Featured Articles

Solutions for Changes to Cross-regional Grid Operation Improving from Electricity System Reform

Masahiro Ichinosawa
Toshiyuki Sawa, Dr. Eng.
Hiraku Tanaka
Shuhei Fujiwara
Atsushi Nishioka

OVERVIEW: Progress has been made on consideration of electricity market reforms prompted by factors such as the growing need to deal with global environmental problems and the tight supply of electric power resulting from the Great East Japan Earthquake. The first stage of the reform was the establishment of the OCCTO in April 2015. This article describes the functions, technical characteristics, and progress of the developments on which Hitachi is currently working in preparation for the April 2016 commencement of operation of the cross-regional operation system for undertaking the activities of the OCCTO in a comprehensive manner, and its work on DC transmission systems that help improve cross-regional interconnection.

INTRODUCTION

GREATER use has been made of renewable energy in Japan in recent years with the aim of preventing global warming. The increasing installation of power sources with a fluctuating output, such as photovoltaic and wind power generation, requires measures for improving grid stability, including strengthening the transmission network, operating thermal power plants in a way that provides adequate regulation reserve, and the installation of large energy storage systems. Progress has been made on consideration of electricity market reforms prompted by factors such as the tight supply of electric power resulting from the Great East Japan Earthquake, and there is a need for mechanisms that extend beyond the existing boundaries between supply networks to enable things like cross-regional grid operation and demand and supply balancing. Hitachi has supplied a wide range of systems in the past, including central load dispatch center systems for power companies, power trading systems for members of the Japan Electric Power Exchange, and substations and other electric power distribution infrastructure for large consumers. This includes utilizing the advanced technology and know-how that Hitachi has built up over time to develop cross-regional grid operation solutions to keep power system reliability with high quality and low cost.

This article describes the functions, technical characteristics, and progress of the cross-regional operation system due to enter service in April 2016, and Hitachi's work on direct current (DC) transmission systems that help improve cross-regional interconnection.

CHANGING ENERGY ENVIRONMENT AND NEW CHALLENGES FOR GRID OPERATION

The Long-term Energy Supply and Demand Outlook[1] that was formulated in the light of the Great East Japan Earthquake reiterated the core considerations of security of supply (energy security), supply of low-cost energy through efficiency improvements (economic efficiency), the environment, and safety ("3E+S"). The electricity market reforms[2] are needed to achieve them. As encouragement for greater installation of renewable energy and stable operation of the power system is also required, new challenges have emerged.

Wider Use of Renewable Energy

Encouragement for greater installation of renewable energy with variable output (photovoltaic and wind power generation) will help with measures for dealing with global warming (environmental conservation) and improving self-sufficiency (energy security). Accordingly, the feed-in tariff (FIT) scheme was introduced in July 2012 with the aim of promoting the large-scale installation of photovoltaic power generation (see Fig. 1). The Action Plan for Achieving

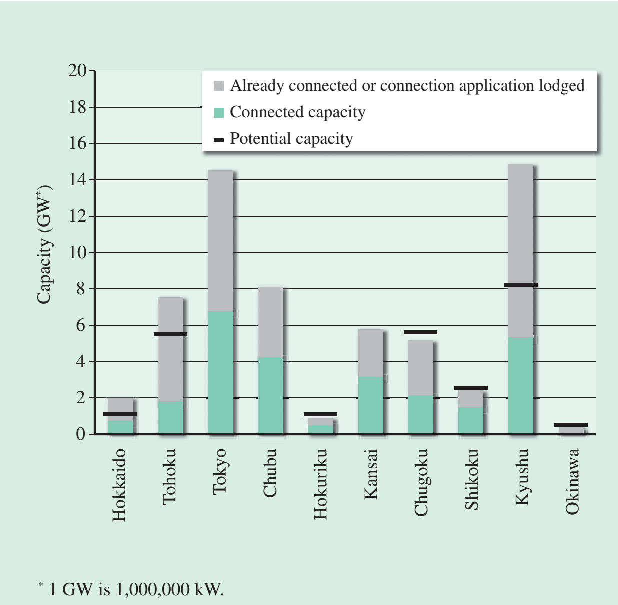

Fig. 1—Actual and Potential Connected Capacity of Photovoltaic Power Generation.
The graph shows the situation at the end of July 2015. No potential capacity has been specified for Tokyo, Chubu, and Kansai (prepared from documents of the New and Renewable Energy Subcommittee of the Committee on Energy Efficiency and Renewable Energy of the Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry[(4)]).

