Hitachi Review

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HITACHI
Inspire the Next

Electric Power and Energy Solutions

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From the Editor

The business environment in which the electric power and energy market operates is undergoing major changes due to the emergence of challenges common to all parts of the world, such as greater use of renewable energy and hydrogen and the supply of electric power to cities where populations are increasingly concentrated, and those specific to particular nations or regions, such as electricity market reform and aging infrastructure.

Hitachi intends to contribute to society by operating solution-based businesses that work with customers to offer solutions to a variety of challenges and draw on information technology (IT) based on the technology and experience with power systems that it has built up over time.

This issue of *Hitachi Review* presents some of the work being undertaken by Hitachi on these electric power and energy solutions. In Expert Insights, Professor Akihiko Yokoyama of the Graduate School of Frontier Sciences at The University of Tokyo contributes an article about the adoption of smart practices in the electric power and energy sectors. Technotalk presents an overview of progress by Hitachi's technology development and solution businesses on the key energy sector issues of the environment, economic efficiency, and security of electric power supply, and looks at the outlook for the future.

Other articles deal with the electricity market reforms currently underway in Japan, describing work on the cross-regional operation system and self-commutated direct current (DC) transmission systems for the national grid, and solutions for electric power companies that are designed for use under the full liberalization of electricity retailing.

In an example of collaborative creation with customers outside Japan, an article describes grid stabilization solutions that incorporate wide-area protection control systems and ancillary services that use energy storage systems. There is also an overview of a smart grid demonstration project and a description of the IT platform that underpins it. Articles on work relating to the energy mix focus on a 5-MW downwind turbine demonstration project and the development of a floating substation for offshore wind farms, and on safety improvement for nuclear power generation. Another article gives examples of solutions that utilize IT, one of Hitachi's strengths, describing engineering work that has been enhanced by use of the latest IT, including an advanced equipment maintenance service based around a technique for using data mining methods to identify signs of equipment abnormalities, and the construction, upgrading, and maintenance of electrical plants.

I hope this issue of *Hitachi Review* will provide you with helpful information about Hitachi technologies and solutions for the electric power and energy sectors.

Editorial Coordinator,
"Electric Power and Energy Solutions" Issue

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Electric Power and Energy Solutions

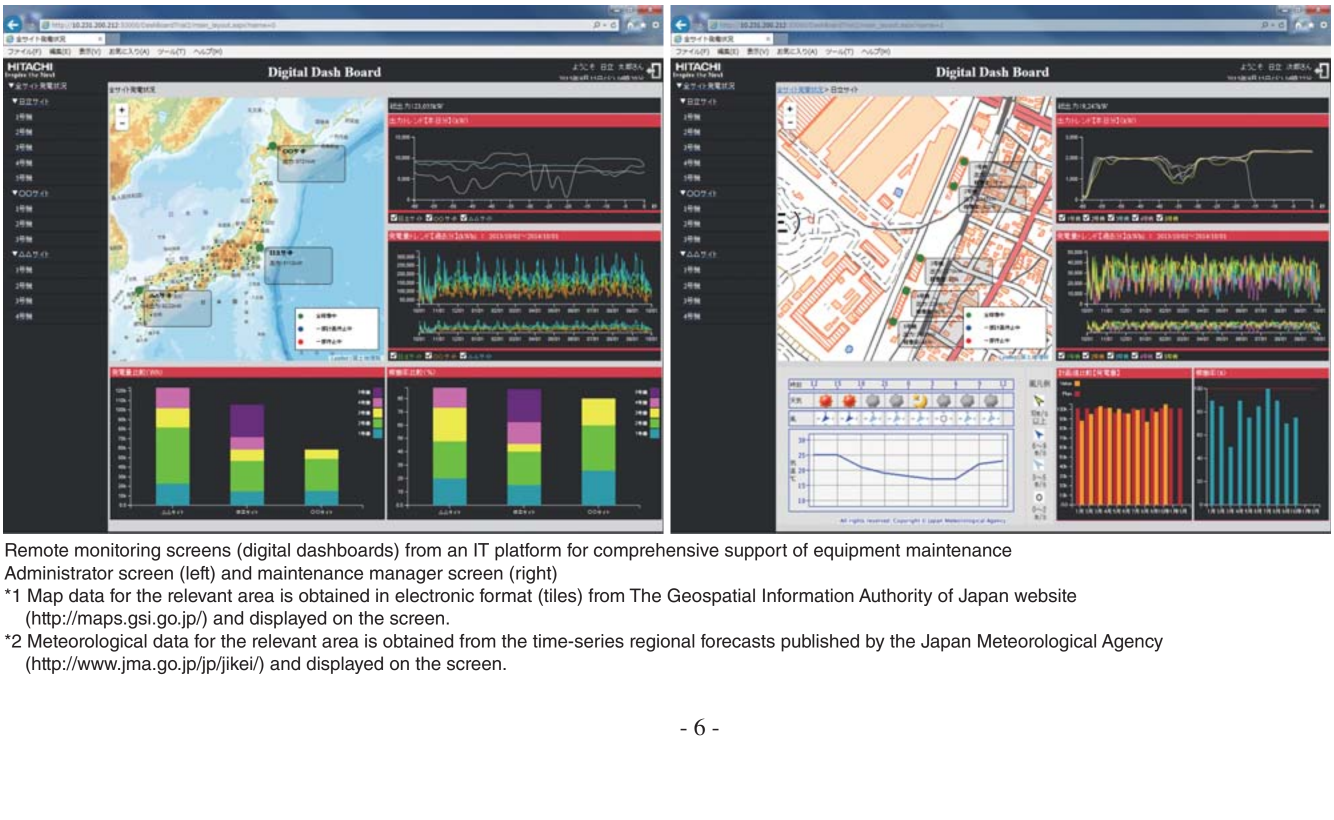
Contents

Electric Power and Energy Solutions

The secure supply of electric power and energy is closely intertwined with the environment, economic efficiency, and safety, and is an important factor in social stability.
Achieving and maintaining this security calls for advances in energy solutions to deal with the challenges facing individual countries and regions.
Having supplied a wide range of equipment and system technologies to the electric power and energy sectors, Hitachi seeks to respond to the diverse challenges facing global markets for electric power and energy by combining IT with this accumulated technology and knowledge.
Hitachi will continue to underpin advances in electric power and energy systems by supplying solutions tailored to particular regions through collaborative creation with customers.

CrystEna container-type energy storage system

Cross-regional operation system control center (artist's impression of completed center)



Remote monitoring screens (digital dashboards) from an IT platform for comprehensive support of equipment maintenance
Administrator screen (left) and maintenance manager screen (right)

*1 Map data for the relevant area is obtained in electronic format (tiles) from The Geospatial Information Authority of Japan website (http://maps.gsi.go.jp/) and displayed on the screen.

*2 Meteorological data for the relevant area is obtained from the time-series regional forecasts published by the Japan Meteorological Agency (http://www.jma.go.jp/jp/jikei/) and displayed on the screen.

Offshore substation
(Photograph courtesy of the Fukushima Offshore Wind Consortium)

Prototype of HTW5.0-126 5-MW downwind turbine

Sub-drain decontamination system (top) and high-performance multiple-nuclide removal system (bottom) for dealing with contaminated water at nuclear power plants

Expert Insights

Smarter Power Systems Utilizing Total Solution Technology

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Fellow of The Institute of Electrical Engineers of Japan, Chairman of CIGRE JNC, IEC TC8 JNC, and the Electric Power Safety Subcommittee and Basic Policy Subcommittee on Electricity, Ministry of Economy, Trade and Industry.

The electric power system is currently midway through the electricity market reforms prompted by the Great East Japan Earthquake. The Organization for Cross-regional Coordination of Transmission Operators, JAPAN commenced its activities in April 2015, with deregulation of the retail market to occur from April 2016 and legal unbundling of transmission and generation from 2020. Furthermore, the Long-term Energy Supply and Demand Outlook for 2030 was formulated in July 2015 and includes the installation of a large amount of renewable energy capacity, especially photovoltaic power generation. Given these circumstances, there are concerns about how to maintain security of supply, including such problems as lack of frequency regulation capacity and the generation of excess power, with power systems currently at the stage of undertaking a variety of technical developments and demonstration projects aimed at overcoming these challenges.

