n° 156

dependability and LV switchboards

Olivier Bouju

After graduating in 1989 as an engineer from the Institut National Polytechnique de Grenoble and the Institut Administratif de l'Entreprise, Olivier Bouju joined Schneider in 1990 where he specialised in dependability studies in the Low Voltage Switchboard Department of the LV Power Equipment Division. He is currently responsible for Technical Management of Low Voltage Power Equipment.

E/CT 156, first issued, May 1997

glossary

HV, high voltage.

IEC, International Electrotechnical Commission.

IP, degree of protection of low voltage switchboards.

LV, low voltage.

MCC, Motor Control Centre, LV switchboard grouping the control and monitoring elements of a number of motors.

MLVS, Main Low Voltage Switchboard.

MTBF, Mean Time Between Failures.

MTTR, Mean Time To Repair.

MV, medium voltage.

PE, protective conductor.

TTA and PTTA, Type-Tested Assemblies and Partially Type-Tested Assemblies: LV switchgear and controlgear assemblies defined by standards imposing certain service conditions, construction requirements, technical characteristics and tests.

UPS, Uninterruptible Power Supply.

Bus (serial), a communications network over which all data elements, including those related to monitoring, are transmitted one after another.

Communicating component, device such as a circuit breaker or relay that is capable of transmitting a wide range of information such as trip unit settings, currents, overloads, causes of tripping and insulation-resistance values.

Intelligent switchboard, an assembly including communicating components (circuit breakers, relays, etc.) and a central unit (processing capacity), connected by a communications network or bus. It can function alone or as part of a supervision system.

Protocol, set of rules ensuring cooperation between entities, generally separated by a certain distance, particularly in order to establish and maintain the orderly exchange of information between them.

Switchboard Central Unit, a processing unit within the switchboard, used to organise digital information forwarded by the communicating components, automate electrical distribution functions and communicate with the installation's supervision system.

dependability and LV switchboards

contents

1. introduction

This Cahier Technique publication deals with the dependability of commercial and industrial low voltage electrical installations. Its aim is to answer the question "which installation best satisfies our growing needs in terms of electrical power availability?".

The subject is dealt with for LV switchboards and focuses on the following problems:

- which switchboard functions guard against failure of the LV distribution system?
- how should they be used?
- with what components?
- in what power system environment (number of sources and loads, type of system earthing)?

The reason for this focus is that LV switchboards are vital links in any power distribution system.

This document is intended to help operators and designers of electrical installations to:

- determine the points which must be considered. These points are related to the technical choices dealt with in the sub-chapter entitled "industrial dependability concepts" . The discussion is based on reliability levels calculated on concrete cases and yields solutions in terms of equipment type. A summary is given in the sub-chapter entitled "required dependability levels".
- realise the increasing influence of power management systems on LV switchboard dependability.

2. switchboard functions

The switchboard is a key part of any electrical installation. It incorporates devices designed to:

☐ distribute electrical power and protect circuits,
☐ protect persons,
☐ control and monitor the installation.

Recent developments in this control and monitoring function have made the switchboard even more vital to the installation. The dependability of the entire installation is largely determined by the dependability of the switchboard. Moreover, the lasting viability of the associated industrial or commercial activity depends on the capacity of the switchboard to keep pace with future needs.
Dependability of electrical distribution means:

■ a very low probability of failure (reliability),
■ no dangerous failures (safety),
■ the ability to operate at any given time (availability),
■ fast repair (maintainability),

... throughout the entire lifetime of the installation.
These notions of dependability must be taken into consideration right from the switchboard design phase.

Today, dependability requires decentralised management of the installation. For instance, load shedding/reconnection and source changeover automation systems, measurement instruments and protective devices, are placed as close as possible to the application to ensure:

☐ optimum modularity,
☐ greater reliability (a local failure does not paralyse the entire installation),
☐ operating flexibility with local control and monitoring possibilities at switchboard level in addition to centralised supervision. The dialogue between the various distribution levels is considerably simplified by the use of digital communications networks.

As a result of this decentralisation, part of "intelligence" is integrated in the various LV switchboards of the installation which house the main electrical components used between the transformer and the load devices (see figure 1).
The result is a switchboard system including:

☐ the Main Low Voltage Switchboard,
☐ the switchboards specific to motor control (MCCs - Motor Control Centres),
☐ the subdistribution switchboards,
☐ the final distribution enclosures.

the switchboard and its functions

The implementation of the functions of a switchboard involves various aspects.

■ the LV installation architecture, broken down into various switchboards, enclosures, etc. at various locations, forming the installation layout.
The switchboards are further divided into a number of zones for:

☐ components,
☐ busbars,
☐ connection,
☐ auxiliaries.

The minimum clearances and safety distances must be satisfied.

■ the functional units, providing the electrical functions needed by the user. Each unit includes the components designed to cover a given function, for example protection of a feeder or a set of feeders, motor control, incoming protection, etc.

■ the enclosure, providing:
- protection of the electrical equipment against external influences,
- protection of persons against electric shocks (direct and indirect contact).

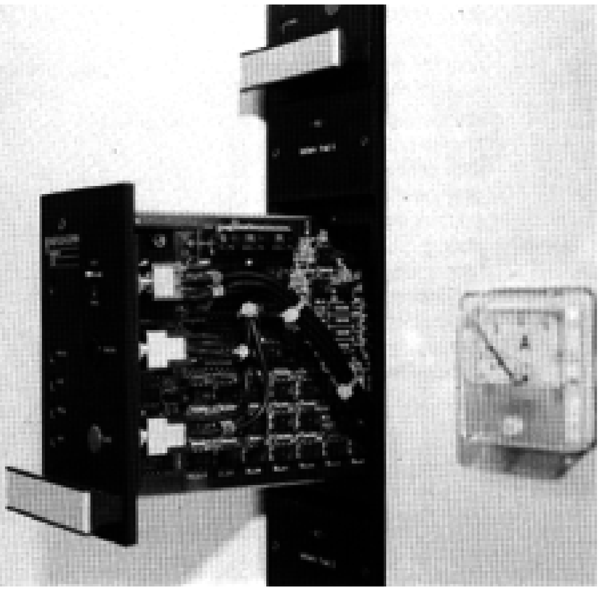


fig. 1: intelligence is now distributed and integrated in LV switchboards. Our example shows a circuit board in an LV assembly (Digibloc board - Schneider).

□ protection of electrical equipment inside enclosures against penetration by solid bodies and liquids;
□ protection of persons provided by:
- interconnection of all metal parts (frames, enclosures, including the door) which are earthed using protective conductors (PE),
- reduction of openings (ventilation, cable entries, etc.) to prevent access to live parts either directly or via tools (e.g. screwdrivers),
- possible use of barriers to avoid contact with live parts when the door is open;

□ degrees of protection (IP)
IEC 529, HD 365 and NF C 20-010 standards define the various degrees of protection of persons (against direct contacts) and equipment (see figure 2) using two numerals and two letters. Impact strength is characterised by a separate IKx index as in European standard EN 50102;

□ adaptability
The enclosure must be adapted both to the volume of the components to be housed and to the size of the premises and means of access.
Connections are made from the top or bottom, front or rear, as required.

■ internal partitions.
For increased dependability, the cubicles can be divided up by partitions and barriers (metal or not). The various equipment items are installed and cabled in the switchboard in such a manner that they do not interfere with each other, for example through electromagnetic fields, vibrations or arcs. Partitioning is a solution for most of these phenomena and suitable ventilation solves the associated thermal problems.

Barriers and partitions also contribute to:
□ protection against contact with live parts belonging to the adjacent functional units,
□ limitation of the probability of initiating arc faults,
□ protection against the passage of solid foreign bodies from one functional unit to another.

The corresponding levels of dependability are evaluated further on in this document.
These partitions are often related to the switchboard architecture and thus delimit the various zones intended for components, busbars, connections and auxiliaries.
The separation of the various switchboard elements and functions (see figure 3) is defined in standards IEC 439-1 paragraph 7.7 and NF C 63-410.

element	**numerals or letters**	**meaning for the protection of equipment**	**meaning for protection of persons**
first characteristic numeral		against ingress of solid foreign bodies:	against access to hazardous parts with:
	0	(non-protected)	(non-protected)
	1	diameter $\geqslant$ 50 mm	back of hand
	2	diameter $\geqslant$ 12.5 mm	finger
	3	diameter $\geqslant$ 2.5 mm	tool
	4	diameter $\geqslant$ 1.0 mm	wire
	5	dust-protected	wire
	6	dust-tight	wire
second characteristic numeral		against harmful ingress of water:	-
	0	(non-protected)	
	1	vertically dripping	
	2	dripping (15° tilted)	
	3	spraying	
	4	splashing	
	5	jetting	
	6	powerful jetting	
	7	temporary immersion	
	8	continuous immersion	
additional letter (optional)		-	against access to hazardous parts with:
	A		back of hand
	B		finger
	C		tool
	D		wire
supplementary letter (optional)		supplementary information specific to:	-
	H	high voltage apparatus	
	M	motion during water test	
	S	stationary during water test	
	W	weather conditions	

fig. 2: elements defining a degree of protection IP as in standards IEC 529, HD 365 and NF C 20-010.

□ form 1: no separation,
□ form 2: separation of busbars from functional units,
□ form 3: same as form 2 plus separation of all functional units, but not of their terminals for external conductors, from one another,
□ form 4: same as form 3 plus separation of the terminals for external conductors which are an integral part of the functional unit.

■ internal electrical connections
Consisting of conductors (busbars and cables) within the enclosure, they carry and distribute the current according to the installation diagram.
□ their cross-sections and number vary according to the nominal currents.

