

Electric Power Supply Systems that Contribute to Low-carbon Society

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OVERVIEW: The creation of a low-carbon society requires the development of technologies for a range of different types of power generation including technologies for boosting their efficiency and cutting their greenhouse gas emissions. Forecasts of global energy demand up to 2035 anticipate that thermal, hydro, nuclear, and new energy sources will remain important. On this basis, Hitachi is working on research and development aimed at establishing technologies to support future power supply systems. These efforts include the development of technology for coal-fired power including CO₂ capture and highly efficient gas turbines, measures aimed at the global deployment of nuclear power, maintaining the quality of power from wind and photovoltaic power plants connected to the grid, adjustable speed pumped storage hydro power systems, and smart grid technologies that facilitate the wider adoption of new sources of energy.

INTRODUCTION

FORECASTS of global energy demand up to 2035 contained in the World Energy Outlook 2010 published by the International Energy Agency (IEA) predict that thermal (coal, oil, and gas), nuclear, and renewable power will be important energy sources⁽¹⁾ (see Fig. 1). For coal and oil, the forecast is that cuts in consumption by nations in the Organisation for Economic Co-operation and Development (OECD) will be outweighed by growing demand from China and other non-OECD nations. Use of gas, which has a low level of CO₂ (carbon dioxide) emissions per unit of energy, is expected to increase rapidly along with growing use of nuclear power and renewable energy, including biomass and other new sources of energy.

However, some latitude is needed when considering the specific figures for the relative proportion of electric power. The Intergovernmental Panel on Climate Change (IPCC) has analyzed a range of different scenarios. While use of renewable energy has the potential to account for as much as 43% of energy supply (including heat) by 2030, in most scenarios the figure is forecast to be only around 17%⁽²⁾.

Also, the Great East Japan Earthquake in March 2011 has the potential to initiate a rethinking of energy policy around the world. In Japan in particular, a debate is beginning on what form its electric power supply should take in the future and its implications for things like CO₂ emission reductions and energy security.

Accordingly, future development of electric power supply systems is likely to be strongly influenced by the global economic situation and the social landscape. Given these circumstances, Hitachi intends to continue contributing to the creation of a sustainable low-carbon society by undertaking research and development with a view to the future, primarily in the fields of thermal, hydro, nuclear, and renewable energy.

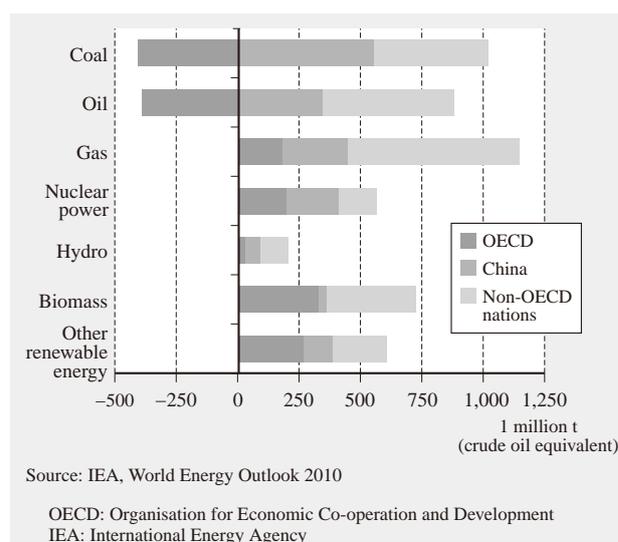


Fig. 1—Changes in Future Energy Demand from 2008 to 2035 (in Crude Oil Equivalent Terms).

The World Energy Outlook published by the IEA identifies thermal, nuclear, and renewable energy as remaining important sources of energy in the future.

At the same time, measures for the safety and reliability of nuclear power generation are being strengthened. The series of events that occurred at Fukushima Daiichi Nuclear Power Station due to the tsunami following the Great East Japan Earthquake have shaken the whole world. Including establishing a joint Japan-US expert team that is collaborating with a major power utility and engineering companies from the USA with extensive experience in recovery measures obtained from incidents such as those at the Three Mile Island Nuclear Power Plant in the USA and Chernobyl Nuclear Power Plant in Ukraine, Hitachi has established the Fukushima Project Supervisory Office specifically for this project and is doing all it can to deal with the problem. In addition to dealing with the situation at the Fukushima Daiichi Nuclear Power Station, Hitachi will continue to contribute in its role as a supplier to improving the safety and reliability of nuclear power plants in the event of disasters such as this one.