At the grid level, new systems are required to deal with functions like the reallocation of base-load capacity between control areas to provide a capacity margin for the thermal power plants used for frequency regulation, and the redistribution via regional interconnections of fluctuations in renewable energy output to areas capable of dealing with them. Within individual areas, meanwhile, the process of managing and controlling supply and demand is becoming increasingly complex, including balancing supply and demand up to the market gate closure (GC) time by the balancing groups created by generators, the supply and demand and frequency adjustment performed by grid operators during the period from GC to actual operation, and trading on the electricity market to enable these adjustments. This calls for the construction of systems that are optimal in both technical and economic terms.

A trend in wider society is the construction of smart systems that use the Internet of things (IoT), big data, and artificial intelligence (AI) to deal promptly, flexibly, effectively, and efficiently with changing circumstances that include advances in technology as well as changes in markets and international trends. In the case of power systems, studies have begun to look at the collection of information from smart meters and home energy management systems (HEMSs) (in the case of households), and phasor measurement units (PMUs) and power system infrastructure (in the case of the grid), and its utilization for purposes such as asset management and maintaining the stability of regional grids. Achieving this requires a common information model (CIM) for information that extends beyond individual control areas, from the grid and from power supply infrastructure. If large amounts of renewable energy capacity is to be installed sustainably and without deteriorating grid stability, it is important to produce a very long-term "grand design" for the transmission and distribution network, and this requires investigations into the installation of innovative technologies, such as superconducting cables or a multi-terminal/self-commutated high-voltage direct current (HVDC) transmission network like that being worked on in Europe and the USA.

This means making the power system smarter. To make the power system more attractive to the students and young engineers who will be responsible for it in the future, I see great potential for further progress being made, with a view to international markets, on the development of solution technologies for the electric power and energy sector, the integration of these systems, and their standardization.

Technotalk

Energy Solutions for Social Innovation

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Energy has grown in sophistication to become an important part of the infrastructure of society. Recent years, however, have seen the emergence of complex issues that need to be dealt with at a global level, including reducing carbon emissions in response to global warming, improving economic efficiency, and ensuring security of energy supply, while, in Japan, moves toward the reform of the electricity market are accelerating. Hitachi is striving to offer solutions to these numerous challenges by drawing on its strengths in IT and on the equipment and system technologies it has supplied to many different parts of the energy sector. Hitachi will support electricity market reform and contribute to Social Innovation through energy solutions based on its accumulated knowledge and technology.

Wider Adoption of Renewable Energy

Yamada: While energy is an important part of the social infrastructure that supports our way of life, it has been facing a variety of challenges in recent years, including increasing emissions of greenhouse gases, generation costs, and security of energy supply. Hitachi strives to develop energy solutions for overcoming these challenges and seeks to provide customers with three forms of value, namely environmental, economic, and reliability performance.

Starting with environmental performance, while the wider adoption of renewable energy is essential for dealing with global warming, it also poses a number of challenges.

Sato: Along with rising environmental awareness, the growing use of renewable energy in Japan has been underpinned by the feed-in tariff scheme. Unfortunately, the wider spread of power sources and their fluctuating output poses problems of voltage and frequency stability when connected to the grid. In response, the Research & Development Group at Hitachi is developing technologies for things like output smoothing and voltage stabilization. In particular, stabilization solutions for regional grids now need to be able to cope with continually varying conditions. This includes a

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demonstration project for regional grid stabilization being run jointly with the Bonneville Power Administration (BPA) in the USA. We have been focusing on grid stabilization techniques that utilize our portfolio of technologies, which include such functions as prediction calculations and high-speed grid calculations developed for past projects like the online transient stability control (TSC) system supplied to Chubu Electric Power Co., Inc.

In the case of frequency instabilities that arise as a result of variations in the balance of supply and demand, we are also trialing the efficacy of using energy storage systems for grid stabilization, conducting a demonstration project in North America that uses the CrystEna container-type energy storage system.

Along with factors such as falling generation prices due to the spread of renewable energy and progress in battery storage technology, rather than simply selling whatever renewable energy is generated, what is needed are measures for regional energy management and solutions that use local consumption of local generation to make the best use of the energy produced. Hitachi intends to contribute to even wider adoption by taking this approach to its participation in projects in different parts of the world.

Yamada: Renewable energy is becoming even more unevenly distributed due to local factors such as the weather.

Sato: The uneven distribution of power sources and the associated redistribution of electric power over long distances is a problem shared by both Japan and other places. We have technology for incorporating output prediction functions for renewable energy into load dispatch office systems and are seeking to deploy this technology overseas as well as in Japan.

Yamada: Meanwhile, there is also interest in local consumption of locally produced energy. Please tell us about demonstration projects aimed at making this possible.

Egashira: Hitachi has since 2013 been participating in a smart grid demonstration project in the Hawaiian island of Maui with the New Energy and Industrial Technology Development Organization (NEDO) and other partners. One of the issues facing Hawaii is that it has the greatest dependency on fossil fuels of any state in the USA. Having set a target of increasing renewable energy capacity to 40% or more of total demand for electric power in the state by 2030, installation is proceeding steadily. The project is supporting the efficient management of renewable energy by providing an electric vehicle (EV) energy control center that handles battery control, a distribution grid control system, and a demand response system in order to create a smart grid that utilizes EVs.

Sato: Adapting to local circumstances is the key to regional energy networks. Examples such as the deregulation of electric power supply by stadtwerkes (communal service providers) in Germany and the expansion of the microgrid market in the USA demonstrate the importance of solutions that suit the characteristics and energy situation in the region. Adapting to local circumstances calls for solutions to be developed through consultation with the residents and other stakeholders, which is another way of saying the use of collaborative creation with customers that is such a focus of effort by Hitachi.

Comprehensive Support for Cutting Energy Costs

Yamada: The second form of value delivered to customers is economic performance. While users are increasingly taking steps to save energy, what sort of initiatives are underway to reduce the cost of energy?

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Joined Hitachi, Ltd. in 1985. Having previously worked in commercial roles relating to information systems for electric power, he is currently engaged in coordinating sales of information systems for electric power.

Egashira: One example of an energy management business that includes energy efficiency is the Kashiwa-no-ha Smart City. Hitachi has participated from the initial planning, building the area energy management system (AEMS) that links the city's various facilities and power sources (including photovoltaic power generation and batteries) via a network to perform centralized management of energy, and has been responsible for its operation since completion. A feature of the system is that it collects and analyzes information such as weather conditions and energy use at each facility for the efficient redistribution of electric power throughout the city to save energy and reduce carbon dioxide (CO_2) emissions, while also keeping the city safe by maintaining electric power during emergencies.

Energy efficiency is also an ongoing concern for companies. However, identifying fundamental solutions that are suitable for all companies is not simple. Furthermore, at workplaces in Japan in particular, problems with energy efficiency are not immediately apparent. Accordingly, our current practice is to install an energy management system (EMS) at the customer site to collect and analyze data and diagnose the problems in order to uncover potential measures for saving energy. With little more that can be done to make energy savings at individual sites, we have reached the stage of looking at energy management across the entire company or multiple sites, offering comprehensive solutions that combine EMS with an energy service company (ESCO) scheme.

A feature of Hitachi's offerings is that they include consideration of life cycle costs 10 to 15 years ahead and adopt a business model under which operation can change in response to changes in the business environment.

Yamada: The second phase of electricity reform involves the full deregulation of the retail market from April 2016. Because ordinary households will now be permitted to choose where they purchase electric power, it is anticipated that their awareness and interest in energy will grow, and that it will prompt the electric power and other markets to offer greater diversity in the value they deliver to consumers in terms of energy and services.

Sakikubo: What consumers are looking forward to most from full retail deregulation is that the cost of electric power will fall. While I myself am interested as a consumer, I also believe it is important that tariffs are set in a balanced way that does not compromise security of supply and safety. As the installation of smart meters will enable households to view their electric power usage history in 30-minute intervals, I expect it will lead to progress on their adopting data-based energy efficiency measures.

Yamada: While a greater diversity and number of players in the energy business is evident in the lead up to full retail deregulation from 2016, are you aware in your contact with customers of a new mood in the air?

