1 Smart Grids and the New Age of Energy

Fig. 1-1: **Siemens offers complete communication solutions for the construction of Smart Grids for power utilities**

Electrical energy is the backbone of our economy and supports every aspect of social and cultural life today. The comfort of always having electricity available is anything but guaranteed, however. We face major challenges in providing adequate power generation, transmission, and distribution to meet the world's needs.

The global demand for energy is steadily increasing at the rate of three percent a year, faster than the two percent annual increase in the global demand for primary energy. There are many factors contributing to this escalation, including rapid population growth and longer life spans. The process of urbanization continues to accelerate, and growing 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 supply systems are also increasing (fig. 1-1).

Fossil fuels, on the other hand, are becoming more scarce, and exploration and production of oil and gas are becoming more expensive. To slow the threat of climate change we must reduce our CO_2 emissions worldwide; for power supply systems, this means increased integration of renewable energy sources such as hydro, wind, and solar power. At the same time, it also means boosting the energy efficiency of power supply systems so they contribute to our 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 integration of power grids across regions requires investment in more transmission power supply systems to ensure system stability and guarantee power supplies.

To meet all these challenges, an intelligent and flexible system infrastructure, smart generation, and smart buildings are essential. Achieving this will require a fundamental shift from the traditional unidirectional flow of energy and communication to a bidirectional power flow (fig. 1-2). In traditional power supply systems, power generation follows the load – but in the future, power consumption will follow generation rather than the other way around.

Power supply systems of today and tomorrow must integrate every type of power generation to bridge the increasing distances between power generation – offshore wind farms, for example – and the consumer.

The objectives set for Smart Grids are as diverse as they are exciting and ambitious. Instead of overloads, bottlenecks, and blackouts, Smart Grids will ensure the reliability, sustainability, and efficiency of power supplies. Information and communication systems within the network will be systematically expanded

Fig. 1-2: **The Power Matrix: The energy system is being transformed. Distributed power generation is growing – increasing the system's complexity. The energy chain has evolved into a multi-faceted system with countless new participants – the power matrix. It reflects the reality of the energy system. Individual power matrices are appearing in each country and region – depending on the specific situation, challenges and goals. Siemens knows the markets and needs of its customers, and offers innovative and sustainable solutions in all parts of the power matrix**

and homogenized. Automation will increase considerably, and appropriately equipped smart substations will help reduce the cost and labor intensity of planning and operation. Ongoing, comprehensive monitoring will improve the way that plants and the grid are run.

Distributed power generation and storage units will be combined into virtual power plants so they can also participate in the development of the market. Susceptibility to failure will be considerably reduced by "self-healing" systems that manage and redundantly compensate for faults at the local level. Consumers will participate as end customers through smart meters that offer them better control of their own consumption, and this will make load management easier because peak loads can be avoided through price benefits. The potential of Smart Grids is enormous, and includes the use of buildings and electric vehicles linked into the network as controllable power consumers, generation, and even storage units.

Information and communication technology forms the crucial links between power generation, transmission, distribution, and consumption. The Smart Grid will create consistent structures, optimize power generation, and balance fluctuating power production with consumption (fig. 1-3).

Siemens plays a leading role in the creation and expansion of Smart Grids. Not only is Siemens uniquely positioned to transmitt and distribute power, Siemens is also the world market leader in energy automation, which plays a decisive role in the creation of Smart Grids.

Fig. 1-3: **A Smart Grid ensures that renewable energy sources can be better integrated into the system thanks to a two-way flow of energy (orange line) and a bidirectional flow of communication data (blue line). Whereas the generation of power in conventional power supply systems depends on consumption levels, a Smart Grid also is able to control consumption – depending on the availability of electrical power in the grid**

Network planning
Building Smart Grids is a highly complex task that begins with a detailed quantitative assessment of the system requirements, definition of actual targets and their required performance levels, and specification of system concepts and equipment. As a result, a comprehensive strategy for building Smart Grids is necessary – including the part of the network that addresses power supply systems.