This article describes what Hitachi is doing in the fields of thermal and nuclear power generation as well as the grid-connection of wind and photovoltaic power generation systems, two promising new forms of energy. It also looks at the state of research and development into the smart grid technologies that support the wider use of new forms of energy.

THERMAL POWER GENERATION ACTIVITIES

Hitachi supplies 600°C-class USC (ultra super critical) power plants that achieve world-leading efficiency for conventional coal-fired power generation. It has delivered eight such plants in Japan and a further 23 in other countries. In the market for highly efficient gas turbines, Hitachi is contributing to reducing global CO₂ emissions by improving the efficiency of thermal power plants, having delivered more than 130 of its 30-MW class H-25 models internationally. Further advances in technology currently being developed include: (1) 700°C-class A-USC (advanced USC), (2) CO₂ capture from coal-fired power plants (using chemical absorption and oxyfuel combustion), (3) IGCC (integrated coal gasification combined cycle)⁽³⁾, and (4) AHAT (advanced humid air turbine) gas turbines with high efficiency. The aim is to conduct large-scale demonstrations and commercialize these technologies between 2015 and 2020. The following sections describe the CO₂ capture technology and AHAT system.

Development of Chemical Absorption Method

Chemical absorption using amine solution, an organic alkali, is the standard method for the separation and capture of CO₂ from the flue gas of coal-fired power plants. Hitachi has been building a chemical absorption system and has developed its own amine-based absorption solution suitable for capturing CO₂ from the flue gas of coal-fired boilers. Hitachi in collaboration with The Tokyo Electric Power Co., Inc. has been operating a pilot plant that uses the newly developed solution and has the capacity to process 1,000 m³/h (Normal) of flue gas. When run continuously for 2,000 hours, the pilot plant was reliably able to achieve an average CO₂ capture ratio of 90%^{(4),(5)}. Hitachi has also developed an improved absorption solution less vulnerable to degradation by the acidic gases in the flue gas and a demonstration using this new solution in a pilot plant with the capacity to process 5,000 m³/h (Normal) of flue gas is scheduled to start during 2011 at an existing coal-fired power plant in Europe (see Fig. 2).



Fig. 2—5,000-m³/h (Normal) Pilot Plant.

This pilot plant can be used to conduct experiments using actual flue gas. Demonstrations at an existing coal-fired power plant in Europe are scheduled to start during 2011 in collaboration with a German power company.

A further demonstration is being planned for Canada based on a 2010 agreement between Saskatchewan Power Corporation of Canada and Hitachi, Ltd. on joint development of low-carbon energy technologies including CCS (carbon dioxide capture and storage). For the future, Hitachi intends to build waste heat utilization systems that improve thermal efficiency and make further performance improvements.

Development of Oxyfuel Combustion System

Oxyfuel combustion is a promising technology for CO₂ capture and sequestration in coal-fired power plants. In this method, coal is burned with pure oxygen diluted by recycled flue gas resulting in highly concentrated CO₂ in the flue gas after eliminating some H₂O (water) by flue gas cooling. Because it resembles a conventional coal-fired plant and other proven technologies, the system along with amine-based CO₂ chemical absorption is gaining attention as one of the most practical methods for CO₂ capture⁽⁶⁾.

Babcock-Hitachi K. K. undertook a joint development and feasibility study of oxyfuel combustion systems with a utility in Finland, Fortum Corporation, from 2007 to 2009. Hitachi Power Europe GmbH has been a key participant in the implementation of system designs for an oxyfuel combustion pilot project in Europe⁽⁷⁾. In 2010, Hitachi's 30-MWth burner for oxyfuel combustion was successfully tested at the Schwarze Pumpe oxyfuel pilot plant in Germany under a technology partnership with Vattenfall (see Fig. 3). In the tests, stable combustion was maintained in both oxyfuel and air combustion mode for a wide range of process parameters like oxygen concentration in the combustion gas. Also, minimum emissions of NO_x



Fig. 3—Schwarze Pumpe Oxyfuel Pilot Plant. The 30-MWth class full-system oxyfuel pilot plant is operated by Vattenfall (image courtesy of Vattenfall).

(nitrogen oxides) and CO (carbon monoxide) were achieved while keeping the excess concentration of O₂ (oxygen) in the flue gas low. These results demonstrate the high performance and flexibility of Hitachi's technology. The findings have been incorporated into the Hitachi proposal for an optimized 250-MWe class oxyfuel pilot plant which is currently being planned by Vattenfall at the Jaenschwalde Power Plant.