Takeiri: While Hitachi supplies a wide range of systems to its power company and other energy business customers, including customer information systems (CISs), meter data management systems (MDMSs), and smart meters, rather than simply supplying equipment and standalone systems, customers are increasingly asking how we can contribute to the expansion of their service businesses in the form of total solutions, by, for example, developing electricity pricing plans. In response to this change, there is scope for us to make use of our expertise in information and operation technology (IT × OT) to provide support that encompasses customer cost reduction and the adoption of business intelligence (BI) to allow management to see what is happening in their business. The aim of our sales force is to work with the customer and create new value by treating the electricity reforms as an opportunity for business expansion.

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Yamada: While the installation of smart meters is costly, there are also potential economic benefits from the application of big data techniques to the data collected by these meters.

Sakikubo: Measuring household electric power use in 30-minute intervals provides detailed information on usage that was not available under the previous practice of taking a monthly meter reading, and it also opens up possibilities that include different billing options. Similarly, equipping meters with communications not only improves the efficiency of meter reading by allowing it to be automated, the ongoing accumulation of data offers other possibilities such as optimal equipment configuration and predictive maintenance using condition-based maintenance (CBM).

Sato: Rather than just electric power data, what is likely to be important is how to provide benefits to users through its use in conjunction with such things as gas, telecommunications, and commerce. For the use of data also, I believe that expanding the range of possibilities lies at the heart of electricity reform.

Egashira: Electricity reform has seen a series of new entrants to energy markets from outside the sector.

This involvement of outsiders may lead to breakthroughs that go beyond what the industry has taken for granted in the past.

Maintaining Security of Energy Supply

Yamada: Given that electric power is fundamental to the social infrastructure, I believe that the third form of value, namely reliability of performance, is something that must be maintained regardless of deregulation. The government's energy policy is based on the "3E+S" concept of energy security, economic efficiency, environment, and safety, and Hitachi is engaged in a variety of work aimed at contributing to security of supply.

Nagashima: The expansion of cross-regional grid operation to help ensure security of supply is included as part of the electricity reforms. While Japan is constrained by the use of different frequencies in the east and west of the country, it is seeking to strengthen capabilities for balancing supply and demand during both normal operation and emergencies, and is also making progress on establishing the transmission and distribution network needed for cross-regional interconnections, with a central role being played by the Organization for Cross-regional Coordination of Transmission Operators, JAPAN that commenced its activities in April 2015. Hitachi is working on the development of systems for managing grid interconnections in preparation for their entering service in 2016.

Similarly, as the technology for direct current (DC) transmission is key to the greater use of cross-regional interconnections, Hitachi is working on the development of related technologies. As there is also growing international interest in the operation of wide-area grids and DC transmission technology, we are considering possible applications.

Sato: Hitachi has established a joint venture between ABB of Switzerland and our domestic high-voltage direct current (HVDC) transmission business with the aim of being an integrated provider of HVDC systems, covering everything from design to engineering, equipment supply and after-sales service. HVDC transmission poses some technical challenges, and looking ahead to the greater use of renewable energy in the future, we are speeding up the development of technology such as the optimal operation of HVDC transmission systems. In parallel with this, to help maintain stability despite greater long-distance redistribution of electric power, we are also pushing ahead with enhancements to alternating current technologies such as the grid stabilization systems being trialed by the demonstration project with BPA mentioned earlier.

Egashira: There is also a move towards the decentralization of power sources for reasons of resiliency. The USA is seeing rapid growth in microgrids, and along with the traditional aim of making grids more robust, there has been a shift in thinking based on considerations of energy self-reliance, business continuity, carbon emissions reduction, and energy efficiency. In anticipation of future market growth, Hitachi is hopeful of using its experience, past success, and technologies to also contribute to energy reform in the USA.

Enhancements to Energy Solutions Based on IT × OT

Yamada: As Takeiri-san mentioned earlier, IT × OT is a strength of Hitachi, and there is potential for the use of IT in the energy sector.

Takeiri: In regard to IT × OT, we are directing our efforts toward offering services that utilize the cloud and other IT platforms. Examples include enabling customers to create value by offering them total solutions that use IT as a base, such as cloud services that utilize human big data techniques for data analysis to help customers make operational and efficiency improvements.

Sato: Hitachi in the past has covered a wide variety of customer business domains. Along with implementing IT × OT in these sectors, it is also important to achieve synergies by coordinating a number of different initiatives as in the smart grid demonstration project in

Maui. Accordingly, in our research and development, we are working to create value by linking different domains together based on the symbiotic autonomous decentralized systems concept.

Egashira: For our customers in manufacturing, we are attempting to combine energy data and production planning data to help produce production plans that use minimal energy. For example, we have found that simulation gives completely different results for things like production sequence and the design of production sites when the priority for production planning is shifted from minimizing inventory to minimizing energy consumption. As energy is essential in all industries, there is a potential for new possibilities to open up depending on how it is utilized in other fields, such as linking energy data to a variety of different management indicators.

Sakikubo: The Information & Telecommunication Systems Company is putting effort into the use of big data, and the energy sector is among the areas where we are looking at how we can combine different forms of data to identify value of benefit to society. In the future, the Internet of things (IoT) and other similar technologies should make possible practices such as the detailed energy management of individual machines. Being a form of personal information, energy data from smart meters and other sources must be handled carefully, and we intend to support its secure use through Hitachi's technologies for things like encryption and anonymization, in compliance with security standards.

Yamada: Batteries are seen as having the potential to transform the model of energy supply.

Nagashima: The international market for batteries is forecast to reach 20 trillion yen in 2020, and I believe batteries will play an important role in energy solutions. We are focusing on the ancillary service market and capacity market, including the CrystEna demonstration project we are running in North America, one of a number of battery solutions from Hitachi. There is also growing interest in batteries in Japan, and along with supplying battery solutions for applications like peak cutting and peak shifting, I also see a need for consulting on how they can be used to help customer businesses.

Egashira: The shift from owing to renting is a major trend in the IT industry, and a similar change is also underway in the energy sector. The battery business, for example, includes a service delivery model that, rather than selling the products themselves, involves providing things like peak shifting and business continuity planning (BCP), or the ancillary services we are already providing in North America. We intend to supply more flexible energy solutions by expanding this business model and shifting to selling outcomes rather than products.

Yamada: Batteries have an important role in all three types of value provision (environmental, economic, and reliability performance) and they are expected to find a wider range of uses in the future. We want to devise solutions that can contribute to society as we go about overcoming the issues of cost and how they are to be supplied.

If electricity reforms are to provide customers with business opportunities, Hitachi has an obligation to develop solutions jointly on the basis of collaborative creation with customers. For ourselves at the Energy Solutions Company, our aim is to collaborate with the research laboratories and other operational divisions and to have those of us in frontline roles who deal directly with customers work as a team alongside engineering staff in order to supply energy solutions that create new value by solving customers' problems. Through these activities, I hope we can contribute to Social Innovation from the energy sector.

Overview

Future of Solution Business for Electric Power and Energy Sectors

Hiraku Ikeda
Tatsuya Yamada
Kenichi Azegami

INCREASINGLY DIVERSE REQUIREMENTS OF ELECTRIC POWER INFRASTRUCTURE

THE requirements for the electric power infrastructure are becoming increasingly diverse, including global environmental problems, the concentration of the population in cities, growing use of renewable energy, and the aging of infrastructure, particularly in developed nations. Dealing with this requires not just equipment reliability but also the combination of different information and other advanced technologies. This article draws on the trends in electricity markets to explain these increasingly diverse requirements and the measures needed to satisfy them, and describes Hitachi's solution businesses for the electric power and energy sectors.

TRENDS IN ELECTRICITY MARKETS

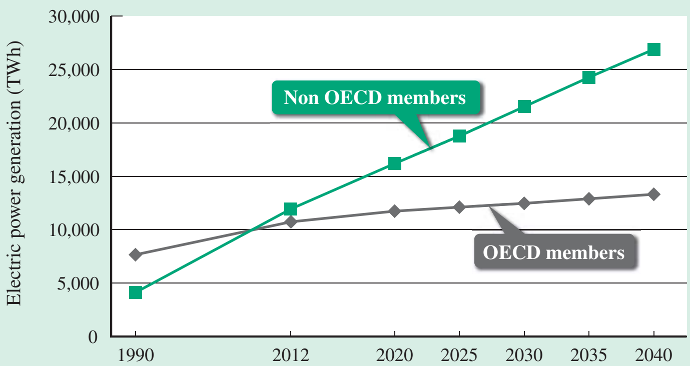
The situations facing electric power infrastructure are becoming increasingly diverse geographically. This article divides these into developed nations that are experiencing flat growth in demand for electric power, emerging nations where growth is strong (see Fig. 1), and Japan, which is in the process of implementing electricity market reforms.