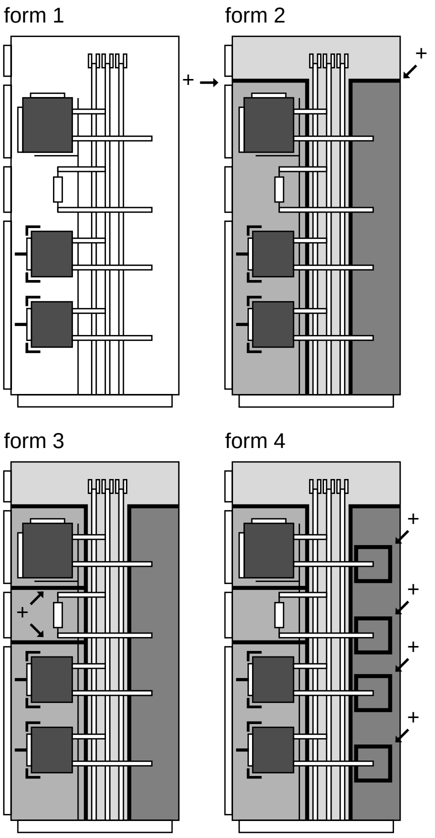


fig. 3: "the forms" defined by standards IEC 439-1, EN 439-1 and NF C 63-410 delimit the various zones in a switchboard.

However their characteristics also depend on other parameters, for example the rated short-circuit withstand current of a switchboard, equal to the root mean square of the current that can be withstood by the switchboard for one second (see standard IEC 439-1).
□ their supports must in turn withstand the corresponding electrodynamic forces and thermal stresses, and also comply with minimum creepage distances.
□ as regards control circuits, their coexistence with power circuit is achieved by running them separately and using appropriate connections. Likewise, the auxiliaries (for form 3 separation or higher) are isolated from the other units and are thus subjected to a less restrictive environment in thermal and electromagnetic terms.

■ component connections
The way a component is connected or installed influences availability and maintainability. Component installation methods include **fixed, withdrawable or disconnectable**.

Reminder:
□ a device is said to be fixed when tools are required to separate it from the main circuit,
□ a device that is withdrawable from a base or frame (for a heavy device) can be moved to a position for which an isolating distance is achieved between its upstream and downstream connecting elements,
□ a disconnectable device has a withdrawable upstream connection and a fixed downstream connection.

Likewise, these installation methods are linked to switchboard technology which may fixed, drawout (racks) or disconnectable (see figure 4).

For example: a withdrawable assembly can be either a switchboard containing fixed devices in drawout units or withdrawable devices (on base or frame) on a fixed panel.

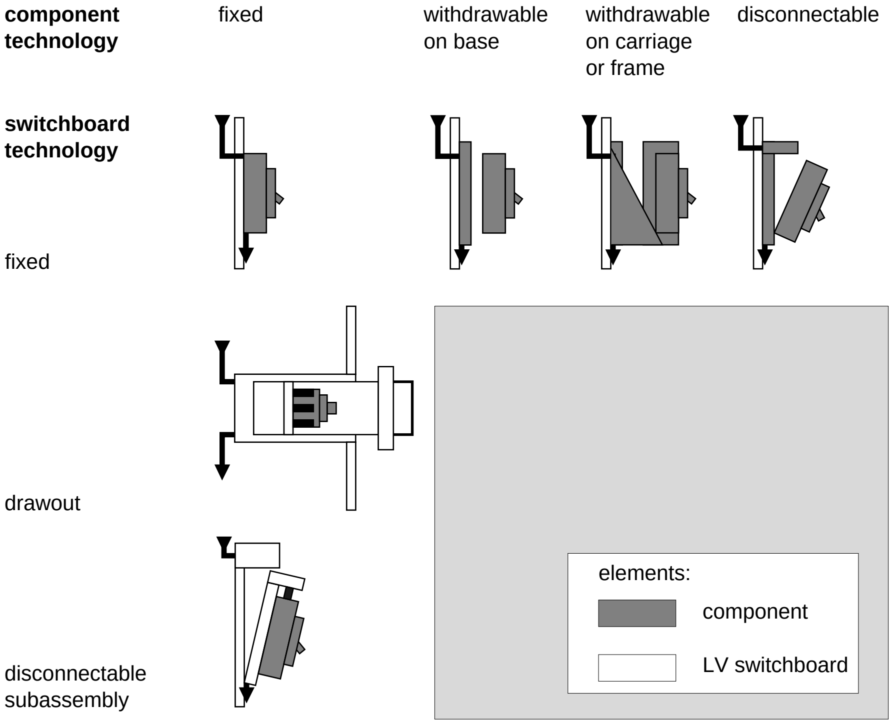


fig. 4: the various possible installation methods for components in an LV switchboard.

the switchboard's functional guarantee

Switchboard design refers to **standards** governing the entire low voltage domain, and, more specifically, to standards relating to assemblies (cubicles, desks,...).
Compliance with these standards is the minimum guarantee of a level of quality and dependability.
Standards IEC 439-1, EN 60 439-1 and NF C 63-410 define the construction requirements, technical characteristics and tests for "type-tested" and "partially type-tested" assemblies.

- assemblies manufactured in accordance with established types are known as "Type-tested assemblies" (TTA),
- assemblies derived from type-tested arrangements (e.g. by calculation) are known as "Partially type-tested assemblies" (PTTA).

The standards are discussed in Cahier Technique n° 145 that deals with thermal studies of LV switchboards.

Heat exchange must be controlled within a switchboard to avoid overheating the equipment installed inside. This requires proper ventilation and in some cases a careful choice of installed components to ensure a suitable level of reliability.
Moreover these thermal studies are part of work currently conducted by the Schneider technical sections and aimed at optimising the technical characteristics of LV switchboards, particularly as concerns:

- **power connections** (definition of a certain number of parameters as a function of currents),
- **short-circuit mechanical and thermal withstand** described above (using computer models),
- **control and monitoring installation** (using studies and tests),
- **dependability** of low voltage distribution systems through switchboards.

In addition to the above work, the switchboards undergo numerous tests (see above-mentioned standards) to validate the theory and guarantee operation of the resulting assembly. These tests include verification of:

- temperature-rise limits,
- dielectric properties,
- short-circuit withstand strength,
- continuity of the protective circuit,
- clearances and creepage distances,
- mechanical operation,
- degree of protection.

Likewise, in order to meet customer needs and ensure the durability of the required quality level, the design, industrialisation and manufacture of LV switchboards must comply with the Quality directives, methods and controls (see figure 5).

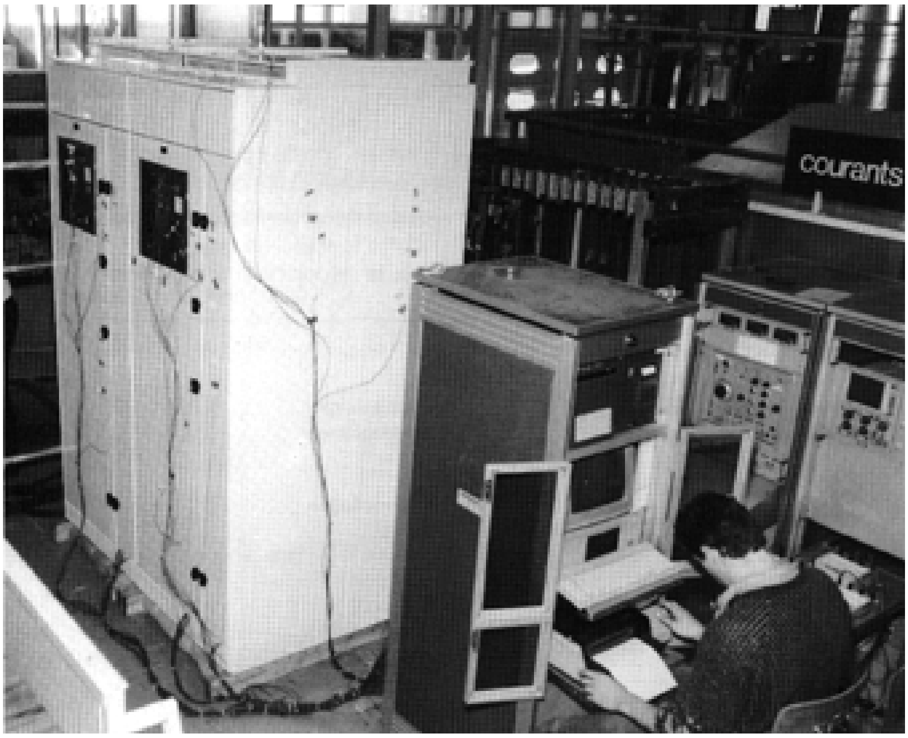


fig. 5: an LV assembly under test... "to meet customer needs and ensure the durability of the required quality level" (LV Power Equipment division, Schneider).

3. optimum dependability

Reduction in the number of failures and of the resulting shutdown times increases safety and productivity in companies.
What is more, users today demand a "tailor-made" level of dependability, i.e. an installation adapted to their needs.
The notion of optimisation is thus vital, meaning just the right level of dependability in order to ensure the best price.
If this is to be possible, manufacturers, installers and specifiers must master the dependability parameters of their installations.

dependability characteristics

■ dependability parameters
The notions involved in dependability (reliability, maintainability, availability and safety) are all linked. Three of these notions can in particular be associated by their representative quantities which are:

☐ for reliability, the failure rate (λ) or its reciprocal (1/λ), the **MTBF** (Mean Time Between Failures).
The failure rate of a transformer is for example 6×10^{-7} h^{-1} which corresponds to a mean time between failures of 195 years, or to 1 device out of 195 failing on the average each year.

☐ for maintainability, the value **MTTR** (Mean Time to Repair) is used. This time covers detection of the failure, the time required to supply the spare parts and the actual repair time.

