g., due to outages of generating units or transmission lines. The objective function of ECD is to minimize the cost of generation in designated OPF zones.

Active Power Remedial Action (ARA)
is a constrained dispatch of active sources and other controls as a form of corrective control action (remedial strategy) used to alleviate existing severe overloads. The primary objective of ARA is correcting the system state with minimum control moves, thus driving the system back into a feasible state as fast as possible. The objective of ARA is to alleviate overloads by minimum shifting of controls from initial values (least squares shift). For that purpose, ARA minimizes an objective function consisting of the sum of the quadratic "cost" curves for all control variables. Each such "cost" curve penalizes its related control variable for a shift away from the initial value. Weighting of the "cost" curves is performed by a factor specified for each control variable. By appropriate setting of the factors, the operator can ensure that control shifts are penalized according to the time needed to move the control.

Penalty Factor Calculation (PFC)
The purpose of this function is to support calculation and management of loss penalty factors for use by power applications (PA) and scheduling applications (SA). Penalty factors are used for taking network transmission losses into consideration when minimizing the cost of generation. This function is executed automatically as part of the real-time network application sequence. It calculates, for the current network state, the sensitivity of system losses to changes in unit generation and interchanges with neighboring companies. In real-time mode, it operates from the network solution produced by the state estimator function, and in study mode from that produced by the dispatcher power flow function.

Contingency Evaluation (CE)
The purpose of this function is to determine the security of the power system under specified contingencies. For each contingency, CE simulates the steady-state power flow solution and checks the network for out-of-range conditions. Contingency evaluation in large meshed transmission networks is an exhaustive task because a lot of contingencies (single outages and also multiple outages) have to be studied in order to get a reliable result. On the other hand, usually only very few of the possibly critical contingencies are actually critical, and therefore a lot of computation effort is wasted. To overcome this difficulty, a two-step approach of contingency evaluation is used. The two sub-functions of CE are as follows:

- Contingency Screening (CS) provides a ranking of contingencies from the contingency list. Contingencies are ranked according to expected limit violations due to the respective operational equipment outages. For that purpose, a fast approximated power flow calculation is performed.
- For small networks – e.g., less than 200 buses – CS may be skipped, because all contingencies can be analyzed by Contingency Analysis (CA). CA checks contingencies from the ranked list produced by the CS sub-function for limit violations. Contingencies are checked going down the list. For each of those contingencies, a complete AC power flow is performed.

Online Short-Circuit Calculation (OSC)
The purpose of this function is to compute the short-circuit values at the faulty elements and throughout the network. The short-circuit values are compared against all circuit-breaker ratings for each circuit-breaker connected to the faulty bus. The symmetrical (3-phase) fault online short-circuit function determines possible overloaded circuit-breakers, especially in networks where frequent rearrangements are routinely made. For practical applications, it is in most cases sufficient to consider 3-phase faults (worst case). The unsymmetrical fault (1-phase) online short-circuit function determines possible overloaded circuit-breakers in cases where this type of fault may be critical.

Outage Scheduler (OS)
This function allows the operator to easily enter data for planned switching of network components, limit derations of 4-poles, transformer tap schedules, busbar voltage magnitude setpoints, and generator derations. The entered data can be viewed, made up as reports, and archived.

Training simulator
To be able to train personnel effectively, training simulators are required with which the network behavior can be simulated accurately using defined scenarios. The training simulator in Spectrum Power is based on the powerful network analysis procedure and calculation methods of the other applications of Spectrum Power. In this way, it is possible to represent the network behavior in a comprehensive fashion. This training simulator provides the environment for the operator (trainee), and a separate environment that allows the instructor to influence the process in order to force responses from the trainees.

By realistic simulation of the current system behavior, the training simulator provides numerous options for training and testing, such as:
- Training new operators in network management
- Autodidactic training of experienced operators who can test their own abilities or learn how to operate new functions
- Trial of new functions of the network management system
- Testing of network changes inasmuch as the network structure, power plants, load behavior and system dynamics of the network are affected
- Testing of structural changes to the power supply system, e.g., in the network, in the power plant park, with the consumers or in the system dynamics
- Studying preventive, corrective and restoring measures that can occur in normal network operation or in stress situations
- Use of the training simulator as a planning tool for network expansions

The operator interface in the management system is identical with that of the EMS system, so there is no difference (during training) in functionality and operation between real work in the network and simulation from the point of view of the operator (trainee).

Distribution management applications
Unlike transmission networks, distribution networks place special demands on the functionality of control systems (number of stations, fault rate, changes in the network).
To meet these requirements, Spectrum Power provides powerful functions with which the operator can operate the distribution network effectively and efficiently.

Fault Location (FLOC)
This function is designed to determine the smallest possible faulty section based on available real-time data from SCADA as well as the outage management system (OMS). One of the methods used by the FLOC function is based on the bisection search, which requires systematic trial switching operations. It should be noted that the FLOC function is not intended to find the exact position of the fault but to find the likely faulty area bounded by switches and/or fault indicators. Depending on the nature of the system involved, faults can be classified as transient or permanent (persistent). Transient faults are only temporary, and so they are not considered by this function. Faults handled by the fault location function are permanent in nature.

Fault Isolation and Service Restoration (FISR)
is part of the distribution network applications. It is used after the fault is identified (refer to the application sheet of fault location) to isolate the faulty equipment and restore power downstream from the fault. The function helps the operator to solve the problem in the network and minimizes the outage time for the affected customers. FISR uses the topological model of the distribution network to generate switching procedures for isolation and restoration. FISR is a set of tools used to support the operator in performing the following tasks:
- Isolate individual equipment or an area of the network
- Restore power to de-energized areas of the network
- Isolate outage area and immediately restore power to de-energized areas of the network that are intact or isolated
- Restore a network to its normal state

The primary aim is to support the operator in selecting the best isolation and restoration scenario. The function generates possible switching procedures for isolation and/or restoration and displays them.

Outage Management System (OMS)
is a collection of functions, tools and procedures that an operator/dispatcher uses to manage the detection, location, isolation, correction and restoration of faults that occur in the power supply system. OMS is also used to facilitate the preparation and resolution of outages that are planned for the network. These processes are used to expedite the execution of the tasks associated with the handling of outages that affect the network and provide support to operators at all stages of the outage life cycle, starting from events such as the reception of a trouble call or a SCADA indication of an outage and extending until power is restored to all customers. This process is used to solve the outage regardless of whether the outage is at the level of a single distribution transformer providing power

to one or a few energy consumers, or at the level of a primary substation providing power to many energy consumers. All operations, authorizations and comments that occur in these processes are documented and collected in outage records. This information is made available to external sites for further statistical analysis and processing. OMS provides the automatic processing of an outage record used to monitor changes in the network and has an internal interface to the crew management or switching procedure management. OMS also provides an interface to the external trouble call systems and an SQL interface.

Switching Procedure Management (SPM)
allows the operator to create, edit, select, sort, print, execute and store switching procedures. Entries in a switching procedure can be created manually by recording the operator's actions in a simulation mode, by modifying an existing procedure or by recording the operator's actions in real-time mode or automatically by applications such as FISR and the OMS system. The switching procedure management capabilities can be used to prepare, study and execute clearance operations. It can also be used to execute switching operations to alleviate fault conditions and to restore power following a fault, as well as to optimize the network operation. SPM provides management capabilities via summary displays and easy-to-use menus.

Crew Management System (CMS)
This system provides convenient access to the information necessary to track, contact and assign work schedules (outage records) to the field crews of a utility. The information consists of data such as crew name, work assignments and locations.

Distribution system network applications
The distribution system network applications (DNA) provide fast and comprehensive analysis and optimization of the current distribution network state. The distribution system power flow (DSPF) solves the distribution network on a subset basis. A subnetwork includes both radial and meshed configurations as dictated by the topology. Relevant equipment (transformer, line, etc.) are modeled to conform to the distribution network type. An individual load can be defined as either conforming or non-conforming. Conforming loads follow a certain load curve. They are calculated based on the nominal rating of the distribution transformer. DSPF algorithm treats load values as voltage-dependent. All possible transformer connections of 3-phase transformers, banks of three or two transformers as well as single transformers are represented in phase components according to their winding connections. All types of voltage regulators and capacitor controllers are simulated in DSPF. Generators such as co-generators (cogens), non-utility generators (NUGs) and independent power producers (IPPs) can be modeled. DSPF supports three modes of operation:

- Online DSPF
  The purpose of this mode is to provide a solution that reflects the actual state of the distribution network using the existing real-time measurements, the actual topology and operator entries. DSPF execution can be triggered periodically, spontaneously or upon operator demand.
- What if? DSPF studies online
  The purpose of this mode is to provide a solution that reflects the status of the distribution network in the very short term, with the actual topology but with a different loading value.

- Study DSPF
  The purpose of this mode is to allow the user to execute short-term operational studies, with different topology and different loading values. Study mode is based on copies of relevant information from the distribution system operational model (DSOM). In study mode, the same model with the same network elements is used as in the online mode results of the DSPF (such as flows, currents, voltages and losses). The elements can be displayed on the network diagrams using queries. Furthermore, they can also be presented in forms, lists and diagrams.

Optimal Feeder Reconfiguration (OFR)
The objective of this system is to enhance the reliability of distribution system service, power quality and distribution system efficiency by reconfiguring the primary distribution feeders. OFR performs a multi-level reconfiguration to meet one of the following objectives:

- Optimally unload an overload segment (removal of constraint violations)
- Load balancing among supply substation transformers
- Minimization of feeder losses
- Combination of the latter two objectives (load balancing and loss minimization), where each objective is included in the total sum with a user-specified or default weighting factor

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. OFR supports two modes of operation: In online mode, the application uses the existing real-time measurements and the current topology. In the study mode, the operator can simulate short-term operational studies with different topology and measurements. The study mode is based on copies of relevant information from the distribution system operational model. That means in study mode the same model with the same network elements is used as in online mode. The output of OFR application includes the switching procedure and the values of the objective functions before and after reconfiguration.

Voltage/Var Control (VVC)
calculates the optimal settings of the voltage controller of LTCs, voltage regulators and capacitor states, optimizing the operations according to the different objectives. The following objectives are supported by the application:

- Minimize distribution system power loss
- Minimize power demand (reduce load while respecting given voltage tolerance)
- Maximize generated reactive power in distribution network (provide reactive power support for transmission/distribution bus)
- Maximize revenue (the difference between energy sales and energy prime cost)
- Keep the system within constraints

System operational constraints such as line loading and consumer voltage limits are automatically accounted for in terms of penalties. VVC supports three modes of operation:

- Online mode
  The purpose of this mode is to provide an optimal solution that conforms to the desired objective function. The VVC application runs periodically (e.g., every 15 min.), upon operator demand, or is triggered by an event (i.e., topology change), based on real-time information.
- "What if?" VVC studies online
  The purpose of this mode is to provide an optimal solution that reflects the current status of the distribution network with the actual topology but with different loading values.
- Study VVC
  The purpose of this mode is to allow the user to execute short-term operational studies, with different topology and different loading values. Study mode is based on copies of relevant information from the distribution system operational model (DSOM). That means that in study mode the same model with the same network elements is used as in online mode.

The output of VVC application includes the switching procedure and the values of the objective functions before and after optimization. Results such as flows, currents, voltages and losses are displayed on network diagrams using queries. Furthermore, they are also presented in forms, lists and diagrams.

This function is designed to use SCADA information, such as fault indications/location, as well as the information from the protection device which has cleared the sustained fault, in order to identify the de-energized sections, and to estimate the probable location of the actual fault. Other information, such as incoming trouble calls from the outage management system, is also evaluated.

The overall procedure for locating the faulty section consists in first determining the faulty feeder and the smallest possible faulty segment using real-time data from SCADA, and then in refining the fault localization using trial switching operations that are based on the well-known bisection search technique. The output of the fault location is the list of the switching devices and fault indicators bounding the faulty area. The faulty area can be shown in a tabular form or graphically by highlighting it on the network diagram.

Fault Isolation and Service Restoration (FISR)
The purpose of this application is to determine and display to the user the switching recommendations for restoring power to the majority of customers through supervisory control of substation and field equipment. After the end of an emergency outage condition, the application provides the operator with the capability to generate a switching procedure that returns the given network to its normal configuration.

FISR is uninitiated after the location of the faulty segment or zone has been determined. Its input can come from the fault location results or from the outage management system. The operator can also manually select the relevant area on the network diagram. This application supports two modes of operation:

- Online mode
  A switching order for remotely and manually controlled switching devices is generated to isolate the faulty section and restore service to the intact sections. The switching order is presented to the operator for approval and execution.
- Study mode
  The purpose of this mode is to allow the user to execute short-term operational studies, with different topology and different loading values and a predefined outage. The application analyzes the study case modified by the user, and generates a switching order under the operating conditions specified by the user.

The isolation and restoration scenarios and the status of the network being studied with the scenarios applied are presented to the operator on the network diagram as well as in tabular displays. The switching procedures are shown in a tabular form in the switching procedure management (SPM). The effect of executing the procedure can be simulated graphically on the network diagram. Each switching procedure is associated with additional information such as load, consumer, transformer restored; load, consumer, transformer not restored; voltage violation index, line overload index and losses.

The Distribution Short-Circuit Calculation (DSCC) function is used to calculate currents that are results of a short-circuit due to a fault or an incorrect connection in an electric network. It solves symmetric or asymmetric faults in balanced or unbalanced distribution networks. The DSCC function is used to determine:

- The maximum short-circuit current that determines the rating of electrical equipment (normally a circuit-breaker for real-time DSCC)
- The minimum short-circuit current that can be a basis for the protection sensitivity checking or fuses selection
- Fault current calculation at selected locations

The following fault types are available, and each of them may contain fault impedance and/or earthing impedance, depending on user requirements:

- 3-phase unearthed
- 3-phases to earth
- 1-phase to earth
- Phase-to-phase unearthed
- 2-phase to earth

There are two modes of operating DSCC. In the real-time mode, DSCC is based on the current electrical network configuration. In the study mode, DSCC works with copies of the database. Different simulations and/or "What if?" studies can be performed.

The real time DSCC can be started on demand. Besides the case maximum current on the entire system, where the calculation will be done for the whole distribution network, the area to be calculated should be selected by the operator. The complete results of DSCC are presented in tabular form. There are tables for switches, branches and buses that show the short-circuit current, the percentage of violation over breaking capacity, current magnitude, voltage magnitude and so on.

Expert system applications
The Spectrum Power expert system supports the operator in solving critical and complex tasks in the field of network operation and disturbance analysis (fig. 7.2-4). Spectrum Power expert system applications provide two functions, an intelligent alarm processor (IAP) and an expert system for advanced network operation (ANOP).

The IAP provides information about the fault location in case of a network disturbance. It is based upon a hierarchical, multi-level problem-solving architecture that combines model-based and heuristic techniques, and works with an object-oriented data structure. Within the diagnosis, the IAP determines the location and the type of disturbances in electrical networks, e.g., fault within a transformer. The model used by the IAP corresponds to the model of the protection system. This provides the additional advantage of monitoring the correct operation of the protection system. The diagnosis results are displayed in the XPS report list.

Advanced Network Operation (ANOP)
This system supports the following network operations of the operator:

- Automatically triggered operations for:
  - Automatic fault isolation and restoration
  - Automatic removal of overload
- Manually triggered operations for:
  - Manual fault isolation and restoration (trigger fault)
  - Planned outage (take out of service)
  - Load relax
  - Resupply (energizing)

The algorithm of ANOP manages all types of distribution networks – for cities or provinces, small networks or large networks – with radial configurations and also with looped configurations. It can be used in telemetered networks as well as in non-telemetered networks. The algorithm is fully generic, considers the actual network status (topology, values, tagging), and provides an authentic and extensive solution for the given task, taking into account all electrical and operational requirements. The algorithm develops the best strategy for the given situation and considers all necessary steps to reach a solution that fulfils the task in a secure, complete and efficient way.

With the help of the built-in power flow, each step is checked; tagged equipment is respected. The proposed solution changes the actual topology of the network in a minimal way. In the exceptional case in which a complete solution is not available under the actual circumstances, a partial solution is evaluated, again taking into account all electrical and operational requirements. The results are displayed in the XPS report list and in the XPS balance list, and a switching procedure is created and inserted in the switching procedure management.

ICCP and ELCOM
The necessity of process data exchange between control centers, often from different vendors, is increasing worldwide. Examples are hierarchical control centers, the interconnection of networks, energy exchange between suppliers or the use of external billing systems.

Fig. 7.2-4: **The Spectrum Power expert system supports the operator to solve critical and complex tasks**

De facto standard protocols for communication between control centers have been established, e.g., ELCOM-90 or ICCP. The ICCP protocol was defined as an international standard (IEC 870-6 TASE.2) and is now widely accepted and used all over the world.

The inter-control center communications protocol (ICCP) is designed to allow data exchange over wide area networks (WANs) between a utility control center and other control centers. Examples of other control centers include neighboring utilities, power pools, regional control centers and non-utility generators. Exchanged data may include cyclic data, real-time data and supervisory control commands such as measured values and operator messages.

Data exchange occurs between a SCADA/EMS server of one control center and the server of another control center. The ICCP server is responsible for access control when a client requests data. One ICCP server may interact with several clients.

Access control of data elements between control centers is implemented through bilateral agreements. A bilateral agreement is a document negotiated by two control centers that includes the elements (that is, data and control elements) that each is willing to transmit to the other.

The ICCP data link supports a redundant configuration utilizing dual communication servers in active and standby mode. A redundant configuration supports two physically separate paths between the Spectrum Power control systems and the remote system to provide backup in the event that the primary data path becomes unavailable.

7.2.2 Decentralized Energy Management Systems (DEMS)

In parallel with the liberalization of the energy markets, the decentralized generation of electrical power, heat and cold energy becomes more and more important. The generation of these types of energy near to the consumers offers economical and ecological benefits. In this context, interest is directed to so-called virtual power plants. A virtual power plant is a collection of small and very small decentralized generation units that is monitored and controlled by a superordinated energy management system. In general, these generation units produce heating and cooling energy as well as electricity.

A successful operation of a virtual power plant requires the following technical equipment:

1. An energy management system that monitors, plans and optimizes the operation of the decentralized power units
2. A forecasting system for the loads that is able to calculate very short-term forecasts (1 hour) and short-term forecasts (up to 7 days)
3. A forecasting system for the generation of renewable energy units. This forecast must be able to use weather forecasts in order to predict the generation of wind power plants and photovoltaics
4. An energy data management system which collects and keeps the data that is required for the optimization and the forecasts, e.g., profiles of generation and loads as well as contractual data for customer supply
5. A powerful front end for the communication of the energy management system with the decentralized power units

First, a virtual power plant needs a bidirectional communication between the decentralized power units and the control center of the energy management system. For larger units, conventional telemetry systems based on protocols such as IEC 60870-5-101 or 60870-5-104 can be used. In the future, with an increasing number of small decentralized power units, the communication channels and protocols will play a more important role. It is likely that the costly conventional telemetry technique will be substituted by other techniques based on simple TCP/IP adapters or based on power line carrier techniques. Siemens is contributing to the upcoming standard "IEC 61850-7-420 Ed.1: Communication networks and systems in substations – Part 7-420: Communications systems for distributed energy resources (DER) – Logical nodes."

All operation planning and scheduling applications require forecasts with sufficient accuracy. For the characterization of the forecasts, several operating figures are used, such as the average forecast error per day or the absolute error per day or per forecasting time period. Depending on the main purpose of the virtual power plant, the requirements for the forecast methods may change. If the primary purpose is to reduce the peak load or the balance energy, the forecast has to be very exact in the peak time or times with the high prices for balance energy. Furthermore, the forecast algorithms must be able to adapt rapidly to new situations. For example, a virtual power plant operated by an energy service company must be able to consider changes in the customer structure.

Based on the results of the forecast algorithms and the actual situation of the virtual power plant, the load to be covered can be dispatched by using the decentralized power units and the existing energy contracts. This is a complex and recurrent task. Therefore, computer-based methods of operations research are used. This is the most important component in a virtual power plant, because it realizes and uses the optimization leeway.

The special structure of a virtual power plant places high demands on the mathematical models for the optimization. The models must be very precise because rough models could yield optimization results that cannot be realized by the power system. Because the virtual power plant must provide an automatic mode for online control of the decentralized power units, e.g., for compensating the imbalance, no operator can check and correct the results. Furthermore, the optimization leeway can only be used if the optimization package is able to determine the solution cyclically within the settlement period.

Based on the requirements defined in the preceding section, a software package for decentralized energy management called DEMS was developed. The DEMS system is not meant to be a substitute for all possible automation equipment necessary for operating the components of a virtual power plant. There must be at least that much local automation equipment available to allow the basic operation of the decentralized power units in order to ensure component and personal safety in the absence of the DEMS system.

The components/units of a virtual power plant and their energy flow topology are modeled in DEMS by some classes of model elements, e.g., converter units, contracts, storage units, renewable units and flexible loads.

The DEMS planning application models all cost/revenue and constraint-relevant energy and media flows, regardless of their type (e.g., electricity, hot water, steam, cooling, emissions, hydrogen).

The DEMS control applications provide control and supervision capability of all generation units, storage units and flexible demands as well as control capability to maintain an agreed-upon electrical interchange energy profile. Fig. 7.2-5 illustrates the modeling of a decentralized power generation system by using DEMS model elements (rectangular objects with unit names), and connecting them via balance nodes (circular objects with node numbers).

The functions of DEMS (fig. 7.2-6) can be subdivided into planning functions and control functions. The respective planning functions are the weather forecast, the load forecast, generation forecast and the unit commitment. Furthermore, DEMS provides generation and load management as an exchange monitor and online optimization and coordination.

The planning functions consider a time period of one to seven days with a time resolution depending on the settlement periods for energy sales and purchases, e.g., 15, 30 or 60 minutes. The planning functions run cyclically (e.g., once a day or less frequently), on manual demand and can be spontaneously triggered.

The DEMS weather forecast function provides the forecasted weather data import/calculation that is used as an input for the other DEMS function modules. The weather forecast function has import capability for forecasted (and maybe also historical) weather data provided by external sources like weather forecast services. If there is local weather data measurement equipment located in the virtual power plant, the external imported weather forecast is adapted to the local site measurements by using a moving average correction algorithm that minimizes the difference of the deviation between the external forecast and locally measured weather data around the actual time step. The resulting internal weather forecast is provided as an input to the other DEMS planning functions.

The DEMS load forecast provides a forecast calculation for multiple load classes. The basic data is the continuous historical measured load data in the time resolution of the planning functions. A piecewise linear model is set up explaining the modeling of the demand behavior as a function of influencing variables such as day types, weather variables or production schedules from industrial loads. The model equation coefficients are estimated cyclically each day after new measurements are available.

For each time stamp of the day (e.g., 96 time stamps for a 15-minute time resolution), a separate coefficient analysis is done. The data used for the analysis starts from yesterday for a parameterized time range in the past (from 0 to 84 days). The mathematical method for calculating the model coefficients is a Kalman filter. By using the Kalman filter, the definition of fully dynamic, partial static and fully static forecast models is possible.

The DEMS generation forecast calculates the expected output of renewable energy sources dependent on the forecasted weather conditions. The forecast algorithm is a piecewise linear transformation of two weather variables to the expected power output according to a given transformation matrix (e.g., wind speed and direction for wind power units, light intensity and ambient air temperature for photovoltaic systems). The transformation matrix can be parameterized according to the unit technical specifications and/or is estimated on the basis of historical power and weather measurements by applying neural network algorithms (in an offline analysis step).

The DEMS unit commitment function calculates the optimized dispatch schedules (including the commitment) for all flexible units such as contracts, generation units, storage and flexible demands. The objective function is the difference of revenue minus costs, the profit. The scheduling considers the parameters of the model elements and their topological connection, which

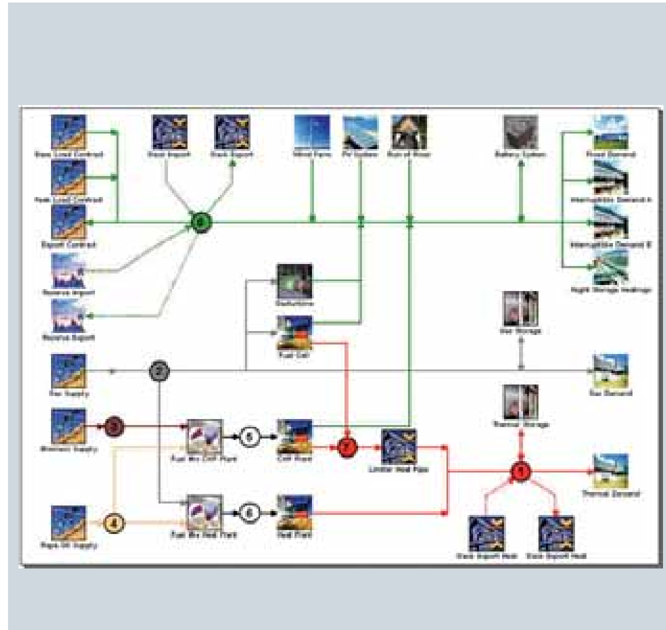


Fig. 7.2-5: **System topology with DEMS model elements (rectangular objects with unit names) and connecting them via balance nodes (circular objects with node numbers)**

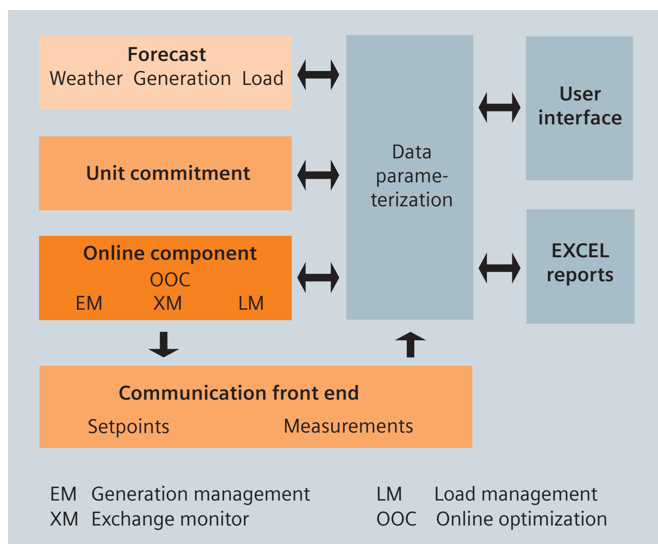


Fig. 7.2-6: **DEMS functions**

defines the financial information, as well as the technical, environmental and contractual parameters and constraints of the virtual power plant. The unit commitment uses mixed integer linear programming to calculate the results of the optimization problem.

The DEMS generation management function allows for the control and supervision of all generation and storage units of the virtual power plant. Dependent on the control mode of the respective unit (independent, manual, schedule or control mode) and the unit parameters (minimum/maximum power,

power gradients, energy content), the actual state (start-up, online, remote controllable, disturbed) and the actual power output of the unit, the start/stop commands and power setpoints for the units are calculated and transmitted via the command interface. Furthermore, the command response and the setpoint following status of the units are supervised and signaled. In the event of a unit disturbance, the generation management can start a spontaneous unit commitment calculation to force a rescheduling of the remaining units under the changed circumstances while also considering all integral constraints.

The DEMS load management function allows the control and supervision of all flexible loads in the virtual power plant. A flexible load class can contain one or several load groups of the same priority, where one load group is supposed to be switched on or off completely with one switching command. Dependent on the control mode of the load class (independent, schedule or control mode) and the actual switching state, the actual control state, the actual power consumption and the allowed control delay time of the load groups, the required switching controls to fulfill the overall load class setpoint are calculated and transmitted via the command interface (applying a rotational load shedding of the load groups of one load class). The optimized load class schedules calculated by the unit commitment function are the basis for load class control in the operation modes "schedule" and "control".

The DEMS exchange monitor function calculates the expected deviation of the agreed-upon electrical interchange schedule of the current accounting period (15 or 30 or 60 minutes) and the necessary power correction value to keep the interchange on schedule. On the basis of the actual energy consumption of the running accounting period and the actual interchange power trend, the expected energy interchange at the end of the accounting period is calculated. The difference between this value and the agreed-upon interchange value, divided by the remaining time of the accounting period, gives the necessary overall power correction value that is needed to be on schedule with the agreed interchange at the end of the accounting period. This value is passed to the online optimization and coordination function for further processing.

The DEMS online optimization and coordination function dispatches the overall power correction value to all individual generation units, storage units and flexible load classes that are running in control mode. The distribution algorithm works according to the following rules: First, the actual unit constraints (e.g., minimum and maximum power, storage contents, power ramp limitations) must be considered. Second, the overall power correction value should be reached as fast as possible. And third, the cheapest units should be used for control actions. "Cheapest" in this context means that the incremental power control costs of the units around their scheduled operating points are taken as a reference. The incremental power control costs of the individual units are calculated by the unit commitment function along with the respective dispatch schedules. The individual unit's power correction values are passed to the generation management function and load management function for execution.

DEMS is based on widespread software components running on Microsoft Windows-based computers with standardized interfaces and protocols (fig. 7.2-7). This secures the owner's investment in the virtual power plant, because it is easy to extend the system with new modules. Fig. 7.2-8 depicts the main components of DEMS. As basic SCADA engine, Siemens WinCC (Windows Control Center) is used.

The application algorithms are realized with Siemens ECANSE (Environment for Computer-Aided Neural Software Engineering). A Microsoft Excel interface exists for time series data input and output. The time series data is stored in the process database of WinCC (using a commercial relational database system). DEMS uses CPLEX for solving the mixed integer linear programming problem. By configuring WinCC, ECANSE and Excel files, a concrete DEMS application system can be configured according to the specific structure of the virtual power plant.