The foundation for designing an efficient Smart Grid is a detailed analysis of the system's required performance. This is the key task for strategic network planning. Keeping a rigorous focus on the system as a whole ensures that the architecture and configuration deliver the necessary performance levels, and meet other requirements as well. The solution will integrate the most innovative technologies for power generation, transmission, distribution and consumption, while taking into account each system's individual history and current condition. In most cases, the transition from today's power supply system to the future Smart Grid cannot be made in one step; instead it requires step-by-step modification plans.

See chapter 9, page 478.

Power electronics (HVDC / FACTS)
Siemens power electronic solutions for High Voltage Direct Current transmission (HVDC) and Flexible Alternating Current Transmission Systems (FACTS) address the greatest challenges in power transmission.

FACTS devices can significantly increase the power transmission capacity of existing alternating current (AC) systems and extend maximum AC transmission distances by balancing the variable reactive power demand of the system. Reactive power compensation is used to control AC voltage, increase system stability, and reduce power transmission losses.

State-of-the-art FACTS devices include Fixed Series Compensators (FSC) and Thyristor Controlled Series Compensators (TCSC), or Static VAR Compensators (SVC) for dynamic shunt compensation. The latest generation of Siemens SVC devices is called SVC PLUS. These are highly standardized compact devices that can easily be implemented in demanding network environments; for example, to allow connection of large offshore wind farms.

AC technology has proven very effective in the generation, transmission and distribution of electrical power. Nevertheless, there are tasks that cannot be performed economically or with technical precision using AC. These include power transmission over very long distances, as well as between networks operating asynchronously or at different frequencies. In contrast, a unique feature of HVDC systems is their ability to feed power into grids that cannot tolerate additional increases in short-circuit currents.

The transmission capacity of a single HVDC transmission system has recently been extended by the Siemens Ultra High Voltage Direct Current transmission system (UHVDC). With a capacity of more than seven gigawatts and low rate of loss, UHVDC transmission is the best way to ensure highly efficient power transmission of 2,000 kilometers or more. Electrical Super Grids based on UHVDC transmission can interconnect regions across climate and time zones, allowing seasonal changes, time of day and geographical features to be used to maximum advantage.

Siemens' most recent development in HVDC transmission is called HVDC PLUS. Its key component is an innovative Modular Multilevel Converter (MMC) that operates virtually free of harmonics. HVDC PLUS converter stations are highly compact because there is no need for complex filter branches. This feature makes HVDC PLUS perfectly suited for installation on offshore platforms; for example, to connect offshore wind farms.

See section 2.2, page 19 (HVDC), and
section 2.4, page 27 (FACTS).

Bulk renewable integration
In order to begin fulfilling the climate protection requirements of 2020, we need to use energy efficiently and reduce CO_2 emissions. Power generation needs to change accordingly. Large power plants will continue to ensure basic supplies, but there will also be renewable energy sources that fluctuate locally depending on weather and other conditions.

Energy Management System (EMS)
At power plants, the focus is on ensuring reliable supply, using generation resources efficiently, and reducing transmission losses. An Energy Management System (EMS) handles these by balancing the demands of the transmission system, generating units, and consumption. Intelligent Alarm Processors (IAPs) reduce the critical time needed to analyze faults in the grid and take corrective action, as well as the risk of incorrect analysis. Innovative Voltage Stability Analysis (VSA) applications running automatically and independently alert the operator before critical situations that jeopardize static system voltage stability occur, giving the operator time to take preventive action rather than having to react under stress. Increased grid reliability is provided by Optimal Power Flow (OPF) applications that continuously work to keep the system's voltage level high and eliminate invalid voltage conditions. Any control measures that must be taken can be automatically executed in a closed-loop-control procedure.