☐ for availability, the quantification depends on the combined aspects of reliability and maintainability.
The opposite of availability, which is obviously **unavailability** (I_D) is expressed (for most systems) by:
$I_D = \lambda$ MTTR
where λ represents the reliability and MTTR the maintainability.
For a transformer, if 12 hours elapse between the failure and resumption of power, its unavailability is
$= 6 \times 10^{-7} \times 12 = 7.2 \times 10^{-6}$, which is equivalent to 4 minutes of unavailability a year (i.e. 7.2×10^{-6} x number of minutes in a year).
Remember that for a given installation architecture, availability is characterised by a combination of good reliability and efficient maintenance.

■ dependability applied to assemblies.
To calculate dependability, the failure tree method must be applied to the LV electrical distribution system studied (see Cahier Technique n° 144).

Analysis
Let us consider the availability of electrical power of application U1, shown in figure 6.

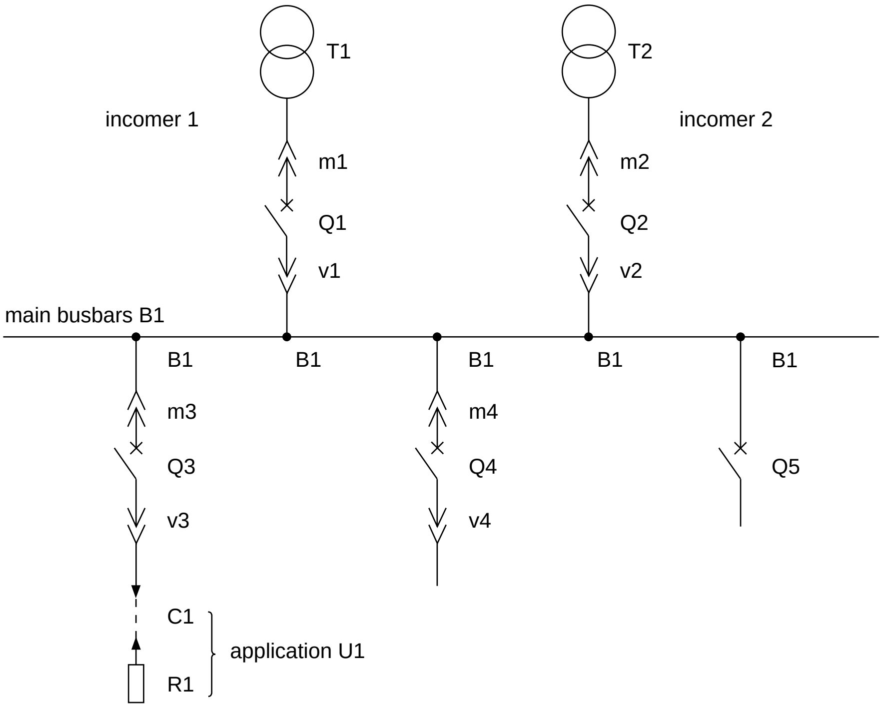


fig. 6: example of an electrical distribution system.

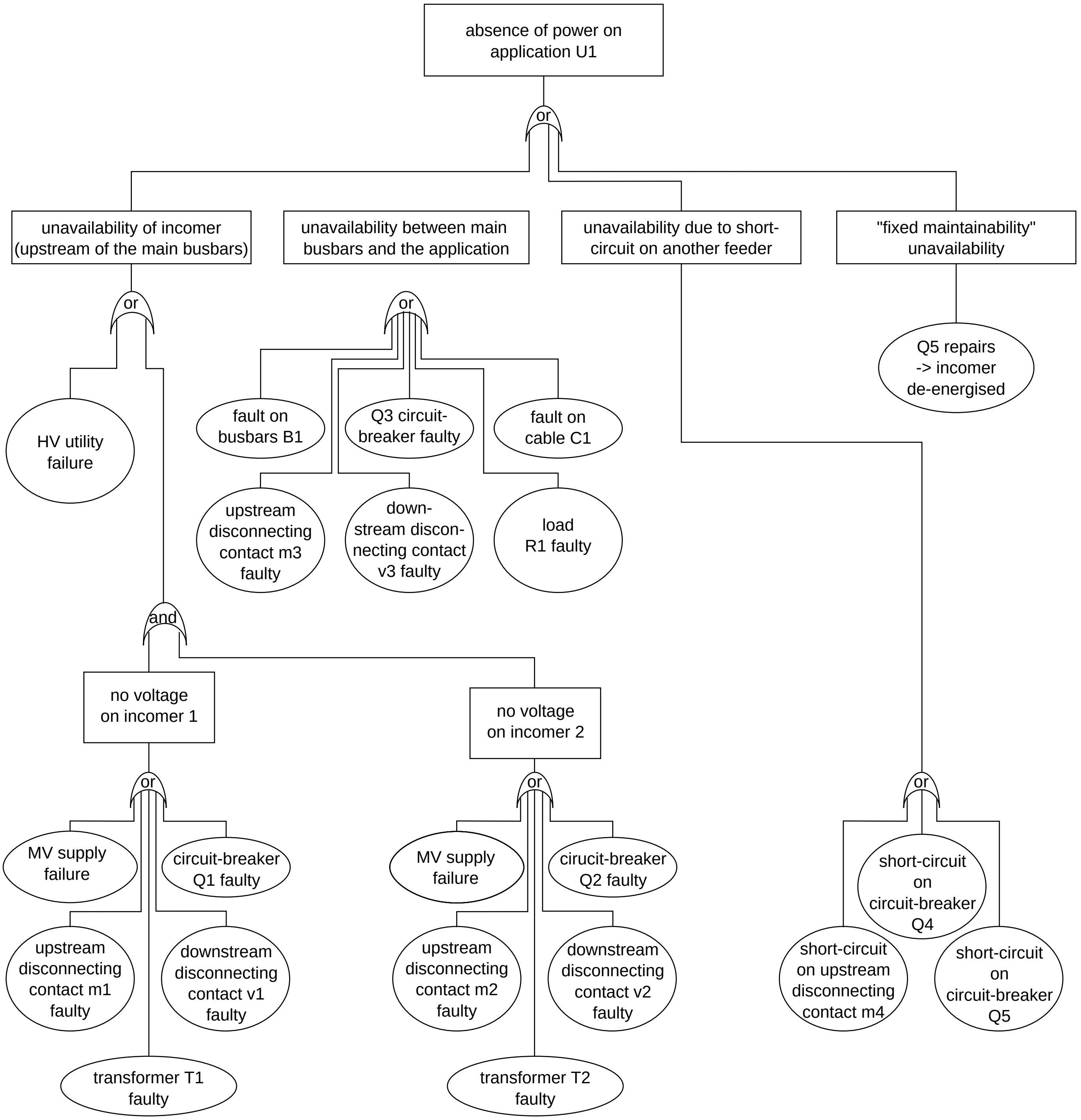


fig. 7: failure tree associated with the diagram in figure 6.

The undesirable event at the top of the failure tree is thus absence of power on U1. This event is broken down into four modules as shown in the chart in figure 7.

■ unavailability of incomer.
Each incomer can alone supply the entire LV distribution system on which the application depends. The two medium voltage (MV) incomers are assumed to be taken from two different substations, which virtually reduces the common failure mode to the unavailability of HV (high voltage transmission).

The circuit-breaker failure modes considered for calculation of incomer unavailability are:
□ spurious tripping,
□ refusal to close,
□ internal short-circuit,
□ temperature rise.
The failures of HV system components, MV incomers, transformers and disconnecting contacts have been considered together.

■ unavailability between the main busbars B1 and the application.
This sums the unavailabilities of the elements encountered from the main busbars to point U1. Each failure is broken down as finely as possible and results in different repair times. For example, for the busbars:
□ loosening of the busbar supports due to strong vibrations may cause the bars to break when they are subjected to a high electrodynamic force. The resulting repair time is several hours (part replacement).
□ an object falling on these bars when energised, although highly unlikely given the construction arrangements chosen (form, IP,...), often results in arcing and in a repair time of several working days.

■ unavailability due to short-circuit on another feeder
The clearing of a short-circuit occurring upstream of the first protective device on a feeder parallel to the feeder considered results in de-energisation of all the feeders.
We thus have to add up all the short-circuit probabilities by descending on each parallel feeder up to the first protective device.
Downstream, a short-circuit affecting U1 is possible only if there is combination of a short-circuit and failure of a protective device to react, the combined probability of which is negligible.

■ "fixed maintainability" unavailability.
Fixed maintainability is the term used to indicate that the repair time depends on the installation method (fixed or withdrawable) and affects use of the other feeders.
Examples (see figure 6): application U1 is affected by repair of Q5 which, as it is fixed, requires shutdown of the incoming supply, whereas repair of Q4, withdrawable, can be carried out with the busbars energised and thus without affecting application U1.

The results

The following results are those corresponding to the usual reliability and MTTR values encountered for the various system components.
Unavailability of the load is 6.4 x 10^{-5}, i.e. 33 minutes a year. An examination of the relative importance of the different aspects gives the following breakdown of unavailability:

□ incomer	45%
□ between busbars and application	51%
of which:	
- cable and load	32%
- rest upstream	19%
□ short-circuit on another feeder	1%
□ fixed maintainability	3%

The various points to be examined are derived from this analysis and will be dealt with in the next chapter.

industrial dependability concepts

As defined above, the installation must be designed to meet the customer’s specific requirements. In all systems, just one small element can often jeopardise overall dependability. So if you do not want to end up "pushing a Porsch", the importance of the various technical choices must be evaluated with regard to dependability.
These choices include:
■ the diagram (incomer, final application, system earthing arrangement),
■ the connections,
■ the electric arcs,
■ the switchboard options (form, connection, fixed or withdrawable components, IP...),
■ the motor feeder units,
■ the control and monitoring auxiliaries.