The user interface plays an import role in operator acceptance. It must be user-friendly in order to reduce the training effort and

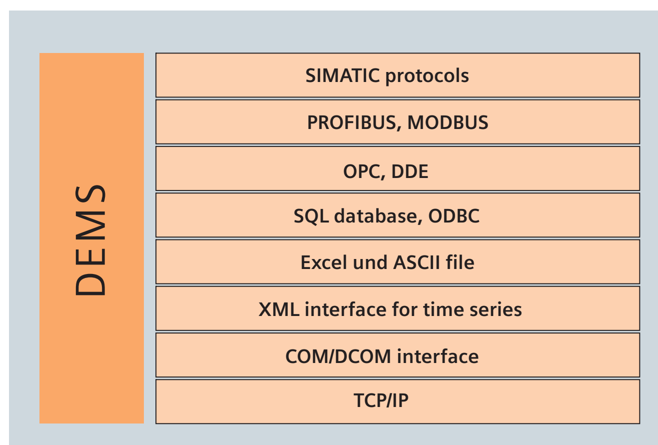


Fig. 7.2-7: **DEMS interfaces**

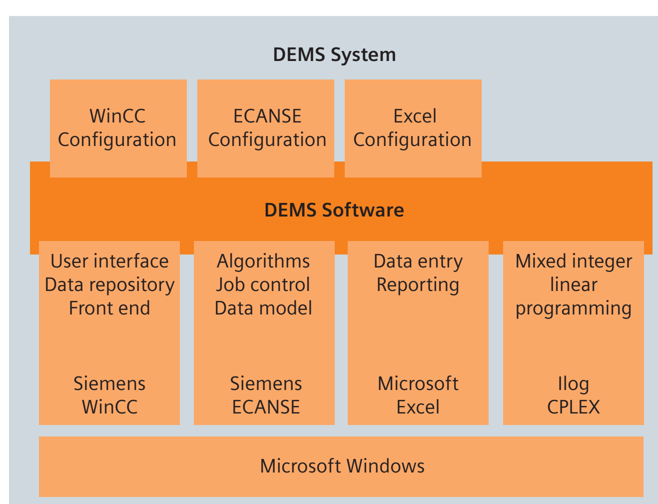


Fig. 7.2-8: **DEMS components**

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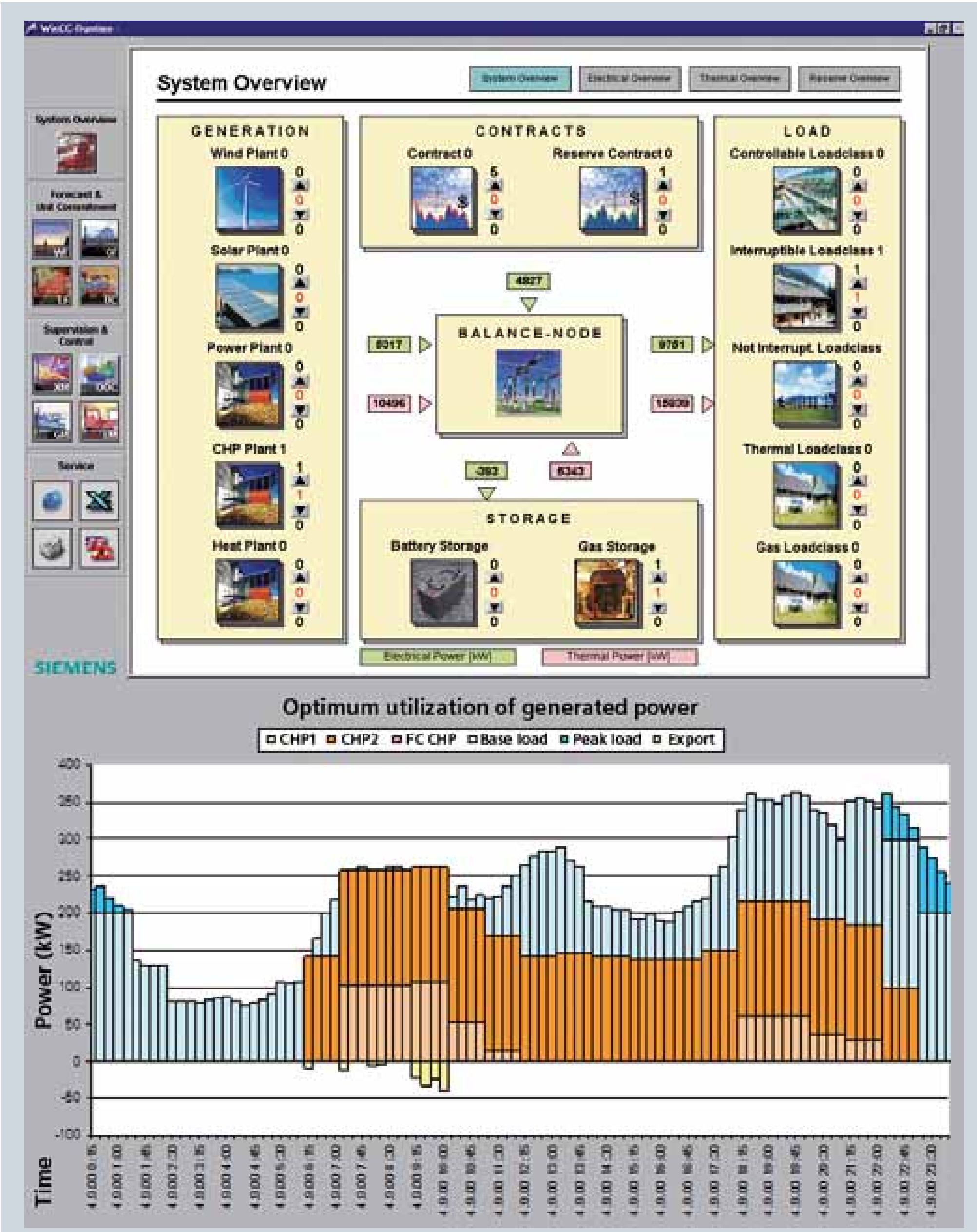

Fig. 7.2-9: **DEMS user interface**

to avoid faulty operations. Therefore, the user interface of DEMS is created using the basis of the WinCC User Interface builder (fig. 7.2-9).

In addition to this, for more complex and flexible graphical analysis of time series information, Excel report files for result presentation can be used. By using either a remote desktop software tool or by using the WinCC Web Navigator option, ISDN or Web-based remote access to the DEMS system is possible. Fig. 7.2-9 shows some examples of the user interface.

As just stated, the interface and protocols of the communication front end are essential for the success of an energy management system in a virtual power plant. Therefore, DEMS provides several interface process data interfaces and protocols:

- OPC
- MODBUS Protocol Suite, MODBUS Serial
- PROFIBUS DP, PROFIBUS FMS
- SIMATIC S5, S7, TI
- Windows DDE
- PLC protocols

In addition, DEMS has a SOAP-based XML Web interface that allows data exchange of process values and time series data from DEMS to DEMS or DEMS to Web applications. Furthermore, DEMS allows the import/export of process values and time series data from/to ODBC data sources, Excel and ASCII files.

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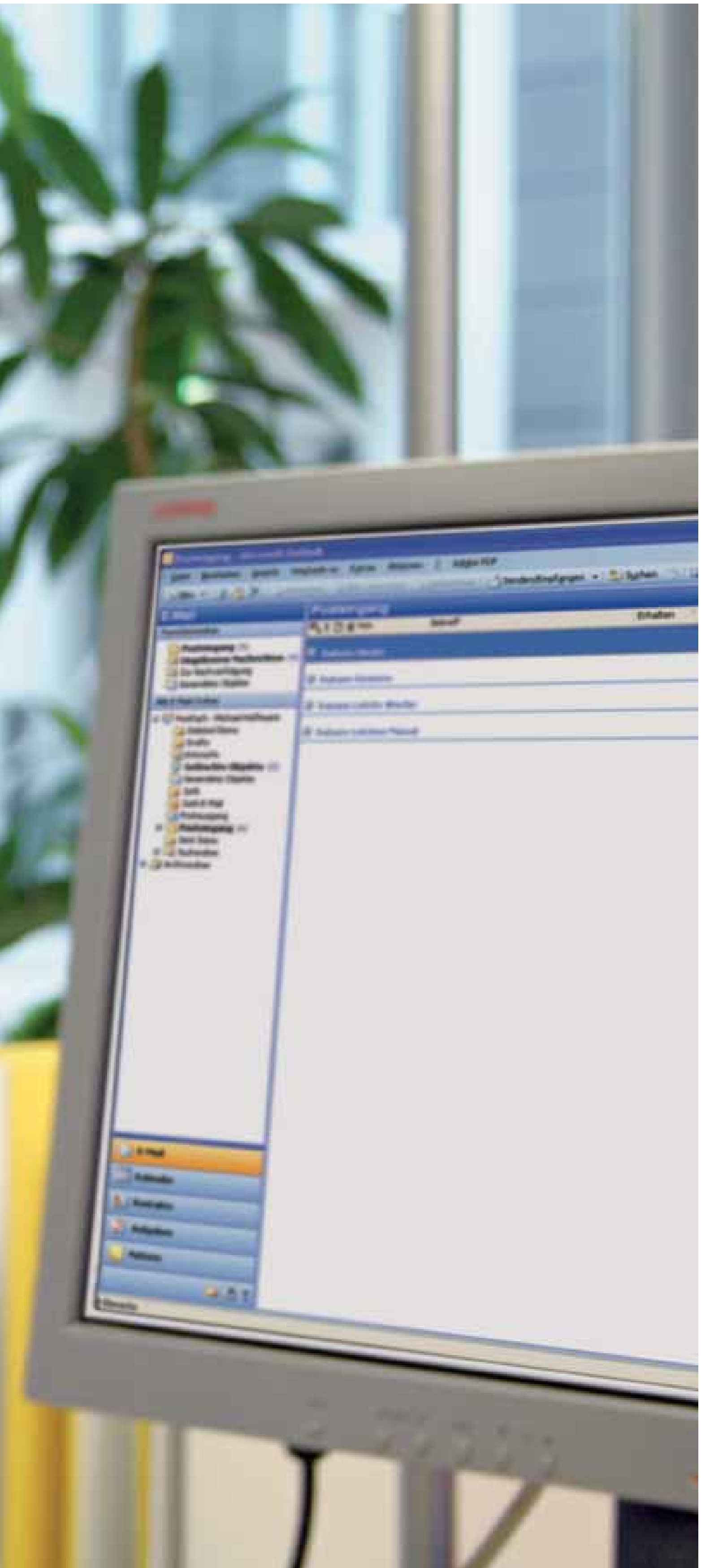

Communication in Power Systems

8 Communication in Power Systems

8.1 Introduction

A secure, reliable and economic power supply is closely linked to a fast, efficient and dependable communications infrastructure. The planning and implementation of communications networks requires the same care as the installation of the power supply systems themselves.

As a result of the deregulation of the energy markets, the unbundling of the vertically integrated structures of the past and the sharp increase in decentralized power production, reliable system management of power supply systems is becoming an increasingly big challenge. This development goes hand in hand with a rapid increase in demand for communications. This is not only a question of higher bandwidths, but also of new communications requirements including integration of private households into the smart grids of power utilities.

Parallel to this, transmission technology has continued to develop rapidly over the past few years and the TCP/IP protocol has also become the established standard in the power supply sector. This also provides a means of continuous TCP/IP communication between field devices and control center in the process control area as well. In addition, international standards such as IEC 61850 further simplify the exchange of data between different communication partners.

The gradual migration of most conventional communication interfaces/products to TCP/IP-based networks is therefore an important task for those responsible at the power supply companies. In this case, team-oriented and interdepartmental planning of the migration concepts is called for. Serial interfaces will, however, continue to play a role in future for small systems.

For these communications requirements, Siemens offers an overall concept and has a tailored solution for all transmission media used (fiber optics (FO), high-voltage lines, synchronous digital hierarchy (SDH), Ethernet, wireless solutions, etc. Naturally this also includes a full range of services, from communication analysis to operation of the entire solution (fig. 8.1-1).

For further reading please visit:
www.siemens.com/utilitycommunication

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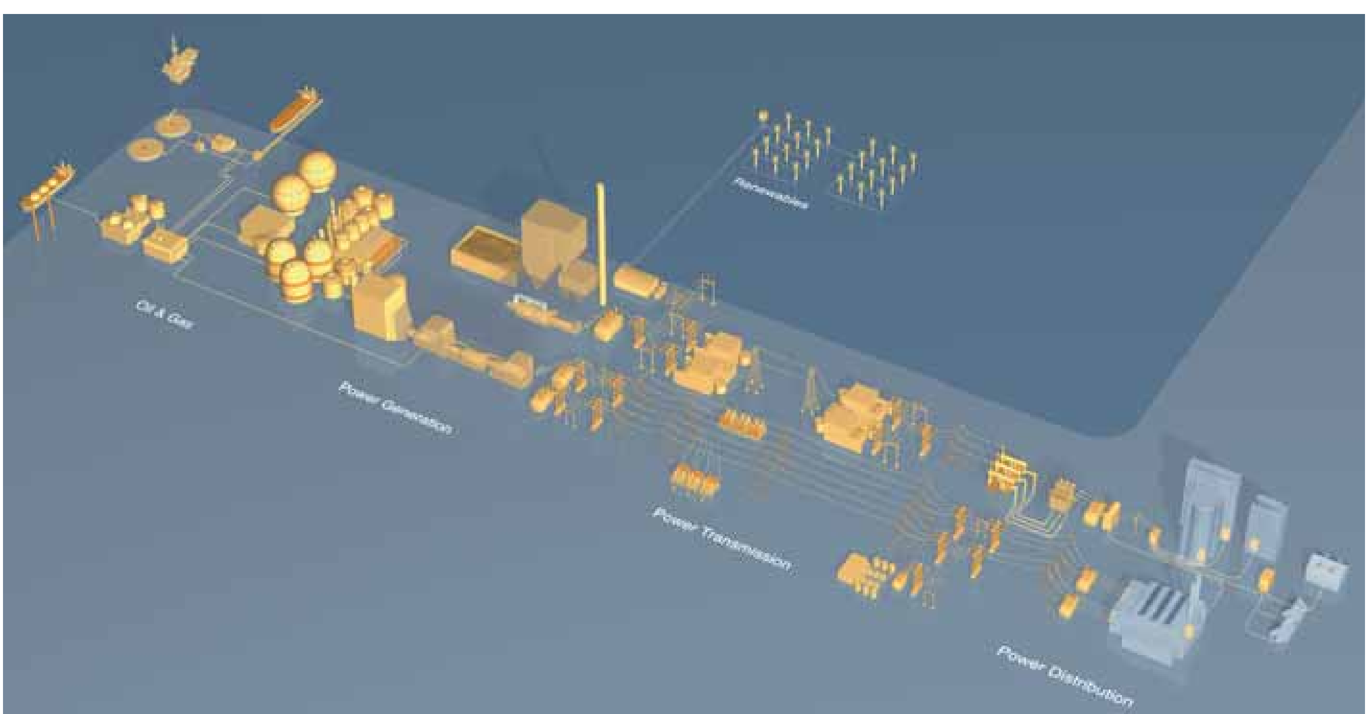

Fig. 8.1-1: **Siemens is offering complete communications solutions to build a smart grid for power utilities**

8.2 Overview

Fig. 8.2-1 shows the most important communication relations and components over the entire power supply process (generation, transmission, distribution and consumption). Wireless communications solutions are shown in section 8.9.

Generally, two logically (and often also physically) separated communication topologies are shown:
- Process communication for monitoring and control of the electricity network
- Administrative network for commercial applications, for example billing, etc.

In future communications networks, there will be no physically discrete networks for operation and administration, but one common IP network for all applications. In this context, data security is gaining in importance. You can find more on the subject of security in section 8.11.

Process communication comprises the entire monitoring and control of a power supply system by the control center down to the protection devices and telecontrol equipment. Fig. 8.2-1 shows firstly the typical communications infrastructure in a high-voltage network, taking special account of the substation-to-substation communication. Fig. 8.2-1 also shows the communications requirements in the medium-voltage area of a power supply company down to the low-voltage level of the end consumers.

In the high-voltage area, fig. 8.2-1 mainly shows the backbone communication via Optical Ground Wire (OPGW) which is installed with the high-voltage cables.

Power line carriers, on the other hand, allow narrow-band transmission of data over the high-voltage cable itself. In the medium-voltage level, today there are only few point-to-point data links between the control center and the major transformer substations. However, small transformer substations today are frequently not integrated into the communications network of a power supply company at all.

In future, broadband transmission via medium-voltage cables and overhead lines (Broadband over Power Lines, BPL) will be possible. BPL will then also enable communication as far as the consumers (e.g., private households) via the low-voltage network.

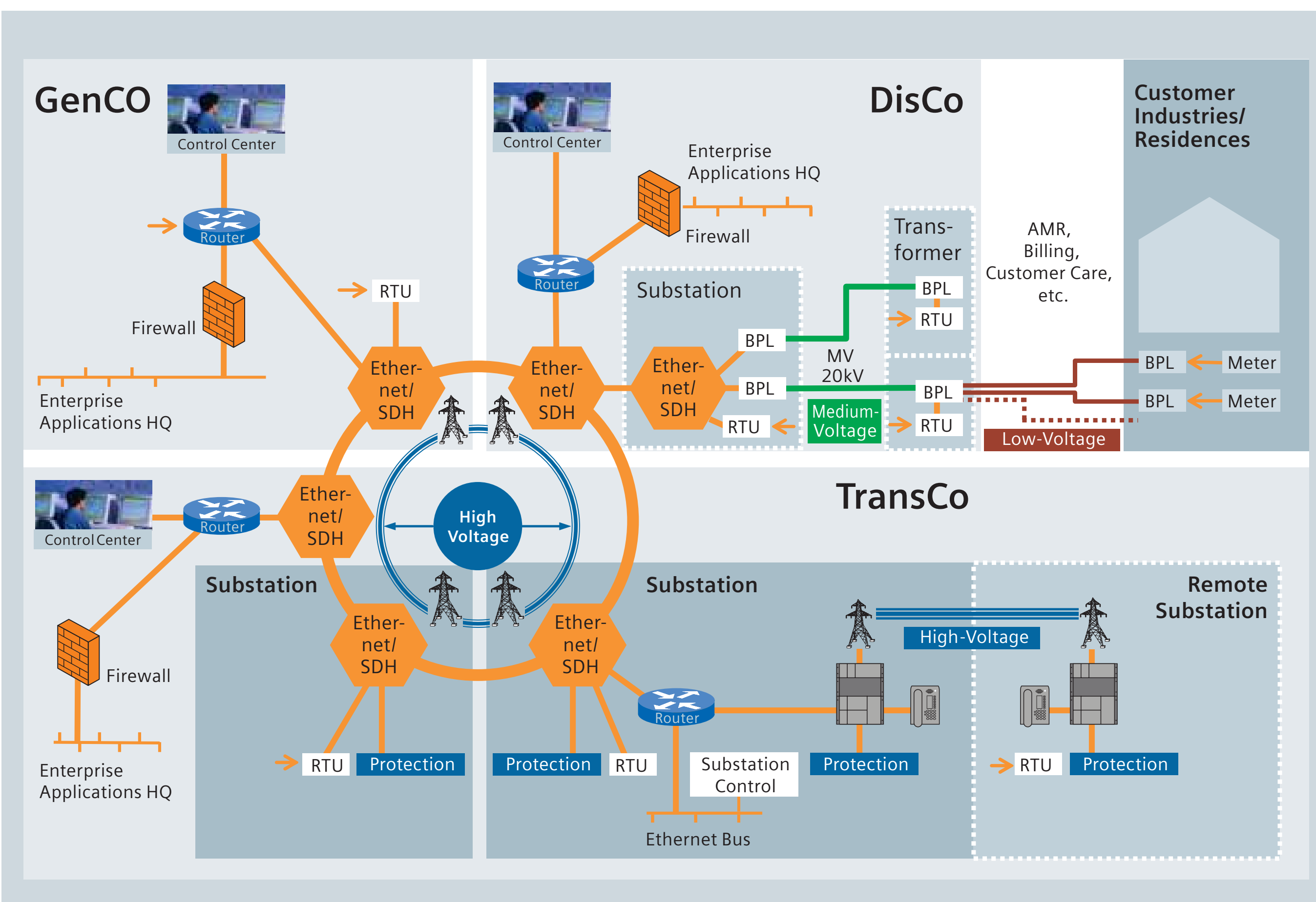

Fig. 8.2-1: **Communications solutions for energy automation (overview wireline solutions)**

8.3 Substation Communication

8.3.1 Overview of IEC 61850

Since being published in 2004, the IEC 61850 communication standard has gained more and more relevance in the field of substation automation. It provides an effective response to the needs of the open, deregulated energy market, which requires both reliable networks and extremely flexible technology – flexible enough to adapt to the substation challenges of the next twenty years. IEC 61850 has not only taken over the drive of the communication technology of the office networking sector, but it has also adopted the best possible protocols and configurations for high functionality and reliable data transmission. Industrial Ethernet, which has been hardened for substation purposes and provides a speed of 100 Mbit/s, offers bandwidth enough to ensure reliable information exchange between IEDs (Intelligent Electronic Devices), as well as reliable communication from an IED to a substation controller.

The definition of an effective process bus offers a standardized way to connect conventional as well as intelligent CTs and VTs to relays digitally. More than just a protocol, IEC 61850 also provides benefits in the areas of engineering and maintenance, especially with respect to combining devices from different vendors.

Key features of IEC 61850
As in an actual project, the standard includes parts describing the requirements needed in substation communication, as well as parts describing the specification itself.

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The specification is structured as follows:
- An object-oriented and application-specific data model focused on substation automation.
- This model includes object types representing nearly all existing equipment and functions in a substation – circuit-breakers, protection functions, current and voltage transformers, waveform recordings, and many more.
- Communication services providing multiple methods for information exchange. These services cover reporting and logging of events, control of switches and functions, polling of data model information.
- Peer-to-peer communication for fast data exchange between the feeder level devices (protection devices and bay controller) is supported with GOOSE (Generic Object Oriented Substation Event).
- Support of sampled value exchange.
- File transfer for disturbance recordings.
- Communication services to connect primary equipment such as instrument transducers to relays.
- Decoupling of data model and communication services from specific communication technologies.
- This technology independence guarantees long-term stability for the data model and opens up the possibility to switch over to successor communication technologies. Today, the standard uses Industrial Ethernet with the following significant features:
  – 100 Mbit/s bandwidth
  – Non-blocking switching technology
  – Priority tagging for important messages
  – Time synchronization
- A common formal description code, which allows a standardized representation of a system's data model and its links to communication services.
- This code, called SCL (Substation Configuration Description Language), covers all communication aspects according to IEC 61850. Based on XML, this code is an ideal electronic interchange format for configuration data.
- A standardized conformance test that ensures interoperability between devices. Devices must pass multiple test cases: positive tests for correctly responding to stimulation telegrams, plus several negative tests for ignoring incorrect information
- IEC 61850 offers a complete set of specifications covering all communication issues inside a substation.

You will find more information about IEC 61850 at:
http://www.61850.com

8.3.2 Protection and Substation Automation

SIPROTEC 4 – communication of protection relays and bay controllers
Communication interfaces on protection relays are becoming increasingly important for the efficient and economical operation of substations and networks.

The interfaces can be used for:
- Accessing the protection relays from a PC using the DIGSI operating program for aspects of configuration, access of operational and non-operational data.

Remote access via modem or Ethernet modem is possible with a serial service port at the relay. This allows remote access to all data of the protection relay.

By using the remote communication functions of DIGSI it is possible to access relays, e.g., from the office via the telephone network (fig. 8.3-1). For example, the error log can be transferred to the office and DIGSI can be used to evaluate it.
- Integrating the relays into control systems with IEC 60870-5-103 protocol, PROFIBUS DP protocol, DNP 3.0 protocol and MODBUS protocol.

The new standardized IEC 61850 protocol (section 8.3.1) has been available since October 2004, and with its SIPROTEC units Siemens was the first manufacturer worldwide to provide this standard.
- Thanks to the standardized interfaces IEC 61850, IEC 60870-5-103, DNP 3.0, MODBUS, PROFIBUS DP, SIPROTEC units can also be integrated into non-Siemens systems or in SIMATIC

S5/S7. Electrical RS485 or optical interfaces are available. The optimum physical data transfer medium can be chosen thanks to opto-electrical converters. Thus, the RS485 bus allows low-cost wiring in the cubicles and an interference-free optical connection to the master can be established.

- Peer-to-peer communication of differential relays and distance relays (section 8.5.2) to exchange real-time protection data via fiber optic cables, communications network, telephone networks or analog pilot wires.

Ethernet-based system with SICAM
SIPROTEC 4 is tailor-made for use with the SICAM power automation system together with IEC 61850 protocol. Via the 100 Mbit/s Ethernet bus, the units are linked electrically or optically to the station unit. Connection may be simple or redundant. The interface is standardized, thus also enabling direct connection of units from other manufacturers to the LAN. Units featuring an IEC 60870-5-103 interface or other serial protocols can be connected via the Ethernet station bus to SICAM by means of serial/Ethernet converters. DIGSI and the Web monitor can also be used over the same station bus. Together with Ethernet/IEC 61850 an interference-free optical solution can be provided. Thus, the installation Ethernet interface in the relay includes an Ethernet switch. Thus the installation of expensive external Ethernet switches can be avoided. The relays are linked in an optical ring structure (fig. 8.3-2).

Further communication options for IED connection
Apart from supporting IEC 61850, modern substation automation systems like SICAM also support the connection of IEDs (Intelligent Electronic Devices) with other protocol standards like the well-known standard IEC 60870-5-103 for protections units as well as DNP3 (serial or over IP) and also protocols such as PROFIBUS DP and MODBUS.

Specifically with SICAM PAS, the devices with serial communication can be reliably connected directly to the substation controller. Moreover it is also possible to use LAN for backbone communication throughout the substation, connecting such serial devices with serial hubs in a decentralized approach.

Additionally it is also possible to connect subordinated substations and Remote Terminal Units (RTU) using the protocol standards IEC 60870-5-101 (serial communication) and IEC 60870-5-104 (TCP/IP).

Especially for communication with small RTUs, dial-up connections can be established based on IEC 60870-5-101.

Additional features of TCP/IP communication
Besides the traditional protocols mentioned for data exchange with IEDs, in the world of Ethernet it is also important to be aware of the status of communication infrastructure devices such as switches. In this context, the protocol SNMP (Simple Network Management Protocol) helps a lot. SICAM PAS supports this protocol, thereby providing status information e.g., to the control center, not only for IEDs and substation controllers, but also for Ethernet switches and other "SNMP-devices".

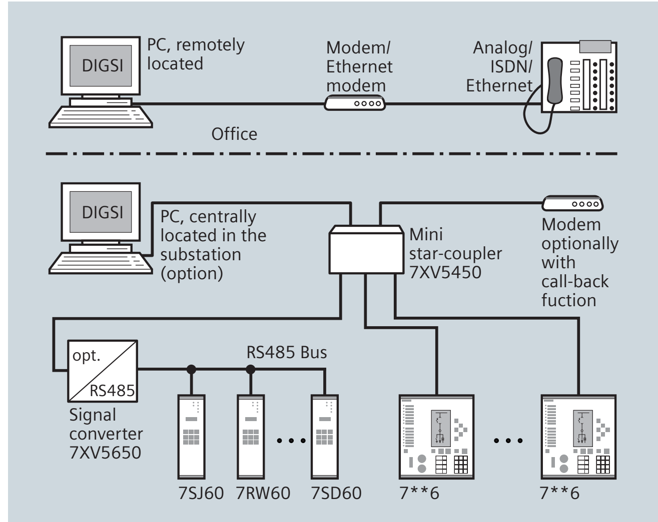


Fig. 8.3-1: **Basic remote relay communication**

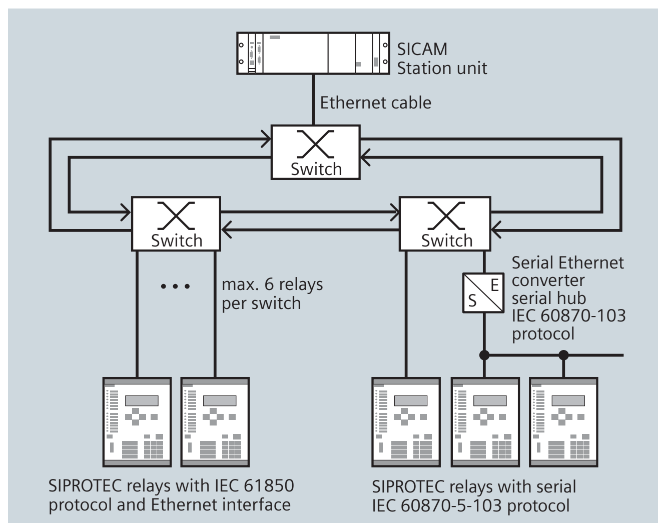


Fig. 8.3-2: **Ethernet-based system with SICAM**

Another communication protocol, well-known from the industrial automation sector, is also required for substation automation applications: OPC (OLE for Process Control, see also Control Center Communication). Additional interoperable solutions are possible with OPC, especially for data exchange with devices and applications of industrial automation. SICAM PAS supports both OPC server and OPC client.

The linking of protection relays and/or bay controllers to the station level is chosen according to the size and importance of the substation. Whereas serial couplings with IEC 60870-5-103 are the most economical solution in small distribution substations (only medium-voltage), Ethernet in compliance with IEC 61850 is normally used for important high-voltage and extra-high-voltage substations. In addition there are a number of different physical designs, based on the local situation as regards cable runs and distances, and on the requirements in terms of availability and EMC influences.

The simplest version is the serial bus wiring in accordance with RS 485 in which the field devices are electrically connected to a master interface on the SICAM central unit (fig. 8.3-3). This wiring is particularly recommended in new installations. Special attention should also be paid to correct handling of the earthing and also to possible impact on the EMC due to the primary technology or power cables. Separate cable routes for power supply and communications are an essential basis for this. A reduction of the number of field devices per master to about 16 to 20 devices is recommended in order to be able to make adequate use of the data transfer performance.

A star configuration of the wiring is rather easy to handle and can be in the form either of electrical wiring as per RS 232, or optical fiber. Here again, the number of devices per master should be limited as before (fig. 8.3-4).

The configurations with Ethernet are similar, with star and ring versions available. Variants with redundancy complete these configurations. The star configuration is especially recommended for central arrangements with short distances for the cable routes (fig. 8.3-5).

An fiber-optic ring can be made up of individual switches. That is especially advisable if several devices are to be connected in each feeder (fig. 8.3-6).