Using the most efficient resources is a challenge under today's more stringent environmental restrictions, increasingly competitive markets, and growing contractual complexity. An integrated set of closely interacting applications – ranging from back office-based, year-ahead resource optimization and maintenance planning to week- or day-ahead unit commitment and hydro-scheduling to online closed-loop control of generating units – ensures maximum efficiency grounded in powerful optimization algorithms and models. Security Constrained Unit Commitment (SCUC) has become the essential application for managing the world's most complex energy market in California at California ISO. SCUC increases grid and market efficiency, reduces barriers to alternative power resources like demand-response and green

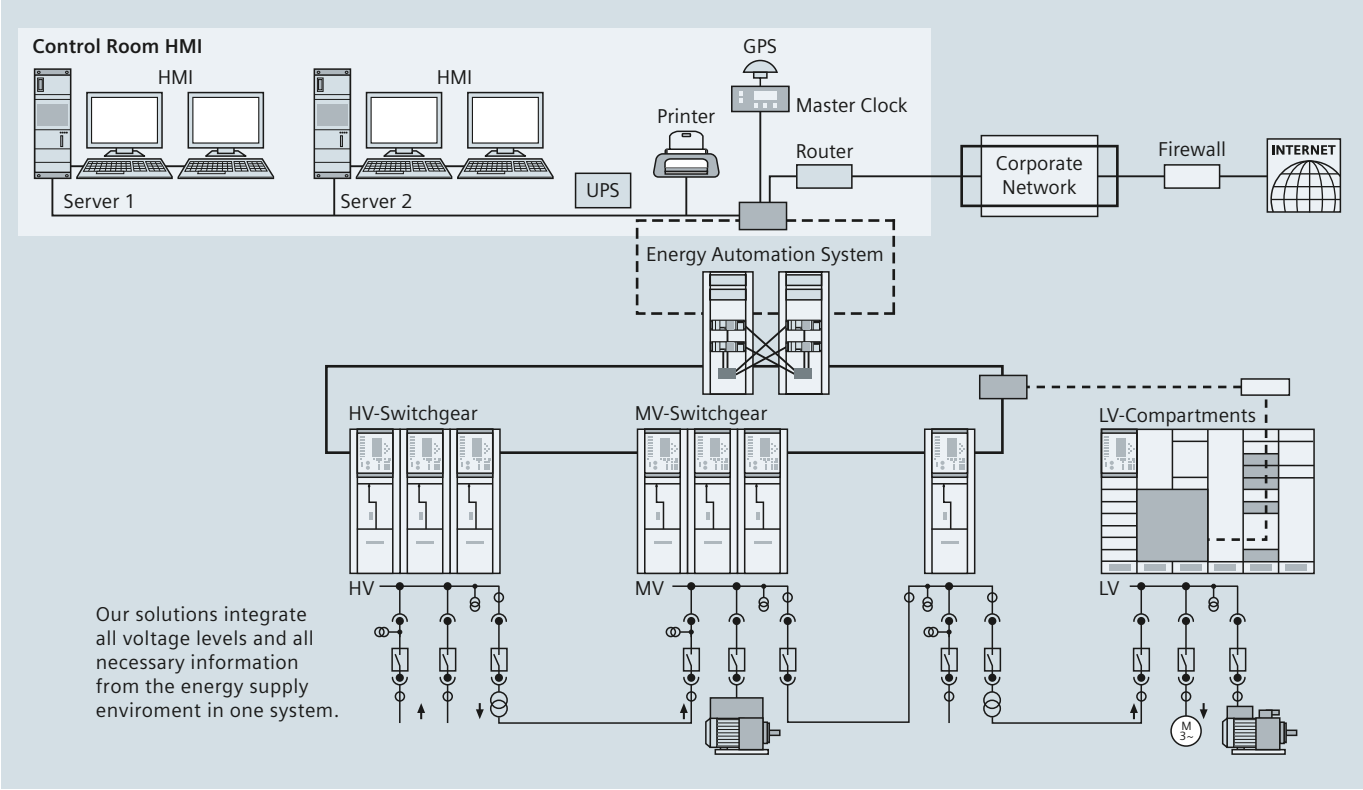

Fig. 1-4: **Siemens Smart Substation Automation Systems**

generation, and gives the operators new tools for managing transmission bottlenecks and dispatching the lowest-cost power plants.

See chapter 7, page 402.