Dependability in relation to the diagram

Two elements are of critical importance to dependability:
□ the incoming diagram,
□ the final applications.
A third element, the system earthing arrangement, also has great influence.

■ the incoming diagram
As availability of the incomer affects all applications, whether or not they are critical, it is important, if at all possible, to choose an incoming configuration in keeping with the downstream need.
The chosen solution will depend on the environment studied. For example:
□ in isolated regions, it may be hard to obtain an MV line with good availability and even harder to obtain two separate MV lines. In this case the study must consider independent energy production such as by an engine generator set.
□ some sectors of industry (chemistry, petrochemistry, paper-making) generate energy (often in the form of steam) through their manufacturing process which they use to drive turbogenerators. The public distribution system is then used as a backup source.

NB: if, despite this, the availability of the incomer is insufficient, a UPS (Uninterruptible Power Supply) must be placed as close as possible to the critical applications.

☐ calculation of unavailability due to the incomer

On the example in figure 8 (2 parallel incomers, 20 motor feeders), unavailability of the application is roughly 1/2 hour a year, 50% of which is due to failure of the incomer. From this we conclude that unavailability of the incomer, although not always preponderant, may nevertheless account for a large part of total unavailability. We shall see later on that the incomer unavailability percentage ranges between 7% and 90% according to the measures taken to ensure reliability of the rest of the system.

The incomer has two main critical points, namely:
- the high voltage transmission line,
- the medium voltage line;

Transformers, circuit-breakers and disconnecting contacts are 100 to 1000 times more reliable than these two sources of failure.

How can the dependability of the incomer function be improved?

There are many possible solutions, and the context is a decisive factor. Greater reliability can be obtained by concentrating on the following points:

☐ redundant incomers

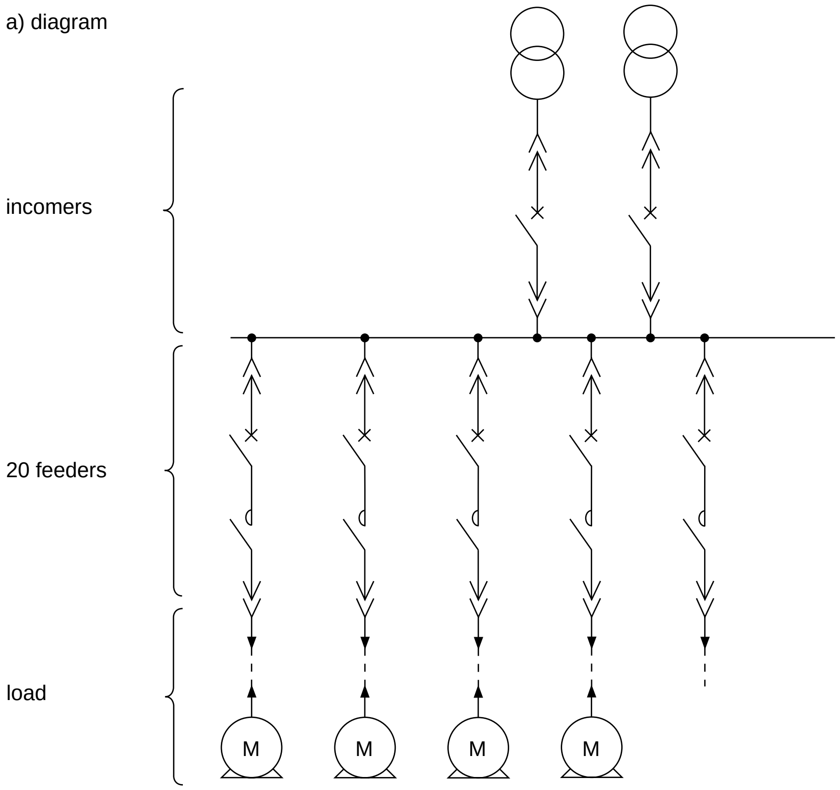
Two medium voltage lines from two different source substations, used in parallel, solve the problem of unavailability of the medium voltage lines. The unavailability of the incomer function is now virtually reduced to that of the high voltage system alone which is roughly 17 minutes a year, compared to 10 hours for the MV system.

Availability can also be increased by adding one or more generator sets (see Cahier Technique n° 148 “High availability electrical power distribution”).

☐ splitting into priority and non-priority feeders

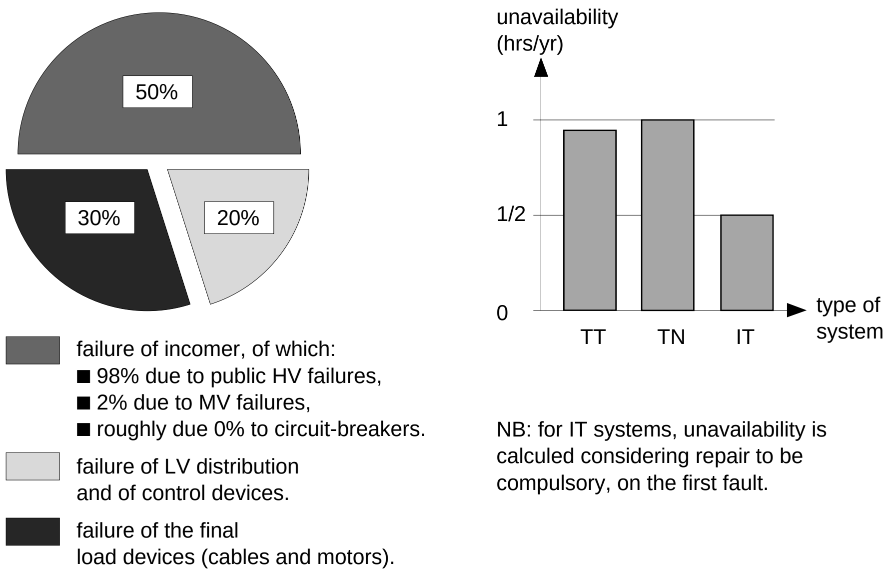
The search for increased availability of electrical power nearly always results (depending on installation size) in dividing applications into two types:
- priority,
- non-priority.

In the event of an overload or failure of the main source, non-priority loads are then shed, while priority loads continue



b) causes of unavailibility on a feeder

c) unavailability on a feeder as a function of the system earthing arrangement



NB: for IT systems, unavailability is calculed considering repair to be compulsory, on the first fault.

fig. 8: unavailability of an incomer may account for a large part of total unavailability, in this case 50%.

to run on a secondary source (second MV incomer, generator set,...).
□ source changeover systems
If a failure occurs, circuits can be transferred to backup sources not used in normal operation or to the sources of non-priority feeders, with load shedding of the latter.
Three types of changeover systems are possible:
-synchronous
The main source and the replacement source are or have the possibility of synchronising, thus ensuring changeover without loss of load supply.
This process is used in installations requiring a high level of dependability.
- delayed
This is the most common type of source changeover system. With transfer times ranging from 0.4 to 30 seconds, its use is widespread for industrial and commercial applications.
- pseudo-synchronous
A fast-acting switching device (60 to 300 ms) is used for the source changeover. This system is found, for example, in the following sectors:
- chemistry,
- petrochemistry,
- thermal power plants.

■ loads
Unavailability due to the load devices is illustrated in the diagram in figure 8 and concerns for instance the motors and the cables supplying them from the switchboard. Reliability calculations show for example that when using a motor M, 30% of its down time due to failures is caused either by the cable or by the actual motor. It is thus necessary to clearly define the technical characteristics of the loads as regards conditions of use, as well as the maintenance procedures intended to prevent failures.
Most electrical failures in motors are due to phase/earth faults occurring on motor startup.
Insulation monitoring before starting a motor, particularly using the Vigilohm SM 20 developed by Schneider, enables:
□ preventive maintenance to be programmed,
□ irreversible motor damage to be avoided.
■ system earthing
The three system earthing arrangements are (see figure 9):
□ TT system (earthed neutral and earthed protective conductors),
□ TN system (earthed neutral and protective conductors connected to neutral),
□ IT system (unearthed neutral and earthed protective conductors).
The system earthing arrangement affects availability and maintainability in that the circuit must be broken on a first fault for TN and TT systems but not for IT systems. In addition, the magnitude of the earth fault current depends on the system earthing arrangement and determines the extent of damage caused to the installation and in particular to the loads.

The results of a reliability study are shown on the histogram in figure 8.
The IT system, with an automatic system for fast locating of the first fault, is the one offering the best availability, as it ensures that:
□ operation is not interrupted (continuity of the production cycle in progress),
□ the fault can be repaired when the installation is not in operation,
□ servicing can be prepared during production, resulting in increased maintainability.
The IT system is recommended in the following cases:
□ presence of loads sensitive to high fault currents,
□ high risk of fire,
□ installations with generator sets (to prevent damage to the generator by an internal fault),
□ need for a high level of dependability (availability + safety), for example in operating rooms in hospitals.

NB: in the IT system, the probability of de-energising due to a second fault (if this fault occurs before the first fault has been located and cleared) is less than in the TN and TT system as the simultaneous presence of the first and second faults is necessary on different phases.

We saw earlier that the system earthing arrangement must be selected with great care. Once this choice has been made, the equipment (switchboard and components) can be chosen, and a certain uniformity sought in the reliability of the different links in the chain making up final unavailability.

Dependability and connections
A switchboard is made up of a large number of connections and it is therefore important to consider the failures they cause.

A connection fails when it ceases to convey the electrical power for which it was designed. A local temperature rise then occurs which may cause irremediable damage to the device and/or the cables.
The importance of good connections is illustrated by the example of an installation with two separate incomers supplying 20 feeders.

system	TT	TN	IT
action during an insulation fault	immediate de-energising	immediate de-energising	■ continuation of operation ■ fault tracking ■ preparation before de-energising
magnitude of fault current (determines damage to installation)	several dozen amps	several kiloamps (short-circuit current)	several dozen milliamps (1st fault)

fig. 9: choice of system earthing arrangement directly affects the dependability and reliability of the installation.

