Hitachi's Smart Grid Technologies for Smart Cities

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OVERVIEW: Prompted by the problem of global warming together with factors such as the power outages resulting from the Great East Japan Earthquake, the growing momentum behind the worldwide adoption of renewable energy is intensifying the need for smart grids. Hitachi is involved in the development and supply of systems for smart grids, including solutions for improving electric power quality and reliability. Different economies and regions around the world have a variety of different needs, and Hitachi is contributing to the building of a greener, smarter, and more robust grid in order to realize a smart grid that can satisfy these needs by converging its extensive know-how in information, telecommunications, monitoring, and control technologies for electricity systems.

INTRODUCTION

A smart city can be defined as an environmentally conscious city that uses IT (information technology) to utilize energy and other resources efficiently[1].

In the context of the electric power industry, Hitachi's smart city concept of a well-balanced relationship between people and the Earth can be interpreted as meaning the construction of power systems that place less of an impact on the environment. In terms of energy, the smart city concept involves consolidating a number of supply and use systems for electricity, gas, water, transportation and so on within an area to increase energy efficiency and maximize the use of renewable energy, such as roof-top photovoltaic generation. The concept is an extension of the smart grid concept for electricity systems and this article describes the technologies used in smart grids.

SMART GRIDS

Smart grids are advanced electric transmission and distribution infrastructures constructed by applying electric power technologies and information technologies. The importance of making electric power grids smarter is growing, with particular background factors including the ongoing increase in energy consumption around the world, the problem of energy resource depletion, the aging of electric power transmission and distribution equipment, the large-scale power outages that have occurred in both advanced and emerging economies and their associated economic losses, the problem of global warming, and the issue of how to maintain local energy supplies during a disaster.

The requirements for smart grids differ significantly in different economies and regions.

The USA faced the problem of diminishing security of supply due to the aging of transmission and distribution equipment and a shortage of generation capacity. In addition to equipment modernization, there are also demands for making improvements through the use of information and telecommunication technologies, including better energy efficiency, lower costs, and greater reliability. As electric power demand is anticipated to continue growing in the future, use of demand response techniques to reduce peak-hour power consumption has advantages for the global environment as well as for consumers and utilities.

Europe adopted the 20-20-20 targets in December 2008 (an environmental policy with three targets: A reduction in greenhouse gas emissions of at least 20% below 1990 levels by 2020, a 20% reduction below 1990 levels in primary energy achieved by improving energy efficiency, and 20% of energy consumption to come from renewable resources). The region has also been making rapid progress on the adoption of renewable energy, assisted by individual country policies such as feed-in tariffs, which offer a guaranteed price for purchase of renewable energy. As a result, the installation of numerous distributed energy sources such as wind and photovoltaic power generation has led to the emergence of power system issues, such as grid operation and the management of supply and demand. Resolving these has become a matter of urgency.

In emerging economies, demand for electric power has been growing rapidly and there is considerable activity in the construction of large conventional and renewable energy plants and new transmission and distribution networks. The aim, when establishing new transmission and distribution networks, is to use the latest smart, low-carbon equipment from the very beginning. The field of urban construction also has examples of projects involving the building of large new smart cities from scratch. Here too, the demand is for the use of smart, low-carbon technology in the electric power system and its associated control.

In terms of both interruption frequency and duration, the extent of power outages in Japan is among the lowest in the world. The country has also achieved world-leading levels of power quality measured by parameters such as electric power frequency and voltage. One of the challenges anticipated for transmission and distribution systems in the future is finding ways to introduce greater use of renewable energy while maintaining and improving on this excellent level of power quality. The government of Japan has announced a plan to increase photovoltaic power generation to 28 GW in 2020 (a roughly 20 times increase on 2005), the majority of which is expected to come from household photovoltaic power generation. This corresponds to more than 15% of peak summer power demand and, at times when demand is particularly low, such as during the daytime in the New Year period, the presence of this capacity will make maintaining the supply and demand balance difficult because the sum of base generation capacity and photovoltaic power generation will exceed total demand. In addition to supply and demand balancing, numerous other issues also need to be solved. These include problems with the distribution grid voltage and the threat of simultaneous drop-out of photovoltaic power generation during grid faults.