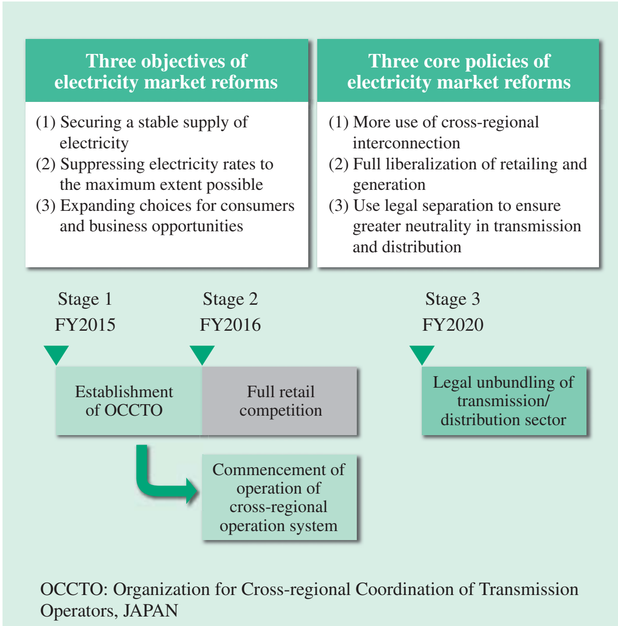

Fig. 2—Objectives and Process of Electricity Market Reforms.
Prepared from "Report of Expert Committee on the Electricity Systems Reform" published by the Agency for Natural Resources and Energy in February 2013[(2)].

a Low-carbon Society (July 2008 cabinet decision)[(3)] set a target of 53 GW* by 2030[(4)], 40 times the installed capacity in 2005. For Japan as a whole, the total capacity of photovoltaic power plants that are already connected or for which connection applications have been lodged is more than 61 GW. In Hokkaido, Tohoku, and Kyushu, the total of actual and applied for connections exceeds the connection capability, with Kyushu placing a moratorium on the granting of new applications in September 2014 (which was lifted in December 2014). The mix of power sources in 2030 planned in the Long-term Energy Supply and Demand Outlook (published by the Ministry of Economy, Trade and Industry in July 2015) set a target for renewable energy to supply between 22% and 24% of total electric energy, roughly double the 12.2% supplied in FY2014.

Implementation of Electricity Market Reforms

The reform of electricity business regulation is already in its fourth phase[(5)]. In response to the changing environment for power systems, and based on the three objectives and core policies, the electricity market reforms have been undertaken in three stages, namely the establishment of the Organization for Cross-regional Coordination of Transmission Operators, JAPAN (OCCTO), full liberalization of electricity retailing, and the legal separation of transmission network operators (see Fig. 2).

One of the main functions for the cross-regional operation system is to make timely decisions about whether electric power can be interchanged between regions while keeping within the operational constraints imposed by the interconnection infrastructure.

The full liberalization of electricity retailing will open up a market of 85 million households and low-voltage consumers that accounts for 38% of electricity usage and is worth 8 trillion yen[(6)]. The number of power producers and suppliers registered to participate in this market doubled from 352 to 762 during the one-year period from September 2014. The arrival of a large number of new businesses is expected to result in an intensification of new competition never seen before as electric power companies establish their own new businesses to supply outside their traditional regions. It is anticipated that this competition will allow consumers to choose their retail supplier and minimize rises in power prices as far as possible. Accordingly, Hitachi is proceeding with the development of solutions for new and existing electric power companies that are designed for a competitive market[(7)].

* 1 GW is 1,000,000 kW.

The legal unbundling of transmission/distribution sector is expected to create an environment that facilitates competition among generators and retailers by improving neutrality and independence and providing fairer access for everyone to the transmission and distribution network.