The results of the reliability study (see figure 10) show that 88% of total unavailability is due to various failures (incomer, components,...) and 12% to connections.
A distinction should be made between factory connections and those made on site, as statistics show that the latter are more prone to failure.

In practice, dependability can be considerably increased by:
■ properly sized contact surfaces (overlapping),
■ proper surface finish (flat and clean),
■ a tightening torque suited to the materials.

Dependability and arcing

■ unavailability due to arcing
A number of events can result in the creation of arcs in the switchboard, for example intrusion of small animals (rodents or reptiles), objects forgotten in the switchboard during maintenance work, a temperature rise or deposition of conducting dust.
The damage caused by electric arcs is frequently serious and leads to shutdown times of up to several hundred hours for an “ordinary” switchboard, i.e. 11% of its total unavailability (see figure 10). In comparison, for an "improved" switchboard, this percentage is negligible as its shutdowns are limited to the time required to put the distribution system back into working order (cable tightening, cleaning of carbonised surfaces...), i.e. roughly one hour.
To prevent this unavailability, the following three points should be concentrated on:
□ risk of arc occurrence,
□ arcing time,
□ propagation of electric arcs in the switchboard.
These actions aim at reducing both repair times and the extent of the damage caused by arcs.

■ preventing arcing
It is better to prevent a problem than to cure it, in other words to take action on the cause of electric arcs. Note that:
□ arcing due to dielectric breakdown does not occur if:
- materials are properly chosen,
- creepage distances and clearances are complied with.
□ introduction of objects or foreign bodies, including conducting dust, and intrusion of small animals, are the cause of numerous electric arcs in LV cubicles.

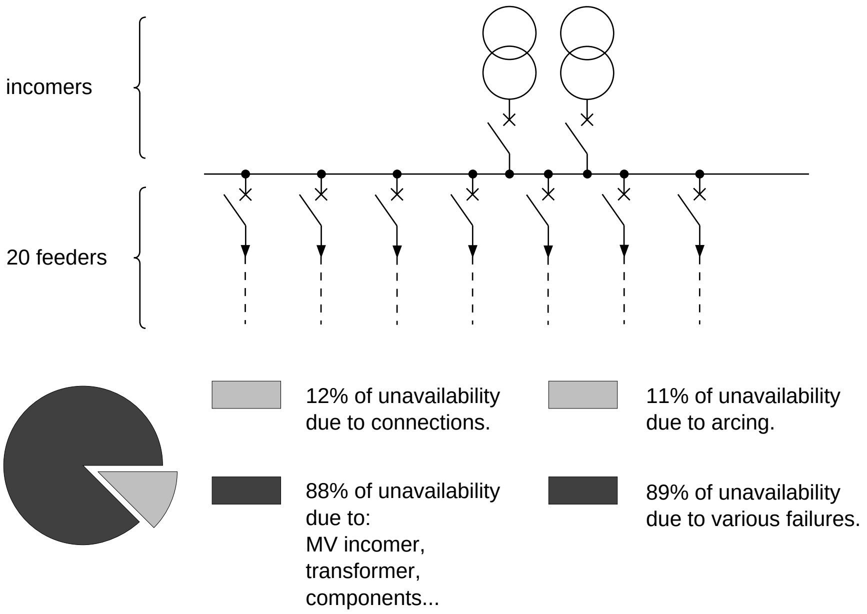


fig. 10: unavailabilities due to arcing and connections account for roughly 20% of causes of system unavailability.

To prevent arcing, considerable care must be taken with enclosure design:
- form,
- choice of IP,
- addition of filter...

□ when breaking occurs (on a short-circuit or overload), pressurised ionised gases are given off by the protective device and may cause arcing, for example on a nearby busbar. This risk can be eliminated by a carefully designed architecture and/or barriers.
□ a faulty connection can often result in creation of an arc. To avoid this, connections must be correctly tightened (see section on "dependability and connections").

■ limiting the arcing time
Damage caused by arcing can be limited by minimising the duration of the arc. Possible solutions are:
□ setting the “short-time delays” (short-circuit protection) to the minimum value that will still provide discrimination. These short delays, designed to implement time discrimination, delay circuit-breaker tripping on a short-circuit, thus prolonging the arcing time.
Note that when zone selective interlocking can be implemented, it is the best solution as it allows absolute discrimination with minimum delays for all distribution stages
(see Cahier Technique n° 18).
□ using limiting devices which quickly break short-circuit currents, thus limiting the fault current. Arcing time is thus reduced and thermal effects limited.
□ choosing a protective device that takes past transient short-circuits into account
The peculiarity of the arc is that it is a somewhat furtive phenomena, for two reasons:
- due to switchboard layouts, an arc is quickly extinguished. However the ionised gases that it generates may cause restrikes on other live parts. A number of extinguishing and restrike sequences are therefore possible.
- moreover, the impedance of the arc varies according to the speed at which it moves and the obstacles that it comes across.

However, each time arcing occurs, the equipment is subjected to a number of stresses which can be cumulated.
The solution to the problem is to provide protection systems which integrate the fault over time, i.e. when a fault appears and disappears (or drops below the trip threshold before the protective device trips), this time and current information must be stored in the protective device to obtain tripping if the fault or brief high current values rapidly reoccur. Thus LV circuit-breakers can be designed to store transient short-circuit information in memory and only gradually return to their initial tripping characteristics (see figure 11).

■ preventing propagation in the switchboard
The laws of physics cause the arc to move quickly away from the source. To limit its consequences, the arc must not be allowed to spread through the entire switchboard. It is essential to control the arc throughout its duration by:

☐ partitioning the various switchboard zones; insulated bushings and partitions prevent the arc and its ionised gases from spreading;
☐ enhancing arc extinction, for instance by implementing
- insulation shrouds around the busbars,
- busbar geometries that lengthen the arc.

Dependability and the switchboard "options"

The form, type of connection (front or rear), device installation method (fixed or withdrawable) and the degree of protection are all possible options when manufacturing and/or purchasing an LV switchboard.
The example in figure 12 shows the effect of these choices on availability at feeder level.

■ form (see figure 3)
Consider form 1 with "unsealed openings" compared to form 2 with "cable access openings sealed".
The abbreviated expression "cable access openings sealed" means that the user has passed the cables through a bottom plate equipped with a cable bushing.

NB: this arrangement is used for form 2 and above.
This example clearly shows that a wise choice of form increases availability (see figure 12), as it affects:
- likelihood of fault occurrence (rodent intrusion impossible),
- arc propagation (presence of partitions).

For good availability, LV switchboards should be partitioned (form 3), including the terminals for external conductor connections (form 4), since, as already pointed out, these connections are the cause of most faults (see paragraph on "dependability and connections").
■ front or rear connection
The space reserved for electrical equipment when designing premises

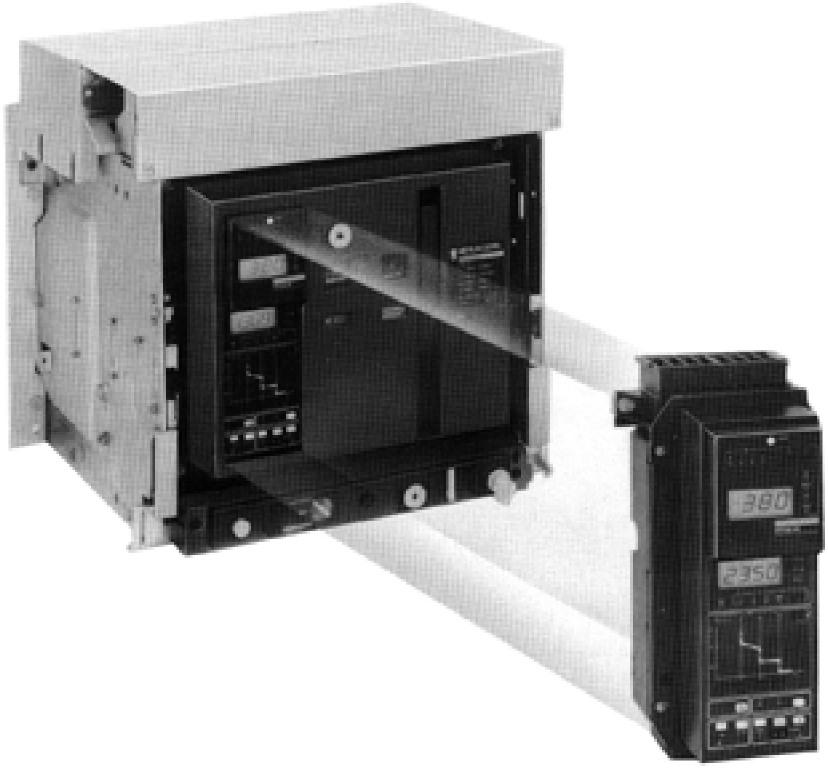


fig. 11: a type B Masterpact circuit-breaker (delayed) equipped with an ST608 control unit temporarily stores short-circuit information in memory (Schneider).