Electricity Market Trends in Developed Nations

The following are some of the problems faced by developed nations that have a high level of existing infrastructure.

(1) Dealing with global warming

At the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change held in November and December 2015, the participating nations sought to agree on targets for reducing emissions of greenhouse gases. In anticipation of this, nations presented ambitious reduction targets in August 2015, conveying a sense of their commitment to dealing with global warming. To give some examples, the USA presented a target of reducing greenhouse gases emissions by 26 to 28% relative to 2005 by 2025, the European Union (EU) presented a target of a reduction within its territory of at least 40% relative to 1990 by 2030, and China presented a target of reaching



OECD: Organisation for Economic Co-operation and Development

Fig. 1—Electric Power Demand Forecast.
While demand is forecast to remain flat in the developed nations of the OECD, rapid growth is forecast for non-member emerging nations.

its peak carbon dioxide (CO_2) emissions around 2030, with emissions per unit of gross domestic product (GDP) to fall by 60 to 65% relative to 2005 by 2030. Japan set a target of reducing its greenhouse gases emissions by at least 32% relative to 2010 by 2030.

(2) Grid stabilization

While the installation of wind, photovoltaic, and other renewable energy is progressing, prompted by this rising environmental awareness, these power sources differ from thermal and other forms of generation in that their output varies due to factors such as the weather. However, electric power grids need to maintain a continuous balance between the supply and consumption of electric power, and this becomes more difficult the greater the proportion of variable power sources. Normally supply and demand are kept in balance by control of thermal power plants such as diesel generators or gas turbines that have a rapid response, meaning that in some cases the capacity of these adjustable forms of electric power set a limit on how much renewable energy can be utilized. This presents an obstacle to implementing the measures for dealing with global warming described above.

(3) Aging of equipment

The bulk of social infrastructure in developed nations, including electric power and energy equipment, has been in place for a long time. The many faults in aging equipment that occur as a result of this are a recognized problem. For example, a document published by the New York Independent System Operator (NYISO), a grid operator in the USA, states that more than 80% of the transmission infrastructure in that state is more than 30 years old, and that dealing with aging equipment has become a challenge.

(4) Introduction of market principles

To enable transmission system operators[(a)] (TSOs) to maintain grid stability while minimizing capital investment, there is a trend toward some developed nations opening up electricity services to the market. This includes moves to open up the ancillary services market for balancing the supply and demand for electric power to third party suppliers in places such as Germany and by some US TSOs. The term “ancillary services” refers to services for balancing supply and demand so as to minimize fluctuations in frequency, voltage, and other power quality parameters. By opening up this business to parties other than the TSO, the market provides the spare capacity needed for maintaining grid stability while keeping investment by the TSO to a minimum.

Electricity Market Trends in Emerging Nations

Fig. 1 shows how recent years have seen a notable rise in the demand for electric power from emerging nations, which are not members of the Organisation for Economic Co-operation and Development (OECD). This is an example of a market trend in emerging nations. The trend is expected to continue, driven by such factors as rising populations, economic growth, and the movement of people from rural to urban living.

Meanwhile, island nations and nations with large land areas have concerns about the size of their investment in grid infrastructure. As many of these nations use small power plants with low efficiency that cost a lot to fuel, there is potential for using renewable energy to reduce fuel costs.

Electricity Market Trends in Japan

This section looks at the trends in the Japanese electricity market in terms of the long-term energy mix and the progress of the electricity reforms.

(1) Long-term outlook for energy supply and demand

Electric power and energy needs to be considered not only in economic terms, but from the “3E+S” perspective of energy security, economic efficiency, the environment, and safety. Accordingly, the Long-term Energy Supply and Demand Outlook published by the Ministry of Economy, Trade and Industry (METI) in July 2015 considered the mix of electric power sources in 2030 Japan shown in Fig. 2. Along with keeping demand for electric power equal to the level in FY2013 through comprehensive energy efficiency measures, achieving this and raising the level of energy self-reliance will require use of nuclear energy to provide base-load power equivalent to about 20% of the total, and an increase in renewable energy to between 13% and 15%, including the aggressive expansion in the use of geothermal, hydro, and biomass energy, which are reliable forms of power generation.

(2) Electricity market reforms

To facilitate progress in things like living standards and economic growth, post-war Japan placed top priority on the security of the electric power supply. This led to the establishment of an electricity market based on vertically integrated regional monopolies. This provided a steady return on investment in large power plants and served as a foundation for security of supply and economic growth.

(a) TSO
Abbreviation of “transmission system operator,” a company that owns and operates the ultra-high-voltage grid in a particular region.

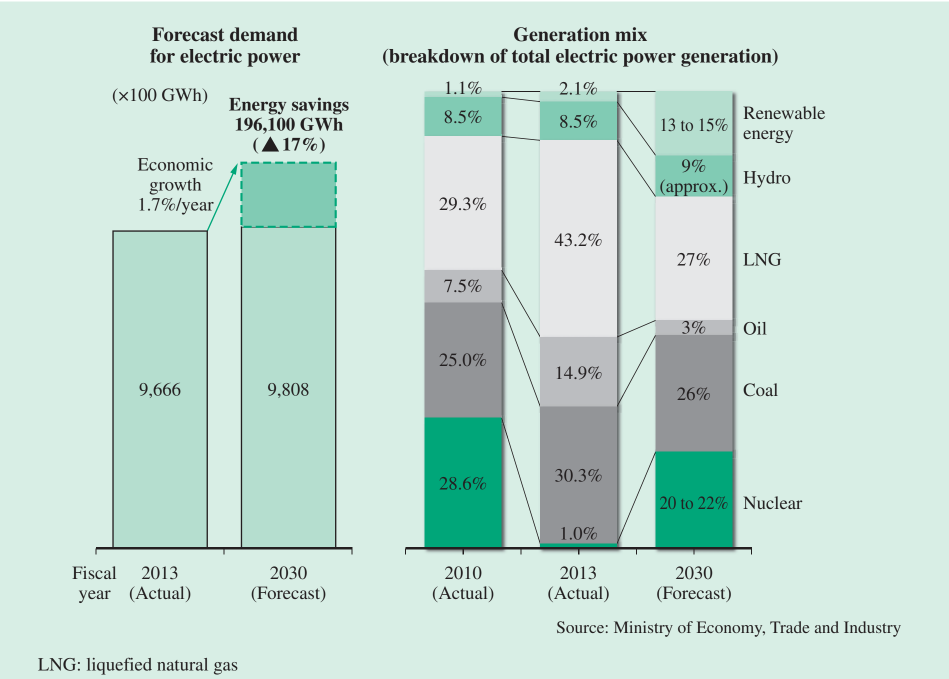


Fig. 2—Long-term Energy Supply and Demand Outlook.
Achieving these targets will require comprehensive measures for energy efficiency as well as a better ratio of energy supply and demand using nuclear and renewable energy.

Reflecting an international trend toward deregulation, however, the 1990s saw growing calls for liberalization from within Japan. The trend toward deregulation, which began in the 1990s with the freeing up of “special high-voltage electric power” retailing, still continues. Subsequent developments include the establishment of the Organization for Cross-regional Coordination of Transmission Operators, JAPAN (OCCTO) in 2015 to expand interconnection between regional grids, full liberalization of electricity retailing, including small consumers in 2016, and the planned legal separation of transmission network operators and abolition of retail price controls in 2020. These measures are being undertaken with aims that include ensuring security of supply, minimizing electricity prices, expanding options or use of electric power, and creating new business opportunities for companies.

In the future, this will accelerate entry into the electric power business by companies from other industries, not just the existing electric power companies, with participation being considered by, for example, gas companies and retailers as well as Internet, mobile phone, and other telecommunication companies. Along with the intensification of competition, this is expected to open up new business opportunities.

PLANS FOR HITACHI’S SOLUTION BUSINESS

Hitachi is a one-stop supplier of optimal solutions to the market for electric power systems, which is subject to the ongoing reforms described above. These solutions extend from generation to distribution and consumer systems. Hitachi is contributing to the establishment of reliable electricity systems by drawing on its accumulated technologies and knowledge to supply best solutions to power companies and new entrants to the electricity markets (known as power producers and suppliers), consumers, and various other stakeholders through collaborative creation with customers that encompasses the implementation and operation of transmission, distribution, and interconnection systems, renewable energy, management services for consumers, and systems for the full liberalization of electricity retailing (see Fig. 3).