It is anticipated that these reforms will enable the supply of low-cost energy through efficiency improvements (economic efficiency).

Challenges for Grid Operation

Greater installation of renewable energy with variable output is expected to cause problems such as overloading of interconnection infrastructure, grid instability, the production of excess power, and voltage problems.

To date, power plants and distribution infrastructure have been built to balance demand and supply within each region. This means there was no need to expand cross-regional interconnection capacity. One of the issues associated with facilitating the economic supply of electric power at a national level by selecting generators in accordance with their relative merits is the upgrading of interconnection infrastructure, including DC systems and frequency conversion facilities. As decisions on the availability of interconnection infrastructure (whether notification changes can be made) take in the order of 30 minutes to an hour(8), another challenge is how to speed up the time taken for deciding whether notification changes can be made in the case of renewable energy sources with outputs that are difficult to predict.

As disruptions to voltage, current, and frequency occur due to factors such as the varying output of renewable energy have the potential to degrade electric power quality or cause major outages, new grid stabilization systems are needed(9), (10).

To provide adequate regulation reserve, it is not possible to shut down all thermal and hydro power plants, and they need to continue operating at their minimum output level at least. Similarly, other forms of generation such as nuclear power plants cannot be started up or shut down quickly. This leads to a problem of excess power if the output of renewable energy is high when demand is low(11).

Voltage regulation systems are installed and configured on the basis of loads being connected at the periphery of the distribution network. However, there is also a problem of voltage rises at the periphery due to the output of a large installed capacity of photovoltaic power generation(12).

HITACHI'S WORK ON SOLUTIONS FOR CROSS-REGIONAL GRID OPERATION

Energy Storage Systems for Grid Stabilization

As it is anticipated that a large amount of photovoltaic, wind power, and other forms of renewable generation capacity will be installed to reduce carbon dioxide (CO_2) emissions with the aim of preventing global warming, there are concerns about grid instability due to inadequate regulation reserve.

The number of operating thermal power plants will fall as more renewable energy is generated, resulting in a lack of short-term regulation reserve. The installation of a large amount of photovoltaic and wind power will lead to an increase in short-term power fluctuations in the order of a few seconds to a dozen or so minutes. The effect these fluctuations have on grid frequency are a cause of instability. These variations of comparatively short duration are dealt with by the governor free (GF) function at power plants, adjustable-speed pumped storage hydro, and load frequency control (LFC) at control centers (load dispatch offices).

Providing additional constant- and adjustable-speed pumped storage hydro is a good way to make up for a shortage of short-term regulation reserve. As installation of renewable energy grows rapidly in the future, it is likely that this option will not be ready in time due to constraints such as the shortage of suitable sites and the length of time taken for construction. The advantage of energy storage systems, on the other hand, is that they are suitable for distributed installation and can be set up at short notice with few site constraints.

Furthermore, as the output of renewable energy becomes large relative to demand, the output of thermal power plants will fall to near-minimum levels and limit their ability to provide regulation reserve by reducing their output, meaning there is a risk of excess power being generated when the output of renewable energy is larger than expected. The advantage of using energy storage systems to store this energy is that it can avoid excess power and increase regulation reserve by thermal plants.

To overcome the problem described above of a lack of regulation reserve, Hitachi has developed a grid stabilization system that uses the CrystEna container-type energy storage system (see Fig. 3). This enables full use to be made of renewable energy by balancing demand and supply for electric power to maintain frequency stability.

Fig. 3—1-MW Container-type Energy Storage System.
The photograph shows the 1-MW container-type energy storage system.