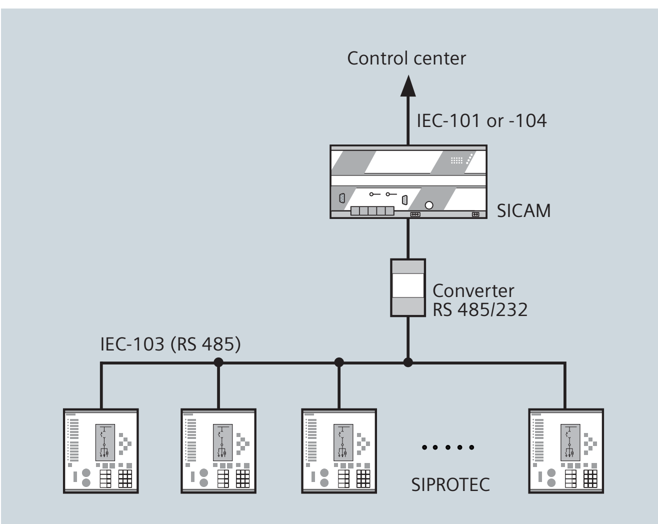


Fig. 8.3-3: **Serial bus wiring in accordance with RS 485**

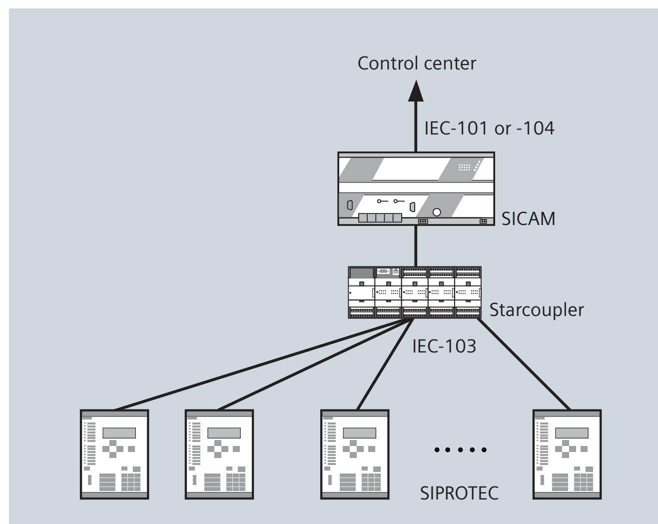


Fig. 8.3-4: **Star wiring in accordance with RS 232 or per fiber-optic cable**

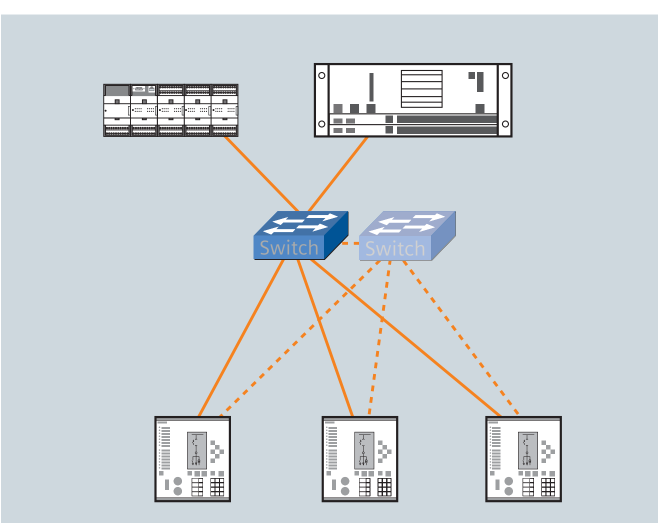


Fig. 8.3-5: **Star configuration with Ethernet**

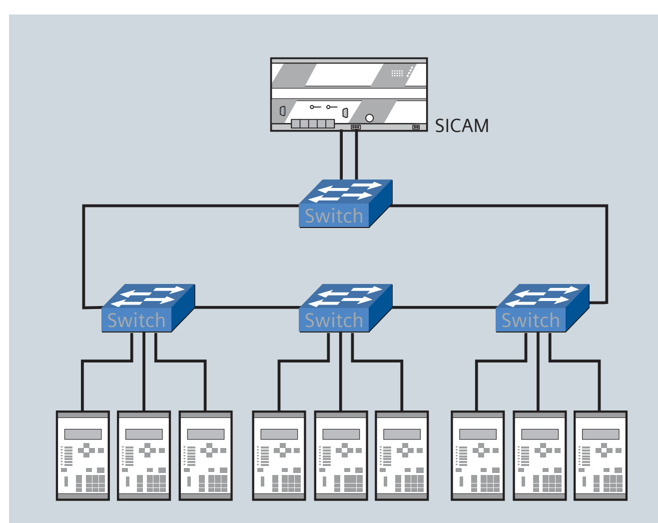


Fig. 8.3-6: **Fiber-optic ring consisting of individual switches**

A more economical solution is the fiber-optic ring with SIPROTEC relays because these devices have a switch directly integrated (fig. 8.3-7). In this application, though, a suitable device from RuggedCom must be used for the central switch so that the fast switchover times can also be used in the case of a malfunction on the ring. The number of devices in the ring is restricted to 27.

Several rings can also be combined on the basis of this fundamental structure, e.g., one per voltage level. Usually these rings are combined to form a higher level ring which then communicates with redundant station devices. This version offers the highest availability for station-internal communication (fig. 8.3-8).

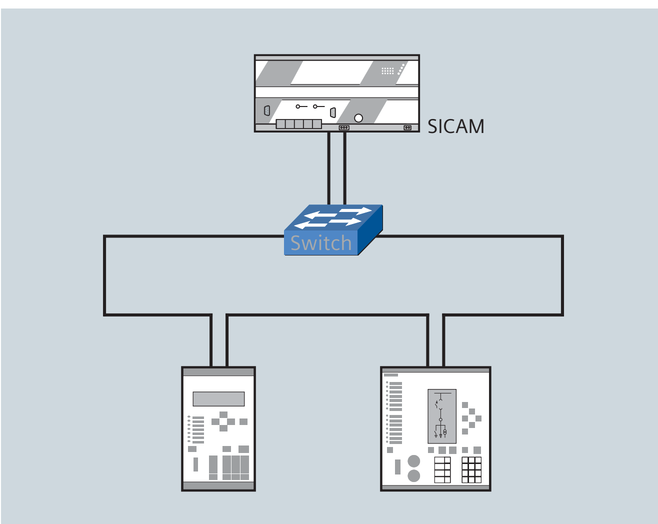


Fig. 8.3-7: **Fiber-optic ring with SIPROTEC relays**

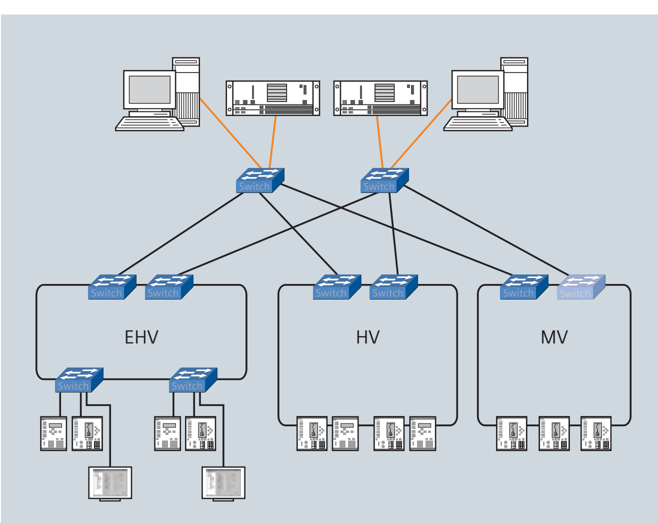


Fig. 8.3-8: **The combination of several rings offers the highest availability**

8.3.3 Differential and Distance Protection between Substations

Typical applications of differential and distance protection are shown in fig. 8.3-9. The differential protection relay is connected to the current transformers and to the voltage transformers at one end of the cable, although only the currents are required for the differential protection function. Direct connection to the other units is effected via single-mode fiber-optic cables and is thus immune to interference. Various communication modules are available for different communication media. In the case of direct connection via fiber-optic cables, data communication is effected at 512 kbit/s and the command time of the protection unit is reduced to 15 ms.

SIPROTEC offers many features to reliably and safely handle data exchange via communications networks. Depending on the bandwidth available a communication converter for G703-64 kbit/s or X21-64/128/512 kbit/s can be selected. For higher communication speed, a communication converter with G703-E1 (2,048 kbit/s) or G703-T1 (1,554 kbit/s) is available.

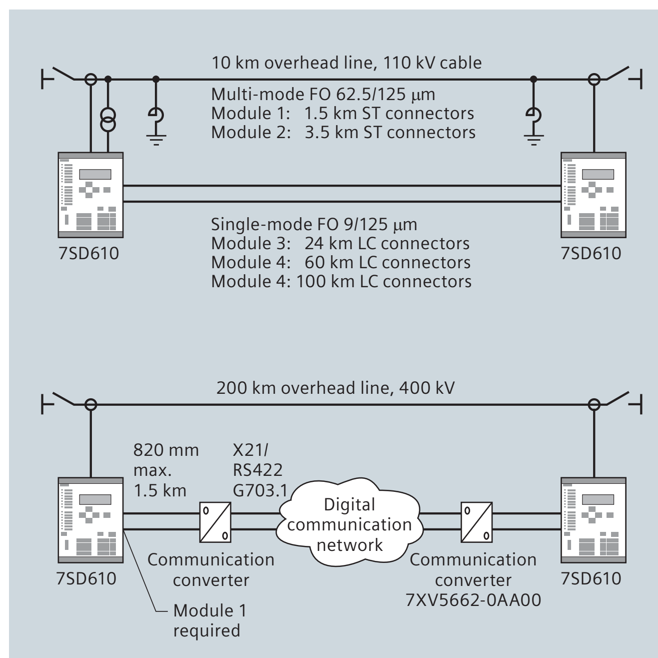


Fig. 8.3-9: **Differential and distance protection applications**

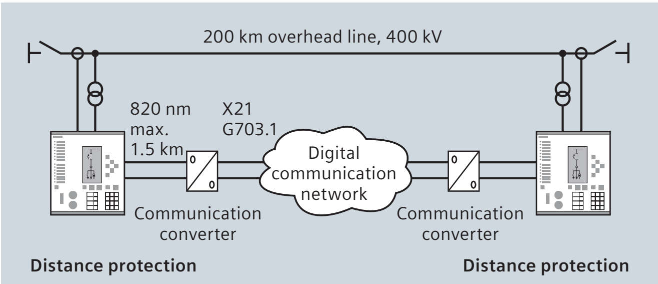


Fig. 8.3-10: **Teleprotection scheme using digital serial communication**

Serial protection data interface

The teleprotection schemes can be implemented using digital serial communication. The distance protection SIPROTEC 7SA6 is capable of remote relay communication via direct links or multiplexed digital communications networks. The link to a multiplexed communications networks is made by separate communication converters (7XV5662). These have a fiber-optic interface with 820 nm and ST connectors to the protection relay. The link to the communications networks is optionally an electrical X21 or a G703.1 interface (fig. 8.3-10).

8.3.4 Requirements for Remote Data Transmission

In principle both RTUs and station automation are very flexible for adapting to any remote communication media supplied by the user.

- Small substations are usually associated with small data volumes and poor accessibility of communication media. Therefore dial-up modems are often used, also radio (if no lines available) or PLC communication. Sometimes even GPRS is an alternative, depending on the availability of a provider. Protocols also depend on the capabilities of the control center, but are mostly based on international standards like IEC 60870-5-101 (serial) and IEC 60870-5-104 (Ethernet), although DNP 3.0 is also found in some places (serial or over TCP/IP). Some small substations do not necessarily need to be online continuously. They can be configured to occasional calls, either locally or by external polling from the control center.
- Medium-size substations are generally connected via communication cables or fiber optics with serial end-end links. Serial lines with 1,200 Bd or higher are sufficient for IEC ...-101 or DNP. Sometimes multiple lines to different control centers are necessary, while redundant communication lines are reserved for important substations only. WAN technology is increasingly used in line with the trend towards more bandwidth.
- Large substations, especially at transmission level, can have serial links as before, but with higher transmission rates. Anyway there is a trend towards wide area networks using Ethernet. For IEC ...-104 or similar protocols a minimum of 64 kbit/s should be taken into account. If large data volumes are to be exchanged and additional services (e.g., Voice over IP, Video over IP) provided, the connection should have more bandwidth (64 kbit/s < Bandwidth ≤ 2,048 kbit/s).

8.4 Control Center Communication

Redundant control center configuration
A typical control center such as Spectrum PowerCC (fig. 8.4-1) can be configured with full redundancy, depending on the safety requirements of the customer. In order to achieve complete redundancy, not only the server components are designed with redundancy, but also the LAN that links the system components.

Process communication to substations and power plants
Process communication to the substations and power plants of a power supply company is implemented via serial interfaces or by means of TCP/IP-based network communication. To increase reliability, these connections are frequently designed with in-built redundancy.

All kinds of different protocols are used for historical reasons. However, as a result of international standardization there is also a market trend here towards standardized protocols. The more recent protocol standards all rely on TCP/IP-based communication. However, it must be possible today and in the near future to continue connecting conventional telecontrol devices (already installed) via serial interfaces.

Interface for industry automation/third-party applications
OPC(tm) (OLE for process control) provides a group of defined interfaces, based on OLE/COM and DCOM technology. OPC enables the overall data exchange between automation and control applications, field systems/field devices and business and office applications, OPC UA (Unified Architecture) as continuation and further innovation of OPC is based on native TCP/IP.

Inter control center communication
The link to other control centers is provided via the communication protocols ICCP or ELCOM and is based on TCP/IP.

Remote workstations/office communication
Remote workstations can communicate with the control center via the office LAN or an Internet connection. The use of a carefully configured security schemes to protect process communication is of crucial significance (section 8.11).

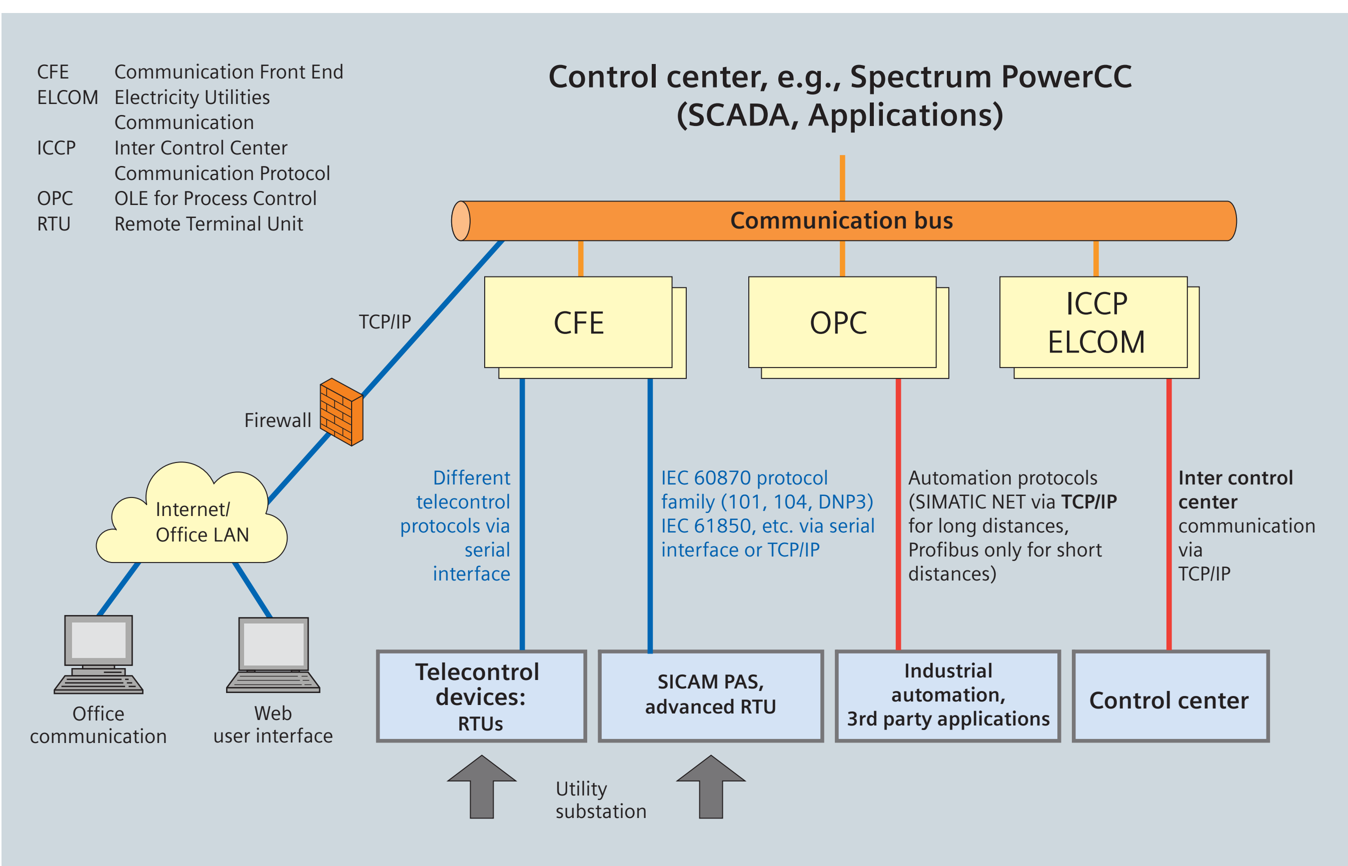


Fig. 8.4-1: **Typical communication interfaces and communication partners of a control center using the example of Spectrum PowerCC**

8.5 High-Voltage Line Communication

8.5.1 Digital Power Line Carrier

The digital power line carrier system PowerLink from Siemens uses the high-voltage line between substations as a communication channel for data, protection signals and voice transmission (fig. 8.5-1). This technology, which has been proven over decades and continuously adapted to the latest standards, is employed for the following applications:

- As communications system for linking substations where there is no fiber-optic link available and where it would not be economical
- As backup system for transmitting the protection signals, in parallel to a fiber-optic link

Fig. 8.5-2 shows the typical connection of the PowerLink system to the high-voltage line via the coupling unit AKE 100, coupling capacitor and line trap.

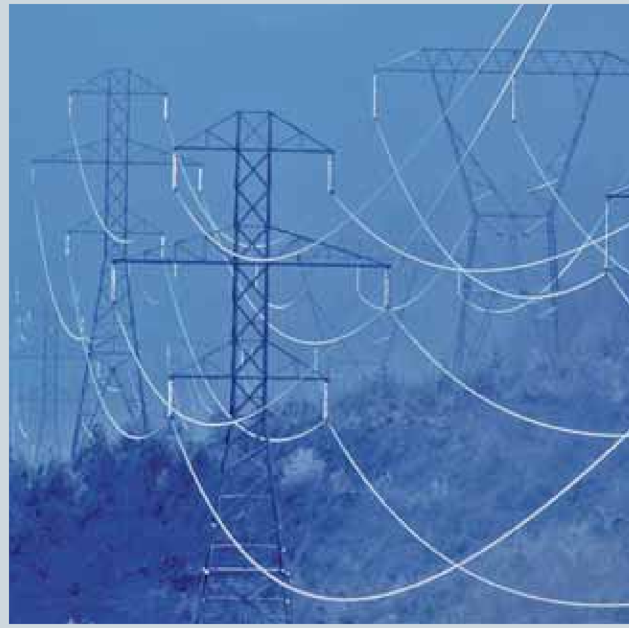
Flexibility – the most important aspect of PowerLink
Versatility is one of the great strengths of the PowerLink system. PowerLink can be matched flexibly to your infrastructure (table 8.5-1).

Variable transmission power
It is possible, for example, to set the system power via the system software in two ranges (20 to 50 W or 40 to 100 W) according to the exact requirements of the transmission route. As far as the transmission itself is concerned, PowerLink operates with variable data rates and bandwidths in the frequency band between 24 and 1,000 kHz, making it easy to comply with specific frequency requirements of customers.

Optimum matching to transmission conditions
PowerLink matches the data rate to changes in ambient conditions. This guarantees optimum transmission power in the network at all times. Due to PowerLink's integral prioritization function, which can be configured for each channel, routing of the most important channels is assured even in bad weather conditions.

Multi-service device
PowerLink offers the necessary flexibility for transmitting every service the customer might want in the available band. All services can be combined in any way within the available bandwidth/bit rate framework.

Automatic crosstalk canceller (AXC)
PowerLink can be operated with or without space between the transmission and reception bands. Band-to-band operation usually requires manual adjustment to minimize the influence of the transmitter on the receiver. AXC automates this adjustment process, thereby optimizing the transmission quality.



Application
Transmission of protection signals, telecontrolling information, data and voice via HV transmission lines
Advantages
Cost-effective for small/medium data volumes over long distances
Use of utility-owned resources
Highest reliability (e.g., for protection signaling)
Smooth integration into all types of communications networks
Works with analog and digital transmission mode at the same time
Integrated versatile multiplexer
Integrated teleprotection system
High-quality voice compression
Powerful management for all applications

Fig. 8.5-1: **Progressive PLC technique with PowerLink**

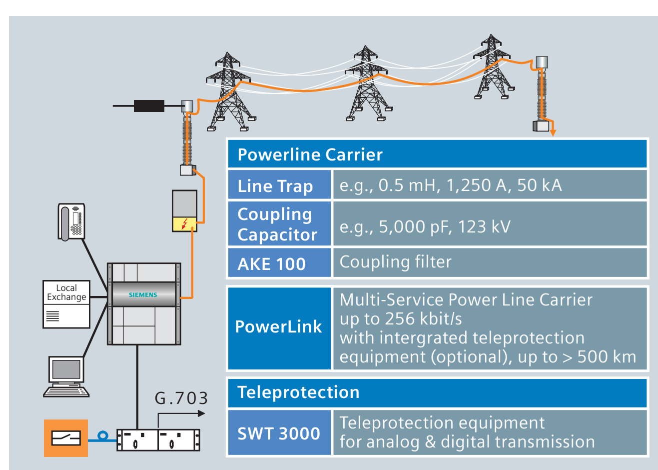


Fig. 8.5-2: **High-voltage line communication (overview)**

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Developed and patented by Siemens, AXC automatically subtracts the interfering transmission signals from reception signals (RX-TX). With changing characteristics of the transmission channel, the quick adaptation of the AXC ensures optimum transmission quality at all times, without time-consuming manual adjustment.

Transmission capacity up to 256 kbit/s
PowerLink offers a transmission capacity of 256 kbit/s, and an integrated TCP/IP interface is available. This means that many different types of IP terminals can use the power line communications network effectively.

Maximum efficiency:
The integrated, versatile multiplexer (vMUX)
A large number of conventional communication interfaces today (e.g., a/b telephone, V.24, X.21, etc.) and in the foreseeable future must be operated in a switching station. For this purpose, PowerLink uses an integrated versatile multiplexer that bundles these communication forms together and transmits them by PLC. The vMUX is a statistical multiplexer with priority control. Asynchronous data channels can be transmitted in “guaranteed” or “best effort” modes, to guarantee optimum utilization of available transmission capacity. The priority control ensures reliable transmission of the most important asynchronous and synchronous data channels and voice channels even under poor transmission conditions. Naturally, the vMUX is integrated in the management system of PowerLink, and is perfectly equipped for the power line communications requirements of the future with extended options for transmitting digital voice and data signals.

Voice compression – less is more
Voice compression is indispensable for the efficient utilization of networks. Naturally, quality must not suffer, which is why PowerLink offers comprehensive options for adapting the data rate to individual requirements. PowerLink offers different compression stages between 5.3 and 8 kbit/s. To prevent any impairment of voice quality, the compressed voice band is routed transparently to PowerLink stations connected in line, without any further compression or decompression.

Protection signal transmission system SWT 3000
A maximum of two independent SWT 3000 systems can be integrated into each PowerLink. This means that no connection components are needed. SWT 3000 systems are also fully integrated into the user interface of the PowerLink administration tool.

One management system for all applications
PowerLink not only simplifies your communications, but also makes communications cost-efficient. The PowerSys software administers all integrated applications of PowerLink under a standard user interface. This ensures higher operating security while cutting training times and costs to the minimum.

Integration of PowerLink in network management systems via SNMP
PowerLink systems can also be integrated in higher level management systems via the IP access by means of the SNMP protocol (Simple Network Management Protocol). System and network state data are transferred, for example, to an alarm, inventory or performance management system.

PowerLink features	Digital	Analog
Universally applicable in analog, digital or mixed operation	■	■
Frequency range 24 kHz–1,000 kHz	■	■
Bandwidth selectable 2–32 kHz	■	■
Data rate up to 256 kbit/s at 32 kHz	■	
Transmission power 20/50/100 W, Fine adjustment through software	■	■
Operation with or without frequency band spacing with automatic crosstalk canceller	■	■
Digital interface		
Synchronous X.21 (max. 2)	■	
Asynchronous RS232 (max. 8)	■	
TCP/IP (2 x electrical, 1 x optical)	■	
E1 (2 Mbit/s) for voice compression	■	
G703.1 64 kbit/s	■	
Analog interface		
VF (VFM, VFO, VFS), max. 8 for voice, data and protection signal	■	■
Asynchronous RS232 (max. 4) via FSK		■
Adaptive dynamic data rate adjustment	■	
TCP/IP Layer 2 Bridge	■	
Integrated versatile multiplexer for voice and data	■	
Max. 5 compressed voice channels via VF interface	■	
Max. 8 voice channels via E1 interface	■	
StationLink bus for the cross connection of max. 4 PLC transmission routes (compressed voice and data) (no voice compression on repeater)	■	
Reverse FSK analog RTU/modem data via dPLC (2 x)	■	
Protection signal transmission system SWT 3000		
Integration of two devices	■	■
Remote operation via cable or fiber-optic cable identical to the integrated version	■	■
Single-purpose or multi-purpose/alternate multi-purpose mode	■	■
Element Manager based on a graphical user interface for the control and monitoring of PLC and teleprotection systems	■	■
Remote access to PowerLink		
Via TCP/IP connection	■	■
Via inband service channel	■	■
SNMP compatibility for integrating NMS	■	■
Event memory with time stamp	■	■
Simple feature upgrade through software (ease-up!)	■	■

Table 8.5-1: **Overview of features**

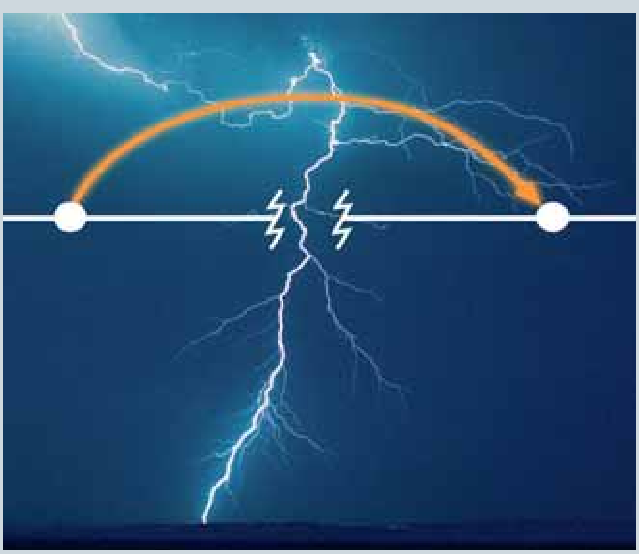
8

8.5.2 Protection Signaling System SWT 3000

The SWT 3000 is an extremely secure and reliable system for transmitting time-critical commands via analog and digital transmission channels (fig. 8.5-3). This enables faults in the high-voltage network to be isolated selectively as quickly as possible. The SWT 3000 system can be integrated in the PowerLink system or be operated as a standalone system. Fig. 8.5-4 shows the different analog and digital transmission paths between SWT 3000 systems.

Security, reliability and speed of protection signal transmission is one of the central factors in the operation of high-voltage networks. The SWT 3000 system has been developed strictly in line with these requirements. For maximum operating reliability it can be configured with two separately fed power supplies (e.g., 1x AC + 1x DC) for connection to totally separate circuits.

If possible, protection signals should be transmitted over two alternative communication paths to safeguard maximum transmission security. The SWT 3000 system offers a variety of different interfaces (fig. 8.5-4) in order to fulfill this requirement.



Application
Transmission of protection signals to quickly identify, isolate and resolve problems in the transmission network of a utility
Advantages
Use of analog and digital transmission paths for a high degree of security while lowering inventory requirements and reducing training needs
Multiple transmission routes for a flexible redundancy concept
Fast, reliable and secure for a minimum downtime of the transmission network
The power supply company can use its own resources efficiently

Fig. 8.5-3: **Protection signaling SWT 3000 (Overview)**

1 2 **Pilot cable connections**
For operation via pilot cable, two SWT 3000 devices can be linked directly throught the analog interfaces (CLE).

3 The analog link (CLE) between two SWT 3000 devices can also be a PLC link. Depending on the device configuration, SWT 3000 can be used with PowerLink in alternate multi-purpose, simultaneous multi-purpose or single-purpose mode.

4 12 **Fiber-optic connections between SWT 3000 and PowerLink**
A short-distance connection between an SWT 3000 and Siemens' PowerLink PLC terminal can be realized via an integrated fiber-optic modem. In this case, an SWT 3000 standalone system provides the same advanced functionality as the version integrated into PowerLink. Each PowerLink can be connected to two SWT 3000 devices via fiber-optics.

5 6 7 11 **SWT 3000 digital connections**
The digital interface (DLE) permits protection signals to be transmitted over a PDH or SDH network.

6 7 9 11 12 14 **Alternative transmission routes**
SWT 3000 enables transmission of protection signals via two different routes. Both routes are constantly used. In the event that one route fails, the second route immediately takes over without any loss of time.