SOLUTIONS FOR MARKET NEEDS

Because customer needs are becoming more diverse, as described above, there is a need for flexibility in the supply of solutions to these needs.

The following are some of the solutions supplied by Hitachi.

Ensuring Reliable Power Sources

As noted above, there is demand for increasing the supply of electric power, particularly in emerging nations.

It is anticipated that thermal power will remain the main form of generation. In this sector, Hitachi, Ltd. and Mitsubishi Heavy Industries, Ltd. established

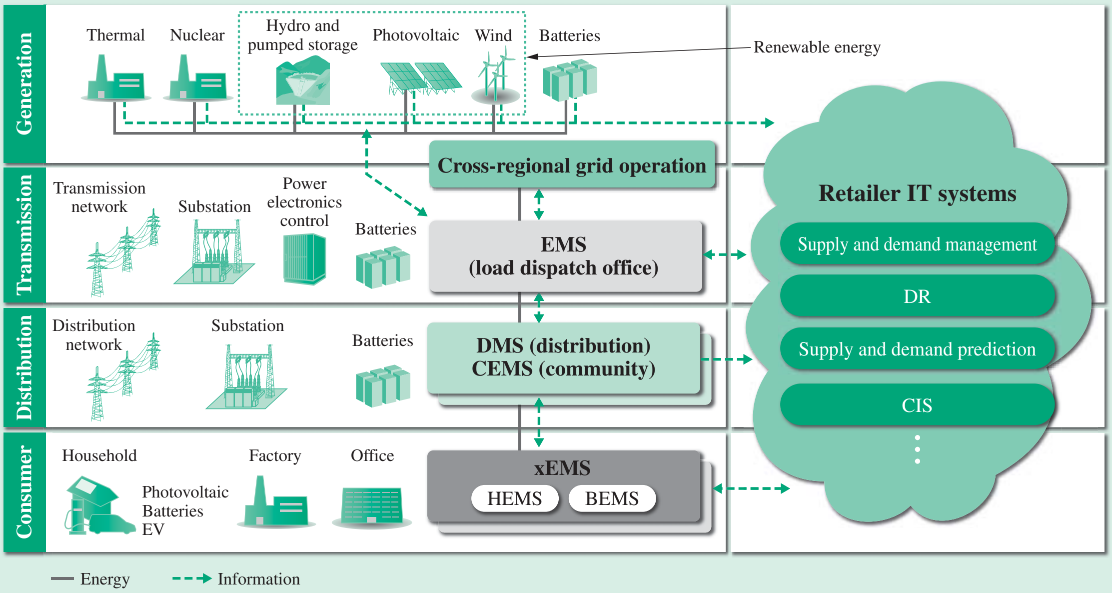


Fig. 3—Hitachi Electric Power and Energy Solutions.
Hitachi supplies total solutions that extend from generation to transmission, distribution, and retailer IT systems.

Mitsubishi Hitachi Power Systems, Ltd. as a joint venture in February 2014 with the aim of becoming a leading international supplier of thermal power plants, including by offering a wide range of gas turbine products, for example, that extends from the highly efficient large models that have been the focus of Mitsubishi Heavy Industries in the past to the small and medium-sized models in which Hitachi has specialized.

Similarly, in the nuclear power sector, Hitachi combined its commercial resources with US company General Electric Company (GE) in July 2007 to form Hitachi-GE Nuclear Energy, Ltd. As one of the few specialist nuclear power manufacturers in the world, Hitachi-GE Nuclear Energy builds nuclear power plants and supplies maintenance and services.

Reduction in Emission of Greenhouse Gases

Having been a subject of debate at international bodies, measures for dealing with global warming are in the process of becoming national obligations. In particular, reducing carbon emissions by forms of electric power generation that emit large amounts of greenhouse gases is a very significant problem for society. Hitachi is able to supply equipment for the generation of renewable energy that includes wind and photovoltaic power plants.

In the case of megasolar projects (large photovoltaic power plants), Hitachi handles engineering, procurement, and construction (EPC). Hitachi has an extensive involvement in a wide range of important equipment used in megasolar power generation systems, including operation monitoring and instrumentation systems as well as highly efficient power conditioning systems[(b)] (PCS) and amorphous transformers that consume low levels of electric power in standby mode.

Hitachi also produces wind turbines with a downwind configuration, meaning that the nacelle is on the upwind side of the blade. A feature of downwind rotors is that they can yaw freely during strong winds (the nacelle is not locked to prevent yaw rotation), meaning the nacelle will naturally orient itself into the wind and move in response to cross winds (which pose the greatest risk to wind turbines). As Japan has a lot of mountainous regions, wind turbines are often located on undulating ground such as hillsides where they are subject to the updrafts caused by the wind blowing across this uneven terrain. However, because the rotor plane of a downwind rotor is oriented downwards

(b) PCS
Abbreviation of "power conditioning system," meaning a device that converts the direct current (DC) power generated by a photovoltaic power system to the alternating current (AC) conventionally used by households and other consumers. PCSs are also used to convert the DC power from fuel cells and batteries.

relative to the upwind direction, they are able to deal with updrafts efficiently and can achieve higher generation efficiency than an upwind configuration.

Hitachi has a model with a maximum output of 2 MW for land and offshore sites, and a 5-MW model primarily for offshore use. The first 5-MW model was completed in March 2015 and Hitachi hopes to expand this business in the future.

Nuclear power is another form of generation that does not emit a large amount of greenhouse gases. The UK government in particular is pushing ahead with nuclear power with the aim of creating a low-carbon society, with Horizon Nuclear Power Limited being established in 2009 with the aim of constructing new nuclear power plants. Hitachi acquired Horizon in November 2012 and plans to build nuclear power plants in the 5,400-MW class or larger at Wylfa on the island of Anglesey, and Oldbury-on-Severn in South Gloucestershire. The intention is to construct the plants using technology from the advanced boiling water reactor (ABWR), the only third-generation nuclear reactor to enter commercial operation.

The construction project is currently at the stage of obtaining approvals from the UK government. One of the main approvals is the generic design assessment (GDA). The project has already completed the third of four steps in the GDA approval process, with the fourth step currently in progress. The nuclear power plant construction project will get underway once all approvals have been obtained.

Response to Electricity Reform and Retail Liberalization

The electricity reforms require a neutral agency that can operate the grid at a cross-regional level over and above the traditional electric power company territories. In Japan, this agency is the OCCTO, and Hitachi is currently working on the cross-regional operation system for which it was awarded the contract. The OCCTO handles the supply and demand monitoring required for electric power suppliers to operate across regional boundaries, and is responsible for issuing supply orders and other tasks associated with cross-regional coordination at times of tight supply such as during disasters. Hitachi will contribute to the reliable operation of cross-regional grids by drawing on its experience with systems for grid monitoring, grid stabilization, and power trading built up through its past work on supplying load dispatch offices (command centers), the power trading system for the Japan Electric Power Exchange, and other infrastructure.

Preliminary applications for registration as an electricity retailer (a requirement for participation in the electricity retail business) have already opened in anticipation of the full liberalization of electricity retailing in 2016. With a total of 40 companies having registered as of October 26, 2015, a large number of new entrants to the electricity retailing market are anticipated. As these new entrants require a variety of information technology (IT) systems, such as those for managing customer information, contracts, meter data, and supply and demand, this has the potential to pose a significant barrier to entry. Hitachi Systems Power Services, Ltd., a Hitachi group company, supplies IT systems able to be used under full liberalization of electricity retailing in the form of a cloud service. Use of a cloud-based service enables businesses to get up and running quickly with a smaller investment, while also providing flexible operation in accordance with factors such as the number of retail customers and the size of the operation.

Grid Stabilization Solutions

The rising environmental awareness referred to earlier has led to increasing use of wind, photovoltaic, and other forms of renewable energy. Unlike thermal power generation, the output of these forms of generation fluctuates due to factors outside human control, such as the weather. Electric power grids need to maintain a continuous balance between the supply and consumption of electric power, and the greater the proportion of variable power sources the more essential it is that this balance be maintained. One way to achieve this is through the use of batteries for energy storage.