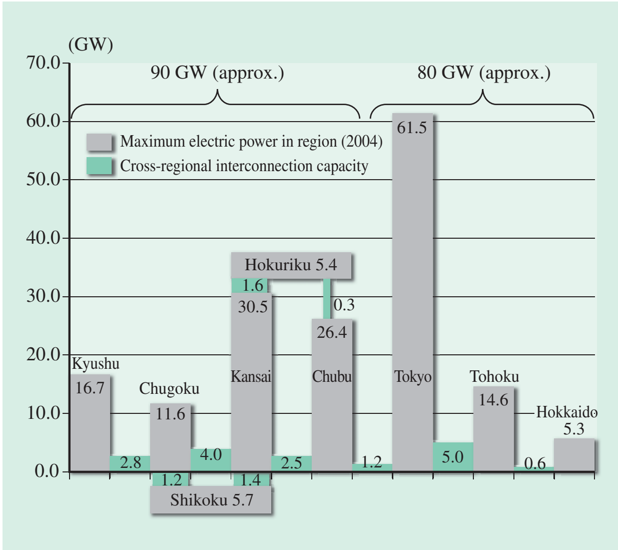

Fig. 4—Relationship between Maximum Electric Power in Each Region and Cross-regional Interconnection Capacity in 2004.
Prepared based on 2004 yearbook of The Federation of Electric Power Companies of Japan.

Cross-regional Operation System

The OCCTO was established in 2015 to enable greater cross-regional grid operation, one of the key parts of the electricity market reforms. The role of the OCCTO includes balancing demand and supply and grid planning; upgrading transmission infrastructure, including frequency conversion facilities; and managing grid operation at the national level (across different power company areas). Hitachi has, since September 2014, been developing systems for the series of tasks that extend from the offline planning needed to undertake the activities of the OCCTO in a comprehensive manner through to online monitoring (these systems are due to commence operation in April 2016).

DC Transmission System

In addition to systems such as those for grid stabilization and cross-regional operation, greater cross-regional operation of the grid also requires additional interconnection capacity (see Fig. 4).

The easiest and cheapest way to provide additional interconnection capacity is to use alternating current (AC) systems. However, use of AC for this purpose also brings potential problems, such as higher fault currents and loop power flows. DC interconnection, on the other hand, provides a way to avoid these problems while still expanding grid interconnection capacity.

SOLUTIONS FOR SUPPORTING CROSS-REGIONAL OPERATION SYSTEM

Techniques for High Reliability and Scalability

The cross-regional operation system has a three-way hot standby configuration, with the backup sites located several hundred kilometers away from the primary site. This enables the system to maintain high reliability without loss of functionality in the event of a mega disaster such as a large earthquake. As part of international standardization, the model used by the system to represent grid infrastructure also complies with the IEC 61970-301 common information model (CIM) standard. This is an abstract model of the energy management system (EMS) information objects used by different applications. It makes the system more scalable by improving interoperability with other systems and ease of integration with package products.

HMI Based on Human-centered Design

The grid monitoring platform must be able to display the macro status of the nationwide grid to the operators stationed at the central load dispatch center so that they can assess the situation at a glance. As OCCTO operates at the national level, the aim was to make it easier for operators to see what is happening so that they can quickly ascertain information such as the location and coverage area of power system infrastructure located over a wide area. Based on a design concept of providing rapid situation assessment, the human-machine interface (HMI) for the national power grid diagram used by operators incorporates the following three features (see Fig. 5).

(1) A clear visual representation of the locations of power system infrastructure was used to show the large number of such sites on a simplified map of Japan as faithfully as possible.