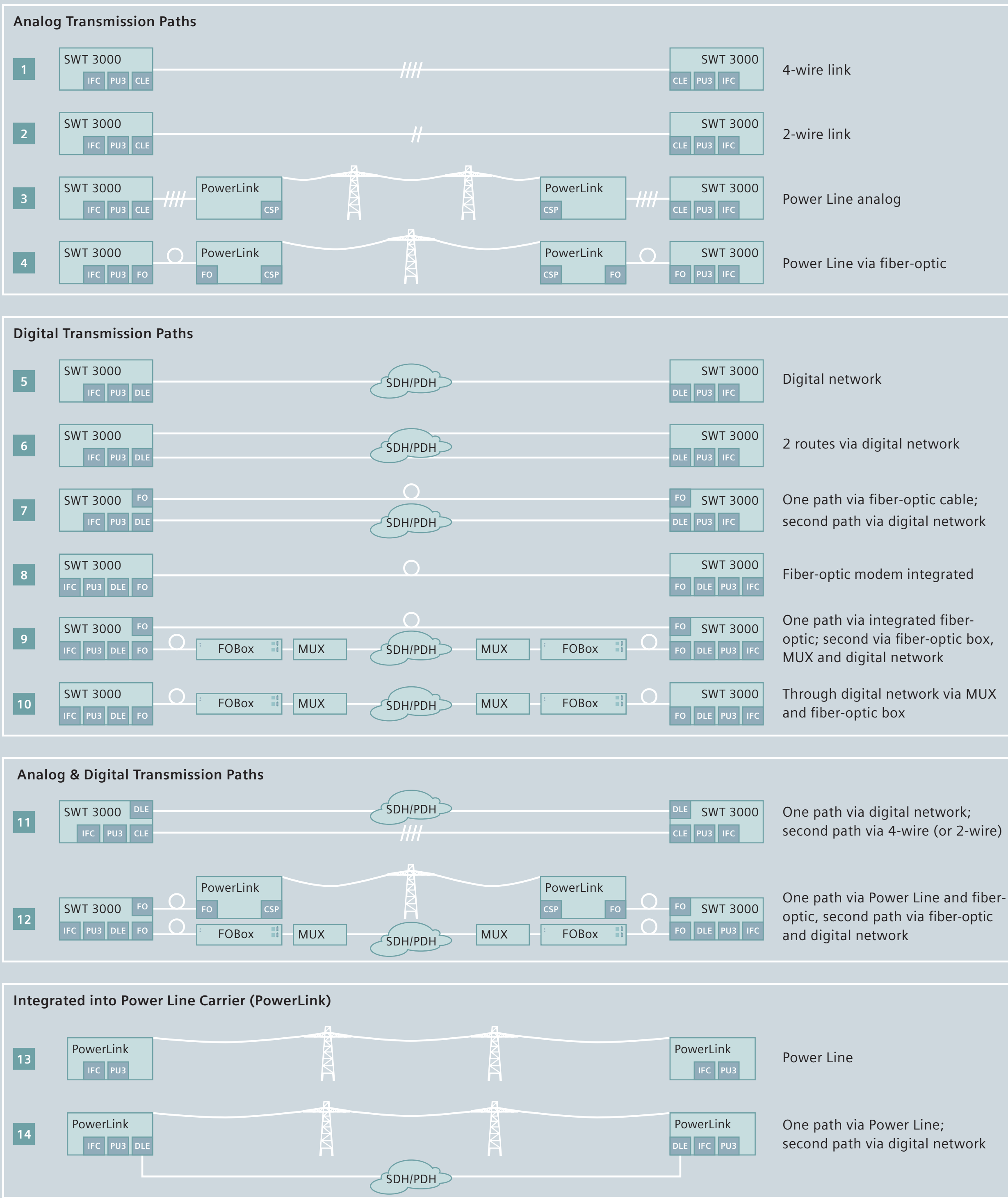
7 8 9 **Direct fiber-optic connection between two SWT 3000 devices**
SWT 3000 protection signaling incorporates an internal fiber-optic modem for long-distance transmission. The maximum distance between two SWT 3000 devices is 150 km.

9 10 12 **Fiber-optic connection between an SWT 3000 and a MUX**
A short-distance connection of up to 3 km between an SWT 3000 and a multiplexer can be realized via an integrated fiber-optic modem. The multiplexer is connected with the SWT 3000's FOBox, converting the optical signal to an electrical signal.

13 14 **SWT 3000 integration into the PowerLink PLC system**
An SWT 3000 system can be integrated into the PowerLink equipment. Either the analog interface or the digital interface, or a combination of the analog and the digital interfaces, can be used.

Fig. 8.5-4: **SWT 3000 transmission paths**

PowerLink	Power Line carrier system	PU3	Processing Unit
IFC	Interface Command	SDH	Synchronous Digital Hierarchy
DLE	Digital Line Equipment	FOBox	Fiber-optic box
CLE	Copper Line Equipment	FO	Fiber-optic module
PDH	Plesiochronous Digital Hierarchy	MUX	Multiplexer



8

8.5.3 Coupling Unit AKE 100

The PLC terminals are connected to the power line via coupling capacitors, or via capacitive voltage transformers and the coupling unit. In order to prevent the PLC currents from flowing to the power switchgear or in other undesired directions (e.g., tapped lines), traps (coils) are used, which are rated for the operating and short-circuit currents of the power installation and involve no significant loss for the power distribution system.

The AKE 100 coupling unit from Siemens described here, together with a high-voltage coupling capacitor, forms a high-pass filter for the required carrier frequencies, whose lower cut-off frequency is determined by the rating of the coupling capacitor and the chosen matching ratio.

The AKE 100 coupling unit is supplied in four versions and is used for:
- Phase-to-earth coupling to overhead power lines
- Phase-to-phase coupling to overhead power lines
- Phase-to-earth coupling to power cables
- Phase-to-phase coupling to power cables
- Intersystem coupling with two phase-to-earth coupling units

The coupling units for phase-to-phase coupling are adaptable for use as phase to-earth coupling units. The versions for phase-to-earth coupling can be retrofitted for phase-to-phase coupling, or can as well be used for intersystem coupling.

8.6 Communication on Cable

8.6.1 Cable

Siemens offers suitable cables for all environmental requirements. All cables are delivered according to the individual specification.

8.6.2 FWT 2000i

Monitoring, control and optimization of technical processes spread over a large geographical area require extremely reliable data transmission systems. The AF transmission system FWT 2000i from Siemens is used for transmitting digital signals through binary frequency modulation Frequency Shift Keying (FSK).

All transmission rates from 50 to 2,400 Bd can be set in all frequencies within a 30 Hz allocation scheme, including the ITU-T frequency raster . The FWT 2000i system permits transmission in the frequency range from 300 to 7,200 Hz.

The modularity of the KS 2000i channel unit, which is part of the system FWT 2000i, is typified by its integration in various other systems, i.e., its use is not limited to the FWT 2000i system. For instance, the channel unit can be integrated in RTUs. By using additional modules, the system can be extended for alternative path switching.

A variety of supervisory facilities and automatic fault signaling systems ensure optimum operation and fault-free transmission of data. Suitable transmission media are communication cables and VF channels of Power Line Carrier systems.

The overall concept of the FWT 2000i system meets the stringent demands placed on power supply and distribution networks. The FWT 2000i meets the special requirements with regard to reliable operation and electromagnetic compatibility.

8.6.3 SWT 3000 connected to Cables

The SWT 3000 system can be connected directly to 2-wire and 4-wire lines (analog) and to fiber-optic cables (digital), (section 8.5.2).

8.6.4 Live Line Installation of OPGW

For a long time, network operators have faced a severe disadvantage installing OPGW. During installation, the respective transmission lines had to be de-energized for safety reasons, interrupting operation and thus creating additional costs. Live line installation (fig. 8.6-1), developed in a joint project by Siemens and a team at Dresden University in Germany, allows to avoid these costs, because the high-voltage line can continue in operation during OPGW installation. Safety of both personnel and equipment is the utmost priority.

Live line installation provides a new earthing concept as well as new pulling machines and brakes on the ground. During OPGW installation, the existing ground wire serves as a messenger and carries all the installation equipment, such as pulleys, the fully dielectric prepulling rope and the OPGW itself. Thus, the new hybrid cable can be pulled from tower to tower across the entire delivery length. In high-voltage lines, the usual delivery length is approximately 4 km.

Built-in advantages

Optical fibers are ideal for integration into a ground wire for high-voltage transmission lines. Because they offer the lowest attenuation values, they allow you to span large distances without the need for a repeater. At the same time, they transmit telecommunication signals optically, protecting data from atmospheric disturbances, lightning or inductance of the high-voltage lines. The enfolding ground wire not only electrically safeguards the high-voltage transmission lines, but it also serves as a mechanical protection for the optical fibers inside. Today, OPGW with 96 integrated optical fibers are state of the art, yet the new OPGW's diameter does not necessarily exceed that of an existing ground wire. Furthermore, a pair of optical fibers can transport up to 10 Gbit/s, a vast amount of data that can even be increased by a factor of 10 using wavelength division multiplex (WDM) technologies.

Application
Changing of existing ground wire into OPGW
Exchange of existing ground wire
Additional OPGW installation between the crossarms
Advantages
Installation of OPGW where shutdown of OHV line is not possible
Connection of areas that are currently inaccessible
No risk of overload of other OHV lines during installation, network security keeps guaranteed
Secure installation based on proved processes, experienced teams and special designed tools and accessories

Fig. 8.6-1: **Live line installation of optical ground wire**

8.7 Backbone/Access Multiplexer

8.7.1 SURPASS HiT70xx Product Line

Fig. 8.7-1 shows a typical utility backbone network based on SURPASS hiT70xx products. This configuration (control center, substation C) is based on TCP/IP communication throughout which is transmitted transparently via SDH technology (Synchronous Digital Hierarchy). The different devices in a substation are connected via switch/router to the particular SURPASS hiT system. In substation B it is shown how the connection to a remote substation can be set up using SDH technology by connecting another hiT system (e.g., hiT7025).

Substation A in fig. 8.7-1 shows the connection of an access multiplexer. Devices with conventional interfaces (e.g., V.24, X.21, a/b, etc.) can be connected via the FMX 2 multiplexer. Section 8.7.2 describes this technology in greater detail. Fig. 8.7-2 shows an overview of the SURPASS hiT70xx product family.

The SURPASS hiT70xx product family covers bandwidths from STM 1 (155 Mbit/s) to STM 64 (10 Gbit/s) with SDH (Synchronous Digital Hierarchy) technology. The functions of the SURPASS hiT70xx product line are described briefly using the example of the SURPASS hiT7035.

SDH SURPASS hiT7035

The SURPASS hiT 70xx series (fig. 8.7-3) is the new Siemens multi-service provisioning platform (MSPP) enabling true multi-service provisioning and serving the requirements of emerging converged networks.

SURPASS hiT 7035 is a highly versatile equipment in terms of its applications and equipping options. While covering the complete range from an STM-1 to an STM-16 system, full-blown ADM-4 or compact ADM-16 applications will form the prime usage. The upgrade to higher bandwidth can easily be effected by simply exchanging the interface board. SURPASS hiT 7035 can support a large variety of data interfaces including Ethernet and ATM-IMA (Inverse Multiplexing over ATM), as well as industry-standard PDH/SDH interfaces.

The system also supports Ethernet Layer 2 switching functionality, providing reliable and efficient data transport. The card commonality within the SURPASS hiT 70xx family members simplifies holding of spares and operational logistics.

Key features are:

- Non-blocking 15.2G@VC-12 with one STM-16/STM-4 port interface on single fabric
- Non-blocking 7.2G@VC-12 with one STM-4/STM-1 port interface on single fabric (used in this project)
- Multi-service platform: 2M, 34/45M, 155M, STM-1/4/16, 10/100BT, GbE
- GFP (Generic Framing Procedure), LCAS (Link Capacity Adjustment Scheme) and VCAT (Virtual Concatenation)

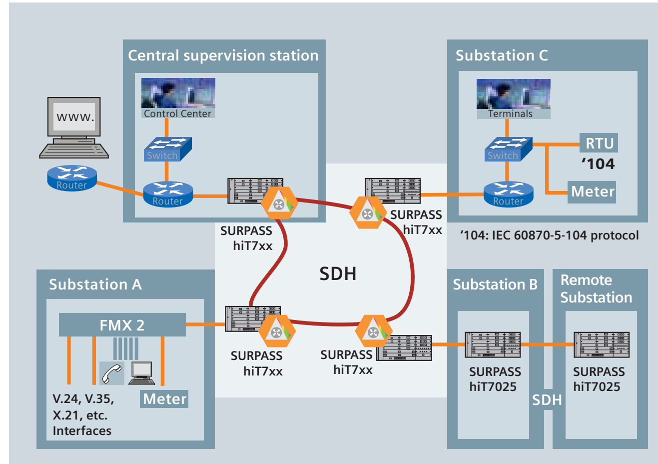


Fig. 8.7-1: **Utility backbone communication with SURPASS hiT**

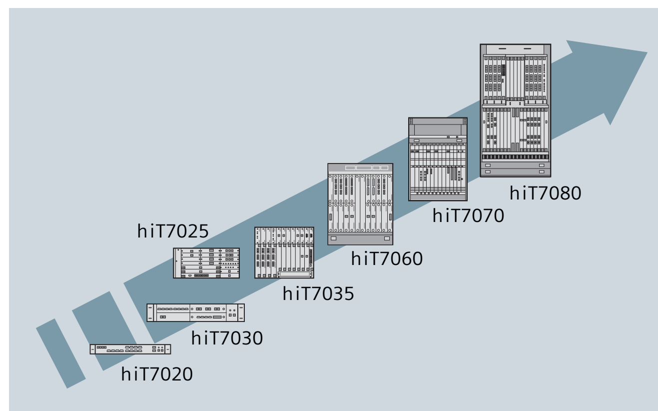


Fig. 8.7-2: **SURPASS hiT70xx portfolio (overview)**

Fig. 8.7-3: **SURPASS hiT 70xx series**

- Layer 2 switching and aggregation
- ATM-IMA aggregation
- Extensive protection mechanisms (SNCP, MSP, 2F-MS-SPRing, hardware)
- Data traffic protection scheme via RSTP
- Suitable for 19 and ETSI racks

8.7.2 FMX 2 Access Multiplexer

Today there is a need to operate a number of different conventional communication interfaces in one substation (e.g., a/b phone, ISDN, V.24, X.21, etc.) and this will also apply in the near future. For this purpose, access multiplexers are used to bundle these communication signals and pass them on to the backbone system. Fig. 8.7-1 shows the interaction of hiT7xxx and FMX 2 system.

FMX 2 can be employed to create flexible networks which can react rapidly to changes in network requirements. The modular design enables channel units to be combined as required for telephone, data and ISDN signal transmission. The multiplexer allows free assignment of user interfaces to the channels in the 2-Mbit/s signal and rapid configuration. Fig. 8.7-4 shows an overview of the interfaces provided by the FMX 2 system.

As already described, many power supply companies have already installed fiber-optic cables alongside existing high-voltage cables. Fig. 8.7-5 shows the configuration via a high-voltage line with the necessary communication components in the backbone and access area.

8.7.3 SWT 3000 Connected to FMX 2 and SURPASS hiT

The SWT 3000 system can also be connected directly via a fiber-optic box to the FMX 2 system and to SURPASS hiT (section 8.5.2).

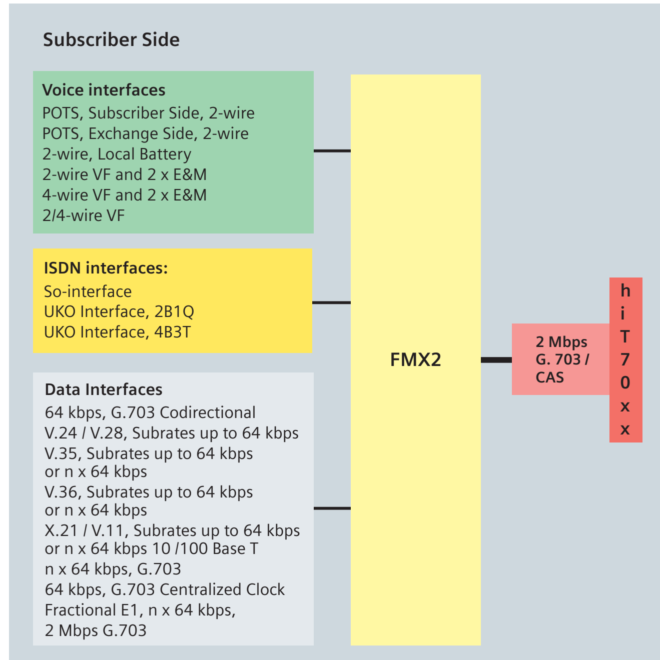


Fig. 8.7-4: **Flexible multiplexer FMX2 interfaces**

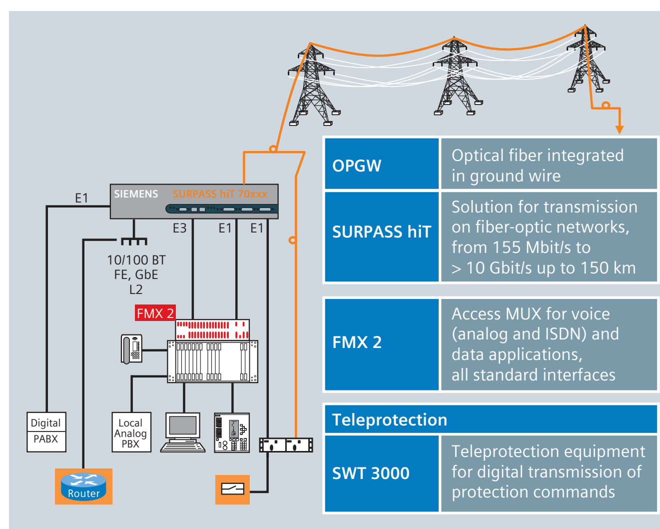


Fig. 8.7-5: **OPGW backbone network and access MUX (overview)**

8

8.8 Medium-Voltage Line and Low-Voltage Line Communication

Section 8.5.1 described how data can be transferred over high-voltage lines with the aid of a Power Line Carrier system. Owing to technical fundamentals and the available frequency ranges, only narrow-band data communication has been possible up to now.

There is sharply increasing demand at power supply companies for broadband data communication via power lines, especially in the access area of the medium-voltage and low-voltage networks. This would allow a communications infrastructure for process control to be built up quickly and cheaply at MV level between substations and transformers, and further down on the LV level to individual customers. To meet these requirements, Siemens in particular is intensifying efforts to standardize BPL (Broadband Power Line) technology. This section briefly describes some typical applications that can be implemented on the basis of BPL technology.

At present, small medium-voltage substations or transformers often do not have any communication link to the control center. Thanks to BPL technology, it would be possible to incorporate the MV level at low cost into the process communication of a distribution network. For example, information about the state of transformers, power quality, etc. could be scanned regularly and transmitted to the control center. Video surveillance of a transformer via BPL would also be possible.

The steady increase in the number of small decentralized power generators (e.g., private photovoltaic plants) also results in further large demand for communications at medium-voltage level. These small generators must be incorporated in the communications network of the power supply companies for optimum controlling of the power supply system.

As part of the integrated Siemens total solution for the automated consumption data acquisition and information system (AMIS), the low-voltage network is used today at the lowest network level (connection of terminals to the transformer substations). For this purpose, special narrowband communication technology has been developed that allows high-availability, secure communication over the power supply system. The corresponding modems are a fixed component of the terminals (meters, load switching devices, gateways to third-party equipment) and the data concentrators of the transformer substations. The modem integrated in the terminals and data concentrators in the transformer substation is fully implemented in the firmware with regard to the physical layer and the communication protocol, and as such can be adapted to communication standards of the future without problem by means of a firmware download.

The greatest potential benefits arise, however, when the BPL infrastructure can be routed seamlessly via the medium-voltage and low-voltage level right up to private households. The power supply companies would be able to offer consumers new services on this basis without having to lay new cables. These services could be, for example, applications for power utilities such as smart metering applications or telecommunication services or IP telephony. So-called Smart Home applications such as remote utility management, security and surveillance as well as appliance monitoring could also be implemented using BPL technology (fig. 8.8-1).

Siemens is working intensively to implement this technology and will offer corresponding products as soon as standardization is completed.

Application
New product for the increasing communication requirements of smart grid applications
Transmission of telecontrolling and monitoring information for energy automation in the MV distribution area
Extension of the utilities communication network to LV areas
Advantages
Use of existing infrastructure (powerline) as transmission medium
Connection of areas that are currently inaccessible
Use of utility-owned resources
Opportunity for value-added services (e.g., broadband access, home security, ...)

Fig. 8.8-1: **Broadband Power Line Carrier for MV and LV communication**

8

8.9 Wireless Communication

The previous sections dealt exclusively with wireline communication technologies. In many cases, though, laying of cables is scarcely possible because of the particular environment, or is not feasible economically. Siemens can address the complete telecommunication spectrum of wireless solutions, ranging from simple low-power radio data modems, via complex point-to-point or point-to-multipoint VHF or UHF solutions, to space diversity or frequency diversity microwave systems covering the largest possible distances. Siemens is familiar with state-of-the-art technologies such as GSM and satellite communications systems.

8.9.1 Transmission Technologies

VHF/UHF point-to-point and point-to-multipoint communication

This technology is used predominantly in the medium-voltage area for connecting RTUs to a substation. With VHF/UHF technology, a distance per transmitter station of 30–40 km can be spanned. The available bandwidth varies between 2.4 and 19.2 kbit/s. Reception problems in cities, especially in the vicinity of multi-level buildings must be taken into account.

Depending on the frequency range and the number of frequencies available, we are able to design, deliver and commission nation-wide systems including many hundreds of master radio stations, and thousands of remote radio stations, distributed over virtually any configuration of primary and secondary substations. The individual radio links may be configured as point-to-point, or point-to-multipoint links. Data, voice, or voice and data can be transmitted via such links.

Radio data modem systems

Radio data modem systems are also based on VHF/UHF transmission (bandwidths 2.4–19.2 kbit/s), although they can also be used in the form of low-cost compact systems for smaller ranges (max. 20–30 km), for example in urban areas. The main application purpose is again the connection of RTUs to substations in the MV range.

Such compact systems have in the past been self-contained with small remote terminal units, and mounted on poles just below transformer or switchgear equipment, thus saving costly additional civil works. One advantage in using intelligent systems, whereby alternative routes may be preprogrammed, is a significant increase in reliability and availability per cost.

Trunk radio

Especially suited to grouped voice and data transmission are trunk radio systems. These systems are also commonly used by security services such as police and ambulance and fire services, etc. around the world. Such systems can be analog or digital, having the advantage of being able to group recipients together dynamically – a huge advantage, for example, to management and maintenance teams, etc.

New systems are based almost exclusively on digital technology. A message channel of 64kbit/s for voice and data is available. The range of a transmitter station is approximately 30–40 km. This technology is employed at utilities first and foremost for voice and data communication by maintenance engineers in the MV sector.

Microwave

When high bandwidths are required, for say transmitting large amounts of data and, for example, video as well, microwave links may be suitable. Invariably such links are used for backbone data transmission over longer distances (point-to-point, 50–70 km) in the HV transmission area, if fiber optic is not available. Such equipment is highly reliable, offering very high degrees of availability. Various bandwidths are available in the megabit range for this medium.

Satellite systems

Satellite systems may be an interesting alternative where terrestrial conditions pose problems, i.e., ensuring radio coverage, or gaining civil works permits present difficulties. Leasing satellite bandwidth, (depending on the bandwidth and transmission time), may present a cost-effective solution, even base-station equipment may be leased, thus minimizing start-up costs for the system operator. This technology is used essentially for communication with far distant RTUs. Bandwidths from 64 kbit/s up to the STM range are available for voice and data.

GSM/GPRS

GPRS (General Packet Radio Service) is a service within the GSM network, just like the two most popular services: SMS and voice connections. GPRS is used for transmitting data (data rates up to 171.2 kbit/s) in the GSM network in packet form. The actual data rate depends on the availability of free time slots within the GSM and the multislot class of the modem, as well as the coding scheme used (CS-1, CS-2, CS-3, CS-4).

GPRS provides a cost-effective leased line that is connected continuously. It can be used within the GSM coverage, and the costs depend on the data packets sent.

WLAN

Wireless LAN stands for wireless local area network, and usually refers to a standard of the IEEE 802.11 family. The data rates of the different standards are shown briefly in table 8.9-1. In the analysis of data rates it must, however, be taken into account that all equipment in the network shares the bandwidth for uploading and downloading. The specified data rates are still gross values, and even under optimum conditions the attainable net data rate is only just over half these figures.

The effective isotropic radiated power (EIRP) of 100 mW (2.4 GHz) or 500 mW (5.4 GHz) of standard commercial 802.11 terminals allows a range of 30 to 100 meters in an open area. With external omnidirectional antennas, a range of 100 to 300 meters can be spanned outdoors on a line-of-sight link. The achievable range is heavily dependent on obstacles as well as the type and form of buildings in the area.

WLAN could theoretically be used by utilities in the substation area or possibly for linking households in the distribution area. In the past, environmental constraints as well as doubts about security have prevented installation of WLAN technology on a larger scale in the utility sector.

WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a synonym for standard IEEE 802.16 (table 8.9-2). With this technology, broadband accesses are available, for example, to the Internet via wireless network. The corresponding network is currently being extended by various suppliers.

WiMAX is introduced to a different degree in different countries. In Germany, WiMAX licenses for frequencies in the range from 3,400 to 3,600 MHz were auctioned off by the Bundesnetzagentur, the German telecoms regulator, in December 2006. 15 percent of the municipalities in the particular supply area must be covered by the end of 2009, and 25 percent by the end of 2011. The first commercial WiMAX products are now available in Germany.

In the utility environment, WiMAX is an option primarily for communication in the distribution area. Initial projects for remote meter data reading are currently planned. To what extent WiMAX can also be used for safety-relevant process communication is still open. The regional availability of WiMAX frequencies must be generally checked for projects.

IEEE 802.11	2 Mbps maximum
IEEE 802.11a	54 Mbps maximum (108 Mbps at 40 MHz bandwidth proprietary)
IEEE 802.11b	11 Mbps maximum (22 Mbps at 40 MHz bandwidth proprietary, 44 Mbps at 60 MHz bandwidth proprietary)
IEEE 802.11g	54 Mbps maximum (g+ =108 Mbps proprietary, up to 125 Mbps possible; 2 Mbps in mixed mode (g+b) with IEEE 802.11b)
IEEE 802.11h	54 Mbps maximum (108 Mbps at 40 MHz bandwidth)
IEEE 802.11n	300 Mbps Draft 2.0 passed on 19 March 2007 as the new draft

Table 8.9-1: **Data rates of the different WLAN standards**

Standard IEEE 802.16 (WiMAX)
Standard IEEE 802.16 belongs to the family of 802 standards, which also includes 802.3 Ethernet, 802.5 Token Ring or 802.11 Wireless LAN. Certain commonalities therefore exist with these standards, such as, for example, the underlying layer model (OSI model). WiMAX only specifies the two lowest layers in this model. Unlike Wireless LAN, with WiMAX the so-called base station is a central entity that decides who may and who may not transmit.
Great importance was attached to high transmission rates with very low latency times (reaction times). An operating mode with guaranteed bandwidths is also integrated. This quality of service (QoS) option is important, for example, for telephony and video applications so that these are not suddenly interrupted due to insufficient bandwidth.
The most important WiMAX/IEEE-802.16 standards are: • IEEE 802.16-2004 (also called WiMAX fixed, changing the wireless cell in operation is not possible) • IEEE 802.16e-2005 (WiBro, also called WiMAX mobile, changing the wireless cell in operation is possible)
WiMAX is under discussion both as a stationary (fixed) and also a mobile alternative (WiBro) or addition to DSL lines and UMTS connections. The radius of coverage of a base station in an urban environment is usually between 2 and 3 km. In field tests the limits of performance of WiMAX were 50 km for range and max. 108 Mbit/s for data transfer rate. As with UMTS, all participating users have to share the available bandwidth.
As of February 2007 there were over 430 technology companies and institutions amalgamated in the WiMAX Forum with the object of ensuring the compatibility of WiMAX with the products of the various manufacturers through standardization of WiMAX. This also includes leading network equipment manufacturers such as Motorola and Siemens, large network operators such as AT&T and British Telecom and mobile phone equipment suppliers such as Nokia and Ericsson.

Table 8.9-2: **Standard IEEE 802.16**

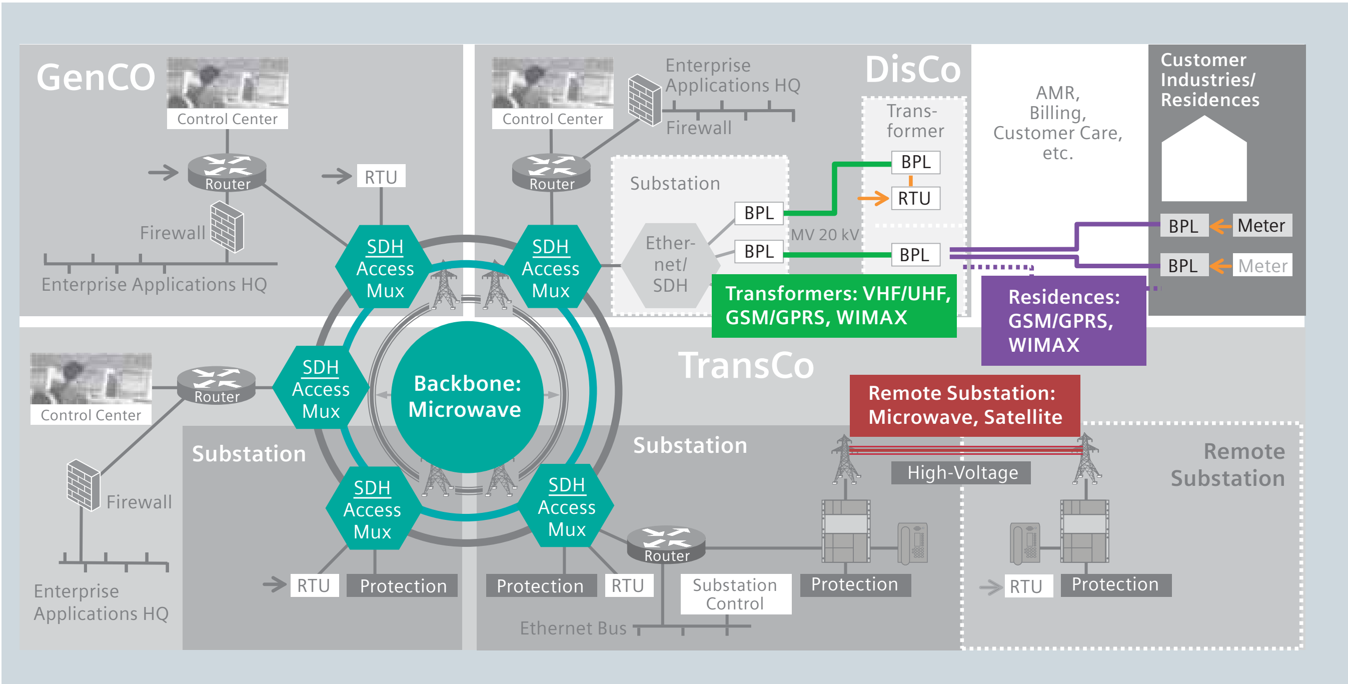


Fig. 8.9-1: **Overview of wireless options**

8.9.2 Overview of Wireless Alternatives

Fig. 8.9-1 provides an overview of the most important wireless applications. For all wireless systems, Siemens is able to provide radio coverage studies, from shortwave to microwave systems in the upper GHz frequencies. Siemens owns and therefore utilizes Pathloss 4.0 software. Obviously an "office" study can never replace a site survey, but Siemens has proven in a multitude of projects that such a study offers an excellent basis for when Siemens conducts an actual local site survey.