Hitachi has developed the CrystEna container-type energy storage system shown in Fig. 4 and is participating in a demonstration project in the US market for frequency regulation.

PJM[(c)], the largest independent grid operator in the USA, operates a market for frequency regulation to provide short-term adjustments to the balance of supply and demand to deal with factors such as the widespread use of variable power sources. The market for frequency regulation in the region managed by PJM is open to participants with batteries or other energy storage systems who submit bids for supply and demand balancing. CrystEna combines lithium

(c) PJM
A regional transmission organization that covers 13 states in the US central east coast and mid-west. The name "PJM" stands for Pennsylvania, New Jersey, and Maryland.

PCS: power conditioning system

Fig. 4—CrystEna.
Providing an all-in-one package that includes the batteries, PCS, controller, and air conditioning minimizes the time and work required for installation.

ion batteries with a PCS, battery management system, cooling, and firefighting system in a 12-m container. Utilizing CrystEna in the demonstration project for the PJM frequency regulation market allows Hitachi to collect operational data and verify the performance of the battery system and its efficacy for grid stabilization.

Meanwhile, factors such as the installation of large amounts of renewable energy and the progress of the electricity reforms have led to a rising need for the cross-regional balancing of supply and demand. In Japan in particular, there is a growing demand for high-voltage direct current (HVDC) transmission systems due to factors such as the different frequencies used in the east and west of the country and the installation of large amounts of renewable energy.

Having participated in all previous HVDC projects in Japan, Hitachi established a joint venture in October 2015 with ABB, an international electrical and automation company, to work on HVDC projects in Japan. Through this joint venture, Hitachi intends to contribute to cross-regional grid interconnection in Japan by combining the project management capabilities and quality assurance it has built up through experience in Japan with the leading-edge HVDC technology of ABB.

Microgrids and Smart Energy Solutions

As already noted, factors such as the installation of large amounts of renewable energy capacity on the grid make its operation difficult. Two advanced measures for dealing with this are microgrids and smart energy practices.

Microgrids are small sub-grids that balance their own supply and demand for electric power without relying on the main grid, and either are not connected to the grid or are able to disconnect and continue operating in the event of an emergency. Hitachi can supply microgrids of many different types using power sources, energy management systems (EMSs), and other component parts.

The balancing of supply and demand is commonly done by controlling the power supply (generation). While it is easier for grid operators to only have to control a small number of generators, the large number of consumers makes it difficult to control demand. Accordingly, conventional grid operation keeps supply and demand in balance through control of thermal power plants with a rapid response, such as diesel generators or gas turbines.

However, advances in IT mean it is now possible to use demand-side control to balance supply and demand. The systems used for this purpose are called demand-side management (DSM) systems. DSM systems may be incentive-based, whereby consumers are paid incentives in accordance with the amount by which they reduce demand at such times as when grid operators find it difficult to balance supply and demand, or time-of-day pricing schemes that are designed to encourage consumers to reduce their peak demand voluntarily.

These smart energy solutions rely on equipment (such as power sources and distribution infrastructure) and on knowledge and expertise in both IT and control technology. By consolidating knowledge in these fields built up over many years, Hitachi intends to build and supply to customers a wide variety of smart energy solutions.

ADOPTION OF SOLUTION-BASED BUSINESS MODELS

To respond to the increasing diversity of societal needs resulting from changing trends in the electricity market, it is essential to establish solution-based business models that can adapt flexibly to customer requirements. Hitachi intends to combine IT with equipment manufacturing know-how built up over time to adopt solution-based business models and contribute to overcoming the challenges faced by society and customers.

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Featured Articles

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

Masahiro Ichinosawa
Toshiyuki Sawa, Dr. Eng.
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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

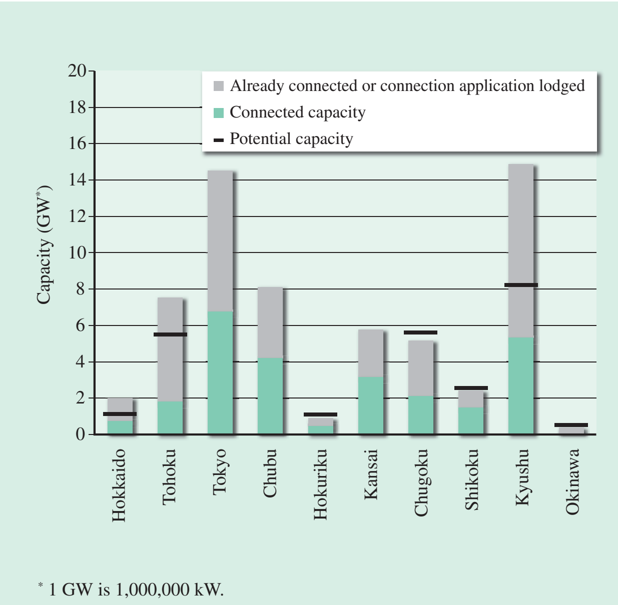

Fig. 1—Actual and Potential Connected Capacity of Photovoltaic Power Generation.
The graph shows the situation at the end of July 2015. No potential capacity has been specified for Tokyo, Chubu, and Kansai (prepared from documents of the New and Renewable Energy Subcommittee of the Committee on Energy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

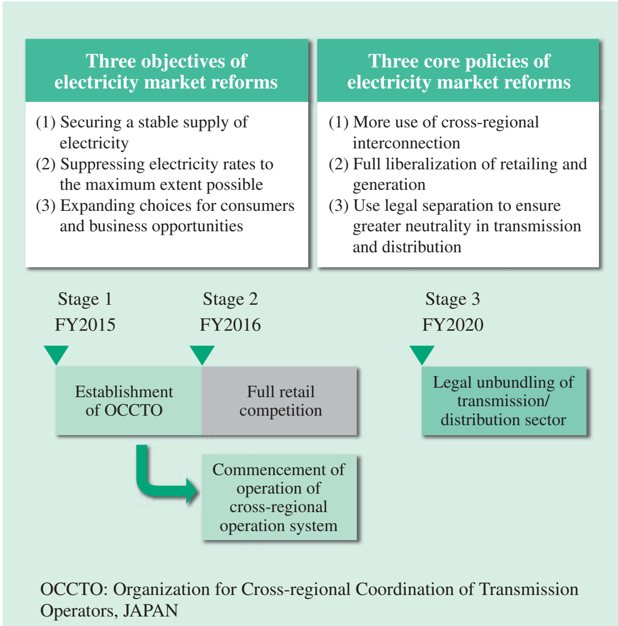

Fig. 2—Objectives and Process of Electricity Market Reforms.
Prepared from "Report of Expert Committee on the Electricity Systems Reform" published by the Agency for Natural Resources and Energy in February 2013[2].

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.

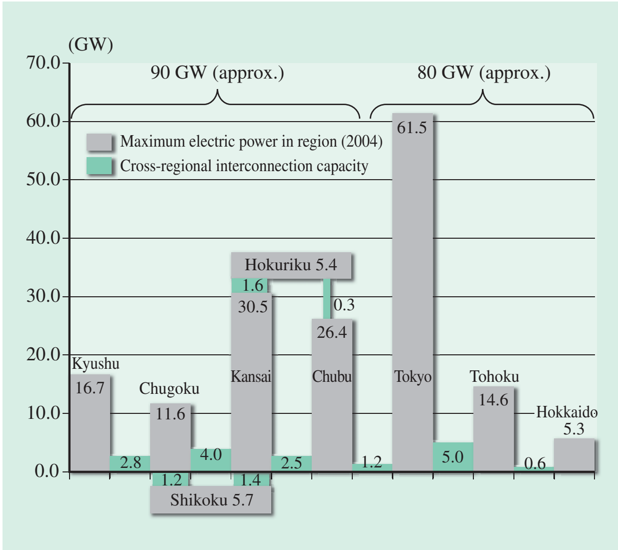

Fig. 4—Relationship between Maximum Electric Power in Each Region and Cross-regional Interconnection Capacity in 2004.
Prepared based on 2004 yearbook of The Federation of Electric Power Companies of Japan.

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.