Although electric power is predominately supplied from electric power companies, in the future, distributed generation systems such as wind and photovoltaic power generation will also supply electricity. Energy consumers will adopt a wide range of energy efficiency measures and these are likely to have a major influence on the power supply system. For this reason, it is anticipated that mechanisms will be established to allow participation in the power supply system to extend beyond power suppliers in the future, and to include power users as well.

In this way, Japan’s electric power system would become more complex and undergo significant changes, including readjustments to the relationships between consumers and suppliers and the associated legal framework and operations, as well as the connection of new supplies and loads. Maintaining and improving power quality in the face of these changes will require more advanced and smarter grid stability equipment, control systems, and information systems, as well as new mechanisms, system configurations, and other innovations.

Hitachi has been involved in a wide range of products over many years, ranging from electric power generation, transmission, and distribution equipment to control systems such as EMS (energy management system), SCADA (supervisory control and data acquisition system), DMS (distribution management system), and AMI (advanced metering infrastructure) systems, as well as utility business systems such as billing systems and call center systems. By drawing on its strengths in equipment, control systems, and information systems, Hitachi believes its integrated solutions can contribute to the creation of the advanced smart grids of the future.

SMART GRID TECHNOLOGIES

This section describes how power grid analysis technology can be used to identify problems and solutions in order to maintain grid quality and reliability in situations where a large amount of renewable energy capacity is installed in a smart grid, along with the technologies for solving these problems.

FACTS (Flexible AC Transmission System) Devices

Advanced power electronics improve the quality of power supply and energy efficiency because they allow the rapid and continuous variable-speed control of generators and motors. They can be applied to reactive power control and HVDC (high-voltage direct current).

A STATCOM (static synchronous compensator) is a voltage regulator based on a voltage-sourced converter that uses power electronics.

Maintaining a suitable transmission voltage is important not only to ensure that users’ electrical devices function properly but also for reasons of transmission capacity, transmission efficiency, and the stability of the power system.

The STATCOM is a solution for increasing the power transmission capacity of existing equipment as well as minimizing and keeping to an appropriate level the voltage fluctuations in the grid caused by variations in the output of renewable energy (see Fig. 1 and Fig. 2).

Fig. 1—STATCOM Unit.
An installed STATCOM (static synchronous compensator) unit is shown.

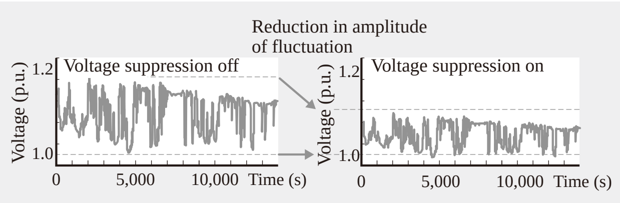


Fig. 2—Suppression of Voltage Fluctuations Resulting from Installation of STATCOM Unit.
This simulation models use of a STATCOM to minimize voltage fluctuations from renewable energy.

The need for STATCOMs, with their fast response, will grow in the future as use of power sources with fluctuating outputs, such as photovoltaic power generation and wind power, increases.

D-STATCOM is the STATCOM for distribution networks.

The connection of large numbers of distributed power sources, such as household photovoltaic power generation, to the grid has the potential to cause instability in the distribution network voltage. Causes include voltage rises due to reverse power flows or voltage drops below the stipulated range due to a rapid drop in the output of photovoltaic power generation following a sudden change in the weather.