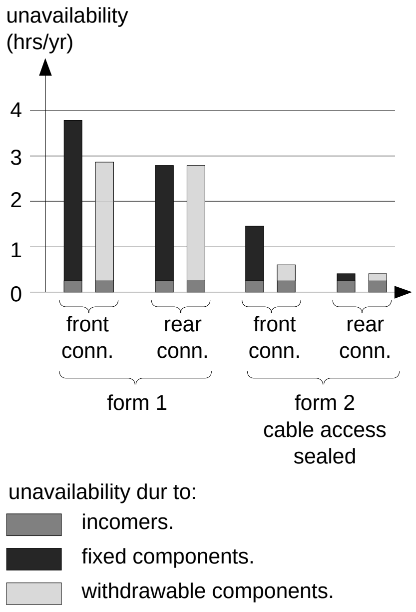


fig. 12: unavailability times depend on switchboard technology and particularly on its connection type (the chart corresponds to the diagram in figure 10).

frequently determines the type of connections used. This constraint has a certain effect on availability. Access to a switchboard with front connections only is often difficult, resulting in lengthy repair times compared with switchboards offering dual accessibility (see figure 13).

Note that the unavailability of a switchboard with front connections is even higher if fixed components are used that require tools for dismantling. To increase maintainability of a switchboard with front connections, designed to stand against a wall, a small servicing clearance should be provided at the rear.

■ fixed or withdrawable
Availability can be improved by choosing withdrawable devices (see figure 12). In this way, maintenance is faster and does not affect adjacent feeders.

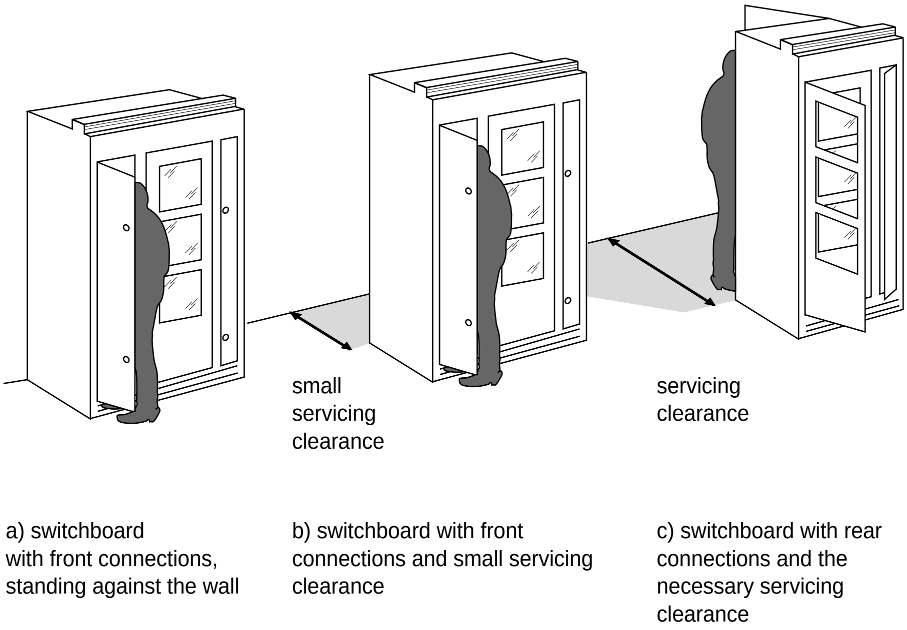
Since withdrawal takes place off-load (with the circuit open) but with power on, breaking is not necessary upstream and interruption of supply to the other feeders parallel to it is not required.

However the withdrawable option may not offer any great advantage for installations subject to a high levels of unavailability elsewhere (unreliable source, single incomer presenting risks,...) or when excellent maintainability does not affect other feeders.
However, in the case of a form 2 switchboard with front connections, the advantage of using "withdrawable" circuit-breakers is clear (see figure 12). In this instance unavailability is divided by 3 compared with the "fixed" solution.

■ degree of protection (see figure 2)
Only the first two characteristic digits of the IP (ingress of solid bodies and liquids) are examined in this section.
The first numeral gives the maximum size of objects or particles likely to enter the switchboard, thus limiting the size of the access points to live parts. This numeral (1 to 6) increases as size decreases.
The second numeral concerns liquids and describes protection obtained by:
☐ canopies, covers or baffles protecting against vertical and/or horizontal liquid splashing and jetting,
☐ seals and suitable devices protecting the enclosure even in the event of immersion.

In conclusion, the higher the first two characteristic numerals of the IP index, the better the protection.

However, all electrical devices produce heat and most of them have a thermal limit.
Excessive imperviousness is contrary to proper switchboard ventilation and may thus affect operation of the components. Heat extraction and/or a suitable choice of devices is thus necessary.
The degree of severity of the environment and the qualification of switchboard operators determine the choice of degree of protection. The necessary protection levels, for each type of premises, are reviewed in figure 14.



a) switchboard with front connections, standing against the wall

b) switchboard with front connections and small servicing clearance

c) switchboard with rear connections and the necessary servicing clearance

fig. 13: a good compromise between maintainability and floor space can be obtained using a switchboard with front connections and a small servicing clearance at the rear.

Dependability and the drawout motor feeder unit

MCC drawout type switchboards are often used in process industries (see figure 15).
Good continuity of service is normally required for motor control. Drawout units allows quick, easy maintenance: the faulty feeder is immediately replaced by an identical device while power continues to be supplied to the switchboard.
A drawout unit corresponding to a motor feeder can be composed (see figure 16) of a fuse, contactor and thermal relay or of a circuit-breaker, contactor and thermal relay.
In terms of availability, both configurations are more or less equivalent in normal operation, but differ considerably should the contactor fail.
In actual fact some 20% of feeder failures are due to contactors (contacts sticking), with the added disadvantage of having to remove the contactor from the drawout unit. The power circuit then has to be opened, which is possible with the circuit-breaker/contactor combination by opening the circuit-breaker. In the other case (fuse/contactor combination) power must be switched off upstream, thus making all the other motor feeders unavailable.

sectors of use	examples	IP degree
domestic premises	bedroom washroom	20 27
technical premises	electrical service air conditioning washer refrigeration chamber	00 24 33
boiler plants and associated premises (power > 70 kW)	fuel storage coal storage boiler plant	20 50 61
garages and parking areas (area > 100 m^2)	repair shop washing area	20 25
buildings for collective use	offices gymnasium large kitchen	20 21 35
farms	alcohol warehouse hen-house fodder storage	23 45 60
industry	electroplating shop paperboard manufacturing quarry	03 33 65
commercial and associated premises	art gallery hardware shop bakery cabine tmaker	20 33 50 60

fig. 14: examples of minimum degrees of protection (as in NF C 15-100 and practical guide UTE C 15-103).

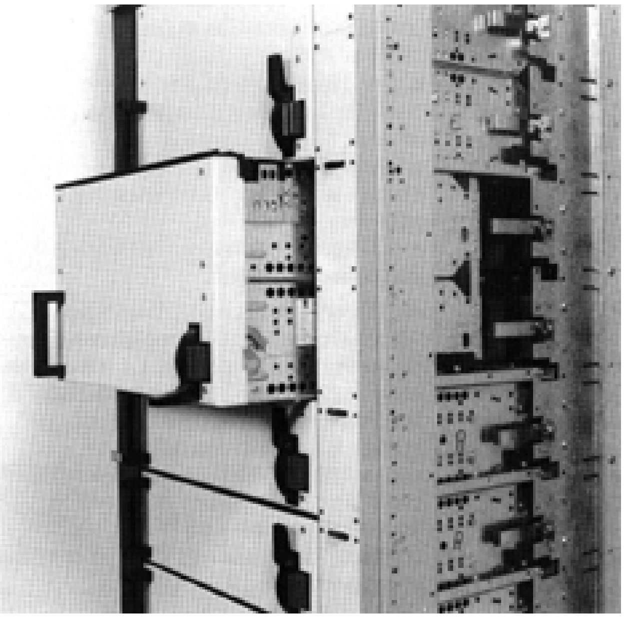


fig. 15: detailed view of an MCC type LV switchboard with drawout units (MB400 model - Schneider).

The consequences of this procedure can be demonstrated for a diagram with 20 motor feeders supplied by 2 separate MV incomers, an example illustrated by the results histogram (see figure 16).

Two contactor operating rates can be identified (low and high). The likelihood of failure of a drawout unit are linked to the operating rate of the contactors. It is thus preferable to use a circuit-breaker rather than a fuse as a protective device if intensive use is made of contactors (operating rate and also utilisation categories of loads AC3, AC4, operating voltage...).

Dependability and the control and monitoring auxiliaries

Using the same example (see figure 16), the influence of the control and monitoring auxiliaries on total availability can be determined. Their associated failures relate to relays, connections or to their power supply.

The individual wiring of non-standardised auxiliaries is a lengthy process and subject to errors by fitters, resulting in potential failures.

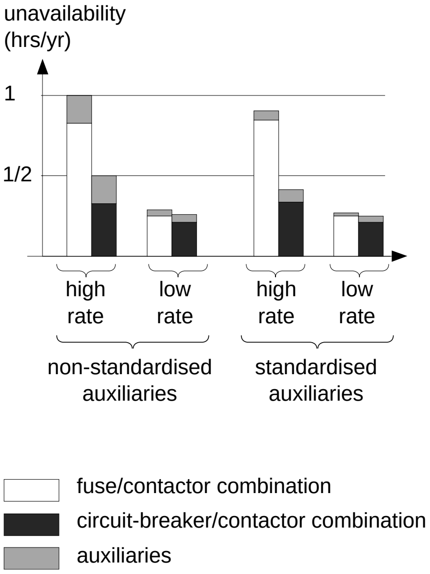


fig. 16: comparison of levels of unavailability for a 20-feeder drawout type switchboard depending on type of components and their operating rate.

To avoid this, Schneider offers standardised products for auxiliary functions (Digibloc, Dialpact,...). These are boards or control and monitoring modules connected by power distribution blocks or by standardised digital links. These elements centralise information and can be used to implement a wide variety of control schemes.

Furthermore, these schemes can be easily modified by setting board parameters or by associating new modules, with the following advantages:

- time savings on implementation,
- increased reliability by eliminating wiring errors,
- repair time reduced to the time required to replace the board or module,
- open-ended solution.