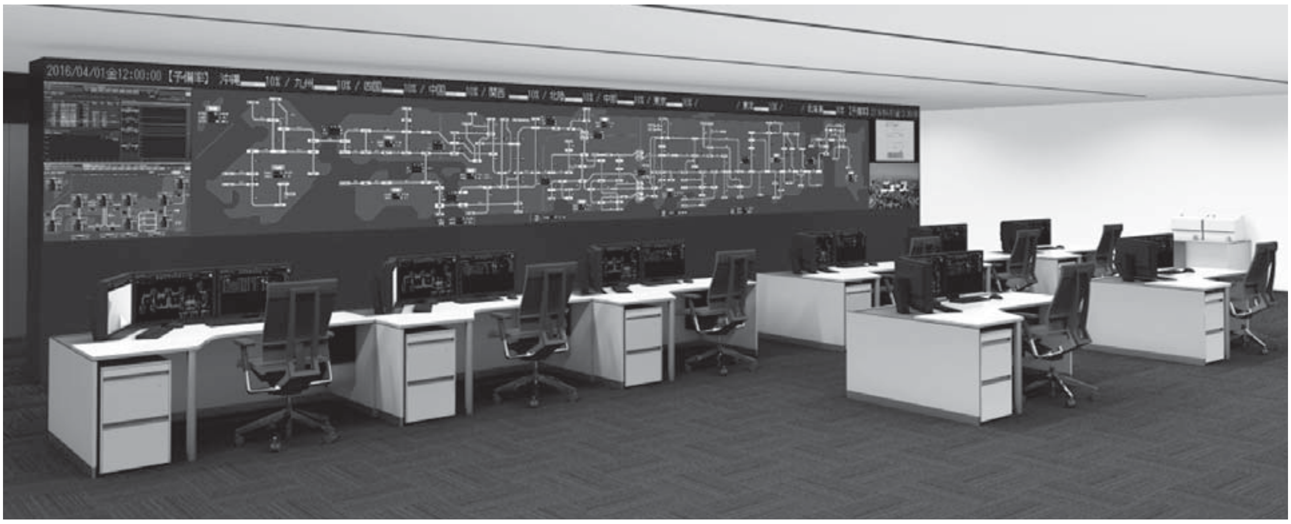

Fig. 5—Cross-regional Operation System Control Center (Artist's Impression of Completed Center).
This computer-generated image depicts the control center of the cross-regional operation system. The large screens in the center show a diagram of the national grid.

(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.

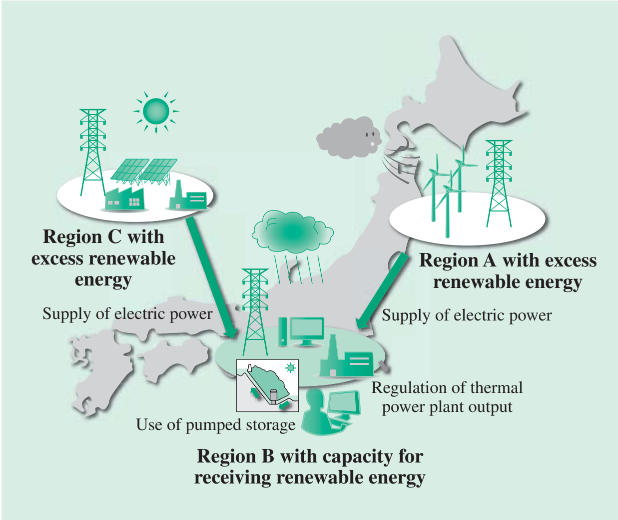

Fig. 6—Cross-regional Use of Grids in Preparation for Greater Use of Renewable Energy.
Prepared from "Establishment of Systems and Rules for Cross-regional Use of Grids in Preparation for Greater Use of Renewable Energy" published by the Agency for Natural Resources and Energy on April 14, 2015.

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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Featured Articles

Hitachi's IT Solution for Creating Value in a Competitive Market of Electricity System Reform/Full Liberalization of Retail Markets

Nobuhiro Gotoda
Ikuo Shigemori
Yoko Sakikubo
Tohru Watanabe
Kengo Uegaki

OVERVIEW: When the Amended Electricity Business Act (2nd Stage) goes into effect in April 2016, Japan will enter an era of full liberalization of the retail electric power market. When added to the recently opened 7.5 trillion-yen low-voltage sector, the revision in the law will create a 16 trillion-yen market into which many providers have announced their intention to enter. Drawing on technology and expertise accumulated over many years of providing solutions for power companies, Hitachi has recently developed a demand cluster analysis technology. It is also providing a supply-demand management solution that will enable electricity retailers to prevail in Japan's new competitive market.

INTRODUCTION

THE full liberalization of Japan's retail electric power market starting in April 2016 will liberalize the entire retail power market, including households and other low-voltage sector users. Many new providers have announced plans to use this opportunity to enter the electric power market, and power companies with previously limited sales areas have announced plans to expand into other areas.

Competition is expected to intensify, with providers also looking into new business strategies never before seen in Japan's power industry, such as sales of power packaged together with other products and services.

In the run-up to liberalization, low-voltage users have been able to apply to change (switch) providers

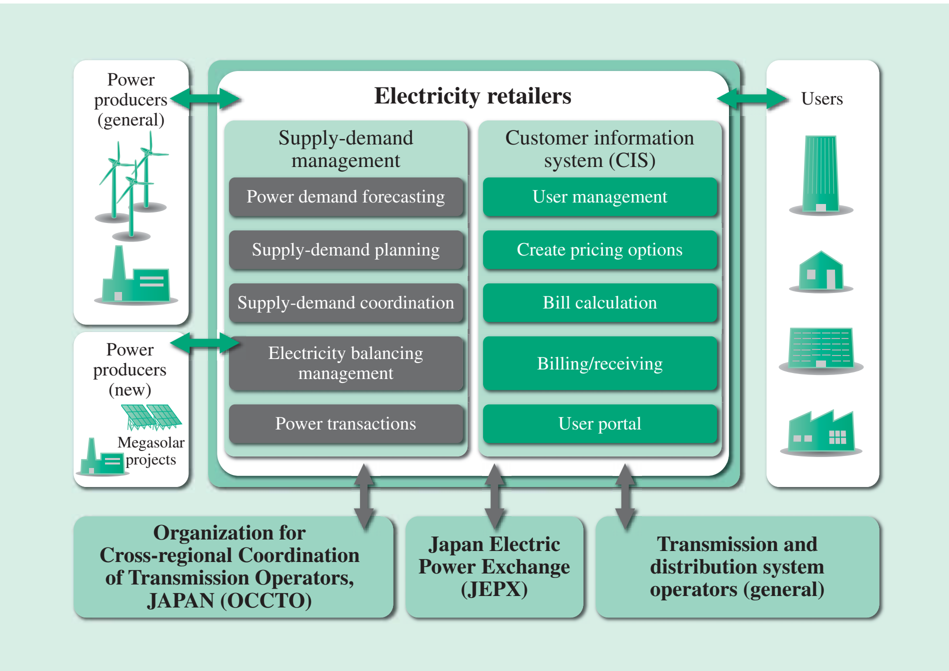

Fig. 1—Positioning of Electricity Retailers in Fully Liberalized Power Market.
In addition to acting as points of user contact for retail power operations, electricity retailers will need to partner with general transmission and distribution system operators and industry bodies such as OCCTO.

since January 2016, creating growing momentum with true competition among providers to expand user bases.

While providers are focusing their energies on sales and marketing activities, they are also being called on by the Japanese government to meet certain standards in order to be recognized as electricity retailers involved selling electric power. The obligations they need to fulfill will include supply-demand management tasks such as power procurement and electricity balancing, and user management tasks such as handling complaints and explaining the provisions of agreements to users.

Implementing more efficient operations will be a key goal for electricity retailers to attain. To meet it, they will need to partner with a large number of other providers such as transmission and distribution system operators, along with industry bodies such as the Organization for Cross-regional Coordination of Transmission Operators, JAPAN (OCCTO) and Japan Electric Power Exchange (JEPX) (see Fig. 1).

CHALLENGES FOR RETAILERS IN A COMPETITIVE MARKET

To outdo the competition, electricity retailers will need to meet their government-mandated obligations while implementing effective measures to grow profits. In the radically altered business environment to come, retailers will need to deal with the following two major challenges.