Development of Highly Efficient AHAT Gas Turbine

Hitachi is working on the development of AHAT technology to reduce CO₂ emissions by improving the efficiency of gas turbines through innovation in the power generation cycle. This next-generation gas turbine system is based on a regenerative cycle in which waste heat from the gas turbine is used to preheat the combustion air combined with the injection of moisture into the combustion air (see Fig. 4). Because moisture injection increases the specific enthalpy and mass flow of the gas that drives the turbine, it is expected to achieve levels of output and efficiency similar to combined cycle while using only a gas turbine.

In a project sponsored by the Ministry of Economy, Trade and Industry, Hitachi has since the fiscal year 2004 been developing a 3-MW class demonstration system in collaboration with the Central Research Institute of Electric Power Industry and Sumitomo Precision Products Co., Ltd. The viability of the system was demonstrated in March 2007 when it achieved an output of 3,985 kW and LHV (lower

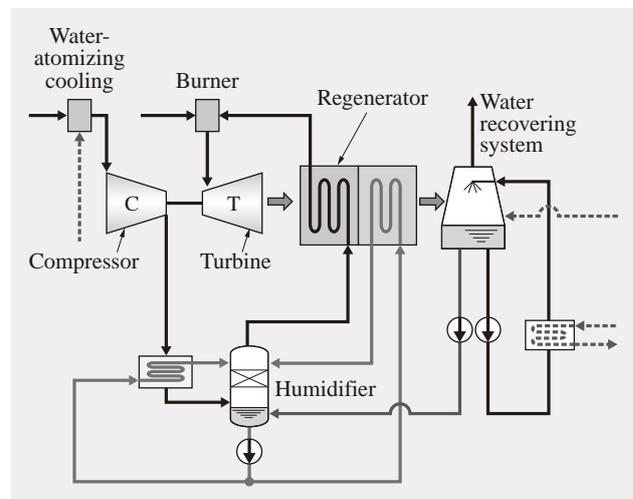


Fig. 4—AHAT System Diagram. AHATs (advanced humid air turbines) achieve efficiency similar to combined cycle using a standalone gas turbine.

heating value) efficiency of 40% measured at the generator⁽⁸⁾. A test facility with a 40-MW class gas turbine for testing specific technologies required for commercialization is currently under construction and is scheduled to commence operation during the fiscal year 2011. The test facility is being used to continue development with the aim of bringing a 100- to 200-MW class model to market through the addition of further techniques for improving efficiency.

NUCLEAR POWER GENERATION ACTIVITIES

ABWR Construction

Research and development to improve further the safety and reliability of BWRs (boiling water reactors) has been ongoing and the latest form of this reactor type, the ABWR (advanced BWR), currently has the status of being the only third-generation reactor type in actual operation.

The first ABWR was Unit 6 (1,356 MWe, commissioned in November 1996) at Kashiwazaki Kariwa Nuclear Power Station of The Tokyo Electric Power Co., Inc. This was followed by Unit 7 at the same site (1,356 MWe, commissioned in July 1997), Unit 5 at Hamaoka Nuclear Power Station of The Chubu Electric Power Co., Inc. (1,380 MWe, commissioned in January 2004), and Unit 2 at Shika Nuclear Power Station of Hokuriku Electric Power Company (1,358 MWe, commissioned in March 2005), all of which are in commercial operation. Unit 3 at Shimane Nuclear Power Station of The Chugoku Electric Power Co., Inc. and the Ohma Nuclear Power Plant of Electric Power Development Co., Ltd. are currently under construction and of the 14 nuclear power plants (19,300 MW) currently planned or under construction in Japan, 10 (13,820 MW) (including these two) are ABWRs. Hitachi was involved in the construction of all four of the ABWRs in commercial operation and Hitachi-GE Nuclear Energy, Ltd. is responsible for major parts of all the ABWRs currently under construction⁽⁹⁾. Given the wider implications of the events at Fukushima Daiichi Nuclear Power Station, Hitachi wants to contribute to making plants safer and more reliable.

Entry into Global Market

Hitachi will use the ABWR construction technologies and experience that it has built up in the Japanese market as a base for entry into the global market. Since joining with the nuclear energy business of General Electric Company (GE) of the USA in 2007, Hitachi has been drawing on the strengths of

both companies to expand overseas. Although Hitachi can offer either ABWRs or ESBWRs (economic and simplified BWRs) depending on market needs, because it has had an ongoing involvement in ABWR construction projects in Japan, it sees this type of reactor as its main product especially in markets (countries) adopting nuclear power for the first time where such a track record is an important factor in decision making.