Siemens is able to offer highly efficient performance-based solutions. The main aim is to offer cost-effective quality solutions; to this end, Siemens minimizes the use of expensively high antenna towers, costly antenna hardware and the use of repeater stations (fig. 8.9-2).

Application
Wireless solutions are used for all environments where cable based communication is not applicable or too expensive
Advantages
Siemens as a system integrator has the expertise to integrate all kinds of wireless solutions depending on customer-specific requirements
Reliable solutions with fast network deployment, even in harsh environments
Cost-effective solutions as an alternative to leased lines

Fig. 8.9-2: **Overview of wireless options**

8.10 Voice Communication with PowerLink

The TCP/IP protocol is gaining increasing acceptance in the voice communication area. However, considerably higher bandwidth requirements must be taken into account in network planning with VoIP compared with analog voice links. Table 8.10-1 shows the bandwidth requirement for a voice link via TCP/IP as a function of the codec used for voice compression.

In the office area today, the LAN infrastructure is usually sufficiently generously dimensioned to make VoIP communication possible without any restrictions. The situation is distinctly different if it is necessary to connect distant substations to the utility's voice network. If these locations are not integrated in the corporate backbone network, Power Line Carrier connections must be installed. Fig. 8.10-1 shows the basic alternatives for voice communication via PowerLink.

8.10.1 Analog Connection

The telephone system is connected to the PowerLink via the analog E&M interface. A telephone system or an individual analog telephone can also participate in a PowerLink system at a different location. The bandwidth requirement can be reduced to about 6 kbit/s (including overload) per voice link by means of voice compression in the PowerLink.

8.10.2 Digital Connection

With digital connection, the telephone system is connected to PowerLink via the digital E1 interface. Because of the restricted bandwidth, up to 8 of the 30 voice channels (Fractional E1) can be used. This alternative is only suitable for communication between telephone systems. Individual telephones must be connected locally to the particular telephone system. The bandwidth requirement is made up of the user data per voice channel (e.g., 5.3 kbit/s) and the D-channel overhead for the entire E1 link (approximately 2.4 kbits/s), (i.e., for a voice channel less than 10 kbit/s).

In the case of series connected locations with both analog and digital connection, multiple compression/decompression of the voice channel is prevented by the unique PowerLink function "StationLink".

Codec	Net bit rate	Gross bit rate
G.711	64 kbit/s	87.2 kbit/s
G.726	32 kbit/s	55.2 kbit/s
G.728	16 kbit/s	31.5 kbit/s
G.729	8 kbit/s	31.2 kbit/s
G.723.1	5.3 kbit/s	20.8 kbit/s

Table 8.10-1: **Bandwidth requirement for VoIP**

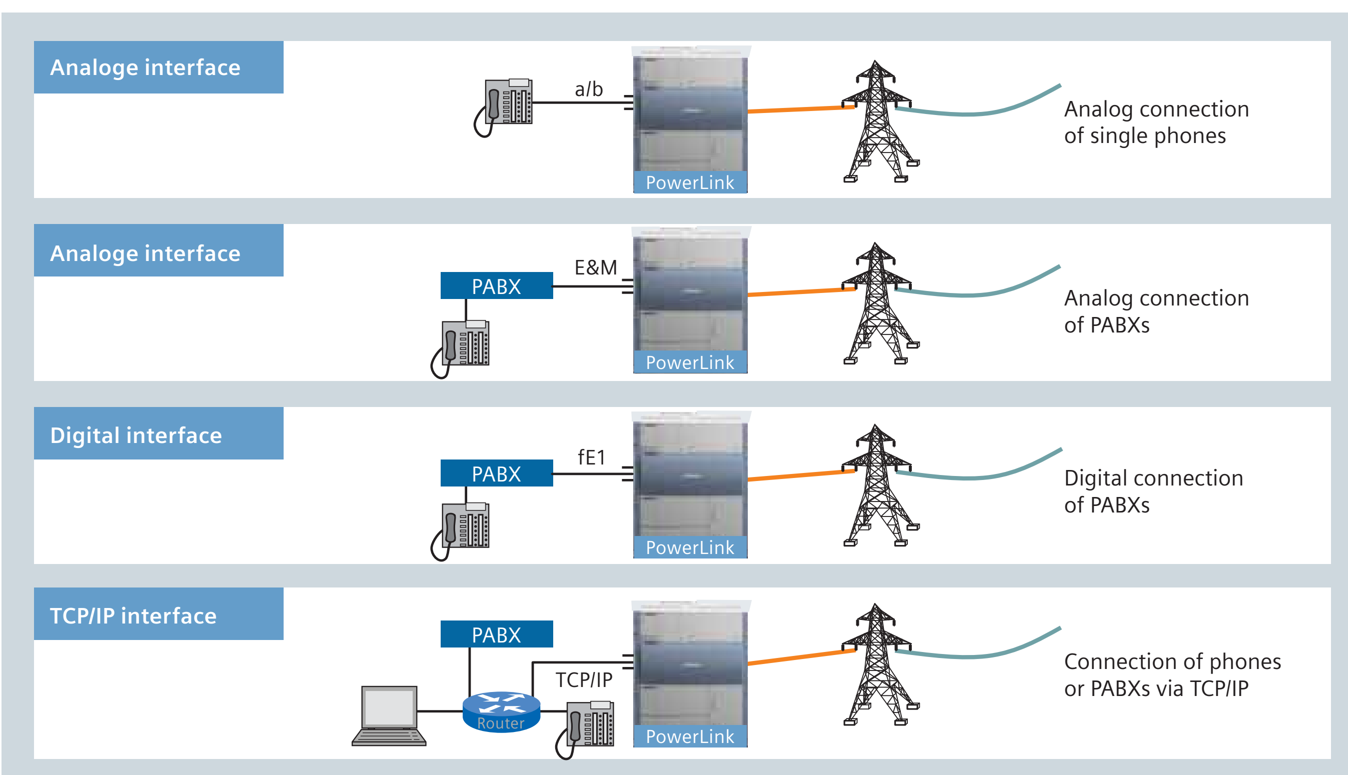


Fig. 8.10-1: **Basic options of voice communication via PowerLink**

8.10.3 TCP/IP Connection

The telephone system, voice terminals and the PowerLink system are connected directly to the TCP/IP network. Voice communication is conducted directly between the terminals. Only control information is transmitted to the telephone system. Use of the TCP/IP protocol results in a broadband requirement per voice channel of at least 21 kbit/s (5.3 kbit/s voice plus TCP/IP overhead).

8.10.4 Telephone Systems

The limited bandwidth availability of Power Line Carrier systems in the high-voltage area will ensure an important role for conventional telephone systems with analog interfaces in this segment in the future as well. Fig. 8.10-2 shows an overview of the HiPath product line from Siemens Enterprise Communications.

The HiPath 3000 and HiPath 4000 systems are known as "converged systems" providing IP as well as all conventional analog and digital interfaces.

HiPath 2000 and HiPath OpenOffice are optimized as "Native IP Systems" for communication between IP terminals. Apart from the specified communication systems, Siemens Enterprise Communications also offers a large number of applications, terminals and services (fig. 8.10-3).

Application
Operational and enterprise voice communication
Advantages
Highly scalable solutions from single analog phones up to corporate IP solutions
Voice compression for optimized integration of narrow band systems
StationLink feature avoids decompression/compression of voice connections via multiple PowerLink stations
Integration of mobile clients
Feature rich applications and clients

Fig. 8.10-3: **Voice communication with PowerLink**

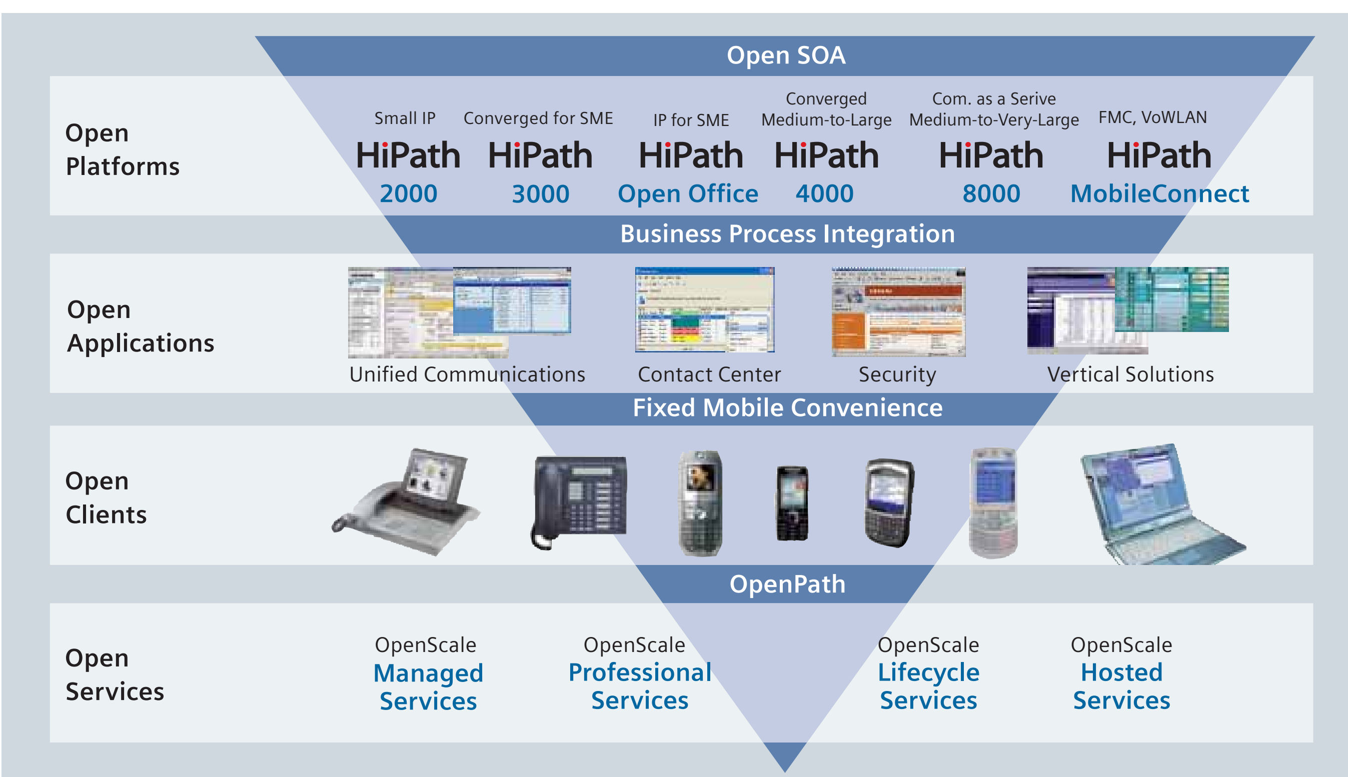


Fig. 8.10-2: **HiPath product range and service offerings**

8.11 IT Security

If you imagine plant availability as an equation with a large number of variables, dependable IT security is one of the essential variables. It comprises, in particular, protection against unauthorized access, physical attacks and operator errors as well as internal or external threats. What counts more than anything ultimately, though, is the result, namely a functioning energy automation system. That is precisely the philosophy of Totally Integrated Energy Automation (IT Security). Integral solutions combine the individual variables to create a transparent equation that is maximized with regard to system uptime. With Totally Integrated Energy Automation, Siemens offers an IT security concept that not only ensures the confidentiality and integrity of data, but most importantly its availability. Users profit especially from the simplified workflow, reliable operation and significantly reduced total costs of ownership.

8.11.1 Integral Approach

The graphical display of the security network or network blueprint, as it is called, forms the infrastructure and architecture of a system. It is the basis for a clear segmentation with which the risk for every link in the automation chain can be analyzed precisely – while still keeping an eye on the impact on the system as a whole.

The network is therefore divided up into manageable zones in order to equip them with precisely the IT security that is necessary and worthwhile in order to protect the data in this zone, as well as ensuring smooth operation of the system at the same time (fig. 8.11-1).

The zones are protected at network level by a SCADA firewall that controls data traffic between the zones and blocks dangerous packets. Suspicious network activities within critical zones themselves, for example the control center network or field level can be detected and signaled by an intrusion detection system.

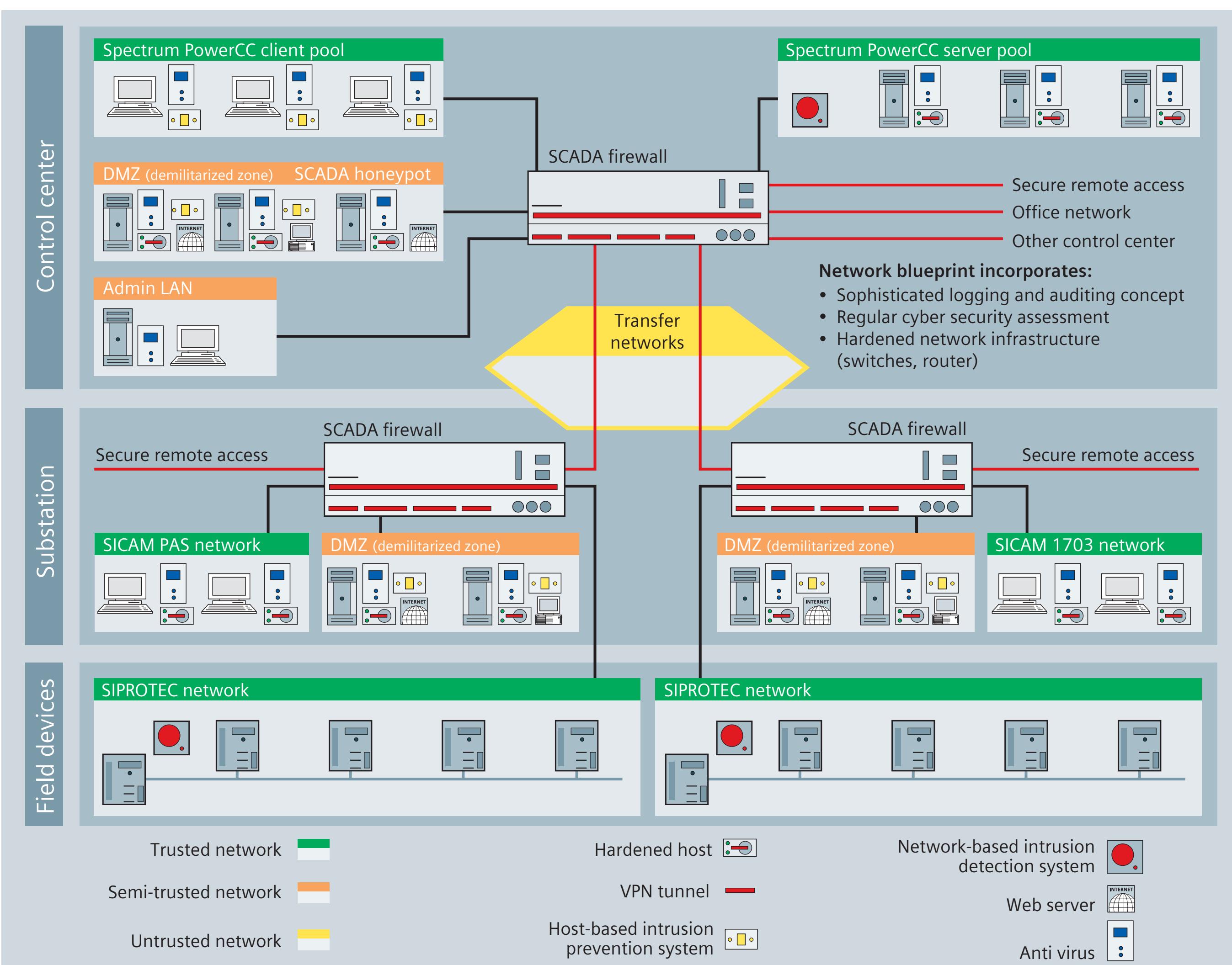


Fig. 8.11-1: **Zoned IT security concept**

Computers exposed to special risks, for example in the demilitarized zone (DMZ), can also be protected with a host-based intrusion prevention system. All computer systems are equipped with virus scanners in order to withstand the permanent threat due to malware. The remote administration and connection of other networks is effected by VPN tunnels that guarantee access protection at the highest level.

The load-carrying network infrastructure itself (routers, switches) also undergoes system hardening in order to match up to the consistently high security requirements for the system as a whole.

8.11.2 Secure Throughout from Interface to Interface

With the advent of the Internet and increasing networking within the systems, every interface represents a potential risk. These risks must be easy to estimate in the system. With Totally Integrated Energy Automation, Siemens therefore applies the philosophy of IT security offering simple protection. For this reason, Siemens attaches greatest importance to homogenization by means of standardized and reproducible processes for authentication, authorization, intrusion detection and prevention, malware protection, effective patch management for third-party components, standard logging and continuous security tests.

8.11.3 Continuous Hardening of Applications

Reliable products are an essential basis for a secure network. Siemens therefore continuously hardens its products to protect them against attacks and weak points. Individual risk analyses and regular tests – also specially for third-party components – with a defined combination of IT security test programs for detecting weak points (Test Suite) are used for this.

8.11.4 In-House CERT as Know-how Partner

Siemens has its own in-house Computer Emergency Response Team (CERT). An organization such as this that discusses subjects critical to IT security and issues current warnings is normally only maintained by universities or governments in order to provide users with cross-industry information.

The Siemens in-house CERT was established in 1997 and since then has issued warnings about security loopholes, while offering approaches for solutions which are processed especially for the company's areas of competence. As know-how partner, the work of the Siemens CERT also involves drawing up rules for the secure development and programming of in-house products and the continuous further training of in-house programmers.

CERT checks the products for weak points by means of selective hacker attacks. The team also collects and distributes reports on weak points and upgrade reports for third-party components and links them to recommendations, concrete proposals and implementation specifications.

8.11.5 Sensible Use of Standards

The object of standards is to guarantee quality, to increase IT security in the long term, and to protect investment. There are now hundreds of IT security standards in existence, but only some of them are really necessary and worthwhile for a system.

On the basis of its many years experience in the market, Siemens chooses those standards and guidelines that protect a network reliably and effectively. This also includes advising customers on which IT security standards need to be observed at international and also at regional level.

The object of Totally Integrated Energy Automation (IT Security) is permanent IT security for the system in the long term. Therefore reliable and secure products and infrastructures are not enough. With Totally Integrated Energy Automation, Siemens also implements appropriate security processes that ensure that IT security is actively implemented throughout, both internally and at the plant operator's, and is guaranteed over the entire life cycle of the plant.

8.11.6 IT Security Grows in the Development Process

The integral approach with Totally Integrated Energy Automation not only involves keeping an eye on the entire system, but also means that security of products is already integrated in the entire development process, and not just in the test phase.

IT security guidelines for development, processing, service and other functions ensure that IT security is actively implemented throughout all processes. Examples of this are security briefings for product management before a product is developed or programmed in the first place. Programmers operate according to defined guidelines for secure coding, which are specified by the Siemens CERT.

For an effective patch management, Siemens tests updates of third-party security products, for example firewalls, already in the development process of the products. Continuous penetration tests of all relevant products are stipulated in a test plan. This also includes the definition and establishment of a security test environment and matching test cases.

In this way, Siemens subjects its products to an objective and critical certification process with which IT security is guaranteed and made transparent on the basis of suitably selected standards.

8.11.7 Integrating IT Security in Everyday Operations

A system is only as secure as the user operating it. A high standard of security can therefore only be achieved by close cooperation between manufacturers and operators. The patch management process is also important after acceptance testing of a system. For this purpose, the Siemens CERT issues automated reports on newly discovered weak points that could affect third-party components in the products. This enables the Siemens customers to be informed promptly, and allows time to define any service activities arising from this.

A very wide choice of helpful tools is available to enable users to make IT security a regular part of everyday operation of a system. Standardized security processes, for example for updates and system backups, are implemented directly. At the same time, efficient tools are provided for administering access in a system network. This includes effective management of rights as well as reliable logging tools. Automatically created protocols or log files are not only stipulated by law, but also help determine at a later time how damage to a system occurred.

With Totally Integrated Energy Automation, Siemens offers an intelligent interaction of integral solutions for simple and reliable energy automation.

8.12 Services

Business with communication solutions for power supply companies does not only mean to provide state-of-the-art products, but to offer a complete range of professional services, support and training. With more than 75 years of experience and know-how, Siemens offers a wide range of products for communications solutions, and a comprehensive portfolio of services tailored to the demand of our customers (fig. 8.12-1).

Consult
Finding the right communication solution for the costumers requires careful planning and analysis. Siemens consultants offer every support in planning and realization of the best technical and economic solution for communications networks, system configuration, and integration of the new equipment into the existing network.

Design
Designing a telecommunication network means more than just supplying hardware and software. The Siemens experience makes it possible to create a communications solution designed exactly for the operator's purposes.

Build
The fast implementation of a project depends crucially on effective management. It ensures that the build-up of a network will be completed quick and effective.

Maintain
The Siemens repair and replacement concept covers the repair or replacement of defective modules. As part of the after-sales service, Siemens gives full technical support and provides the required hardware and software for upgrading communications systems already in operation in existing networks.

Educate
Well-trained staff that knows how to bring the communication network to its optimal use is crucial in obtaining the full benefits from the investments. Siemens therefore focuses not only on providing custom-made communication network solutions, but also on sharing its knowledge and experience with its others. Siemens offers a comprehensive training program for the complete area of communications solutions for power supply companies. Training is always tailored to the area of responsibility, as well as to the corresponding technology and practice.

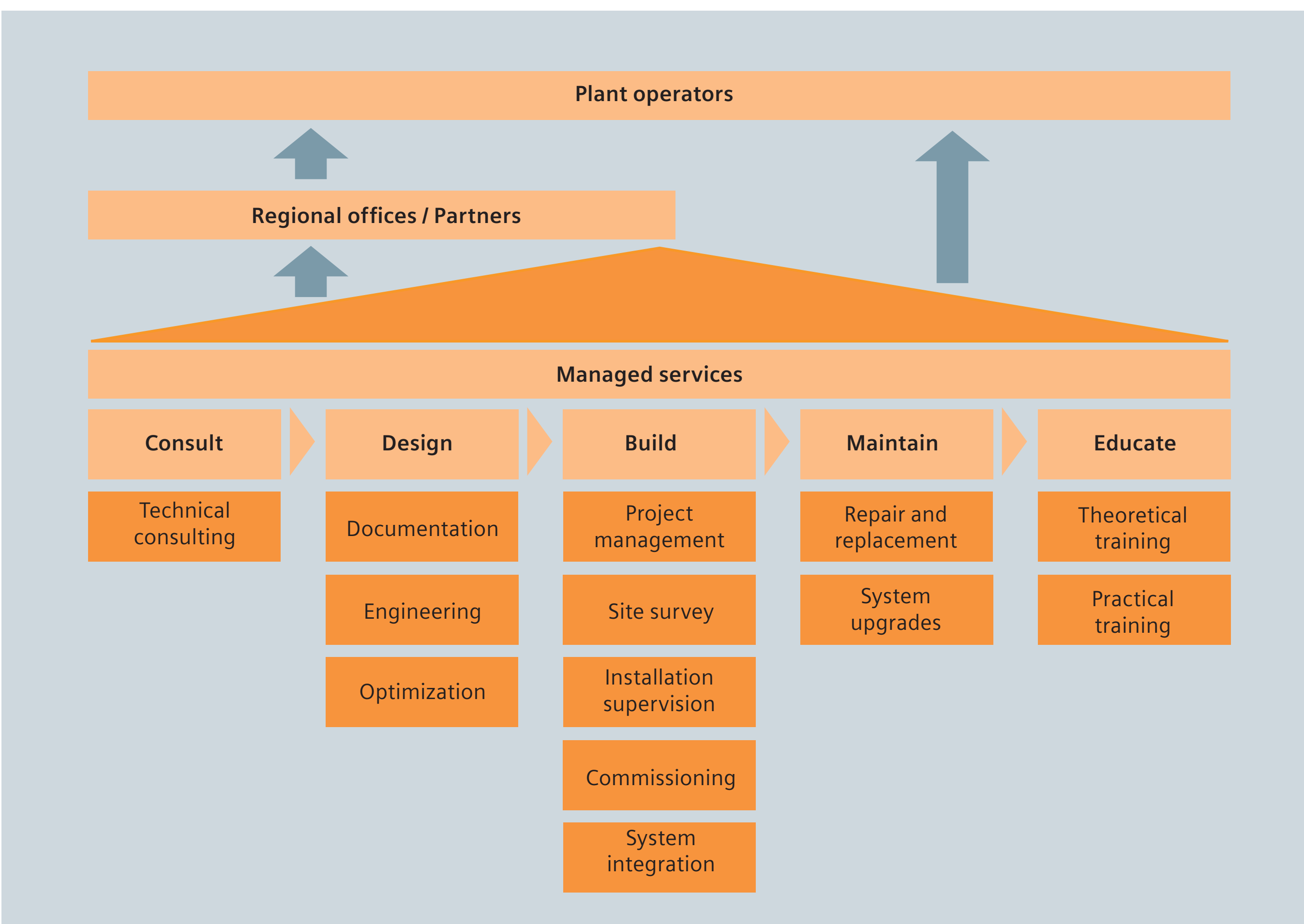


Fig. 8.12-1: **Service portfolio**

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Network Planning

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9 Network Planning

9.1 Introduction

Every society today is highly dependent on electricity – as becomes evident when blackouts or large disturbances occur. In our increasingly "digital societies," almost all aspects of business and private life are based on the availability of electricity. The reliability of power supply systems cannot be taken for granted – especially not with a target reliability of 99.9 % or higher, a value not often met by any other technical system of comparable complexity.

The challenge to provide electricity – any amount required, at any time, at any customer's premises, and with the appropriate quality – is achieved by a large and complex system of power plants and power systems. Building and operating the power supply system are comprehensive tasks of their own, and several trends in large parts of the world today require special attention:

- In several countries, the electricity sector has been liberalized, which means that the economic and legal framework has been thoroughly changed, and in many cases, it has caused a complete restructuring of power supply companies.
- Whether it be a consequence of liberalization or not, in most electricity markets the economic pressure on utilities has increased tremendously.
- The ecological awareness of societies is increasing and posing new questions for utilities.
- Finally, customer appliances are becoming ever more complex and thus sensitive to power quality issues, while at the same time the devices are also emitting ever more quality disturbances into the electricity systems.

Examining these trends, and considering the inherent requirements for changes in the power supply system, based on variations in customer structure (location and power demand), new technologies in generation (renewable generation by wind energy converters) and network equipment (devices based on power electronics) and, secondly, to age of system components, it is obvious that the power supply system is subject of constant modification, redesign and extension. Despite the multitude of different requirements of power supply systems and their different states of development in different parts of the world, there is a typical high-level structure common to almost any power supply system, as shown in fig. 9.1-1.

- The typical hierarchical structure of power supply systems resembles a pyramid. The base is formed by the low-voltage (LV, up to 1 kV) distribution networks, to which most customers are connected. Starting from household customers requiring a few kW on average up to large commercial or industrial customers in the range of a few MW, the large number of customers demands a significantly wide range of power requirements and a lot of components in the LV system. Typically, highly standardized design concepts are used in very simple network structures (mostly radial networks) in order to cope with the large amount of equipment and with economic constraints. While a large number of small generation units are installed at several different places (called distributed generation) – and many of those distributed generation (DG) units are being driven by renewable energy sources (RES) like solar or wind power – most of the power demand is supplied from the higher-level medium-voltage (MV, above 1 up to 50 kV) distribution network.
- The geographic distribution of the load demand defines the locations for the MV/LV substations commonly known as ring main units (RMU), and for the direct MV connection of larger commercial or industrial customers. The electrical configuration and overall network structure of the MV distribution system is mainly governed by these load requirements, and by the placement of larger DG units or groups of DG units, e.g., wind parks, or of small power plants. Standardized design concepts and simple network structures are primarily used; however, it is also common to use individual and more complex solutions for special areas like important HV/MV or MV/MV substations, or customers with special power quality requirements.
- The subtransmission system typically consists of regional high-voltage (HV, above 50 up to 200 kV) networks and medium-sized power plants. Power is supplied to the separate HV/MV substations feeding the subordinate MV networks. While failures in distribution networks often lead to individual or local supply interruptions for customers, failures in the subtransmission level can lead to more widespread, regional supply interruptions. Therefore, these networks are typically operated in a meshed structure.
- Finally, the transmission level contains HV and extra-high-voltage (EHV, 200 up to 750 kV and above) networks with

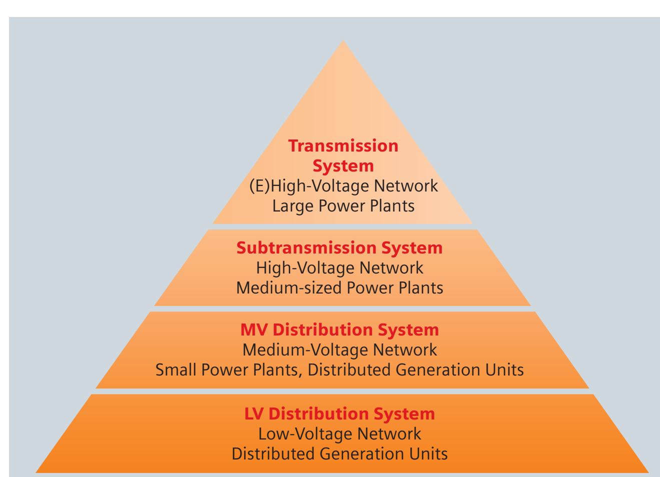

Fig. 9.1-1: **Hierarchical structure of power supply systems**

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interconnections to neighboring systems and countries, where possible. The networks are characterized by a comparably low number of components and customized concepts. Large power plants providing the bulk of the power generation are connected to the transmission-level structure. Interconnected operation enables the system operators to make use of the balancing effects of different load patterns and different characteristics of power plants in different areas, e.g., pump storage hydro power plants in the Alps. Such an approach is a highly economical way to provide reserve generation capacity and support in emergency situations. Failures in the transmission system involve the risk of blackouts in large areas or even whole countries. Besides meshed operation, special attention is also paid to the substation design in transmission networks.