While possible measures for dealing with this voltage problem include splitting pole-top transformers, adopting low-impedance conductors, or shifting to higher distribution voltages, the D-STATCOM offers an effective solution in terms of cost and its ability to ensure power quality over a wide area through integration with distribution management systems and its rapid response to sudden changes.

HVDC transmission systems including FCs (frequency converters) and BTB (back to back) HVDC use DC (direct current) to interconnect between bulk power network systems.

To reduce electricity costs, electric utilities (power companies) are obliged to operate their electric power systems over a wide area. However, connecting an electric power grid across a wide area carries the risk that a local failure will affect the entire grid. Technologies that can help to prevent this and achieve trouble-free interoperation over a large grid include HVDC. Also, because the transmission distance possible using AC (alternating current) transmission is limited by stability issues, DC transmission is being adopted around the world for use in long-distance transmission systems that carry power to consumers from large remote power sources.

Hitachi has been working on all of the DC projects in Japan, and has also embarked on the development of a new HVDC system based on voltage-sourced converter technology that helps achieve better grid stability.

Advanced Network Technology

Power grid analysis technologies that analyze grid behavior are essential for predicting and resolving the many complex problems that arise in power grids. A variety of different phenomena are likely to accompany the connection of significant amounts of photovoltaic power or wind power and the analysis techniques used range across a variety of methods, from steady analysis to instantaneous value analysis, depending on the time constant of the phenomena concerned. In particular, the behavior of the power system in the event of a grid fault is expected to be made more complex by the presence of large amounts of photovoltaic power generation or wind, and a variety of research about this topic is already underway.

Hitachi provides an analysis service to suit different needs depending on the nature of the project, and is working on the development of actual systems based on the results of this analysis.

A grid stabilization system is a solution that applies grid analysis techniques to make effective use of existing equipment and prevent wide-area outages. For example, a grid fault caused by lightning strike has the potential to result in a major outage if it leads to a chain reaction of generators dropping out. Preventing this requires limiting output in line with the amount of power that can no longer be transmitted as a result of the grid fault, but the choice of which generators to govern depends on factors such as the location of the original grid fault and how it propagates across the grid.

The grid stabilization system runs an online stability calculation continuously based on grid information and prevents an outage from spreading over a wide area by pre-loading the on-site equipment at substations with information on the appropriate measures to take in the event of a grid fault, such as generation shedding.

In the future, increased use of distributed power sources will require grid stabilization systems that monitor the output of these power sources or produce estimates based on factors such as the weather, and that incorporate models of how the distributed power sources will behave in the event of a grid fault.

Energy Storage

It is assumed that greater energy storage capacity at various levels will be needed as more renewable energy capacity is added to power systems. Batteries are one form of energy storage and it is expected that they will play a major role.

The ideal capacity and power output for an electrical storage system differ depending on factors such as its intended purpose and how it will be used. Peak shifting, for example, requires large storage and discharge capacities but can get by without an instantaneous response. In contrast, an instantaneous response is needed to suppress fluctuations in renewable energy output, whereas the storage capacity and discharge power output can be small. By utilizing the characteristics of fixed lead-acid batteries, lithium-ion batteries, and lithium-ion capacitors in accordance with these diverse needs, it is possible to supply highly reliable optimum systems that can maintain long-term operation for a range of different applications.

Information Communication Technology

Wide deployment of communication networks and new energy management systems are indispensable to enable grid automation, online services, and DSM (demand side management) including active demand control.

The distribution network has been designed and constructed to deliver electricity at safe voltages to customers supplied from high voltage substations in a passive manner.

The connection of many active devices such as photovoltaic generation and EVs (electric vehicles), however, will transform the distribution network from a passive to an active network.

In active distribution grids, the voltage situation in the MV (medium voltage) and LV (low voltage) networks becomes more complex and changes dynamically. In some cases, it is not possible to keep the voltage within the stipulated range using conventional tap control of transformers and SVRs (step voltage regulators) alone.

Active distribution networks require advanced distribution management systems with VVC (voltage var control) voltage optimization control.