The reactions to the events at Fukushima Daiichi Nuclear Power Station in markets for nuclear power outside Japan have varied widely from country to country. Many nations in regions such as Asia and the Middle East contemplating the adoption of nuclear energy have announced their intention to press ahead with such policies provided the experience from Fukushima can be closely studied and the necessary countermeasures put in place. To meet the expectations of these nations, Hitachi will work to supply products and technologies that enhance safety and reliability.

NEW ENERGY (WIND AND PHOTOVOLTAIC) POWER GENERATION ACTIVITIES

There is growing demand for wind and photovoltaic power generation systems as ways of reducing CO₂ emissions and consumption of fossil fuel. Hitachi is constructing a 13-MW megasolar system that will be among the largest in Japan and has plans to market this technology in Japan and elsewhere. One of group companies of Hitachi launched a wind power business in 1995. In 2010, it completed Shiura Wind Farm, the world's first wind farm capable of smoothing short-duration fluctuations in output power. Operating wind farms is another important part of its business. Hitachi has also developed its own wind power turbines in cooperation with Fuji Heavy Industries Ltd. A prototype large wind turbine called the SUBARU Wind Turbine was completed in 2006. The first mass-produced 2-MW wind turbine was commissioned in 2008 and was followed in 2010 by Wind Power Kamisu which was the first off-shore wind farm to commence operation in Japan. For the future, Hitachi aims to increase sales of SUBARU Wind Turbines to other similar wind farms.

Other initiatives being taken by Hitachi in response to global market growth include expanding its factory for wind power generators and supplying wind power PCSs (power conditioning systems) for China. It is expanding annual production capacity for wind power generators to 2,400 units by 2013.

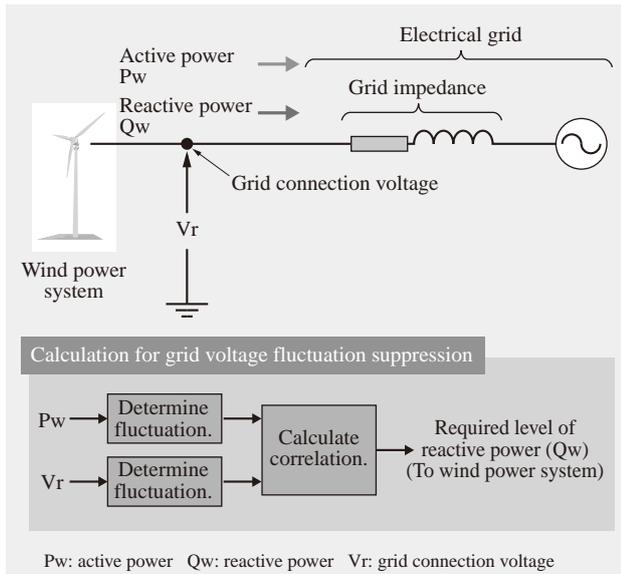


Fig. 5—Use of Reactive Power to Suppress Grid Voltage Fluctuation.

Grid voltage fluctuations can be suppressed by using auto-tuning to estimate and output the optimum level of reactive power [$Q_w = P_w \times (R/X)$].

Because wind and photovoltaic power obtain their energy from nature, the quantity of power produced varies with weather conditions and this can lead to voltage and frequency fluctuations on the electrical grid. In response, Hitachi is working hard to develop technologies that can be used to build wind and solar power generation systems that suppress these fluctuations and are compatible with the grid.

Grid Voltage Fluctuations

Suppressing voltage fluctuations on the grid is done by outputting Q_w (reactive power) based on the level of P_w (active power) output. Hitachi has developed a technique for suppressing this fluctuation that uses auto-tuning to estimate the appropriate level of reactive power to output under conditions in which the grid impedance ($R + jX$) is unknown (see Fig. 5). Working with The Kansai Electric Power Co., Inc., Hitachi has tested this voltage fluctuation suppression technique and verified its effectiveness by linking a wind power mini-model incorporating the same control as an actual installation to The Kansai Electric Power Co., Inc.'s APSA (advanced power system analyzer) grid analysis mini-model⁽¹⁰⁾.

Grid Frequency Fluctuations

Hitachi is developing battery-using technology and wind farm control technology for suppressing

grid frequency fluctuations caused by fluctuations in active power output.