The results of the reliability calculations on the histogram show that these standardisation efforts increase the availability of control auxiliaries depending on the operating rate (from 30% at low rate to 60% at high rate).

required dependability levels

A large number of technical options are available for LV installations, all offering different dependability levels. The right choices depend on the application and on the choices made at other levels.

For example use of a form 4 switchboard is advantageous provided that the other major sources of failures on the installation have been overcome.

The right approach when designing an LV installation is not therefore to choose and install at random a range of effective, reliable devices in the hope of gaining maximum "peace of mind".

In actual fact, each application or sector using LV electrical power requires an appropriate level of dependability, depending on operating imperatives (see figure 17):

- the commercial and service sector includes both of small shops and schools..., as well as supermarkets, shopping centres, large banks, office blocks, hospitals.
- industry comprises all types of factories (automobile, aeronautic, textile,...) and has special needs in terms of distribution (power system protection and architecture) and processes (motor control, control system), which are vital in continuous production applications such as petrochemistry, cement works, food processing...

In what way do these sectors represent different needs? Accidents such as BHOPAL (December 1984), CHERNOBYL (April 1986) and PASADENA (October 1989) are evidence of the high risks run by people and the environment. Hence the unfailing question "is it dependable?".

In fact this question is meaningless. As the possibility of failure is always present, however small, the right question is rather: "is it dependable enough?".

For all sectors this means choosing an acceptable level of probability of dangerous failure (in safety terms) and of dependability (in economic terms):

- in telecommunications, France Telecom has a probability of unavailability of 1 hr/century for telephone exchanges ($\lambda < 10^{-6}\ h^{-1}$).
- in air transport, two dependability conditions are laid down to ensure that:
  - all "overall catastrophic" failures are extremely unlikely ($\lambda < 10^{-9}\ h^{-1}$),
  - all "critical" failures are extremely rare ($\lambda < 10^{-6}\ h^{-1}$).

  This figure can be compared with the likelihood ($\lambda < 10^{-6}$) of a human being dying within the next hour.
- in banks, power failures result in lost entries and recording of erroneous operations. The costs involved in tracking and recovering these errors provide the necessary reference elements.
- in hospitals, safety of persons can be immediately affected by a failure. Operating theatres and reanimation wards are especially designed to ensure a high level of dependability.
- in industry, failures also considerably affect continuity of service. An article written by Y. Lafarge and published in "Le Monde" quotes two examples:
  - for BSN (Danone), a 10 minute shutdown causes a production loss of 20,000 items,
  - for Peugeot, out of a production of 1,650 vehicles a day, a one hour computer failure means 100 cars are not manufactured, i.e. a loss of profit of 4 million francs.

It is thus easy to understand the importance attached by firms to availability of the electrical power on which the entire activity of the company depends.

Thus, in the commercial and service sector and industry alike, failures may have economic consequences, cause damage or be a source of major risks. All of which may affect our everyday life in which good service in 99% of cases ($\lambda = 10^{-2}$) would mean:

- more than 140 new-born babies would accidentally be dropped by doctors and nurses each year;
- no electricity or water for several dozen hours each year;
- your telephone and television would be out of order for more than 10 minutes a week;
- 400 letters an hour would never reach their destination.

These evocative images clearly show the consequences of choice of dependability level. The table in figure 17, although not complete, gives the most important choices for an LV installation and for the various sectors of activity. To specify these choices, the need must be defined and the dependability concepts examined in the previous chapter must be implemented.

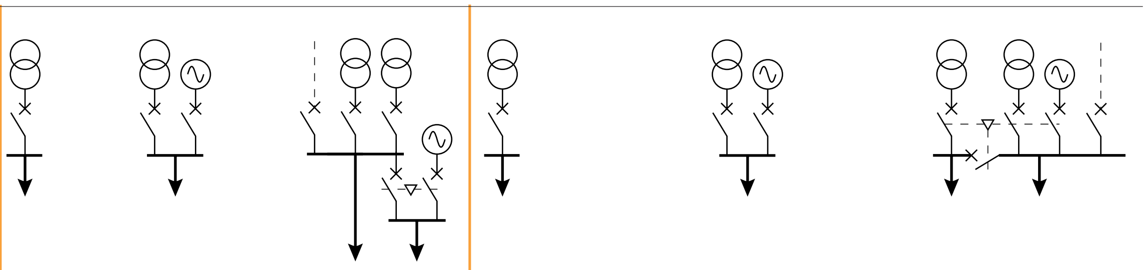
	sectors of activity				
	commercial and service sectors		industry		
	shops	hospitals	workshops	plants	process manufacturing
the problem to be solved:					
types of incoming diagrams					
operating imperatives	numerous mobile and portable loads, frequent changes to distribution system, supply by a public power system.	continuity of service for certain sectors, risk of fire, presence of generator sets.	uncertain earth circuits (worksites), supply by a public power system.	continuity of service for certain sectors, presence of backup generator sets.	continuity of service for most of the operation. risk of serious damage by insulation faults (motors, automation). risk of fire
↓ recommended system earthing arrangements	↓ TT	↓ IT	↓ TT	↓ IT	↓ IT
			numerous auxiliaries (machine-tools), loads with low insulation resistance. ↓ TN	atmosphere and/or loads corresponding to high risk of insulation faults. ↓ TN sub-system	
solutions implemented:					
component type	fixed or disconnectable or withdrawable		fixed or disconnectable or withdrawable		fixed
switchboard type	fixed		fixed or with disconnectable subassemblies or with drawout units		with drawout units
form	F1 to F4		F2 to F4	F2 to F4	F2 to F4
degree of protection IP (first two numerals)	2 to 5		2 to 5	3 to 5	3 to 5
motor control components					
low rate			fuse/contactor combination		
high rate			circuit-breaker/contactor combination		
technology of control and monitoring auxiliaries	non-standardised (individual wiring)	standardised (boards, modules and connections)	non-standardised	standardised	

fig. 17: the sectors of activity and operating imperatives determine the system earthing arrangement and the solutions implemented depend on the form used and on the degrees of protection required.

4. future perspectives for switchboards

Modern switchboard technology has been and continues to be greatly influenced by the development of power management systems. We must therefore look into the implications of power management on dependability. The reader will see that power management provides the installation with greater dependability by integrating information processing electronics in the LV switchboard which thus becomes "intelligent".

Power management

Power management is already used in Building Management systems, which have gradually replaced more centralised systems in industrial, commercial and even domestic applications to supervise, monitor and control the following standard functions and facilities:
■ heating and air conditioning,
■ fire protection,
■ intrusion protection,
■ access and worktime control,
■ lifts, lighting...,
■ energy tariff management.
Power management is becoming more and more decentralised for reasons of availability, user convenience and modularity (already mentioned in chapter 1). Over and above the traditional functions performed by electrical equipment (protection, automation, transfer of loads to backup sources), a power management system provides a number of functions in the electrical control and monitoring field.
To cite a few examples:
■ automatic, progressive resumption of feeder supply after a fault,
■ alignment of consumption to energy supply possibilities at a specific time (load shedding and reconnection, generator startup and shutdown),
■ optimisation of sources according to consumption to derive maximum advantage from electricity contracts with differentiated tariffs,
■ optimisation of capacitor bank operation,
■ contribution to discrimination (coordination of protective devices).
It also enables:
■ local and remote control and monitoring (indications, alarms, controls and setting modifications,...),
■ supervision (graphic representation of system status, event logging and installation control).

The need for power management increases with the need for availability and, more generally, for dependability.

Power management systems have been made possible by the introduction and widespread use of microprocessor technology which at the same time provides an opening towards greater, distributed "intelligence".

power management for greater dependability

A power management system relies on two principles when a failure occurs:
■ the electrical distribution system can remain as it is and is not at risk by failure of a management module. This is simplified by the use of bistable power control devices such as switches, impulse relays and circuit-breakers.
■ the protection, control and monitoring systems continue to be independently activated, thus making operation in crippled mode possible. This principle ensures the prime objective of dependability even though certain functions of convenience are temporarily lost. Thus even if the supervision system fails, protection functions will continue to fulfil their task and the switchboard central unit will remain operational.

Moreover, power management reinforces dependability of the LV installations in terms of:

■ reliability
□ the power management system reduces the major risk of failure represented by human intervention,
□ complete information eliminates the risk of error in system management.

■ maintainability
Reliability can be obtained by rigorous design, but product dependability also requires a high level of maintainability.
There are two types of maintenance:
□ preventive maintenance is designed to anticipate problems and thus to limit the risk of shutdown due to a fault (it prevents the fault from occurring),
□ curative maintenance is designed to quickly restore the system to its "operating" condition (it locates the fault).
Preventive maintenance takes priority over curative maintenance as it avoids problems during operation. However it requires sound knowledge of the products at all stages and the capacity to detect potential failures. Experiments and tests on equipment can provide this knowledge and a power management system can use it in an optimum manner:
□ a preventive maintenance system is established to reduce the number of failures, using the following:
- operation counters,
- insulation resistance measurement devices...
□ a curative maintenance system locates the fault in the event of a failure.
□ two other systems, remote maintenance and/or remote diagnostics, considerably enhance switchboard operation:
- remote maintenance ensures surveillance without the need for a control room and a permanent maintenance team on site. Remote transfer of information on failures makes frequent inspections of the various electricity supply points unnecessary.
- remote diagnostics enable troubleshooting to be conducted on the basis of quantifiable parameters transmitted via a telecommunications system. The reduction in maintenance time is obvious, particularly when

outside suppliers are responsible for management and servicing of the installation. Remote diagnostics give them the best chance of repairing the failure on their first visit to the site.