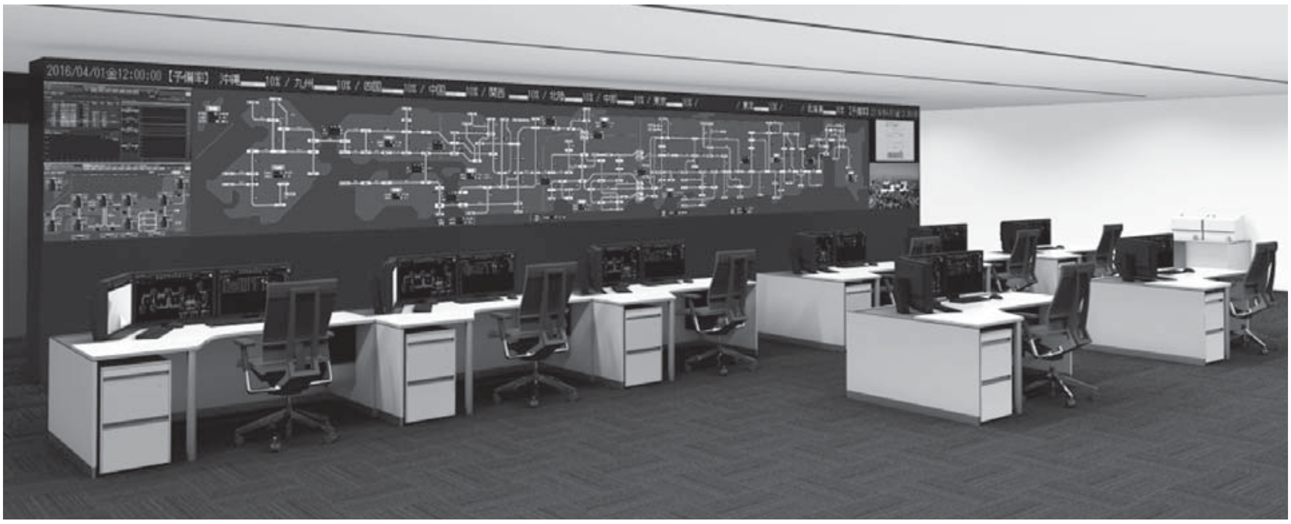

Fig. 5—Cross-regional Operation System Control Center (Artist's Impression of Completed Center).
This computer-generated image depicts the control center of the cross-regional operation system. The large screens in the center show a diagram of the national grid.

(2) Ease of interpretation was improved by adopting a display layout based on the density of power system infrastructure in areas where there is a high concentration of such equipment.
(3) In the case of a fault on a dual transmission line, display symbols were adopted that provide a clear indication of which of the two lines has the problem.

Based on these features, Hitachi created a design for the grid monitoring platform that enabled the OCCTO operators to go about their work on the new system without human errors. By making the HMI more geographically realistic (reproducibility of the map), Hitachi implemented a new customer value proposition based on human-centered design in the cross-regional operation system.

Security Measures

The methods used for cyber-attacks have become more complex and ingenious in recent times, with the risk that such attacks may result in system shutdowns. The government's Cyber Security Strategy (June 2013, Information Security Policy Council) listed a major power outage caused by a cyber-attack on the power system as one of the risks that was on the rise(13), indicating that appropriate countermeasures are needed.

Against this background, the cross-regional operation system has adopted measures with reference to such guidelines as the "Report on FY2013 Security Survey of Next-generation Electric Power Systems"(14), the Critical Infrastructure Protection (CIP) Standards of the North American Electric Reliability Corporation (NERC)(15), and IR 7628 of the National Institute of Standards and Technology(16).

One example is the analysis of the security risks for each segment and the implementation of countermeasures for each risk. Another is the detection of intrusions by detecting unauthorized access between segments, monitoring external communications, and identifying abnormal communication activity.

Solutions Provided by Cross-regional Operation System

One of the core objectives of the electricity market reforms is to increase electricity market liquidity. To enable grid users to trade electric power across the electric power company areas, there is a need for trading to be managed across multiple areas so as to balance demand and supply in each area and satisfy the operational constraints on AC and DC interconnection infrastructure (decide whether or not transmission is available).

Under the current system, grid users submit a request for each transaction to the dispatch systems for each relevant area, and the operators at the corresponding central load dispatch center decide whether or not transmission is available. Their responses are then collected and output the final result of the request.

Once the cross-regional operation system commences operation, it will take over the role of deciding whether or not transmission is available from the separate dispatch systems. This means that grid users will now only need to issue a request to the OCCTO. In addition to providing centralized handling by the cross-regional operation system, this will also allow the process of deciding whether or not transmission is available to be automated. As a result, this not only provides greater convenience to grid users by delivering the responses to their requests more quickly, by allowing users to issue requests closer to the actual time, it also helps with grid stabilization and with the accurate balancing of demand and supply in an economic manner.

SOLUTIONS FOR CROSS-REGIONAL INTERCONNECTION

Advantages of DC Transmission Systems for Cross-regional Interconnection

Discussion of the need for cross-regional grid interconnection to accompany the progress of electricity market reform and greater installation of renewable energy has taken place primarily at the OCCTO (see Fig. 6).