Smart substation automation and protection

The automation and protection of substations must be enhanced to securely meet the extended requirements of future Smart Grids. The substation is in the process of becoming a node on the utility IT network for all information from the distribution substation to the customer. For example, data from the feeder automation units, power quality, meters, decentralized energy resources and home automation systems will be collected and analyzed to improve the system. Besides the new Smart Grid challenges, the usual tasks of protection, control and automation have to remain as reliable and efficient as ever. The objectives for substations are beginning to cross departmental boundaries, encompassing operations, maintenance and security requirements. Smart substation solutions and their individual components should be designed with this overarching vision and framework in mind. The use of intelligent feeder devices, an open IEC 61850 communication architecture, powerful substation computers, equipment knowledge modules and local storage all support this approach. The automated substation for Smart Grids must integrate all aspects of intelligence, from protection, automation and remote control to operational safety and advanced data collection. Going beyond the traditional concept of substation control and protection, the new automated substation must reflect the point of view of operators and maintenance personnel to become a best-in-class system that is simple both to operate and maintain. Smart Substation Automation ensures rapid and – more importantly – correct responses to unpredictable system events. The ability to reliably supply electrical power on demand can only be guaranteed by considering the power supply system in its entirety (fig. 1-4).

Smart Substation Automation Systems from Siemens support the following goals:

- Secure and reliable power supply
- Guaranteed high levels of protection for facilities and people
- Reduction of manual interactions to enhance rapid self-healing operations
- Implementation of intelligent remote error monitoring, detection, reporting
- Enabling condition-based predictive maintenance
- Support for engineering and testing through plug-and-play functionality
- Proactively distributing substation information to all relevant stakeholders
- Reduced costs for installation and maintenance.

Siemens Smart Substation Automation Systems are always customized to meet each customer's specific requirements. The use of standard components allows the system to scale in every respect. Siemens solutions offer a fully integrated and fully automated way to operate substations under normal and emergency conditions. The system is flexible and open for future

modifications, making it easy to expand the substation while allowing the addition of new Smart Grid functions.

See chapter 6, page 262.

Integrated Substation Condition Monitoring (ISCM)
Integrated Substation Condition Monitoring (ISCM) is a modular system for monitoring all relevant substation components, from the transformer and switchgear to the overhead line and cable. Based on known, proven telecontrol units and substation automation devices, ISCM provides a comprehensive solution perfectly suited to substation environments. It integrates seamlessly into the existing communication infrastructure so that monitoring information from the station and the control center is displayed.

See section 10.1.3, page 496.

Communication solutions
The new Age of Electricity is characterized by a mix of both central and decentralized power generation, which requires bidirectional energy flows – including power from smart buildings and residential areas where consumers are becoming "prosumers." A key prerequisite for this paradigm shift is a homogeneous, end-to-end communication network that provides sufficient bandwidth between all grid elements.

Telecommunication systems for power grid transmission have a long history in the utility industry. In today's transmission grids, almost all substations are integrated into a communication network that allows online monitoring and controlling by an Energy Management System (EMS).

In a distribution grid, the situation is quite different. Whereas high-voltage substations are often equipped with digital communication, the communication infrastructure at lower distribution levels is weak. In most countries, fewer than ten percent of transformer substations and ring-main units (RMUs) are monitored and controlled remotely.

Communication technologies have continued to develop rapidly over the past few years, and the Ethernet has become the established standard in the power supply sector. International communication standards like IEC 61850 will further simplify the exchange of data between different communication partners. Serial interfaces will, however, continue to play a role in the future for small systems.

Because of the deregulation of energy markets, unbundling of vertically integrated structures, sharp increases in decentralized power production, and growing need for Smart Grid solutions, the demand for communications is rapidly increasing. And this applies not just to higher bandwidths, but also to new Smart Grid applications, such as the integration of RMUs and private households into power utilities.

For these complex communication requirements, Siemens offers customized, rugged communication network solutions for fiber optic, power line and wireless infrastructures based on energy industry standards.

An important element in creating and operating Smart Grids is comprehensive, consistent communication using sufficient bandwidth and devices with IP/Ethernet capability. Networks of this kind must eventually extend all the way to individual consumers, who will be integrated into them using smart metering. Consistent end-to-end communication helps meet the requirement for online monitoring of all grid components and, among other things, creates opportunities to develop new business models for smart metering and integrating distributed power generation.