■ in terms of availability
Availability is naturally the result both of reliability and maintainability, as well as:
□ prevention of overloads with the solution of load shedding and reconnection to prevent tripping,
□ management of sources (switching, coupling and startup of generator sets),
□ discrimination of the various protection levels which, as explained above, has an important role in installation availability.

■ in terms of safety
□ safety of persons is guaranteed by reflex protective devices (placed as close as possible to the fault) which, although part of the management system, can function independently if a fault occurs.
□ maintenance operations are fewer and can often be scheduled, allowing personnel to work under less stress.
□ operating staff are guaranteed additional protection by indication of device status in maintenance areas, and by warning of potential failures.

the technology

Control and monitoring "intelligence" must be organised with sufficient care to ensure a good level of dependability. It particularly calls for implementation of:
□ high-performance electronics,
□ communication networks using reliable buses,
□ software of recognised reliability, for overall control.

■ electronic components and circuits are today increasingly reliable, driven by developments in the aerospace, military, nuclear and general public sectors. The reliability levels are easily controlled, since the statistical reliability laws associated with components are perfectly applicable and reliability calculations for assemblies well controlled.
Critical points are backed up by redundancy of all or some parts of the electronic modules or by using components with increased reliability.

■ buses are responsible for the development of decentralised intelligent systems and form the communication backbone. The serial links making up the buses enable the transfer of data to many points via a single cable (coaxial or twisted pair). Their reliability has recently been upgraded and it is now possible to isolate them from external disturbances of the electromagnetic type and by using protocols including monitoring of information exchanges. This subject is developed in Cahier Technique n° 147 "Introduction to digital communications networks".

■ system dependability also depends on that of the software controlling the system. In this case, rather than a revolution, we witness a systematic race for rigour at all levels, from design to commissioning (specification and development methods, special tools, highly sophisticated verification and test procedures).

the "intelligent" switchboard

The "intelligent" switchboard includes a large part of the power management system (see figure 18), in particular:
□ the "intelligent" electrotechnical components,
□ specific systems
(e.g. insulation monitoring),
□ the switchboard central unit

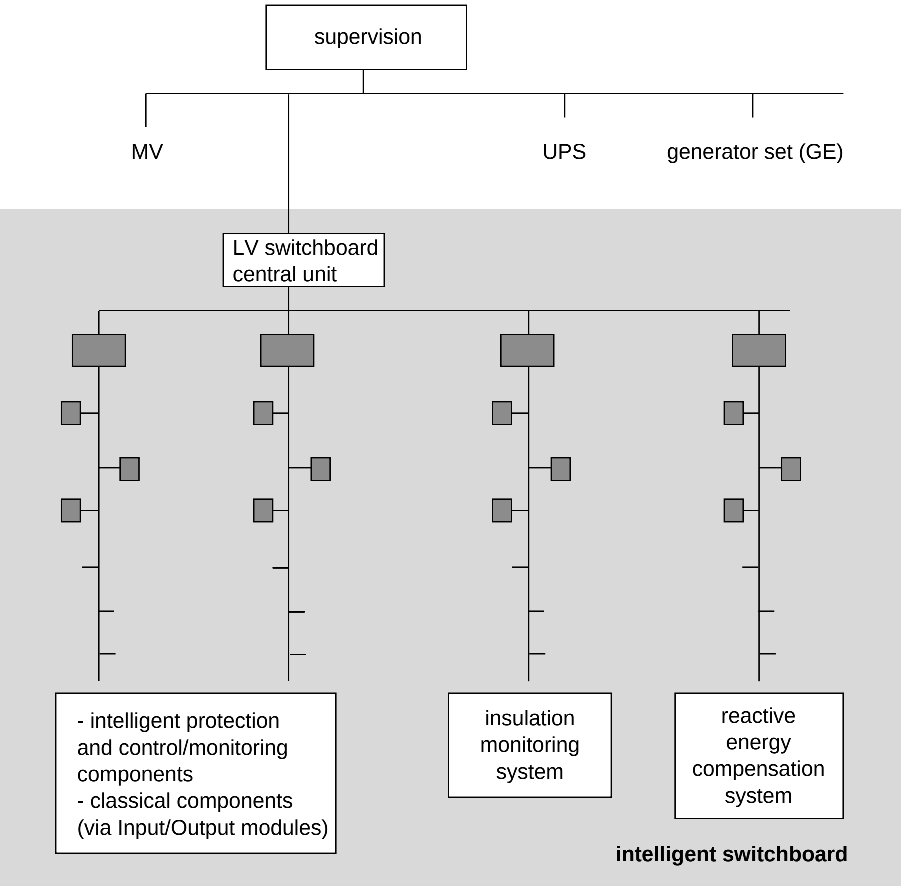


fig. 18: general diagram showing control and monitoring of an electrical installation and its links (BUS) supervision.

☐ the digital communications buses.
Use of microprocessors means that intelligence is distributed right through to component level (circuit-breakers, switches,...). In addition to their basic function, they process a variety of information and communicate with the switchboard central unit, thus ensuring:

- "sequencing" of actions (logic and time sequencing),
- capacity to calculate and process many pieces of digital information sent by these devices, sensors and specific systems,
- remote transmission by “serial” bus enabling the control and monitoring system to communicate with the operator and/or the supervision system,
- control and monitoring, both local and remote, as well as supervision (orders are transmitted by bus).

The switchboard can now be said to be "intelligent": the intelligence integrated in the power management system will depend on the degree of complexity of the installation to be managed. The distribution of electrical power in small commercial applications may only require the display of measurements and status information on the front panel of the switchboard, whereas in large buildings, remote control functions are required (lighting, source changeover,...).

Power management is at present implemented in MV and LV by means of various components. These components, more and more standardised and convenient to use by electricians, will be available in increasingly wide ranges.
The various components in the intelligent switchboard are designed to work together. The consistency, both in terms of hardware and software, guarantees easy implementation and use.

An "intelligent" switchboard with appropriate overall design and made up of consistent, carefully designed and manufactured products, opens the way to efficient power management and the mastering of electrical power will greater dependability.

5. conclusion

The distribution of electrical power must meet increasing requirements in terms of:

- dependability,
- upgradability,
- user friendliness.

Designers thus aim at producing installations which are "intelligent", independent, communicating, modular, reliable and easy to service.
These criteria can all be achieved by decentralisation. The basic functions (protection and control) are performed as close as possible to the application, and only supervision has a "central" position, playing a vital role in distribution management as regards the man/system relationship.
Decentralisation is a design feature of each product, both in their connections (defined between them) and in their overall architecture.

All these items (high power components, control and monitoring devices and electrical connections) are integrated in the LV switchboard. Its role is thus vital for distribution as a whole, given that it has to guarantee overall dependability.
The following points should be borne in mind:

- the incoming diagram and the reliability of the final loads are the points which may most handicap dependability,
- the system earthing arrangement affects availability of final loads and must therefore be chosen carefully,
- connections seriously affect switchboard reliability, thus calling for careful design and implementation,
- switchboard technology, form, degree of protection, connection,... must be adapted to the environment in which the equipment is installed (degree of pollution of premises, qualifications of operators,...),
- withdrawable components are used when they provide the added dependability required,
- drawout motor feeder units are particularly used in process industries for the flexibility and increased availability that they provide,
- auxiliaries with standardised connections and implementation guarantee the reliability of installation control and monitoring.

Dependability is everybody’s job, including that of the designer (the right choices from the start), the installer (implementation in accordance with the manufacturer’s recommendations and proper practices) and the maintenance engineers (surveillance and preventive maintenance of critical points).

This Cahier Technique shows how dependability objectives can be achieved and how, by choosing the right options, particularly in terms of technology, the required level of dependability can be obtained.

The "intelligent" LV switchboard, associated with power management, meets the criteria of dependability and user convenience particularly well, providing a solution for both present and future needs. The degree of built-in "intelligence" required depends on the complexity of the installation.

This intelligent switchboard, designed to ensure maximum standardisation, integrates power, control and monitoring and communication via buses. Should changes be made to the distribution system, switchboard modularity and simple parameter resetting of the control and monitoring system ensure easy upgrading . There is no need to redo studies and tests for each application as the product has already been thoroughly tested.

appendix: bibliography

Schneider Cahiers Techniques

- Analyse des réseaux triphasés en régime perturbé à l'aide des composantes symétriques,
  Cahier Technique n° 18
  B. DE METZ NOBLAT
- Méthode de développement d'un logiciel de sûreté,
  Cahier Technique, n° 117
  A. JOURDIL, R. GALERA
- Introduction to dependability design,
  Cahier Technique n° 144
  P. BONNEFOI
- Etude thermique des tableaux
  Cahier Technique n° 145
  C. KILINDJIAN
- Initiation aux réseaux de communication numériques,
  Cahier Technique n° 147
  E. KOENIG
- High availability electrical power distribution,
  Cahier Technique n° 148
  A. LONCHAMPT, G. GATINE

Standards

- NF C 12-101: protection of workers in buildings implementing electric currents.
- NF C 15-100: rules for LV electrical installations.
- IEC 529: classification of degrees of protection provided by enclosures.(NF C 20-010; NF C 20-011; HD 365);
- NF C 20-030: electric shock protection, safety rules.
- NF C 20-040: creepage distances and clearances in air.
- IEC 439-1: low-voltage switchgear and controlgear assemblies.

Various publications

- Les automates programmables sont-ils plus fiables que les relais?
  Revue J3E - October 1990
  F. SAGOT
- Experience in critical software development,
  IEEE Fault Tolerant Computing Symposium, 26-28 June, 1990. Newcastle
  C. SAYET, E. PILAUD (Schneider)
- Risque et sécurité dans le domaine du transport,
  Revue Maintenance - November 1990
  J-C LIGERON

Real.: Illustration Technique - Lyon
Edition: DTE - Grenoble
05-97 - 1500 - Printing: Clerc