AC methods provide the simplest ways to interconnect the grids in different areas. However, overuse of AC interconnections could cause impacts to the devices such as protection relays, circuit breakers, and transformers due to higher short circuit currents, increase the potential of a fault on one grid affect to the other grid, and cause instabilities such as loop power flows and low-frequency oscillations.

Furthermore, because Japan has different grid frequencies in the east (50 Hz) and west (60 Hz), direct AC interconnections between these systems are not possible. DC transmission systems are an effective means to increase the grid interconnection capacity without causing these problems on AC interconnection (see Table 1).

DC transmission systems are also useful not only for interconnection between grids, but also for the transmission of the power from large renewable energy sites to distant demand area, or for offshore wind farms that connect to submarine cables to connect to the grid.

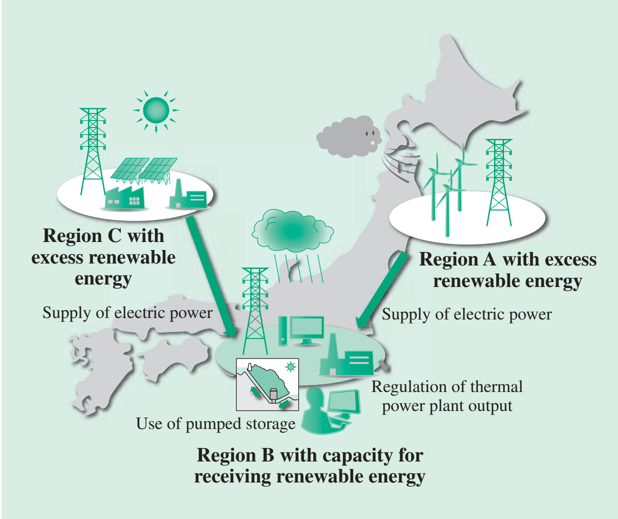

Fig. 6—Cross-regional Use of Grids in Preparation for Greater Use of Renewable Energy.
Prepared from "Establishment of Systems and Rules for Cross-regional Use of Grids in Preparation for Greater Use of Renewable Energy" published by the Agency for Natural Resources and Energy on April 14, 2015.

TABLE 1. Comparison of AC and DC Grid Interconnections
DC links have advantages such as being able to connect different frequency grids or connect two grids without increasing short circuit capacity, etc[17]*.*

Item	AC	DC
Cable interconnection	Short distance only (up to several tens of kilometers)	Can be used for long-distance links
Control of power flow	Difficult	Accurate control is easy to achieve.
Short circuit capacity	Has potential to increase fault current. May influence existing protection relays, circuit breakers, transformers, and other devices in some cases.	Interconnection capacity can be increased without increasing short circuit capacity.
Interconnection of grids with different frequencies?	No	Yes
Influence of power system fault	Potential for fault on one grid to affect the other grid (large-scale outages have occurred in Europe, USA, and elsewhere).	A fault on one grid does not affect the other grid.
Emergency response	Emergency response is difficult because a fault on one grid may affect the healthy grid.	An emergency response from the healthy grid can be available easily and quickly. Can deal with frequency fluctuations on faulty grid and prevent the cascading power plant outages.

AC: alternating current DC: direct current

TABLE 2. Comparison of Line-commutated and Voltage Source Type HVDC
Voltage source type HVDC system has advantages in terms of operation, economics, and grid stabilization[17].