See chapter 8, page 442.

Distribution Management System (DMS)
Today's distribution grid operation is primarily characterized by manual procedures that rely on the expertise of an aging workforce. Using Spectrum Power Distribution Management Systems (DMS) will create a smart, self-healing grid by providing the following enhancements:
- Reduction of the occurrence and duration of outages through the application of advanced fault location and network reconfiguration algorithms.
- Minimization of losses through improved monitoring.
- Optimized utilization of assets through management of demand and distributed generation.
- Reduction of maintenance costs through online condition monitoring.

The smart management of power distribution grids is one of the key success factors for achieving ambitious Smart Grid goals.

See section 7.1, page 404, and section 7.2, page 420.

Distribution automation and protection
The prerequisite for comprehensive automation and protection design is determining the required levels of automation and functionality for distribution substations and RMUs. This could differ among the RMUs in one distribution grid or in the same feeder because of different primary equipment or communication availability. However, with or without limited communication access, a certain level of automation and Smart Grid functionality can still be realized, as can a mix of functions in one feeder automation system. The following levels of distribution automation can serve as a roadmap for grid upgrades moving toward the implementation of a Smart Grid:

Local Automation (without communication)
- Sectionalizer (automated fault restoration by using switching sequences)
- Voltage regulator (automated voltage regulation for long feeders)
- Recloser controller (auto reclose circuit-breaker for overhead lines)