This function can work with new power distribution system equipment such as D-STATCOMs, PCSs (power conditioning systems) for photovoltaics, and battery systems, as well as the traditional transformer taps and SVRs.

These devices differ in terms of characteristics such as control response and control range. Therefore, sudden fluctuations might be handled by the high-speed local voltage control provided by a D-STATCOM whereas phenomena with a longer time constant are handled in advance using measures such as D-STATCOM set points, changes to SVR taps, and control of battery charging and discharging through a FAN (field area network). By coordinating the control of these devices and the communication network, it is possible to maintain appropriate voltage levels throughout the active distribution network (see Fig. 3).

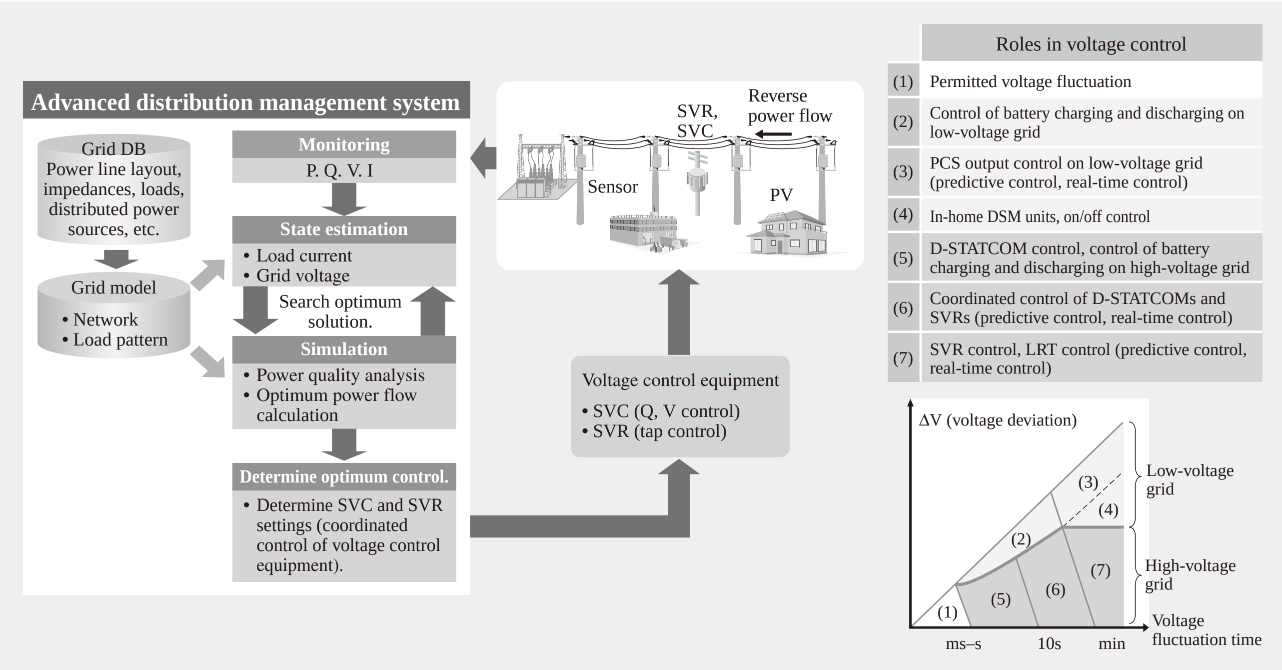
SMART CITY/COMMUNITY

A smart city integrates several energy supply and use systems within a given region in an attempt to optimize operation and allow for maximum integration of renewable energy resources—from large-scale wind farm deployments to micro-scale rooftop photovoltaics and residential energy management systems. Smart cities are a logical extension of the smart grid concept used in electricity systems to other types of infrastructure systems(2).