Item	Line commutated	Voltage source
Commutation method	Line commutated (by AC voltage)	Self commutated
Device	Thyristor	IGBT, etc.
Cable (in case of cable transmission)	Oil paper (heavy and expensive), long joint time	XLPE (light and inexpensive), short joint time
Dynamic reactive support?	No	Yes
Independent control of active and reactive power?	No	Yes
Restrictions on connected AC grid	Requires larger (more than twice of converter) short circuit capacity	Does not require larger short circuit capacity
Black start	Cannot operate when power outage occurs on AC grid	Can start the converter and energize the grid when power outage occurs on AC grid
Losses (total)	2.5 to 4.5% (depends on cable length)	Close to line commutated (in recent years)
Zero-power-flow operation	No	Yes
Filter, phase modifying equipment	Requires large footprint	Not required or only uses small area
Past installations	More than 100 past installations, highly reliable (Maximum capacity and voltage: 6,400 MW/800 kV)	Developed over the last 15 years or so, with more than 20 systems in operation (Maximum capacity and voltage: 800 MW/500 kV)

IGBT: insulated-gate bipolar transistor XLPE: crosslinked polyethylene

Moreover, if the systems incorporate the latest technology for voltage source type HVDC, they can also support the grid stability by supplying reactive power and also enable a "black start" restoration of power after an outage.

Compared to existing HVDC in Japan, which applied line-commutated type HVDC, voltage source type HVDC system, which uses self commutating semiconductors such as insulated gate bipolar transistors (IGBTs), provides numerous advantages (see Table 2).

Hitachi's Work on DC Transmission Systems

Since the 1970s, Hitachi has been involved in a total of eight DC interconnection system projects in Japan. While there have been no new projects in Japan for more than a decade, a resumption in demand for DC interconnection is anticipated due to the need for making more robust grids, enhancing cross-regional interconnection, and the connection of renewable energy.

To supply the latest technology in response to this demand, Hitachi has established a joint venture with ABB, which has world-leading technology and experience in this field. The new company, Hitachi ABB HVDC Technologies, Ltd., commenced operation in November 2015[18].

The joint venture will handle system design, engineering, manufacture, assembly, testing, sales, and after-sales service for the AC/DC converters and other related equipment for high-voltage direct current (HVDC) projects in Japan that have been awarded to Hitachi. Fig. 7 shows an HVDC system. The joint venture will contribute to making a strong power grid in Japan by combining the strengths of the two companies, namely Hitachi's sales network, the project management knowledge it has built up through experience in Japan, and its quality assurance processes, and the leading-edge HVDC technology and system integration capabilities of ABB.

HVDC: high-voltage direct current

Fig. 7—Skagerrak 4 Project (700-MW/500-kV Link between Norway and Denmark)[19].
The photograph shows an ABB self-commutated HVDC system (Skagerrak 4, 700 MW, ±500 kV).

CONCLUSIONS

This article has described solutions for cross-regional grid operation. Along with ongoing changes in the business environment as electricity reform progresses, it is likely that a wide variety of needs will arise out of the market for electric power from electric power companies and numerous other stakeholders. Hitachi intends to continue contributing to the development of electric power systems and the reliable supply of electric power to consumers by offering new solutions to diverse challenges that take the market as their starting point.

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ABOUT THE AUTHORS

Masahiro Ichinosawa

Power System Information & Controls Department, Solution Systems Division, Energy Solutions Company, Hitachi, Ltd. He is currently engaged in the business development of supervisory control and data acquisitions systems (SCADA) and energy management systems (EMS). Mr. Ichinosawa is a member of the International Council on Large Electric Systems (CIGRE) and The Institute of Electrical Engineers of Japan (IEEJ).

Toshiyuki Sawa, Dr. Eng.

Power System Information & Controls Division, Solution Systems Division, Energy Solutions Company, Hitachi, Ltd. He is currently engaged in energy management systems, energy trading and risk management systems, and power market systems for electricity market reform. Dr. Sawa is a member of the IEEE and IEEJ.

Hiraku Tanaka

Power System Information & Controls Department, Solution Systems Division, Energy Solutions Company, Hitachi, Ltd. He is currently engaged in the expanding sales of domestic SCADA/EMS, and proposing solutions in response to electricity market reform in Japan.

Shuhei Fujiwara

Customer Co-creation Project, Global Center for Social Innovation – Tokyo, Research & Development Group, Hitachi, Ltd. He is currently engaged in developing power distribution solutions for the North American market and designing the HMI for these systems.

Atsushi Nishioka

Hitachi ABB HVDC Technologies, Ltd. He is currently the Representative Director, Chairman & CEO. Mr. Nishioka is a member of the IEEJ and CIGRE.