9.2 Network Consulting

Network planning process
The key characteristic of network planning is always the system context. The power supply system is more than just a combination of switchgear, transformers, overhead lines, cables, and secondary equipment for protection, control and communication. It is the integration of all these components in an overall solution meeting the customers' requirements with respect to load demand and power quality. While there are highly complex and important tasks to be addressed in the detailed planning and design work on the equipment level, it is the task of network planning to define the functional specifications for each separate component and to ensure the safe and secure operation of the system as a whole.

The complexity of the power supply system requires very thorough and precise planning in order to meet the following requirements:

- Adequacy, i.e., the ability of the system to supply all customers in normal operation
- Safety, i.e., protection of people and equipment against harm and damage caused by electricity
- Security, i.e., the stability of the system, especially after disturbances like load shifts or electrical failures
- Power quality, i.e., continuous supply of electricity within constant frequency, voltage level and other quality parameters – also in disturbed operation
- Economical performance, i.e., keeping defined budgets and other economic performance criteria
- Ecological performance, i.e., preventing pollution and minimizing the impact of electrical equipment (e.g., lines) on the environment

Network planning is required to develop and prove the strategic perspective of any renewal, extension or modification project in an power supply system, and it links to all steps in the life cycle of such projects (fig. 9.2-1). Initially, it is obvious that network planning assists in the development of the general project idea and in feasibility studies, as well as in the subsequent planning phase. During operation of the equipment, issues like failure investigations, performance analyses and definition of maintenance strategies call for network planning support. Finally, the requirement for modification, extension or renewal closes the life cycle and/or triggers new projects with the associated network consulting.

The complexity of network planning does not only arise from the significant geographic extent of power supply systems and the different hierarchical levels with their distinctive functions. It is also complex because of the fact that different targets are often contradictory, e.g., technical performance vs. economical performance. Network planning covers a wide range of different time horizons – the far future, the near future and the next few days, hours or minutes.

In a running system, time and cost constraints are often the most relevant targets in planning the required modifications and updates. Typically, each of those cases will involve small changes to the network – but there is a continuous demand for such projects. Often the system develops into more and more complex network structures and operating principles.

Therefore, strategic network planning projects are required at regular time intervals. The goal is to re-assess the load demand and quality expectations to be met by the system, to integrate the latest developments in equipment technology and system design principles and to trim the expected technological and economical performance of the network to the current requirements and budgets – that is, to make the network "fit for the future". In this context, the development of suitable long-term concepts is a key requirement, and typically this is the first task

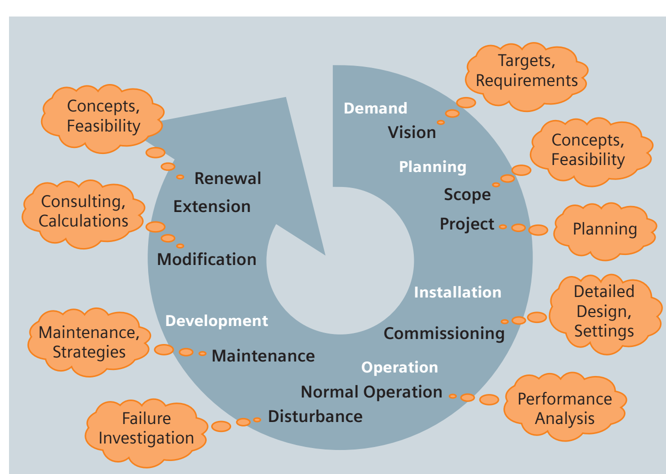


Fig. 9.2-1: **Project life cycle and network planning tasks**

requested in planning projects – following the initial data collection and analysis of the existing system model (fig. 9.2-2), which might reveal certain weak points for immediate action. Actual network planning needs to start with the long-term view to be able to develop the strategic perspectives that then act as guidelines for the development of short and medium-term concepts, as appropriate for all concepts following the defined planning criteria.

The development and analysis of such network concepts are the core tasks of strategic network planning (fig. 9.2-3). As just indicated, this process starts with the compilation of the system model, which in most cases is the model of the system in its current condition. This network planning model has to consider at least the topological and electrical data of the equipment, and may be extended to several other data items as required for the technical analyses to be conducted in the study. In practice, the availability of data is often one of the most critical aspects in network planning, especially for more sophisticated analysis and the corresponding data requirements.

Based on this network model for a precisely defined base scenario, the creative task of developing new variants is executed. This process defines the basic system architecture, considering planning criteria and standard equipment configurations as identified by separate investigations of, for example, pilot areas of the system or abstract network models. This process covers very basic questions, such as those relating to voltage levels and network structures, and also very detailed aspects of individual solutions where needed. Several different system variants – each meeting the relevant requirements with respect to overall network structure and equipment types – result from this step.

In order to arrive at a final solution, a detailed technical and economical analysis of these different system variants is required. Here, various technical network calculations and economic evaluations are performed, such as:

- Power flow calculation and reactive power analysis, identifying, for example, voltage levels at all busbars, the loading of lines and transformers, transformer tap changer settings, losses
- Short-circuit current calculation, evaluating, for example, indices for maximum and minimum short-circuit currents for different failure types in various failure locations
- Probabilistic reliability calculation, delivering the expected values of reliability indices such as SAIDI (system average interruption duration index), frequency of interruption
- Dynamic stability calculation, investigating, for example, the effect of failures on the stability of generators in the system
- Protection coordination, defining concepts and suitable parameters for selective and fast disconnection of electrical failures
- Economic analysis, assessing, for example, the required CAPEX (capital expenditure) and OPEX (operational expenditure) for a network
- Development of automation and control concepts, ensuring that operational performance requirements are met

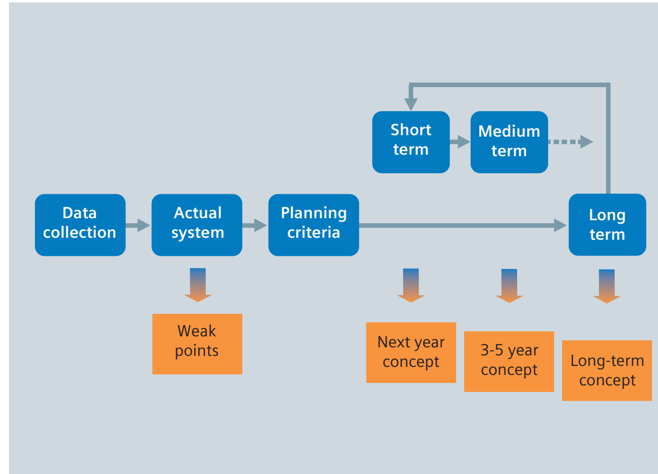


Fig. 9.2-2: **Strategic network planning loop**

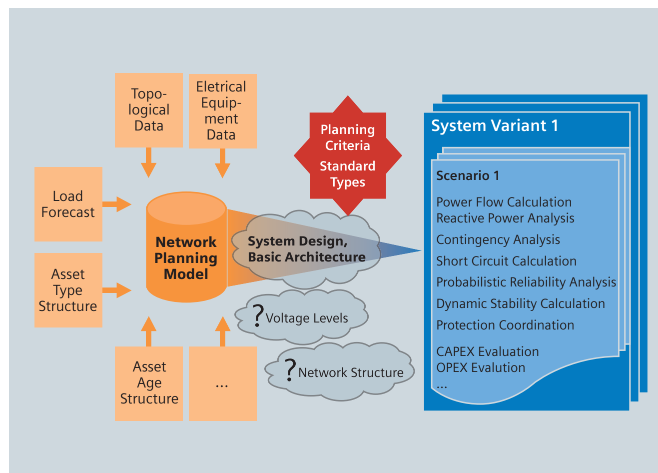


Fig. 9.2-3: **Schematic overview of network planning process**

- Any other investigations and calculations, depending on the scope of study

The technical calculations have to follow the international and national standards relevant to the respective project, as well as customer-specific standards and requirements. It might not be sufficient to execute the defined set of calculations only once – typically, several different system scenarios need to be analyzed for each variant. Different system scenarios are characterized by, for example, different load situations (winter/summer) or operating conditions (normal/disturbed operation), or as different phases in the transition of the present network state into the desired target state. In the end, comprehensive information on the technical and economic performance of the various network variants is available. Assessing these results leads to the final solution, or recommendation, for the problem addressed in the study.

Typical issues addressed in a network planning project
Network planning projects are highly individual, because in each case the special conditions of the supply area, load demand and geographic distribution, technical standards and requirements, current status of the existing system and so on have to be considered. The actual scope and goal of each project are different as well. Typical topics that may be addressed in network planning include:

- Strategic network planning
  Completely new structures, modifications or extensions are to be developed for individual plants, certain areas within the system, or even for whole power supply systems. The project scope can comprise anything from the selection of general network structures and voltage levels down to detailed functional specifications for substation design. The typical aspects of the system level under consideration – transmission network, distribution network or industrial network – need to be considered as well.
- Dynamic performance of generators and transmission networks
  Transmission networks are responsible for the secure operation of the power supply system in large areas. A major concern is system stability, including several different aspects such as inter-area and intra-area oscillations of generators, transient stability or voltage stability. In large power systems, several generators or groups of generators may start to oscillate against each other as a result of operational changes or system disturbances. These inter-area oscillations need to be damped effectively in order to prevent system instability. By suitable calculations, the oscillations are analyzed and the optimal placement and settings of damping devices is evaluated.
- Dynamic performance of industrial networks
  In industrial networks comprising local generation, the dynamic performance is of crucial importance. Besides the requirement to run the local generation in operation, special scenarios like decoupling from the public network, island operation, or system recovery after voltage dips need appropriate planning. In addition, the start-up of large motors may pose challenges to the dynamic performance of the system.
- Protection design and coordination
  Electrical failures in power supply systems occur rarely, but nevertheless regularly, e.g., lightning strikes. They need to be cleared as fast and as selectively as possible in order to minimize safety risks and disturbances of system operation. The design of suitable protection systems, considering also backup protection functionality, and the calculation of appropriate functional parameters for each protection relay ensure that these requirements are met.
- Asset management
  This is the systematic and comprehensive consideration of technical and economic performance indicators of both individual equipment and the entire system over the complete life cycle requires detailed data. Certain information can only be provided by appropriate network calculations and supports, e.g., the prioritization of equipment in maintenance schedules or renewal programs, or the prognosis of expected technical system performance.
- Power quality
  Today, many electrical appliances are becoming increasingly sensitive to power quality issues, like harmonics, voltage fluctuations or voltage dips. It is important to identify the current status of such power quality aspects in the system through evaluation, and to include these facets in the system model in order to derive suitable mitigation measures, such as filters. Harmonics are becoming an even more widespread problem, because new kinds of electrical appliances often generate significant levels of harmonics. As a result, the total harmonic distortion is increasing, and certain network configurations may even lead to resonances.
- Earthing and interferences
  Earthing is an important aspect of power supply systems and highly relevant for safety issues. Appropriate earthing has to ensure that fault currents are limited to acceptable levels, and in the design of earthing systems the local geological features have to be considered. Fault currents or magnetic fields may also cause disturbing interferences with other technical networks. Such interferences on other electricity, pipe or communication networks, for example, need to be studied in order to delineate suitable mitigation and protection measures (called electromagnetic compatibility, EMC).
- Insulation coordination, switching transients
  Electrical phenomena related to switching and lightning strikes, for example, can lead to high transient overvoltages in power supply systems. In order to prevent significant equipment damage, a suitable insulation level for all components is required. Related studies can include measurements of such transient phenomena, suitable modeling in special network analysis tools and the placing and rating of surge arresters and other mitigation equipment.
- Special power supply systems
  Alongside the generally known networks for public and industrial power supply, special power supply systems are employed for exceptional tasks, such as oil-drilling or pumping platforms and vessels, underwater systems in wind parks or oil and gas plants, or isolated supply of ore mines. For all these systems, different planning tasks need to be defined and performed in order to ensure a safe and reliable operation despite the many components and aspects involved.

Siemens network consulting competences
Power Technologies International (PTI), the provider of network consulting, software solutions and T&D training within the Siemens Energy Sector, offers network consulting services for any aspect relating to the planning and operation of power supply networks. With more than 100 dedicated consulting engineers employed in three main offices and various international locations, there are experienced and internationally recognized experts available for any project.

Such projects vary from small studies, e.g., determining the functional parameters for one protection relay to be installed in a container crane – to very large projects, e.g., developing a master plan for the transmission system of a complete country, and to long-term partnerships with clients. The common thread is the high quality of the technical results and the high level of professionalism in the execution of the consulting project.

The PTI scope of competences is illustrated in fig. 9.2-4:
- Expertise and experience in any system level, from LV distribution networks to EHV transmission systems – in three-phase AC systems, of course, but also in single-phase AC or DC systems and in the integration of DC devices like HVDC lines or FACTS
- Familiarity with the special requirements of both public utilities in distribution as well as transmission levels, and of industrial or commercial customers in any branch and of any size
- Consideration of both primary equipment, i.e., network structure and functional requirements for switchgear, transformers and lines, and of secondary equipment, i.e., protection system design, relay coordination, or network automation

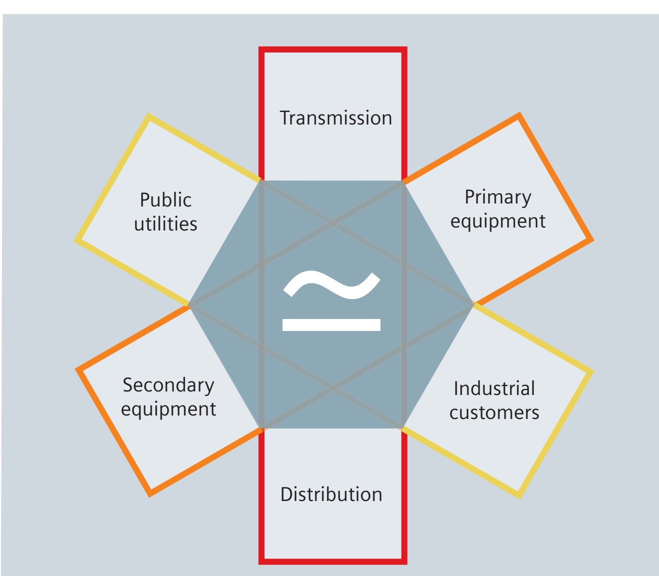


Fig. 9.2-4: **PTI network consulting competences**

More information on Siemens Power Technologies International visit:
http://www.siemens.com/power-technologies

9.3 Software Solutions

Various calculations of technical and economic characteristics of the actual system or of planning variants are part of the network planning process. The availability of suitable tools is highly important. Besides the obvious requirement that calculation results should be as accurate and reliable as possible, particularly with regard to the quality of both calculation tools and input data, several other aspects are also relevant for the successful and efficient use of network planning tools:
- Network model
  The quality of calculation is dependent, above all, on the quality of the input data. The structure and complexity of the data model must support the various calculations, including those for very large network models. In large systems, the question of how the network and the data are structured and presented to the user is of crucial importance for the effective use of the software tools.
- User interface
  Calculation algorithms implemented in the software tools have reached a very high level of complexity and are controlled by a multitude of different parameters. The handling and management of large network models is a complex task on its own. Therefore, an intuitive but comprehensive user interface is a key requirement for modern software tools.
- Management of calculation results
  After the actual calculations have been performed, the results need to be analyzed and presented. In many cases, this means more than printing tables or network diagrams with certain result values attached to the respective components. The compilation of comprehensive graphical representations, tables and reports – both according to predefined and user-defined structures – provide significant support in the execution of network planning projects and should be supported by the software tools.

Siemens has used its great experience and know-how in network planning to develop powerful system simulation and analysis tools to assist engineers in their highly responsible work. The software tools of the Power System Simulator PSS® Product Suite are leading products with respect to technical performance and user-friendliness. Comprehensive interfaces enable the interaction of all PSS® Product Suite tools, and also support the integration with other IT systems.

PSS®E

With over 800 customers and 10,000 users in more than 100 countries, PSS®E (Power System Simulator for Engineering) is the premier software tool used by electrical transmission utilities and consultants worldwide.

PSS®E is an integrated, interactive program for simulating, analyzing, and optimizing power system performance – providing transmission planning and operations engineers a broad range of methodologies for use in the design and operation of reliable networks.

PSS®E has a modern, easy-to-use, Microsoft® Foundation Class (MFC), graphical user interface (GUI). The GUI contains command recording capability to aid the user in building macros, which can be used to automate repetitive calculations. PSS®E has been used in production mode on the largest network-size models being simulated. Common reports in readable formats are standard. Most data can be entered and modified via the one-line diagram (fig. 9.3-1).

PSS®E Program Sections:

- Power flow
  - PV/QV Analysis
  - FACTS/HVDC Modeling
  - Advanced Contingency Analysis with Corrective Actions
- Dynamics
  - Graphical Model Builder (GMB)
  - Small Signal Analysis
  - Wind Turbine Modeling
  - Eigenvalue Analysis (NEVA)
- Reliability
- Short Circuit
- Optimal Power Flow (OPF)
- Python Scripting

PSS®SINCAL

PSS®SINCAL (Siemens Network Calculation) is a high-performance planning tool for the simulation, displaying and evaluation of utility and industry power supply systems. It offers state-of-the-art software technology and a fully featured scope of methodologies for the planning, design and optimization of electrical networks as well as gas, water and district heating networks – integrated in one powerful and intuitive user interface (fig. 9.3-2). PSS®SINCAL is successfully applied in municipal power companies, regional and national utilities, industrial plants and consulting firms, covering aspects such as:

- Electrical networks
  - Power flow for balanced and unbalanced networks
  - Short-circuit calculations for balanced and unbalanced networks
  - Protection coordination and simulation
  - Optimal power flow, optimal branching and compensation optimization
  - Strategic network development
  - Harmonics and ripple control
  - System dynamics: motor start, transient stability, electromagnetic transients, eigenvalue and modal analysis
  - Contingency analysis
  - Probabilistic reliability calculation
- Pipe networks
  - Gas/water/heating steady-state calculations
  - Gas/water/heating contingency analysis
  - Gas/water/heating profiles
  - Water tower filling

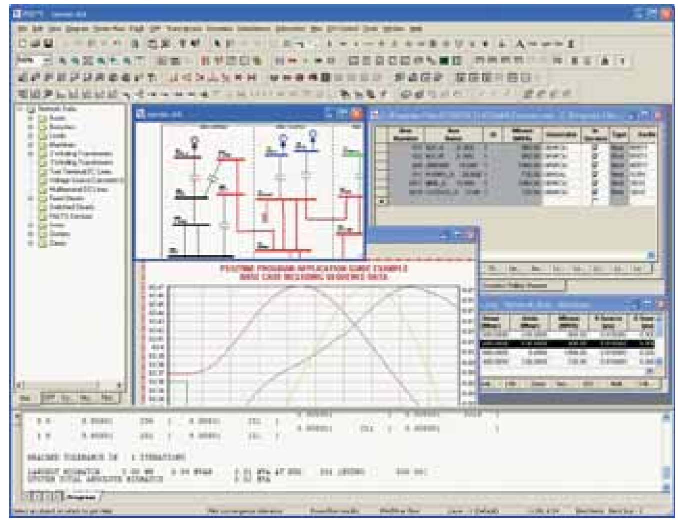


Fig. 9.3-1: **PSS®E for electrical transmission system planning tasks**

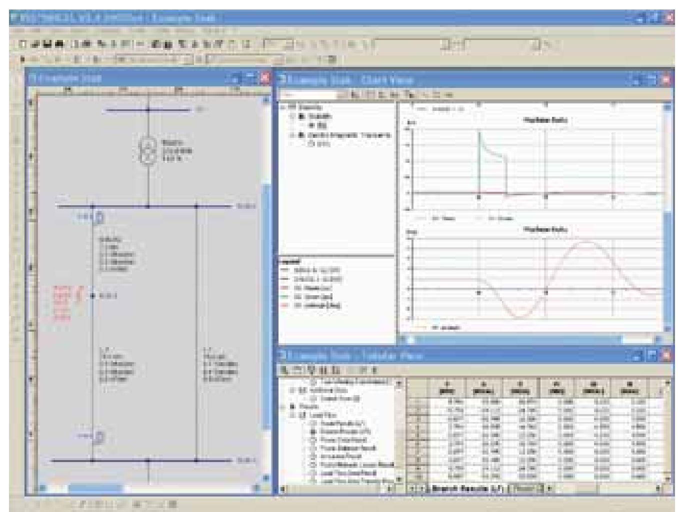


Fig. 9.3-2: **PSS®SINCAL for utility and industry network planning tasks**

PSS®NETOMAC

PSS®NETOMAC (Network Torsion Machine Control) is a program for simulation and optimization of the dynamic performance in electrical systems that consist of network, machines, and closed-loop and open-loop control equipment (fig. 9.3-3). Two modes of time-domain simulation, instantaneous value mode and stability mode, can be used separately or in combination.

The program is used for:

- Simulation of electromechanical and electromagnetic phenomena
- Special load-flow calculations
- Frequency-range analysis
- Analysis of eigenvalues
- Simulation of torsional systems
- Parameter identification
- Reduction of active and passive systems
- Optimization
- Dynamic modeling via Block Oriented Simulation Language (BOSL)
- Graphical Model Builder (GMB) for BOSL models

DINEMO

DINEMO (Digital Network Model) is an intelligent signal treating device that works as a real-time transceiver between protection relays or turbine controllers and simulation programs for electrical power systems like PSS®NETOMAC. DINEMO runs on a standard Windows® PC and allows real-time simulation with up to sixteen analog output signals that are continuously calculated in PSS®NETOMAC. Four analog or sixteen digital feedback signals of the equipment under test can be treated, allowing a closed-loop interaction between protection relays or controllers and the simulation program. Such real-time tests, with round-trip times of up to 0.15 ms, are possible using PSS®NETOMAC with its high-speed calculation algorithms running on Dual Core CPUs. DINEMO is used for tests with analog controllers with input voltages of max. ±10 V and with frequencies of up to 5 kHz. With additional power amplifiers, close-to-reality tests can be accomplished with standard protection relays. DINEMO allows extensive tests on protection relay configurations using detailed models of all network elements.

PSS®ODMS

PSS®ODMS is a data management and network applications suite centered on the international standards Common Information Model (CIM) and Generic Interface Definition (GID). PTI's Operational Database Maintenance System (ODMS) and Power System Simulator for Operations (PSS®O) have been integrated into PSS®ODMS, making this product one of the most advanced network modeling and applications tools for network operation and network planning (fig. 9.3-4).

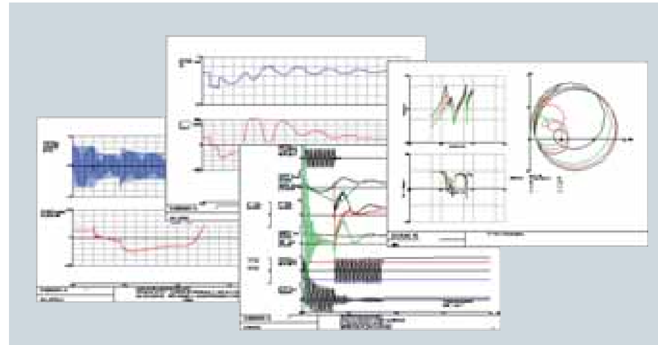


Fig. 9.3-3: **PSS®NETOMAC for dynamic analysis of electrical systems**

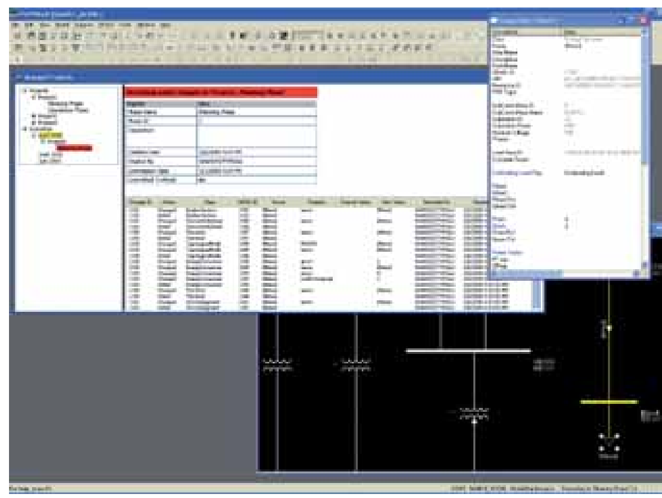


Fig. 9.3-4: **PSS®ODMS data management and network applications suite**

PSS®ODMS is designed to create or install into a CIM environment, and optionally to either create or install into a GID-based enterprise platform. It offers the user tools to:
- Decipher models from many different sources
- Import and export a full model, partial models and incremental models
- Aggregate the models
- Apply an extensive set of business rules to increase the accuracy of the resulting model
- Store that model in an open, industry-standard database structure that may be used by many current and future applications

MOD®

MOD® (Model On Demand) significantly extends the capabilities of PSS®ODMS by enabling the user to manage a great number of change cases for PSS®E. MOD® assembles sets of model changes into “projects” (fig. 9.3-5). Projects can then be managed and organized in various fashions depending on the needs of the PSS®E user.

These modeling projects are coupled with MOD® seasonal and annual profiles to provide the PSS®E user with a procedure for organizing and reorganizing system investigations. All this can be done without generating a great number of PSS®E base cases or repeatedly rerunning PSS®E cases when planning sequence changes.

Via the existing data interfaces, PSS®SINCAL and PSS®NETOMAC can process the PSS®E-formatted models as well. MOD® revolutionizes transmission planning data manipulation and the generation of major study data sets.

MOD® allows the system study engineer to:
- Organize and reorganize study cases without the need to generate a multitude of PSS®E “base cases”
- Store a single master network model
- Accommodate seasonal and annual profile data sets
- Treat projects as sets of data changes that are applied serially in any order specified by the user
- Export a PSS®E file with equipment commissioning/decommissioning dates, out-of-service and in-service dates
- Provide an unlimited number of ratings to be applied as Rate A, B, C in the exported PSS®E case

TAI©

Today, diverse software applications must be designed to readily interchange many types of data. Ease of data transmission helps to eliminate both duplicate data and duplicate data management. The PSS®ODMS product line uses the CIM and GID at its core to provide integration of PTI software. PTI provides services to clients based on these same technologies to assist them in integrating other software to the PSS®ODMS CIM and GID architecture. What Technical Applications Integration (TAI©) offers PSS®ODMS clients is the ability to efficiently integrate their technical applications with all the benefits of the message bus integration methodology (fig. 9.3-6).

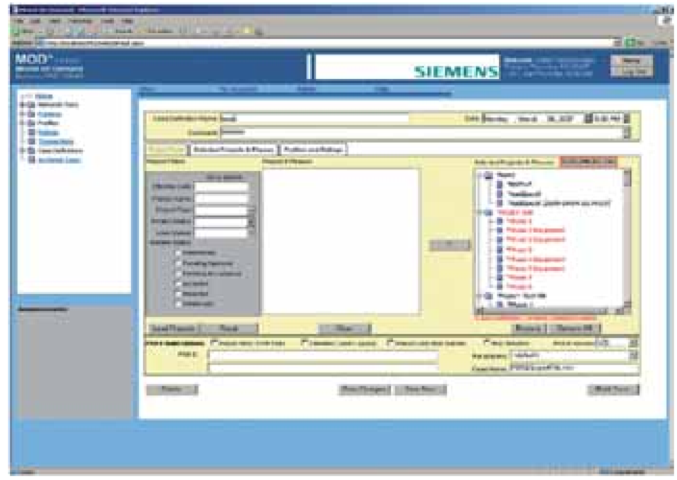


Fig. 9.3-5: **MOD® extension for PSS®ODMS**

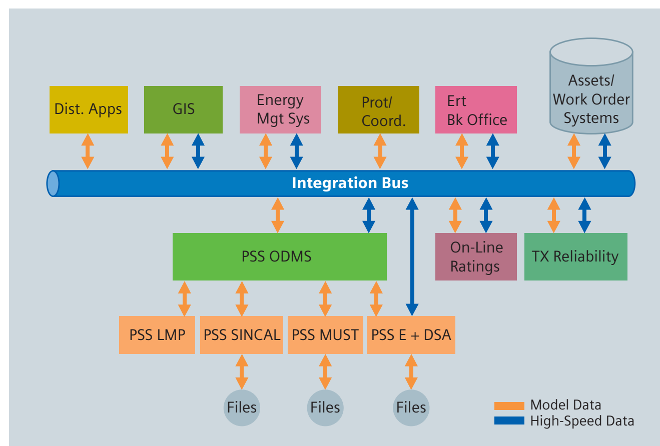


Fig. 9.3-6: **Technical Applications Integration (TAI©) for PSS®ODMS**

The values of TAI© are many, and include:
- Use of industry standards throughout will maintain conformance and will reduce future software purchase, installation and maintenance costs
- Eliminate vendor “captivity” when replacing software applications in the TAI© environment

SIGRADE

SIGRADE (Siemens Grading) is a software program for overcurrent protection coordination of high, medium and low-voltage networks. It allows the selection of grading paths and drawing of tripping characteristics of fuses and protection relays into a log-log current-time diagram. SIGRADE guides the user from the initial simple sketch of the project through the collected information and data to short-circuit calculations, supports the user in developing a protection concept, and documents the complete relay coordination of overcurrent protection devices (fig. 9.3-7).

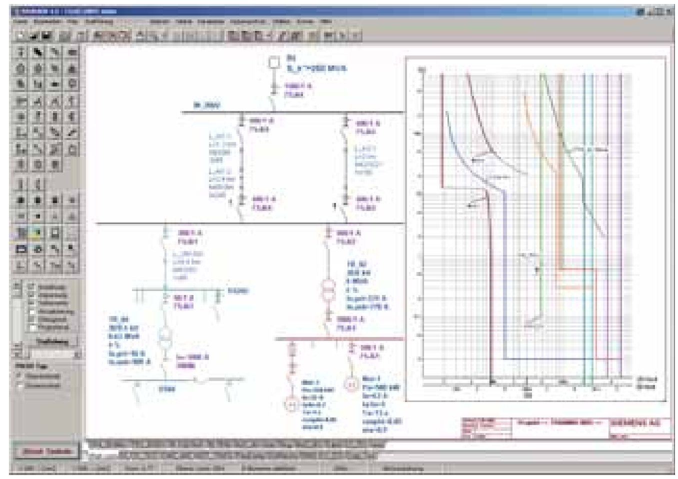


Fig. 9.3-7: **SIGRADE for overcurrent protection coordination**

CTDim

CTDim (Current Transformer Dimensioning) is a software program for current transformer (CT) dimensioning, dynamic simulation of CT behavior and drawing of saturation curves (fig. 9.3-8). Reports are prepared automatically. The optimization of current transformers with regard to technical requirements and economic aspects is becoming more and more important. CTDim makes current transformer dimensioning more efficient. CTDim saves engineering and production costs by optimizing the current transformer data.