In the future, smart cities will have a micro grid function known as “islanding.” The islanding function supplies power generated by distributed energy resources within the city to customers for several hours when power from the bulk grid is absent. The grid in a smart city is connected to a high-voltage bulk network and power is usually supplied from the bulk network. If the connection is lost, however, the grid can continue to operate autonomously using the islanding function.

In addition to an advanced distribution management system incorporating FACTS devices and IT infrastructure, islanding also requires a DR (demand response) function and energy storage in the form of “spinning reserve.”

The DR function contributes not only to balancing supply and demand during islanding, in normal operation it also helps reduce energy consumption



DB: database SVC: static var compensator SVR: step voltage regulator PV: photovoltaic PCS: power conditioning system DSM: demand-side management D-STATCOM: STATCOM for distribution network LRT: load ratio transformer

Fig. 3—Advanced Distribution Management System.
This example shows how an advanced distribution management system divides up distribution voltage control between its different parts.

and obtain resources for ancillary services such as voltage control.

The energy management system that has advanced distribution functions, islanding function and DR function is called CEMS (community energy management system).

CEMS performs functions such as peak shifting and using control of consumer equipment (such as heat pump water heaters and EV chargers) for load balancing.

For example, demand can be induced at times of excess supply by automatically starting washing machines and dryers or by having heat pump water heaters operate during times when the output from photovoltaic power generation is high. Peak shifting can be achieved by measures such as shifting the EV charging times within the community so that they do not start charging at the same time at night. This sort of control of consumer equipment is handled via the HEMSs (home energy management systems) described below and is done in a way that works in with people's lifestyles without compromising their comfort. HEMSs, building energy management systems, and FEMSs (factory energy management systems) are all types of consumer EMSs (energy management systems).

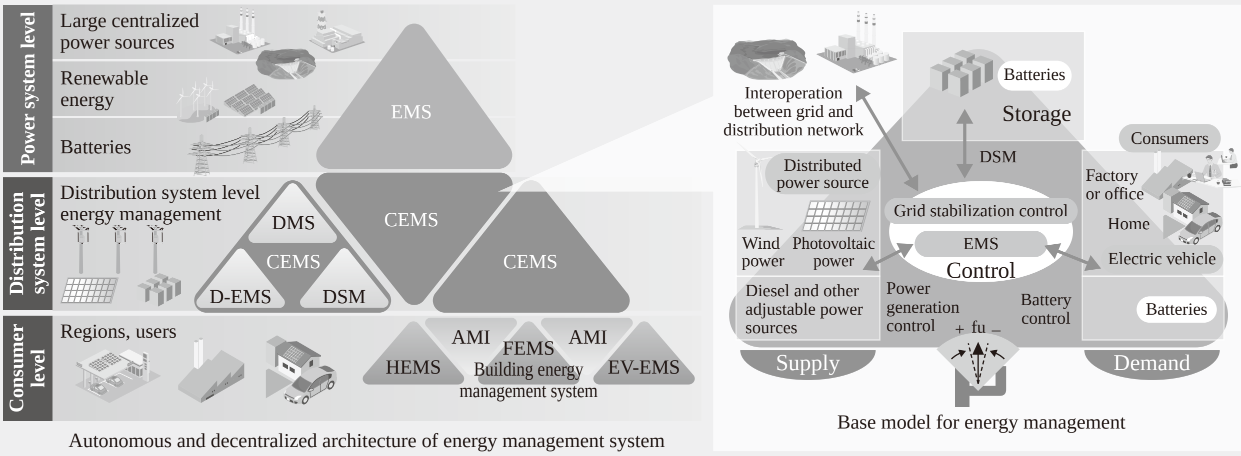
In addition to making energy use in the home visible, HEMSs have functions for controlling the electric equipment in the home to optimize energy consumption while maintaining comfortable living. They also provide a range of services through interoperation with information systems.

Similarly, building energy management systems and FEMSs make visible the energy use in buildings and factories respectively while also providing optimization (energy efficiency) and other energy services. In some cases, they handle gas as well as electric power.