Although the battery-using technology aims to use batteries to compensate for fluctuations in wind generation output, the high cost of batteries imposes a bottleneck on this approach. In response, Hitachi has developed a battery control technique that minimizes the required electrical storage capacity⁽¹¹⁾ and has commissioned a wind farm that uses batteries to smooth output fluctuation.

For wind farm control, Hitachi has developed a technique that eases output limits while minimizing fluctuation in the overall wind farm output by adjusting each turbine's output limit independently based on its actual output⁽¹²⁾. Testing of the technique at an actual wind farm is planned.

Other Activities

There is a concern that grid failure could occur due to wind, photovoltaic, and other power plants dropping off the grid one after another in response to a sudden spike in grid voltage caused by lightning or similar. Technologies being developed by Hitachi in response to this threat include FRT (fault ride-through) technology that allows equipment to continue operating when grid faults occur and PSS (power system stabilizer) technology that outputs reactive power from wind generators to suppress disturbances from generators connected to a weak grid. PSS technology using wind generators has been developed in collaboration with The Kansai Electric Power Co., Inc. and its effectiveness verified using APSA and the same control circuits as an actual installation⁽¹⁰⁾.

Hitachi has also developed a technique to suppress the harmonic currents that result when renewable energy systems are connected to the grid with voltage distortion present. This has completed demonstrations at a large photovoltaic generation system at Hokuto City in Yamanashi Prefecture⁽¹³⁾.

ADJUSTABLE SPEED PUMPED STORAGE HYDROPOWER SYSTEMS

Compared to previous pumped storage hydro power systems, a feature of the adjustable speed pumped storage hydropower system developed by The Kansai Electric Power Co., Inc. and Hitachi is its ability to vary its power level rapidly during both pumping and generation modes. This allows the adjustable speed pumped storage hydropower system to play a role in balancing supply and demand that

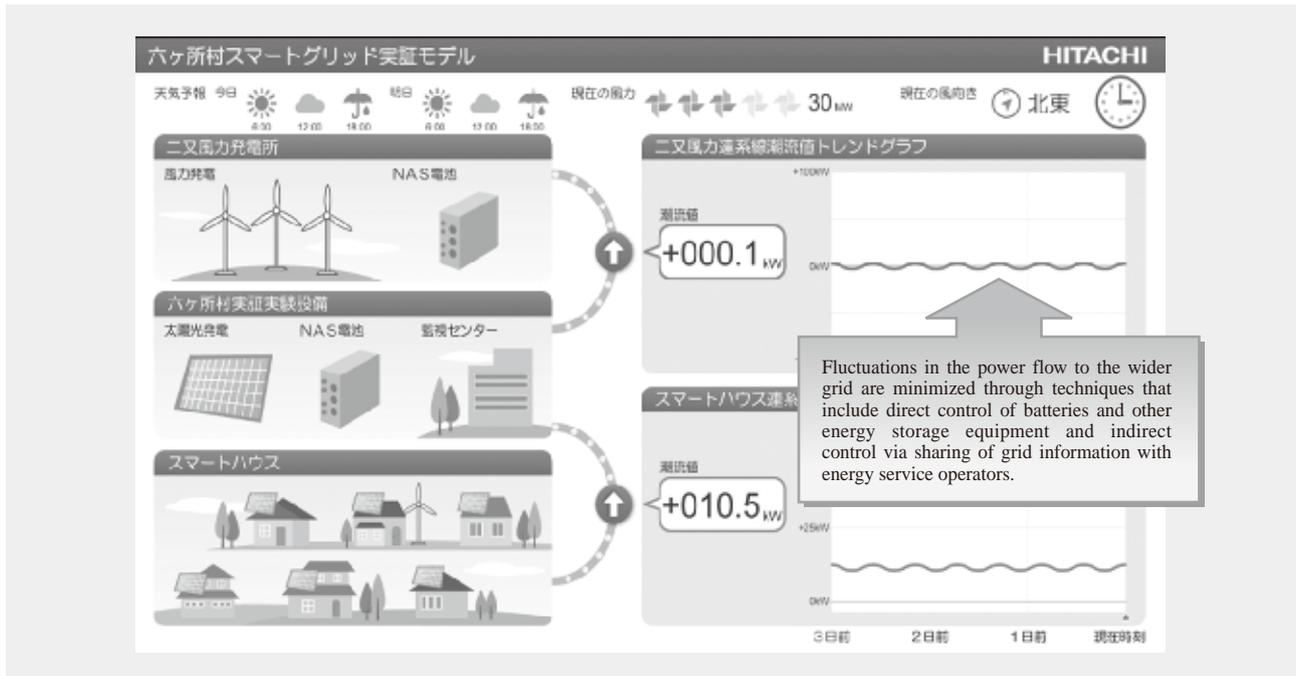


Fig. 6—Example Screen from Rokkasho Village Smart Grid Demonstration in Aomori Prefecture.