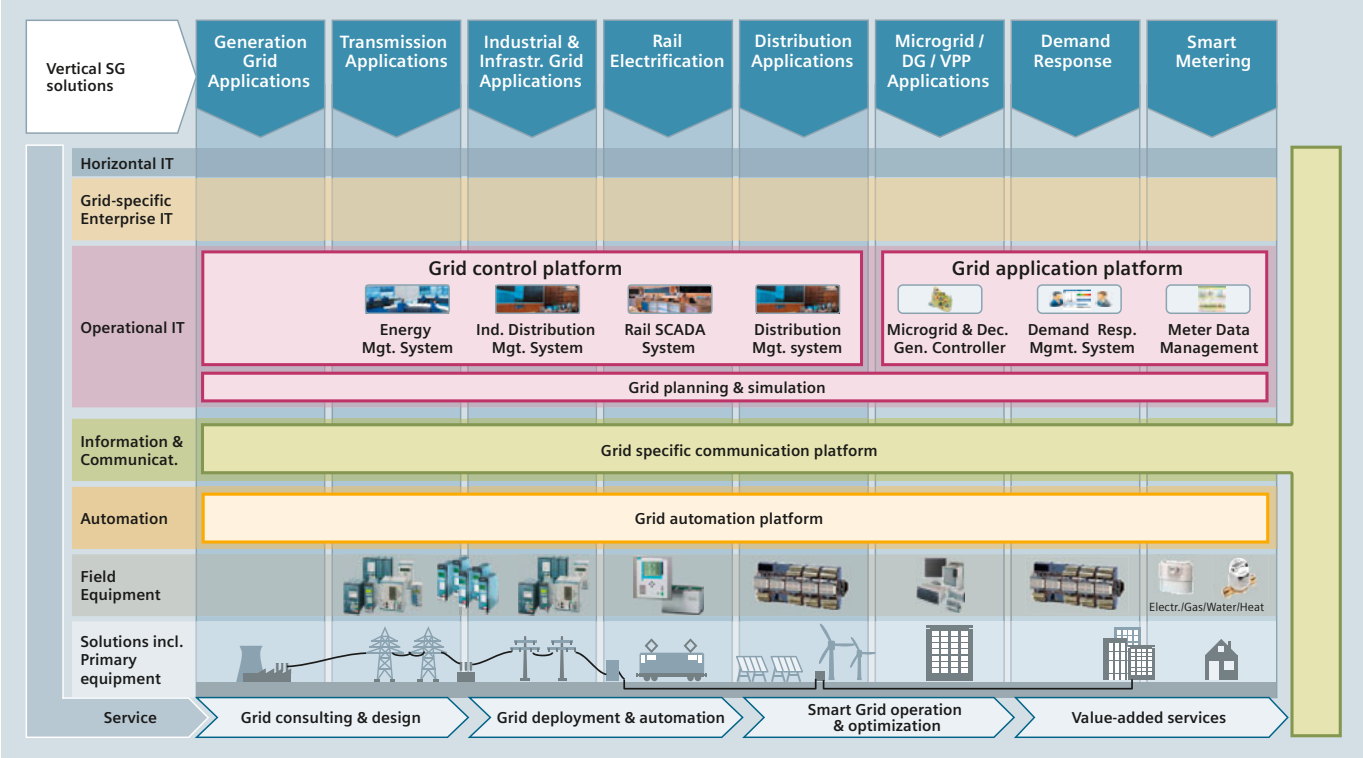

Fig. 1-5: **Siemens refers to its Smart Grid portfolio as Smart Grid Suite. The Suite contains everything necessary for a Smart Grid: hardware, software, IT solutions, and services for the development of intelligent grids. This refers not only to power supply grids, but also gas, water, and district heating networks. In power supply grids, Siemens also includes networks for railway electrification**

Monitoring only (one-way communication to distribution substation or control center)

- Messaging box (for example, short-circuit indicators with one-way communication to distribution substation or control center for fast fault location)

Control, monitoring, and automation (two-way communication to distribution substation or control center)

- Distribution Automation RTU (DA-RTU) with powerful communication and automation features applicable to Smart Grid functions, for instance:
  - Automated self-healing routines
  - Node station for power quality applications
  - Data concentrator for smart metering systems
  - Node station for decentralized power generation
  - Node station for demand-response applications

Protection, control, monitoring, and automation (two-way communication to distribution substation or control center)

- Recloser controller for overhead lines, plus auto reclose breaker with enhanced protection functionality and advanced communication and automation features

To fulfill all these requirements in a Smart Grid feeder automation system, a modular approach to protection, monitoring, automation and communication equipment is needed. Siemens offers a complete portfolio for each level of Smart Grid application:

- Robust primary and secondary equipment to withstand tough outdoor conditions
- Flexible IO-modules adapted to the requirements of the specific RMU type, for example, for direct output to motor-driven switches or input from RMU sensors
- Optimized CPUs with advanced automation and protection functions to secure a safe and reliable power supply, with automated system recovery functions and convenient remote access
- Reliable (emergency) power supplies for all components in the RMU, for example, to operate the switchgear motor drive, to run a heating system for outdoor application, or to power the controller and communication units
- Future-oriented, fast communication via different infrastructures, for example, GPRS-/GSM modem, fiber optic, and power line carrier
- Multiple communication protocols like IEC61850 and DNPi to connect the RMU with the distribution substation, control center, or end-user applications
- Modular, sustainable controller functions to fulfill specific Smart Grid requirements like fault detection and isolation, automatic reclosing functions, voltage or load-flow regulation, and more
- A user-friendly, powerful engineering tool with seamless integration in the overall engineering process of the distribution automation system to enable maximum re-use of data
- Open interfaces for all system components, enabling the integration of other applications; in other words, a system that is equipped for future Smart Grid modifications

To manage these tasks with a global perspective, it is crucial to fully understand the overall structure of distribution grids: primary and secondary equipment, voltage levels (from high voltage via medium voltage to low voltage), indoor and outdoor applications, and multiple local regulations and standards. A big advantage derives from the use of flexible components in the same system family for the diverse feeder automation applications. Siemens provides this and more with our comprehensive Advanced Energy Automation portfolio, which transforms a Smart Grid vision into reality.

Distributed Energy Resources (DER)
The integration of distributed energy resources (DER) calls for a completely new concept: the virtual power plant. A virtual power plant connects many small plants that participate in the energy market in a completely new way. It makes it possible to use sales channels that otherwise would not be available to the operators of individual plants. Linked together in the network, the plants can be operated even more efficiently – and therefore more economically – than before, benefiting the operators of decentralized generating facilities.