In addition to these functions such as energy efficiency and visualization of energy use, it is anticipated that consumer EMSs will also interoperate with the DSM function of CEMSs (described above) to assist with the optimization of electric power consumption through operations such as load balancing and peak shifting (see Fig. 4).

Also, the practice of having consumers contribute to grid stabilization through active steps such as minimizing demand is called DR. Through interoperation with AMI and other information systems, consumer EMSs prompt consumers to optimize their power consumption in a range of different situations, such as taking advantage of times when electricity tariffs are lower or when incentives are offered for participating in demand minimization.

Another potential benefit is the provision of a range of different information distribution services,



EMS: energy management system DMS: distribution management systems CEMS: community energy management system
D-EMS: distribution energy management system AMI: advanced metering infrastructure HEMS: home energy management system
FEMS: factory energy management system EV-EMS: electric vehicle-energy management system

Fig. 4—Base Model for Energy Management.
Having the energy management systems for each level control each segment in an autonomous and decentralized way contributes to the stability of the power system while also providing an expandable configuration.

maintenance management services, or lifestyle support services for the elderly by using this mechanism to link together consumers and information systems (see Fig. 5).

CONCLUSIONS

This article has described the use of energy management systems to help realize smart cities.

Hitachi will continue to contribute to further enhancements to power systems and the building of smart grids through its participation in a variety of smart grid demonstration projects and other research in Japan and overseas, and by developing and supplying total systems that combine the equipment, control technology, and information technology described in this article.

REFERENCES

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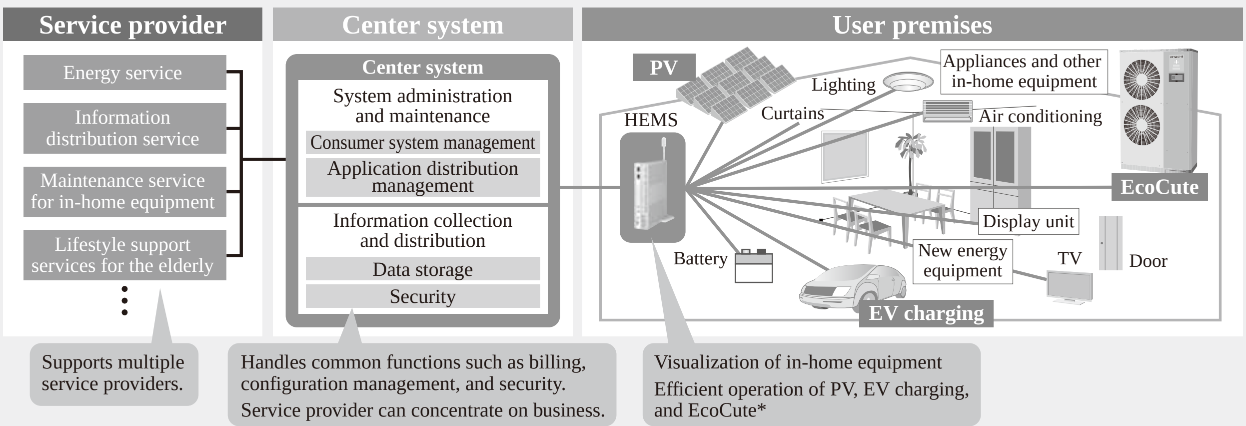

EV: electric vehicle CO_2: carbon dioxide
* EcoCute is the general name in Japan for heat pump water heaters that use CO_2 as a natural refrigerant and are supplied by power companies and water heater manufacturers.

Fig. 5—HEMS System Configuration.
In addition to giving access to information on in-home equipment (visualization), the HEMS operates photovoltaic power generation, EcoCute, and EV charging in a way that best suits the residents' lifestyle. The center system handles common functions such as billing, system configuration management, and security and provides a range of services to consumers.

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