CTDim comprises the following features:
- Easy dimensioning of CT data
- Dynamic simulation of saturation curves
- Input of CT data according to IEC, VDE, BS and ANSI standards
- Database of protection device-specific CT requirements
- Automatically customized documentation

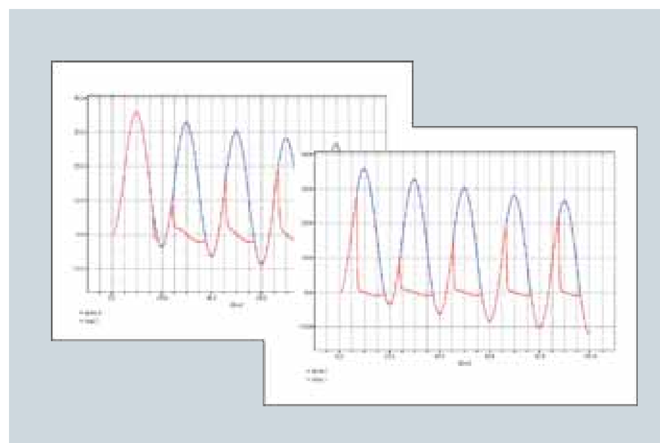


Fig. 9.3-8: **CTDim for current transformer dimensioning**

PSS®MUST

The capability to move power from one part of the transmission grid to another is a key commercial and technical concern in the restructured electric utility environment. Engineers determine transmission transfer capability by simulating network conditions with equipment outages during changing network conditions. Many uncertainties remain in the process.

The purpose of the PSS®MUST (Managing and Utilizing System Transmission) software is to efficiently calculate:
- Transaction impacts on transmission areas, interfaces, monitored elements or flowgates
- Generation redispatch factors for relieving overloads
- Incremental transmission capability (FCITC)
- FCITC variations with respect to network changes, transactions and generation dispatch
- The impact of transmission element outages on power flow by both DC and AC contingency analysis

PSS®MUST complements PSS®E data handling and analysis functions with the most advanced linear power flow and user interface available (fig. 9.3-9). The program's speed, ease-of-use and versatile Microsoft® Excel interface simplifies and reduces data setup time, and improves both results display and understanding.

Fig. 9.3-9: **PSS®MUST for transmission transfer capability analysis**

10

Services & Support

10 Services & Support

10.1 Asset Services

With a comprehensive set of service offerings, Siemens, on one hand, is a reliable product-related services partner for customers. On the other hand, Siemens also offers value-added services for utility and industry customers.

The following chapters will provide the reader with an overview of the different service portfolio elements in asset services.

10.1.1 Product-Related Services

Spares and repairs, on-call services

The objectives of the maintenance services offered by Siemens are to avoid emergency repairs and ensure fault-free operation. If a failure nevertheless occurs, Siemens will be on-site rectifying the fault as soon as possible. Operators can contact Siemens at any time 24/7 via the on-call duty service. The prerequisite for successful and fast fault recovery is, of course, the availability of required spares. Siemens delivers spare parts, components and kits for all asset type series – from current production to phased-out series.

10

Portfolio	Portfolio clusters	HV switchgear service	MV switchgear service	Transformer service	Energy automation service
Installed base services	Spares and repairs, on-call services	Delivery of spare parts and components On-site repair and maintenance On-site heavy repair Call standby 24/7	Delivery of spare parts and components On-site repair and maintenance On-site heavy repair Call standby 24/7	Delivery of spare parts and components On-site repair and maintenance Oil degasification Oil dehydration, oil drying Oil reclamation and regeneration On-site heavy repair (active part, insulation system) Call standby 24/7	Spare parts Field-based repairs and fault recovery EA helpdesk service is part of contract or available separately
	Maintenance and overhauls	Preventive maintenance and inspection Workshop-based overhauls and repairs Renovation, retrofit and modernization Modifications and upratings	Preventive maintenance and inspection Workshop-based overhauls and repairs Renovation, retrofit and modernization Modifications and upratings	Preventive maintenance and inspection Refurbishment, e.g., renewal of core and coil including internal examination Retrofit Upgrades	Maintenance (on-site) Workshop-based overhauls and repairs Upgrades (on-site) system upratings (on-site)
	Diagnostics and monitoring, testing	Fault investigation Site testing Condition monitoring Relay function and protection tests	Fault investigation Site testing Condition monitoring Relay function and protection tests	Fault investigation Site testing Condition monitoring Oil analysis	Fault investigation (remote service) Use of EA equipment functionality for monitoring and diagnostics purposes Relay function and protection tests

Table 10.1-1: **Product-related services portfolio: installed base services**

Maintenance and overhauls
Equipment and systems with a long service life and continuous fault-free operation provide the best conditions for efficient utilization of the operator's system.

The Siemens maintenance service ensures that all components work safely and reliably. It comprises major revisions and overhauls to bring back assets to reference condition. Siemens keeps customer network assets, such as switchgear, transformers and the substation secondary equipment, well maintained at all times by means of regular inspections and revisions. Naturally, the system operator cannot upgrade equipment at the pace that technology changes. However, the retrofitting and upgrading capabilities of Siemens offer many opportunities for optimization, so that the customer can profit from the latest technical improvements. With these cost-effective solutions, the system operator will be investing capital wisely and taking advantage of the experience offered by Siemens in adapting older systems to new technical standards with reduced lifecycle costs.

Diagnostics and monitoring, testing
Faults do occur, and when they happen, Siemens analysis and diagnoses them, assesses their origin, and recommends prevention strategies. Critical assets in the network should be monitored wisely. Identifying critical assets is part of the Siemens asset management support, which also delivers recommendations on how to adapt maintenance schedules accordingly. During scheduled maintenance, Siemens tests the function of control and protection relays, including parameter settings. During scheduled the parameter settings of the control and protection relays.

10.1.2 Value-Added Services

Substation (S/S) maintenance contracts and projects
A substation maintenance contract secures the best possible service: assured availability of staff and spares as well as short response times. Substation maintenance contracts thus minimize the operational risk for the system operator to a calculable factor. They define which individual maintenance and emergency response services will be provided by Siemens.

Substation modernization and extension of phased-out GIS
A large number of aged substations worldwide are not regularly serviced, or are installed in growing cities and cannot be replaced by new ones, or are part of industrial or power plants with a life extension plan. For these substations, S/S modernizations and extensions are ideal. Siemens offers a variety of service solutions for extending the lifespan or even the size of the substation.

Asset management support
In order to streamline system operation, Siemens offers a comprehensive portfolio of services to support the optimization of OPEX (operational expenditure) and CAPEX (capital expenditure). Siemens can ensure both a reliable, cost-efficient network operation and efficient management. For both purposes, Siemens offers methodologies and expert know-how. The key features of these services are Assessments, Integrated S/S Condition Monitoring, Reliability-centered Asset Management and Management Business Review. Siemens is a strong partner, offering consultancy with tangible recommendations based on economic and ecological audits.

Network modernization and extensions
Distribution networks need to be kept in a state-of-the-art position in terms of asset condition as well as grid layout. Asset modernization and grid extension or rebuilding are also part of the Siemens portfolio. Siemens offers support for implementing carefully designed improvement plans on a project basis.

Network asset management
Distribution networks are smaller in terms of geographical size and voltage level than transmission networks, yet this does not mean that they are easier to operate. As already mentioned previously, Siemens can ensure both reliable and cost-efficient network operation of distribution networks and efficient management. For both purposes, Siemens offers methodologies and expert know-how. The key features of these services are audits, assessments, reliability-centered asset management and management business review. Siemens is a strong partner, offering consultancy with tangible recommendations based on economic and ecological audits.

Operation and maintenance contracts
The system operator wants to focus on his real business, and the power supply is not a part of that. Alternatively, the size of his power supply system does not justify having own personnel for operation. Nevertheless, he requires a safe supply and wants the operation to be done by someone else. With an operation and maintenance contract, the system operator defines the supply security he needs. He decides on reaction time in case of a failure. He delegates commitments from laws and regulations. He does not commit any personnel with the supervision and operation of his power supply systems. He assures that the value of his assets is maintained.

Portfolio	Portfolio clusters	HV switchgear service	MV switchgear service	Transformer service	Energy automation service
Transmission services	S/S maintenance contracts and projects	• S/S maintenance contracts • Spare parts management, including security stock			• Service contracts, including post-delivery support agreements • Spare parts supply and administration, holding and supply of spare parts
	S/S modernization and extensions of phased-out GIS	• S/S modernisation Projects • Vintage HV GIS extensions • Disposal service		• Disposal service	• S/S modernization of secondary equipment • Dismantling and disposal (on-site)
	Asset management support	• On-site condition assessment • Documentation services • Integrated S/S condition monitoring (ISCM) • Reliability-centered asset management (RCAM) • Management Business Review® (MBR)		• On-site condition assessment • ISCM • RCAM	• S/S condition assessment of installed equipment • Documentation services of S/S circuit diagram packages
Distribution services and industrial energy service	Network modernization and extensions		• Household connections • Commercial and industry connections • Network modernization projects • Decommissioning and recycling	• Disposal service	• Network modernization projects of secondary equipment • Dismantling and disposal (on-site)
	Network asset management		• Condition and economic value assessments, installation audits • Documentation services • Reliability-centered asset management (RCAM) • Management Business Review® (MBR)	• On-site condition Assessment, preliminary assessment • Technical consultancy and support	• Documentation services of S/S circuit diagram packages
	Operation and maintenance contracts		• Network contracts for reactive maintenance, including fault recovery • Network assets administration contracts • Operation and maintenance contracts • Spare parts management including security stock		

Table 10.1-2: **Value-added services**

10.2 Siemens Power Academy

The expert knowledge of our customer's staff is their greatest asset. Siemens Power Academy offers a broad and comprehensive range of professional training courses for employees in the power generation, transmission and distribution environment. Siemens provides life-long training options through virtual learning and interactive training modules at the point of need. Latest product information and network design skills are taught in class to be transferred into real work situations.

Siemens as a product supplier, system integrator and service provider, has expert knowledge and experience concerning power plants, substations, secondary equipment, power system control, metering services and system planning.

The Siemens Power Academy TD (Transmission and Distribution) is focussed on areas of power transmission and distribution. The training portfolio (table 10.2.1) comprises courses in all kinds of transmission and distribution equipment as well as industrial networks, including the following:

- Gas and air-insulated switchgear for high and medium-voltage
- High and medium-voltage networks
- Vacuum switches, outdoor circuit-breakers, minimum-oil circuit-breakers, high-voltage circuit-breakers
- Surge arresters
- Power transformers
- Filter circuits
- On-load and off-load tap changers
- Monitoring devices
- Energy management
- Power systems control
- Energy meters
- Protective systems
- Energy automation
- Telecontrol
- Substation control and protection
- Power quality
- Communication
- Power System Simulator software (PSS™ Product Suite)

Courses for all technical tasks in power generation, transmission and distribution as well as industrial networks include the following:

- Transport and storage
- Erection and commissioning
- SF_6 gas handling
- Fault clearing and analysis
- Operation, maintenance, disturbance correction
- Planning and configuring
- Construction and function
- Oil filling, oil checking, oil handling regulations for transformers, parameter setting and programming
- Analyses and calculations

In addition to technical and product-specific topics, Siemens also offers the following courses that are generally related to the energy market or energy management:

- Customer focus
- Marketing
- Communication
- Succeeding in the energy market
- Project management
- Methods competence
- Personal aptitudes
- E-learning
- Qualification programs

Standard Training Courses	Customized Training Courses
Service portfolio overview training	Siemens also offers customized training according to specific needs.
General power engineering training	
Power system simulator software (PSS™ Product Suite)	
Innovative power transmission and distribution concepts	
High-voltage switching technology	
Medium-voltage switching technology	
Excitation systems	
Power quality	
Protection systems	
Substation automation systems	
SIT – substation information technology	
Energy management and information systems	
Transformers	
Asset services/maintenance	
E-learning	

Table 10.2-1: **Overview of the training courses offered for all areas of power transmission and distribution**

Besides standard training courses, the Siemens Power Academy TD offers customized courses. The training programs are designed as modular packages that cover all possible requirements. Thus, each program is flexible, and individualized training programs can be compiled.

Courses can be conducted in the following ways:

- Dedicated Siemens Power Academy training centers have been established in several locations (fig. 10.2-1). With modern classrooms and access to actual products, these centers provide excellent conditions for transmitting theoretical knowledge and practical experience.
- In-house trainings are especially recommended when a number of employees need to learn about a new technology or when there is a general interest in a particular subject within a company.
- E-learning is frequently a feasible alternative, especially for small groups, and is individually adapted to the customer's preferences and requirements.

In whatever way courses are organized, the benefit to the participants is the key focus. Success for learning is achieved by combining theory and practice. Detailed theoretical explanations are always accompanied by practical exercises involving actual devices and systems. To make such a methodology possible, the Siemens Power Academy training centers are equipped with original operational components, and utilize devices and systems from the broad Siemens product portfolio. A commitment to hands-on training guarantees all participants an optimal learning experience. Another key factor is the limitation of the number of participants. Keeping this number to a manageable level is essential for the efficient transmission of knowledge and focused, individualized instruction.

For further information, please contact:
Siemens Power Academy:
http://www.siemens.com/power-academy
Siemens Power Academy TD:
http://www.siemens.com/power-academy-td

Fig. 10.2-1: **Locations of Siemens Power Academy TD training centers**

10.3 Metering Services

The Siemens metering services portfolio delivers measurable improvements to the acquisition and processing of meter data, to meter management and to customer communications. Siemens supplies integrated solutions right through the value chain, from metering to billing. The key offering is high-quality, accurate meter data and the services which provide it. As a leading provider of metering services, Siemens works in partnership with some of the largest global utilities for electricity, gas and water. All Siemens services are provided within the framework of strict industry and regulatory standards.

The following sections provide an overview of customer requirements and the different elements of Siemens service portfolio. Fig. 10.3-1 summarizes the ranges of services Siemens offers in the UK and globally.

10.3.1 Portfolio Overview

Services offered by Siemens include „meter-to-cash" services to power supply companies as well as to business-to-business (B2B) customers.

The role of meter operations for utilities and B2B customers is fundamentally concerned with meter installation, meter functionality changes, meter fault resolution, meter removals and connection of new supplies. Siemens installs both credit and prepayment meters. The provision, installation and operation of fiscal meters has to be carried out only by a fully accredited service provider like Siemens.

Before meter purchasing takes place, Siemens carries out site surveys to determine the best design, sizing and location of meters. Siemens configures and commissions the metering systems (fig. 10.3-2) and provides ongoing maintenance, including calibration, storage, removal and repair of equipment as needed.

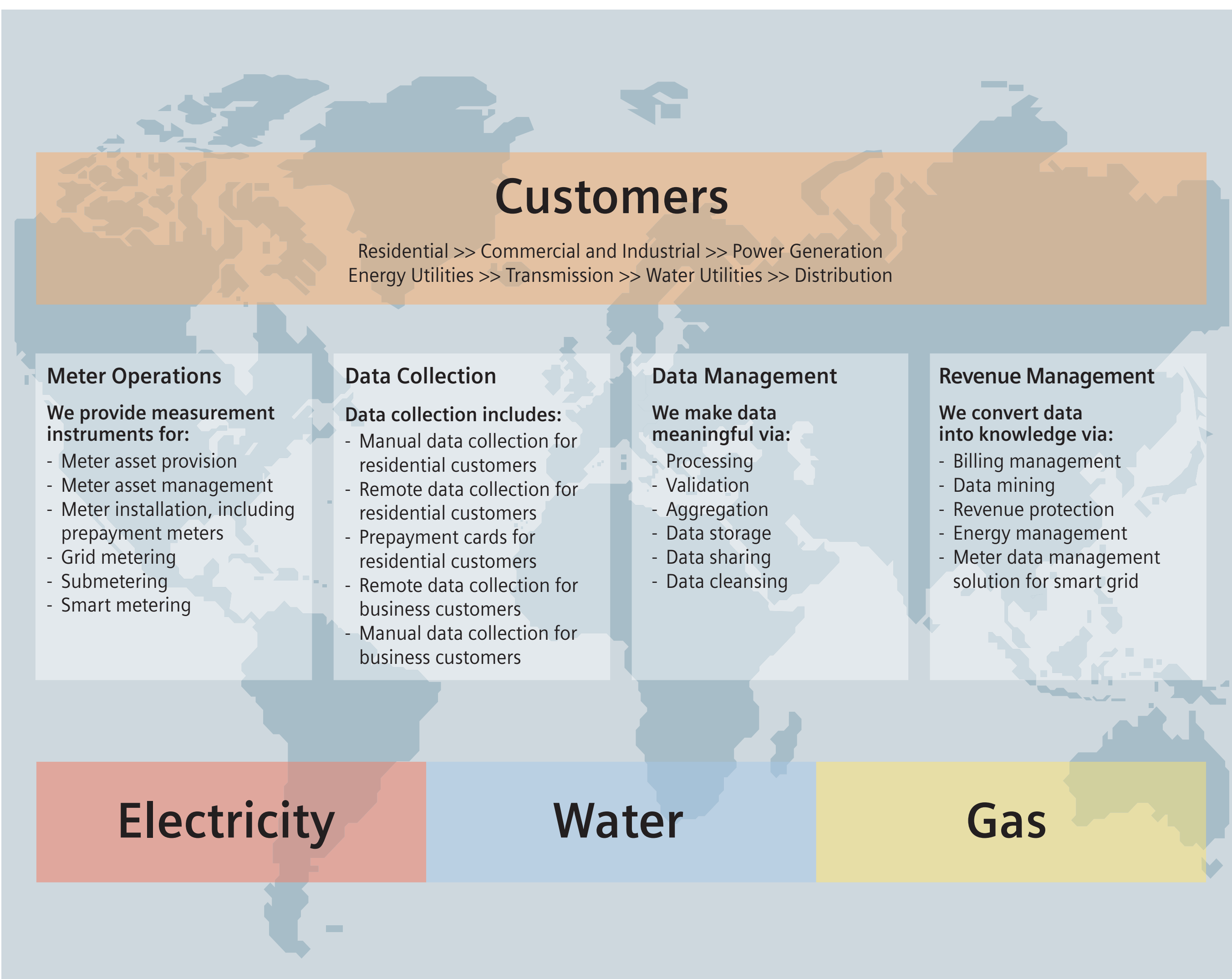


Fig. 10.3-1: **Metering services portfolio overview**

Siemens offers expert advice in high-accuracy metering, grid metering and submetering solutions to monitor the consumption levels of equipment.

Typical users of Siemens metering services include large energy and water retailers and millions of residential, commercial and industrial customers – potentially everybody who has an interest in their meter equipment for gathering up-to-date and accurate data. The Siemens meter operations service supports the data collection process. All these services together help to ensure the highest levels of data quality.

Meter asset maintenance and provision
Siemens provides energy and gas distribution companies with meter equipment and ongoing maintenance service, an additional service that is frequently used by meter operations customers. Siemens also has experience in financing and leasing meter assets, and has access to expert knowledge regarding meter asset purchasing.

Prepayment
Some domestic customers prefer to pay for their energy before they use it, adopting a "pay-as-you-go" approach to energy. This can be done via a special prepayment meter that uses a top-up card or key mechanism.

The UK has the world's largest meter system, with over 2 million meter points.

Siemens is responsible for maintaining the system as well as for installing new prepayment meters and for distributing top-up cards to customers. The latest technologies and process knowledge are combined in this prepayment meter in order to ensure that the customer is completely satisfied (fig. 10.3-3).

Grid metering
Siemens is a leading provider of grid metering and high-accuracy metering solutions in the electricity value chain. Siemens offers services to power generation and transmission companies worldwide, which enables them to get the most accurate view of the electricity they produce and put through the network. This product and service offering fits perfectly with the meter operations element of the value chain, and enables power generation and distribution customers to manage and maintain their revenue stream.

Submetering
Siemens provides meter operations services for non-fiscal purposes, including submetering applications. These can be installed and integrated into energy management systems for individual or multi-utility (gas, water, electricity) applications.

Siemens provides accurate consumption information at the point of use and visibility via Web-based solutions. Siemens offers tailored solutions and enables the system operator to monitor and control energy usage in different business locations. Large retailers and industrial customers use this service, which can be linked to their billing or finance system.

Fig. 10.3-2: **Meter installation**

Fig. 10.3-3: **Q-Smart prepayment meter installed**

10.3.2 Data Collection

Data collection services comprise meter reading (data retrieval), data processing and data aggregation services. Siemens data collectors carry out routine reads, special request reads and change of tenancy reads as well as re-programming of meters.

The data processing system has been developed to comply with strict industry standards and fully supports all work scheduling, validation and distribution of meter readings for up to 12 million meters. To meet special needs and requirements, ad-hoc projects such as providing solutions for "hard-to-read" sites can be performed upon request. The field force consists of 750 Siemens employees. Siemens reads over 14 million residential meter points in the UK on behalf of energy and water suppliers. Systems are continually being enhanced to provide greater flexibility and adaptability, which enables Siemens to meet the constantly evolving market requirements. The automated remote collection systems utilize a range of technologies (e.g., in-field mobile data terminals), providing affordable data collection solutions.

10.3.3 Data Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is accurate. That means Siemens aggregates and processes the data, deletes duplicates in the database and verifies the data before passing it on to the system operator. In most cases, the system operator uses this data directly for billing purposes.

For commercial and industrial customers, Siemens provides a full range of utility metering data – from electricity to gas and water meters. Large nationwide retail chains are particularly interested in this service so that they can monitor and control the energy consumption of their stores. The IT warehouse enables Siemens to collect a wide variety of data, and Siemens can provide custom-designed solutions based on the operator's in-house IT system. Siemens also offers custom-designed reporting systems and works with various communication interfaces to transfer data to the system operator.

10.3.4 Revenue Management

In this section of the meter-to-cash value chain, Siemens ensures that the data is meaningful to the system operator. For instance, revenue protection affects the whole value chain – from energy generation, transmission and distribution down to the energy retailers.

The key features of the Siemens revenue protection service are investigation of power theft, selective and sensitive targeting and helping to increase the rate of loss discovery, with special focus on high non-residential usage. Siemens packages these features as a non-technical losses solution and offers loss assessments and training to data collection agents.

Property management is part of the revenue protection services portfolio. Siemens is a member of the UK Revenue Protection Association and can offer these services internationally.

10.3.5 Smart Metering

Smart metering is the combination of automatic meter reading with the ability to control and update the meter point. Having two-way communications between the meter and the central communications "hub" allows data to be collected on demand whilst enabling critical actions to be taken without having to make a visit to the property.

It is anticipated that smart metering will drive:
- Consumers to become more aware of their consumption and to participate in energy saving initiatives
- Energy retailers to bill more accurately with few, if any, estimated readings, and even to forecast and settle their energy based on actual rather than synthesized energy profiles

As the global competency center within Siemens for metering services, Siemens has a smart metering portfolio which is "meter independent" enabling a variety of devices to be used for electricity, gas and water metering.

Siemens also has the ability to support a number of different communications technologies – GPRS, Power Line Carrier (signaling wire for the low-voltage cables) and fixed radio technologies – depending upon what the customer or market requires.

The core of the offering is the smart metering "scheme". This is a business process solution combining IT technology, business process execution and field force management.

The smart metering scheme brings together the data processing and device control systems with business processes designed to optimize the operation of the smart meter asset and the skills to transition from a dumb meter to an installed base of smart meters.

Smart metering is an important global trend, and our regional capability and sales network combined with specialist resources makes Siemens the ideal provider of smart metering and smart grid solutions.

10.3.6 Meter Data Management Solution

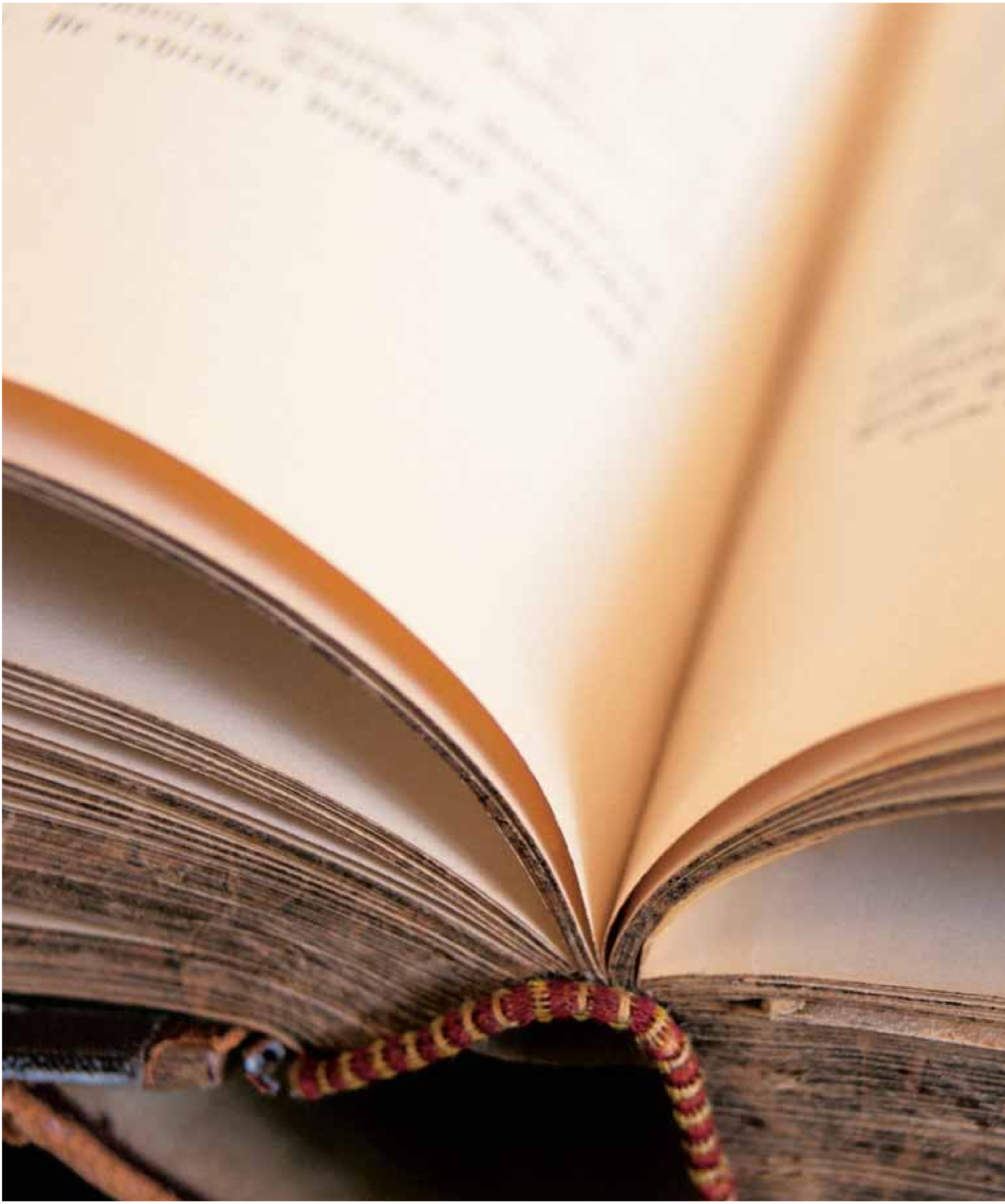
The need for a Meter Data Management Solution (MDMS) has increased dramatically over the last 12 months, especially in the US energy market.

What does MDMS mean?
MDM is:
- A platform to enable fundamental changes in the operating company using near real-time information
- The integration point for current and future Automated Meter Infrastructure (AMI) technologies
- The information toolkit required to empower AMI operations department
- Step one toward a smart grid

MDM is NOT:
- Just a data warehouse of meter data
- Just for commercial and industrial meters and complex billing systems
- Limited to utility metering data

A smart metering solution has three distinct elements: the meter, a communication network and a data hub. MDM systems provide a necessary link between metering communication networks and other utility IT systems ,e.g., billing, call center and distribution automation. In March 2008, Siemens entered into a partnership agreement with eMeter for the sale and promotion of the EnergyIP™ Meter Data Management software worldwide.

Siemens is seeking to establish a market leading position by combining the MDM systems with other elements of the metering services portfolio.