In addition to power flow monitoring, voltage and current monitoring, and smart house demand and supply monitoring, the project also includes the control of energy storage based on monitoring and forecasting of demand and the level of renewable generation.

conventionally has been performed using thermal power plants. The result is that the amount of time thermal power plants need to operate can be cut and this contributes to a reduction in CO₂ emissions.

Also, even if the grid includes an increasing proportion of wind, photovoltaic, and other power sources that find it difficult to produce a steady level of power, the adjustable speed pumped storage hydropower system can contribute to the stability of electric power supply through its use to balance supply and demand.

The two Hitachi-made adjustable speed pumped storage hydropower systems installed at Okawachi Power Plant of The Kansai Electric Power Co., Inc. have the world's largest capacity and have been operating successfully for more than 15 years.

Pumped storage requires separate upper and lower reservoirs (dams) and the need to avoid damage to the environment imposes significant geographical constraints. Accordingly, Hitachi set out to develop technology for converting existing pumped storage facilities to adjustable speed operation and an adjustable speed conversion is scheduled to commence operation in 2013 at the Okutataragi Power Plant of The Kansai Electric Power Co., Inc. which was constructed in the 1970s.

SMART GRID ACTIVITIES

To prevent global warming, the development of small electrical networks has an important role in supporting the wider use of numerous distributed power sources. In the IEA forecasts, it is anticipated that 43% of electricity investment over the 20 years from 2010 will go into small electrical networks⁽¹⁾.

Hitachi is utilizing microgrid techniques to develop community-level energy monitoring and control technology. It is also participating in smart grid demonstrations being run in Japan and elsewhere.

The Rokkasho Village smart grid demonstration in Aomori Prefecture is testing an electricity control center that maximizes use of renewable energy and supplies carbon-free power to smart houses. In addition to power flow monitoring, voltage and current monitoring, and smart house demand and supply monitoring using automatic metering, the project also includes the control of energy storage based on monitoring and forecasting of demand and the level of renewable generation. It is also demonstrating a participatory approach to self-adaptive management of power demand by supplying information from the system to residents (see Fig. 6).

Hitachi is also participating in a joint Japan-US smart grid demonstration. In the fiscal year 2009, it was contracted by the New Energy and

Industrial Technology Development Organization (NEDO) to participate in the Japan-U.S. Smart-Grid Collaborative Demonstration Project in New Mexico, USA and is proceeding with this work in collaboration with other participating companies. The demonstration system is connected to the actual electrical grid in Los Alamos and is being used to test technologies such as advanced uses of photovoltaic power PCSs (which convert power to alternating current) and hybrid operation using lead-acid and a number of other types of battery.

In addition to PCSs, Hitachi is also developing a number of other FACTSs (flexible alternating current transmission systems) that use power electronics⁽¹⁴⁾. These include technologies for frequency conversion and direct current transmission as well as improving grid stability and suppressing voltage fluctuations. Through these activities, Hitachi is making possible the flexible operation of smart grids.

Given the power supply disruptions that resulted from the recent Great East Japan Earthquake, it is anticipated that a fresh view will be taken of the value that smart grids offer as community-level power supply systems. Utilizing the knowledge it has gained through these smart grid demonstrations in Japan and elsewhere, Hitachi intends to go on contributing to the renewable energy activities described above and to the building of smart grids through the implementation of community-level energy monitoring and control technologies, FACTSs, and AMI (advanced metering infrastructure).

CONCLUSIONS

This article has described what Hitachi is doing in the fields of thermal and nuclear power generation as well as the grid connection of wind and photovoltaic power generation systems, two promising new forms of energy. It has also looked at the state of research and development into the smart grid technologies that support the wider use of new forms of energy.

The optimum form for an electric power supply system changes over time and depending on local circumstances. In order to make solid progress toward a low-carbon society on a global scale, Hitachi intends to contribute to building environmentally conscious electric power supply systems throughout the world by combining smart grid technology with the thermal, nuclear, and renewable energy sources described in this article.

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