In the virtual power plant, decentralized energy management and communication with the generating facilities play a special role, and thanks to the Siemens products Decentralized Energy Management System (DEMS) and DER Controller, are optimally supported. The centerpiece is DEMS, which enables the intelligent, economical and environmentally friendly linkage of decentralized energy sources. The DER Controller facilitates communications, and is specifically tailored to the requirements of decentralized energy sources.

See section 7.2.2, page 436.

Decentralized Energy Management System (DEMS)
DEMS, the core of the virtual power plant, is equally appropriate for utilities, industrial operations, operators of functional buildings, energy self-sufficient communities, regions and energy service providers. DEMS uses three tools – predictions, operational planning and real-time optimization – to optimize power. The prediction tool anticipates electrical and heat loads; for example, as a function of the weather and the time of day. Predicting generation from renewable energy sources is also important, and is based on weather forecasts and the unique characteristics of the plants. Short-term planning to optimize operating costs of all installed equipment must comply with technical and contractually specified background conditions every 15 minutes for a maximum of one week in advance. The calculated plan minimizes the costs of generation and operation, while DEMS also manages cost efficiency and environmental considerations.

See section 7.2.2, page 436.

Smart metering solutions
The Automated Metering and Information System (AMIS) records the power consumption of each individual consumer over time, and in turn, consumers are given detailed information about their power consumption. Experts estimate that the use of smart meters can save up to ten terawatt-hours of electricity, or almost two percent of total energy consumption. For the expansion of Smart Grids, Siemens has developed a Smart Grid solution based on its AMIS system, which covers both smart metering and the automation of distribution systems. In addition, Siemens has for the first time integrated in this application the energy automation, power quality and multimedia functions. For example, the power snapshot analysis is the first Smart Grid application worldwide, which provides synchronous grid information via AMIS smart meters. Power quality data supplements this information, with the aid of which grid stability and supply security can be enhanced. Open interfaces for tablet computers or smart phones, via which consumption and energy data can be graphically displayed, are also available. Since Siemens acquired eMeter, a California-based MDM company, in January 2012, the Metering Data Management System (MDM) EnergyIP also has been part of Siemens' Smart Grid portfolio.

See section 10.3, page 502.

There is no doubt that the future belongs to the Smart Grid, and that power generation will change significantly by the time it becomes a reality. Large power plants will continue to ensure the basic supply, but there will also be renewable energy sources, causing fluctuations in the grid. In the not too distant future, flexible intermediate storage of temporary excess power in the grid will be possible using electric vehicles and stationary storage units. Sensors and smart meters will switch these units on or off, ensuring efficient load management. From generating large offshore wind farms to delivering smart metering in homes, Siemens is one of the worldwide leading providers of products, systems, technology and solutions for Smart Grids.

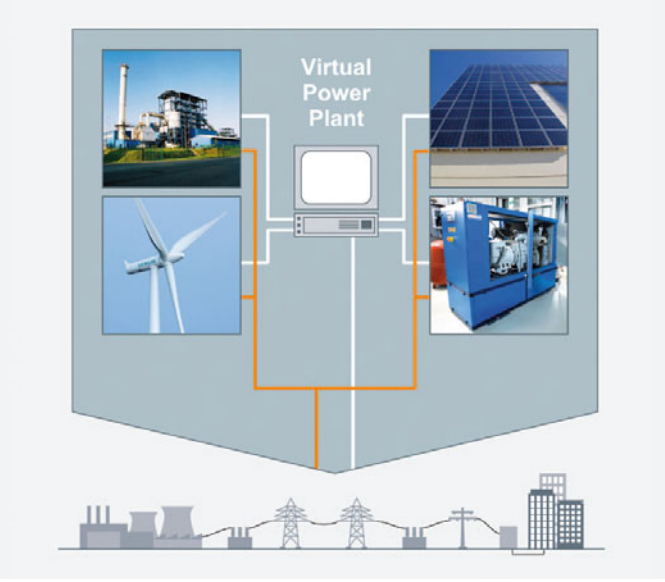

Fig. 1-6: **In vitual power plants, decentralized energy management and communication with generating facilities play a special role, and thanks to the Siemens products DEMS and DER controller, are optimally supported**