11

Glossary

11

A	
Air circuit-breaker	A –> circuit-breaker in which the contacts open and close in air at atmospheric pressure.
Air-insulated outdoor switchyards of open design (AIS)	High voltage substation where all live parts are insulated by air and are not covered. AIS are always set up in a fenced area with access for authorized personal only.
Ambient temperature	Temperature (measured under specific conditions) of the air surrounding an item of electrical equipment. The ambient temperature affects heat dissipation, which can make it necessary to reduce the –> rated current.
Auto-reclosing (of a mechanical switching device)	The operating sequence of a mechanical switching device whereby, following its opening, it closes automatically after a predetermined time.
Automatic multiple shot reclosing	An automatic reclosing repeated two or three times (usually not more) if it is not successful.
B	
Back-up protection	Interaction of two carefully matched overcurrent protective devices connected in series at points where, in the event of a fault, a single device is not capable of switching the prospective short-circuit current. If a correspondingly high short-circuit current occurs, the back-up overcurrent protective device relieves the next downstream overcurrent protective device, thus preventing it from being overloaded.
Blackout	Complete power outage.
Breaking operation	Interruption of an electric circuit as a result of the contact members of a switching device being opened.
Breaking capacity	Highest current a switching device is capable of breaking under specific conditions.
Busbar	A low impedance conductor, to which several electric circuits can be connected separately.
Busbar trunking system	Extended enclosed busbars, equipped with outgoing points for supplying machines and other loads with power via variable tap-off units.
Bushing	Device that enables one or several conductors to pass through a partition such as a wall or a tank and insulate the conductors from it.
C	
Capacitor voltage transformer (CVT)	A –> voltage transformer comprising a capacitor divider unit and an electromagnetic unit designed and interconnected so that the secondary voltage of the electromagnetic unit is substantially proportional to the primary voltage, and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.
CAPEX	Capital expenditures of an enterprise for fixed assets, e.g. means of production, buildings etc. –> OPEX.
Continuous improvement process (CIP)	–> Kaizen
Circuit-breaker	A mechanical switching device, capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit.
Common information model (CIM)	The Common Information Model (CIM) is an open standard that defines how managed elements in an IT environment are represented as a common set of objects and relationships between them. This is intended to allow consistent management of these managed elements, independent of their manufacturer or provider.
Contactor	Load breaking device with a limited short-circuit making or breaking capacity, used for high switching rates.
Continuous Function Chart (CFC)	A Siemens engineering tool that offers graphical interconnection and parameterization of off-the-shelf or user-defined function blocks to solve sophisticated continuous control applications –> SFC.
Current limiting	Ability of an overcurrent protective device (fuse or circuit-breaker) to reduce the peak current in a circuit beyond the value of the peak short-circuit current expected on the basis of the circuit constants (R, L), by opening and clearing the fault in a sub-cycle time frame.
Current-limiting circuit-breaker	A circuit-breaker with a break-time short enough to prevent the short-circuit current reaching its otherwise attainable peak value
Current transducer	Transducer used for the measurement of an alternating current.
Current transformer (CT)	Type of instrument transformer designed to provide a current in its secondary winding proportional to the alternating current flowing in its primary. CTs facilitate the safe measurement of large currents, often in the presence of high voltages. The current transformer safely isolates measurement and control circuitry from the high voltages typically present on the circuit being measured.
D	
DCF77	A longwave time signal and standard-frequency radio station. The transmitted data repeats each minute the current date and time, a leap second warning bit, a summer time bit, a primary/backup transmitter identification bit, and several parity bits. The callsign DCF77 stands for D=Deutschland (Germany), C=long wave signal, F=Frankfurt, 77=frequency: 77.5 kHz.
Dead tank circuit-breaker	A –> circuit-breaker with interrupters in an earthed metal tank.
Dielectric strength	Capability of an electrical component to withstand all voltages with a specific time sequence up to the magnitude of the corresponding withstand voltages. These can be operating voltages or higher-frequency voltages caused by switching operations, earth faults (internal overvoltages) or lightning strikes (external overvoltages).

Demilitarized zone (DMZ)	A subnetwork between an organization's LAN and an external network, usually the internet. The hosts in the DMZ contain and provide all external services of an organization such as e-mail or web server, but are not allowed to connect directly to the internal LAN.
Disconnector (isolator)	Mechanical switching device which, in the open position, disconnects all the poles of an electric circuit. Disconnectors are used for no-load closing and opening operations, e. g. to isolate downstream devices so they can be worked on.
Distributed generation units	Generation units, such as PV panels, wind turbines, or cogeneration units, which are connected to the LV or MV distribution network.
E	
Ear and mouth (E&M)	A technology in voice over IP (VoIP) that uses a traditional telephone handset with an earphone (or earpiece) for listening to incoming audio and a microphone (or mouthpiece) for transmitting audio. Calls using an E&M interface can be made from, received from, or disconnected by a private branch exchange (PBX) as well as from a VoIP-capable computer. The term ear and mouth interface is sometimes used as a synonym for a telephone handset itself, or for a headset-and-microphone combination that allows hands-free operation.
Earth fault	Occurrence of an accidental conductive path between a live conductor and the earth.
Earthing switch	Mechanical switching device for earthing parts of an electric circuit, capable of withstanding for a specified duration electric currents under abnormal conditions such as those of short-circuit, but not required to carry electric current under normal conditions of the electric circuit.
ECR	A zero boron glass that is free of added fluorides. It conforms to ASTM D578-1999 specification for E glass. It combines the electrical and mechanical properties of E glass with superior inherent corrosion resistance. ECR glass fiber is an electrical grade corrosion resistant glass fiber.
F	
Feeder	An electric line originating at a main substation and supplying one or more secondary substations.
Flexible AC transmission system (FACTS)	A power electronic based system and other static equipment that provide control of one or more AC transmission system parameters to enhance controllability and increase power transfer capability.
File transfer protocol (FTP)	Transfer protocol for exchanging files over any –> TCP/IP based network.
Fuse	A protective device that by the fusing of one or more of its specially designed and proportioned components, opens the circuit in which it is inserted by breaking the current when this exceeds a given value for a particular period of time. The fuse comprises all the parts that form the complete device.

G	
Gas-insulated switchgear (GIS)	Indoor and outdoor switchgear of compact design and small dimensions for substations up to 550 kV to be installed in urban or industrial loadcenters. All components are housed in earthed metal enclosures filled with sulfur hexafluoride (SF_6) gas for insulation.
Gas-insulated transmission line (GIL)	Transmission lines composed of pipes that house conductors in highly insulative sulfur hexafluoride (SF_6) gas, which have high load-transfer capacity.
Generic Interface Definition	A set of common services used for enterprise integration in the utility industry, defined in IEC standard IEC 61970.
GPRS	A packet oriented mobile data service available to users of –> GSM.
Grid-connected photovoltaic system	A photovoltaic system in which the photovoltaic array acts like a central generating plant, supplying power to the grid.
Grid power flow controller (GPFC)	A concept in system technology within the –> FACTS family of devices that provides an economic solution for the purpose of power transmission between two or more adjacent AC systems. The AC systems can be either synchronous or nonsynchronous. The most proper power rating is between 10 MW and 300 MW, although higher ratings are also achievable.
GSM	A worldwide standard for mobile phones.
H	
Harmonics	The sinusoidal (harmonic) oscillations in the Fourier analysis of non-sinusoidal, periodic oscillations that oscillate at a frequency which is an integer multiple of the fundamental (= system) frequency. The amplitudes of harmonics are considerably smaller than the fundamental frequency.
High voltage	In general a set of voltage levels in excess of –> low voltage (< 1 kV). In a more restrictive sense HV is used for voltage levels typically used for bulk transmission of electricity (> 60 kV).
HTTP/HTTPS	The hypertext transfer protocol/hypertext transfer protocol secure is a communications protocol for the transfer of information on the intranet and the World Wide Web; HTTPS is widely used for security-sensitive communication.
I	
Incoming feeder	In a substation a feeder bay which is normally used to receive power from the system.
Instrument transformer	Transform high currents and voltages into small current or voltage values for measuring or protection purposes.
Inter-Control Center Communication Protocol (ICCP)	The Inter-Control Center Communications Protocol (ICCP or IEC 60870-6/TASE.2) is being specified by utility organizations throughout the world to provide data exchange over wide area networks (WANs) between utility control centers, utilities, power pools, regional control centers, and non-utility generators.

Insulated gate bipolar transistor (IGBT)	A three-terminal power semiconductor device, noted for high efficiency and fast switching.
IRIG timecodes	Family of standardized timecodes used by the U.S. Government and the private industry for the correlation of data and time.
IT system	Power supply system that does not provide a direct connection between live conductors and earthed parts; exposed conductive parts are earthed.
J	
K	
Kaizen	A Japanese philosophy that focuses on continuous improvement throughout all aspects of life, which was first implemented in several Japanese businesses as a management strategy after World War II, adopted to businesses throughout the world also as Continuous Improvement Process (CIP).
Konnex (KNX)	Standardized bus system for home and building applications according to EN 50090 and ISO/IEC 14543, comprising switching, signaling, controlling, monitoring, and indicating functions in the electrical installation.
L	
LCAS	Link Capacity Adjustment Scheme or LCAS is a method to dynamically increase or decrease the bandwidth of virtual concatenated containers to effectively transfer asynchronous data streams over –> SDH.
Live tank circuit-breaker	A –> circuit-breaker with interrupters in a tank insulated from earth.
Low voltage (LV)	Set of voltage levels used for the distribution of energy up to 1,000 V AC, or 1,200 V DC.
L-tripping	Overload protection.
M	
Miniature circuit-breaker (MCB)	Automatically-operated low-voltage switching device designed to protect an electrical circuit from overload or short-circuit. Also used to manually connect or disconnect an electric circuit at will. Rated current not more than 125 A.
Moulded-case circuit-breaker (MCCB)	A circuit-breaker having a supporting housing of moulded insulating material forming an integral part of the circuit-breaker.
Medium voltage (MV)	Set of voltage levels lying between –> low voltage (LV) and –> high voltage (HV). The boundaries between HV and LV depend on local circumstances and history or common usage. The band 1kV to 52 kV is commonly accepted in Europe. The term medium voltage is nor used in the U.K. nor in Australia.
Metall oxide varistor (MOV)	A discrete electronic component that is commonly used to divert excessive current to the ground and/or neutral lines.
N	
Neutral conductor (N)	A conductor connected to the neutral point of a system, which is suitable for transmitting electrical energy.
N-tripping	Neutral conductor protection.

O	
OASIS	System for reserving transmission capacities in the US power transmission networks.
ODBC	Standard database access method for using database management systems.
OLE	Object Linking and Embedding (OLE) is a technology that allows embedding and linking to documents and other objects developed by Microsoft.
OPC	A set of connectivity standards for industrial automation from the OPC Foundation, which offers interoperability between gauges, databases, programmable logic controllers (PLCs), distributed control systems (DCSs) and remote terminal units (RTUs).
Operating voltage (in a system)	The value of the voltage under normal conditions, at a given instant and a given point of the system.
OPEX	On-going cost for running a product, business, or system.
OSCOP® P	A PC program for retrieving and processing of records made with the SIMEAS R digital fault and power quality recorder, the SIMEAS Q power quality recorder, or with numerical protection relays using the IEC 60870-5-103 protocol.
OSI	A layered, abstract description for communications and computer network protocol design.
Outgoing feeder	A feeder bay in a substation which is normally used to transmit power to the system.
Overcurrent	Any current in an electric circuit that exceeds the –> rated current.
Overload	Operating conditions in an electrically sound, fault-free electric circuit that give rise to an –> overcurrent.
P	
PABX	A telephone exchange that serves a particular business or office, as opposed to one that a common carrier or telephone company operates for many businesses or for the general public.
Pulse-code modulation (PCM)	A digital representation of an analog signal where the magnitude of the signal is sampled regularly at uniform intervals, then quantized to a series of symbols in a numeric (usually binary) code.
PDH	An international multiplexing standard.
PE conductor	Conductor provided for purposes of safety, for example protection against electric shock. In an electrical installation, the conductor identified PE is normally also considered as protective earthing conductor.
Phase-shifting transformer	A device for controlling the power flow through specific lines in a complex power transmission network.
(Photovoltaik) Peak Watt	Maximum "rated" output of a photovoltaic cell, module, or system. Typical rating conditions are 1000 W/m² of sunlight, 20 °C ambient air temperature and 1 m/s wind speed.
PEN (conductor)	Combined –> PE and –> N conductor.

Power-line carrier	A device for producing radio-frequency power for transmission on power lines.
Potential transformer (PT)	A device required to provide accurate voltages for meters used for billing industrial customers or utility companies.
Python	A dynamic object-oriented programming language.
Q	
R	
Rated breaking capacity	Value of the short-circuit current a switching device is c apable of breaking at the rated operating voltage, rated frequency and specified power factor (or specified time constant).
Rated breaking current	The load breaking current in normal operation.
Rated current	The current that an electrical device can carry, under specified conditions, without resulting in overheating or mechanical overstress.
Rated insulation level	The –> dielectric strength from phase to earth, between phases and across the open contact gap, or across the isolating distance. The dielectric strength is verified by a lightning impulse withstand voltage test with the standard impulse wave of 1.2 / 50 s and a power-frequency withstand voltage test (50 Hz/1 min).
Rated peak withstand current	The peak value of the major loop of the short-circuit current during a compensation process after the beginning of the current flow, which the device can carry in closed state.
Rated short-circuit breaking current	The root-mean-square value of the breaking current in case of short-circuit at the terminals of the switching device.
Rated short-circuit making current	The peak value of the making current in case of short-circuit at the terminals of the switching device.
Rated voltage	The maximum voltage at which an electric component can operate for extended periods without undue degradation or safety hazard.
Release (of a mechanical switching device)	A device, mechanically connected to a mechanical switching device, which releases the holding means and permits the opening or the closing of the switching device.
Residual current	The sum of the instantaneous values of all currents that flow through all the active conductors of an electrical system at one point.
Residual current device (RCB)	A mechanical switching device designed to make, carry and break currents under normal service conditions and to cause the opening of the contacts when the residual current attains a given value under specified conditions.
Ring main unit (RMU)	Switchgear in distribution systems comprising of switches for switching power cable rings and of switches in series with fuses for the protection of distribution transformers.
Rapid spanning tree protocol (RSTP)	Networking protocol according to IEEE 802.1w to deactivate redundant paths in a local net or to activate them if required (e.g. in case of a failure of a switch, brigde etc.).
Resistance temperatur device/ detector (RTD)	Device for temperature detection based on the resistance change in a metal, with the resistance rising more or less linearly with temperature.
Remote terminal unit (RTU)	An electronic device to transmit data to a distributed control system or a SCADA-system and to alter the state of connected objects based on control messages received from the system.
S	
Switch-disconnector	A switch which, in the open position, satisfies the isolating requirements specified for a disconnector.
Switch-disconnector-fuse (SDF)	A switch-disconnector comprising a –> switch-disconnector and (connected in series zo this) fusebases for insertign fuse-links.
SDH	A multiplexing protocol for transferring multiple bit streams over the same optical fiber.
Selectivity	Combined operation of overcurrent protective devices connnected in series to provide graded disconnection.
Series reactor	A reactor intended for series connection in a network, either for limiting the current under fault conditions or for load-sharing in parallel circuits.
SFC	A graphical programming language used for PLCs. It is one of the five languages defined by IEC 61131-3 standard. The SFC standard is defined in IEC 848, “Preparation of function charts for control systems”.
Short-circuit	Connection of two or more points of an electrical circuit that are meant to be at different voltages across a nebligible small resistance or impedance.
Short-circuit current	Overcurrent which flows through the –> short-circuit which may result in thermal or mechanical overloading of the electrical equipment.
Short-circuit strength	The mechanical resistance of switching devices to short-circuit stress, particularily of busbars in switchgear stations and distrivution boards.
Shunt release	A release energized by a source of voltage.
Shunt reactor	A reactor intended for shunt connection in a network to compensate for capacitive current.
Single-line diagram (SLD)	A simplified notation for representing a three-phase power system in which the polyphase links are represented by their equivalent single line.
Smart grid	Evolving intelligent power distribution network using communication, advanced sensors, and distributed computers to improve the efficiency, reliability and safety of power delivery and use. It includes the possibility for demand side management, facilitating grid connection of distributed generation power (with photovoltaic arrays, small wind turbines, micro hydro, or even combined heat power generators in buildings), grid energy storage for distributed generation load balancing, and improved reliability against many different component failure scenarios.

SNCP	A protection mechanism used in –> SDH
SNMP	SNMP is used in network management systems to monitor network-attached devices for conditions that warrant administrative attention. It consists of a set of standards for network management, including an Application Layer protocol, a database schema, and a set of data objects.
SOAP	A protocol for exchanging –> XML-based messages over computer networks, normally using –> HTTP/HTTPS. Formerly SOAP was a acronym for Simple Object Access Protocol, which was dropped with Version 1.2.
SONET	Multiplexing protocol for transferring multiple bit streams over the same optical fiber.
SQL	Database computer language designed for the retrieval and management of data in relational database management systems.
STM	Synchronous Transport Module (STM), the basic unit of framing in –> SDH
S-tripping	Short-time delay short-circuit protection.
Substation	A part of an electrical system, confined to a given area, mainly including ends of transmission or distribution lines, electrical switchgear and controlgear, buildings and transformers. A substation generally includes safety or control devices (for example protection).
Surge arrester	A device designed to protect the electrical apparatus from high transient overvoltages caused by lightning strikes or switching operations.
Switch/switching device	Device for making or breaking a current in an electric circuit.
Switch-disconnector	A switch which, in the open position, satisfies the isolating requirements specified for a –> disconnector.
T	
Total harmonic distortion (THD)	The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.
TN-S, TN-C, TN-C-S	Power supply systems; in the TN-S system the neutral conductor and the protective-earth-conductor-function is separated throughout the system; in the TN-C system neutral-conductor and protective-earth-conductor-function are combined throughout the system; the TN-C-S system is a combination of a TN-C and a TN-S system. In one part of the system neutral-conductor and protective-earth-conductor function are combined, in another part, they are separate.
Total harmonic distortion (THD)	The THD of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.
Transformer substation	A substation containing power transformers interconnecting two or more networks of different voltages.
Transient overvoltage	Very short duration increase in voltage, between two or more conductors. Transient overvoltages are mainly caused by the secondary effects of lightning or by electrical switching events and may cause serious damages to components of the electrical supply network.
Tripping current	Current value at which a tripping element trips within a particular time.
TT system	Power supply system; in the TT system one point is directly grounded, all exposed conductive parts are connected to grounding electrodes which are separated from the system grounding.
TTA	Type-tested low voltage switchgear assembly.
Type-tested LV controlgear and switchgear assembly (TTA)	Assembly of low-voltage controlgear and switchgear built and type-tested according to IEC 60439-1/EN 60439-1/DIN VDE 0660-500.
U	
UMTS	Universal Mobile Telecommunications System; third-generation cell phone standard that allows significantly higher data transfer rates than GSM.
USB	Serial bus standard to interface devices.
V	
Virtual power plant (VPP)	A cluster of distributed generation installations which are collectively run by a central control entity. The concerted operational mode shall result in an extra benefit as to deliver peak load electricity or balancing power at short notice.
Visual Basic for Applications (VBA)	An event-driven programming language and associated integrated development environment (IDE) which is built into most Microsoft Office applications.
Voltage divider	Device comprising resistors, inductors, capacitors, transformer(s) or a combination of these components such that, between two points of the device, a desired fraction of the voltage applied to the device as a whole can be obtained.
(Line) voltage drop	The difference at a given instant between the voltages measured at two given points along a line.
Voltage regulator	A tapped step autotransformer used to maintain a desired voltage level all the time.
Voltage surge	A transient voltage wave propagating along a line or a circuit and characterized by a rapid increase followed by a slower decrease of the voltage.
Voltage transducer	Transducer used for the measurement of an alternating voltage.
Voltage transformer	An instrument transformer in which the secondary voltage, in normal conditions of use, is substantially proportional to the primary voltage and differs in phase from it by an angle which is approximately zero for an appropriate direction of the connections.

W	
WDM	Wavelength division multiplex; technology which multiplexes multiple optical carrier signals on a single optical fiber by using different wavelengths (colours) of laser light to carry different signals .
WiBro	South Korean service name for the international standard IEEE 802.16e (mobile WiMAX).
WiMAX	A wireless broadband telecommunications technology based on the IEEE 802.16 standard.
X	
extensible markup language (XML)	Markup language to faciliate the sharing of structured data across different information systems; it is used both to encode documents and to serialize data.
Y	
Z	

Abbreviations and Trademarks

12

Abbreviations and Trademarks

12.1 Abbreviations

A	
AAC	All-aluminum conductor
AC	Alternating current
ACB	Air circuit breaker
ACSR	Aluminum conductor, steel-reinforced
ADC	Analog-to-digital-converter
ADM	Asynchronous digital multiplexer
AF	Air-forced; (cooling type [of cast-resin] transformers)
Al	Aluminum
AN	Air-natural
AIS	Air-insulated switchyard
AMI	Automated meter infrastucture
AMIS	Automated consumption data acquisition and information system
ANSI	American National Standards Institute
AR	Auto-reclosure
ASC	Arc suppression coil
ASCII	American Standard Code for Information Interchange
ATM	Asynchronous transfer mode
ATM-IMA	Inverse multiplexing over ATM
AVR	Automatic voltage regulator
B	
BCU	Bay control unit
BF (protection)	Breaker failure (protection)
BFI (time)	Breaker failure initiation (time)
BFT (time)	Breaker failure tripping (time)
BIL	Basic impulse level
BIPV	Building-integrated photovoltaik system
BOSL	Block oriented simulation language
BPL	Broadband over powerlines
B2B	a) Building-to-building; b) Business-to-business
BS	British Standard
C	
CAD/CAE	Computer aided design/computer aided engineering
CAPEX	Capital expenditure
CB	Circuit-breaker
CCS	Cubicle for customized solutions
CERT	Computer emergency response team
CFC	Continuous Function Chart
CFM	Communication front end
CHP	Combined heet and power
CIM	Common information model
CIP	Continuous improvement process
CIT	Combined instrument transformer
CO_2	Carbon dioxide
CSA	Canadian Standards Association
CVT	Capacitor voltage transfomer
CT	Current transformer
Cu	Copper
D	
DAC	Digital-to-analog converter
DAU	Data acquisition unit
DC	Direct current
DEMS	Decentralized energy management system
DER	Distributed energy ressources
DG	Distributed generation
DIN	germ.: Deutsches Institut für Normung e. V.; German Institute for Standardization
DINEMO	Digital network model
DIP	Distributed interface processor
DisCo	Distribution company
DMAIC	Define-measure-analyse-improve-control
DMS	Distribution management system
DMZ	Demilitarized zone
DN	Damping network
DNP	Distributed network protocol
DQS	germ.: Deutsche Gesellschaft zur Zertifizierung von Managementsystemen; German registrar for management systems
DSL	Digital subscriber line
DT	Distribution transformer
DTC	Dead tank compact
E	
E&M interface	Ear and month interface
EAF	Electric arc furnace
ECANSE	Environment for Computer Aided Neural Software Engineering
ECR (glass fibre)	Electrical grade corrosion resistant (glass fibre)
EDP	Electronic data processing
EHV	Extra high voltage
EIB	European Installation Bus
EIRP	Effective isotropic radiated power
ELCOM	Electricity utilities communication
EM	Environmental management
EMC	Electromagnetic compatibility
EMS	Energy management system
EN	germ.: Europa-Norm; European Standard
EPC (contract)	Engineering, procurement, construction (contract)
EPROM	Erasable programmable read-only-memory
ERIP (design)	Epoxy resin impregnated paper (design)
ETSI	European Telecommunications Standards Institute
ETU	Electronic trip unit
EU	European Union

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F	
FACTS	Flexible AC transmission system
FCITC	First contingency incremental transfer capability
Fe	Iron
FEM	Finite element method
FMS	Fieldbus message specification
FO	Fiber optic
FR	Filter reactor
FRP	Fiber glass reinforced polyester
FSC	Fixed series capacitor
FTP	File transfer protocol
G	
GA	Generator connection cabinet
GenCo	Generation company
GFP	Generic framing procedure
GID	Generic interface definition
GIL	Gas-insulated transmission line
GIS	Gas-insulated switchgear
GMB	Graphical model builder
GMS	Generation management system
GOOSE	Generic object oriented substation event
GPFC	Grid power flow controller
GPS	a) General power supply; b) Global positioning system
GPRS	General packet radio service
GSM	Global system for mobile communications (originally from French: groupe spécial mobile)
GSU transformer	Generator step-up transfomer
G-tripping	Ground-fault tripping
GUI	Graphical user interface
H	
HF	High frequency
HIGS	Highly integrated generator switchgear
HIS	Highly integrated switchgear
HMI	Human machine interface
HRC (fuse)	High-rupturing-capacity (fuse)
HTTP/HTTPS	Hypertext transfer protocol/ hypertext transfer protocol secure
HTV silicone rubber	High-temperature-vulcanizing silicone rubber
HV	High voltage
HVDC	High voltage direct current
HVDCT	High voltage direct current transmission
I	
IAC	Internal arc classification
ICCP	Inter-control center communication protocol
IDS	Intrusion detection system
IEC	International Electrotechnical Commission
IED	intelligent electronic device
IEEE	Institute of Electrical and Electronics Engineers
IGBT	Insulated gate bipolar transistor
ILSA (protocol)	Industrial link state advertisment (protocol)
IMM	Information model management
IP (code)	Ingress protection (code)
IP	Internet Protocol
IPP	Independent power provider
IRIG timecodes	Inter Range Instrumentation Group timecodes
ISCM	Integrated Services and Support Condition Monitoring
ISDN	Integrated services digital network
ISO	a) International Organization for Standardization; b) independent system operator
IT	Information technology
I-tripping	Instantaneous short-circuit protection
J	
K	
KNX	Konnex
L	
LAN	Local area network
LCAS	Link Capacity Adjustment Scheme
LCD	Liquid crystal display
LED	Light emitting diode
LF	Ladle furnace
LI	Lightning impulse
LPVTG	Low power voltage transducer for medium voltage GIS systems
LSC (category)	Loss of service continuity (category)
LTT	Light-triggered thyristors
LV	Low voltage
LVMD	Low voltage main distribution
M	
MBR	Management Business Review
MCB	Miniature circuit breaker
MCCB	Molded-case circuit breaker
MD	Main distribution
MFC	Microsoft foundation class
MMC	Modular multilevel converter
MO	Metal oxide
MOD	Model on demand
MOV	Metal oxide varistor
MPCB	Motor protection circuit breaker
MPDSL	Maximum permissible dynamic service load
MPSL	Maximum permissible service load
MSC	Mechanically switched capacitor
MSCDN	Mechanically switched capacitor bank with damping network
MSP	Motor starter protector

Abbreviations and Trademarks

12.1 Abbreviations

MSPP	Multi-service provisioning platform
MSR	Mechanically switched reactor
(2F-) MS-SPRing	(2 fiber) Multiplex section-shared protection ring
MTBF	Meantime between failures
MUX	Multiplexer
MV	Medium voltage
N	
N (conductor)	Neutral (conductor)
N_2	Nitrogen
NERC	North American Electric Reliability Corporation
NEVA	Eigenvalue analysis
NIP	Network interface processor
NLTC	No-load tap changer
NTP	Network time protocol
N-tripping	Neutral conductor protection
O	
OASIS	Open Access Same Time Information System
ODBC	Open DataBase Connectivity
ODMS	Operational database maintanance system
OHL	Overhead power line
OIP (design)	Oil impregnated paper design (of transformer bushings) (–> ERIP)
OLE (–> OPC)	Object linking and embedding
OLTC	On-load tap changer
ONAF	Oil-natural/air-forced; cooling type of transformers
ONAN	Oil-natural/air-natural; cooling type of transformers
OPF	Optimal power flow
OPEX	Operational expenditure
OPGW	Optical ground wire
OSI	Open Systems Interconnection Basic Reference Model
P	
PABX	Private Automatic Branch Exchange
PCI	Peripherical Component Interconnect
PCM	Pulse code modulation
PDH	Plesiochrone digital hierarchy; an international multiplexing standard
PD value	Partial discharge value
PE	Polyethylene;
PE (conductor)	Protective earth (conductor)
PEHLA	germ.: Prüfung elektrischer Hochleistungsapparate
PEN (conductor)	combined –> PE and –> N conductor
PLC	a) Power-line carrier; b) programable logic controller
POD	Power oscillation damping
POTT	Permissive overreach transfer trip
PP	Polypropylene
PQ	Power quality

PROFIBUS	Process Fieldbus
PROFIBUS DP	PROFIBUS for Decentralized Peripherals
PROFIBUS FMS	PROFIBUS with –> FMS protocol
PST	Phase-shifting transformer
PTC (thermistor)	Positive temperature coeffizient (thermistor)
PT	Potential transformer
PTI	–> Siemens PTI
PUTT	Permissive underreach transfer trip
PV	Photovoltaiks
PV/QV (analysis)	Power/voltage var/voltage (analysis)
PVC	Polyvinyl chloride
Q	
QM (system)	Quality management (system)
R	
R&D process	Research and development process
RCAM	Reliability-centered asset management
RCD	Residual current protective device
RC voltage divider	Resistive-capacitive voltage divider
RES	Renewable energy sources
RMS; rms	Root mean square
RMU	Ring main unit
RPS	Redundant power supply
RSTP	Rapid spanning tree protocol
RTD	Resistance temperatur device/detector
RTU	Remote terminal unit
S	
SAIDI	System average interruption duration index;
SAS	Station automation system
SCADA	Supervisory control and data acquisition
SCCL	Short circuit current limiter
SCL	Substation configuration description language
SD	Switch-disconnector
SDF	Switch-disconnector-fuse
SDH	Synchronous digital hierarchy; multiplexing protocol for transferring multiple bit streams over the same optical fiber
SFC	Sequential function chart
SF_6	Sulphur hexafluoride
SiC	Silicium carbide
Siemens PTI	Siemens Power Technologies International
SIM	Serial module interface
SIP	Serial interface processor
SLD	Single-line diagram
SNCP	Sub-network connection protection
SNMP	Simple network management protocol

SONET	Synchronous optical network
SPS	Safety power supply
SQL	Structured Query Language
SSR	Subsynchronous resonance
STATCOM	Static synchronous compensator
STM	Synchronous transport module
STL	Short-circuit Testing Liaison
S-tripping	Short-time delay short-circuit protection
SVC	Static var compensator
T	
TAI	Technical applications integration
TCP	Transmission control protocol
TCR	Thyristor-controlled shunt reactor
TCSC	Thyristor controlled series capacitor
THD	Total harmonic distortion;
(Siemens) TLM	(Siemens) Transformer Lifecycle Management
TM (tripping)	Thermal-magnetic (tripping);
TM (bus)	Terminal module (bus)
TPSC	Thyristor-protected series capacitor
TransCo	Transmission company
TRV	Transient recovery voltage
TSC	Thyristor-switched capacitor reactor
TSR	Thyristor-switched reactors
TSSC	Thyristor-switched series capacitor
TTA	Type-tested low voltage switchgear assembly
U	
UCTE	Union for the Co-ordination of Transmission of Energy
UHF	Ultra high frequency
UHVDC	Ultra-high-voltage direct-current
UI	User interface
UML	unified modeling language
UMTS	Universal Mobile Telecommunications System
USB	Universal serial bus; serial bus standard to interface devices
UPS	Uninterruptible power supply
V	
VBA	Visual Basic for Applications
VCAT	Virtual concatenation
VDE	germ.: Verband der Elektrotechnik, Elektronik und Informationstechnik; German association for electrical, electronic and information technologies
VDU	Visual display unit
VF	Voice frequency
VHF	Very high frequency
VPP	Virtual power plant
VSC	Voltage-sourced converter
VT	Voltage transformer
W	
WAN	Wide area network
WDM	Wavelength division multiplex
WLAN	Wireless local area network
WiBro	Wireless broadband
WiMAX	Worldwide interoperability for microwave access
X	
XML	Extensible markup language
Y	
Z	
ZnO	Zinc oxide

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