(1) Identifying user characteristics

Low-voltage customers can currently obtain a low-voltage power agreement just by providing basic information such as their name, address, and payment method. And, except in cases of delinquent accounts or similar problems, more detailed user information has not been of particular importance to retailers up to now. But the new providers will be starting out with small user bases, making it much more important for them to be able to identify types of users and power consumption figures than it is for existing power companies. An inability to identify these

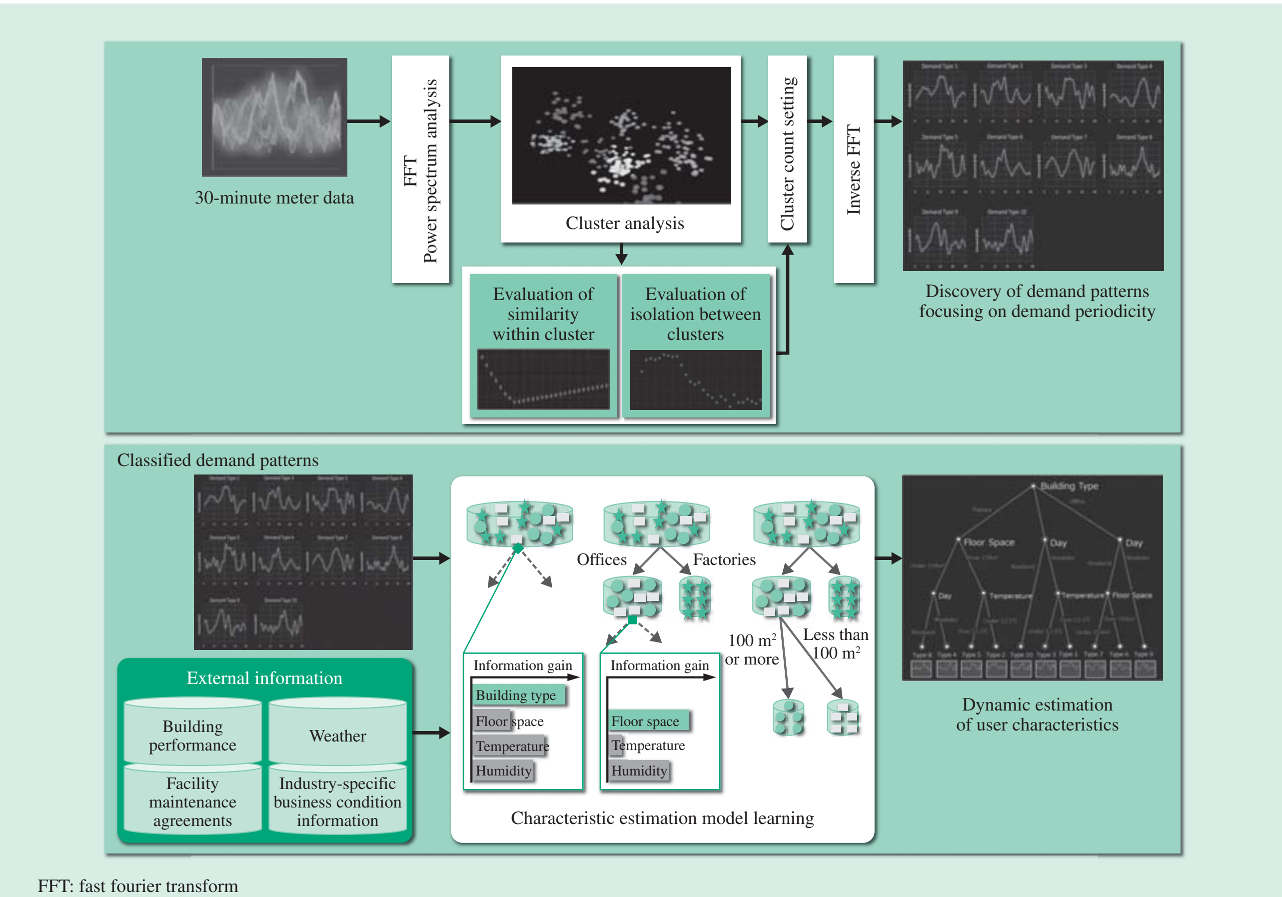

Fig. 2—Demand Cluster Analysis Technology.
The technology analyzes the power consumption (load curve) of large users in 30-minute increments, generates similar clusters from demand patterns, and performs profiling.

user characteristics will result in less precise power demand forecasting, making proper supply-demand management difficult, and sales and marketing activities such as creating pricing options tailored to user characteristics ineffective.

(2) Lack of smart meter data

Providers are installing 'smart meters' for low-voltage customers at a rapid pace throughout Japan. Smart meters can gather power consumption data in 30-minute increments, enabling past power consumption data to be used in supply-and-demand plans that require a 30-minute resolution, for more precise planning. But it will take several years before smart meters have been installed nationwide under the current schedule, and even when fully installed, a certain amount of missing data is expected from glitches such as communication problems. Technical challenges therefore remain. Without a sufficient store of past data, smart meters will not be a sufficiently effective tool for improving power demand forecasting precision in 30-minute increments or creating pricing options for different times of day.

TECHNOLOGY AND SOLUTION FOR OVERCOMING CHALLENGES

Demand analysis is a key tool for enabling providers to deal with the challenges currently facing them and to outdo their competitors. Hitachi has therefore developed demand cluster analysis technology and a supply-demand management solution that uses it. This technology is based on the idea that analysis that groups demand and models its characteristics is a more effective approach than using limited data to analyze radically varying demand as discrete data points.

Demand Cluster Analysis Technology

Demand cluster analysis technology is used to analyze demand trends to enable precise power demand forecasting, optimum power procurement, and more effective sales and marketing activities (see Fig. 2).

By transforming past demand data into data in a feature space, features can be found from demand data samples without limiting the time scale to a particular scale such as minutes or months, and clusters can be generated from data with similar features. Using multiple information criteria to set the number of dimensions and number of clusters in the feature space enables the acquisition of good-quality demand patterns with ample ability to express demand features. Information criteria are used to evaluate the isolation between clusters, the similarity of the data within a cluster, and frequential features. Demand features are extracted from generated clusters to identify demand patterns. By tagging demand patterns with attributes of samples belonging to clusters as external information, the major factors generated by demand patterns can be analyzed, and demand patterns can be identified for users outside the gathered sample data using simple analysis from external information.

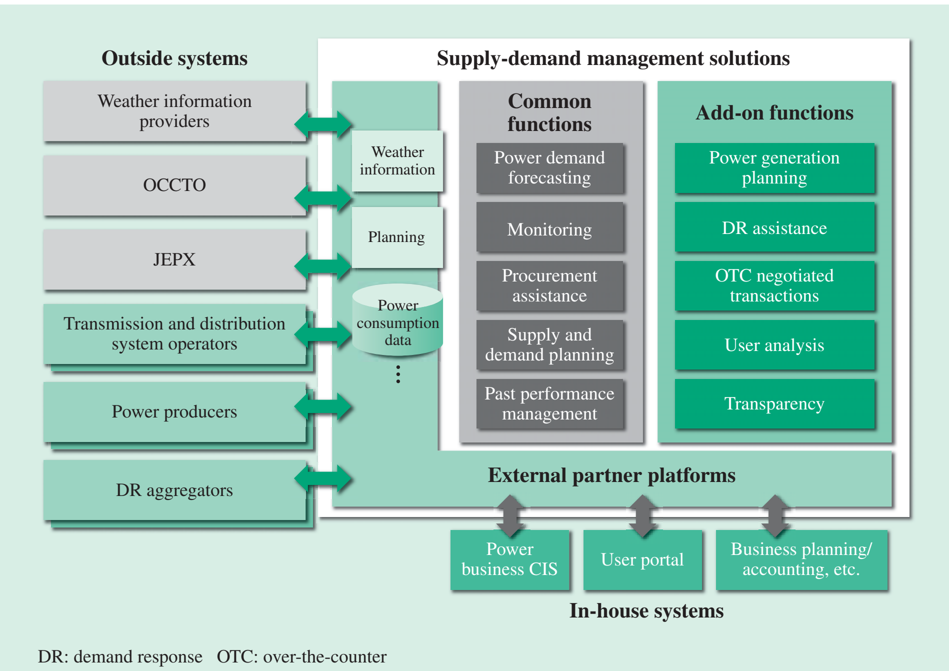

Fig. 3—Hitachi's Supply-demand Management Solution.
The solution provides the functions electricity retailers will need to start business in April 2016, and assists in the startup process. By adding functions needed for future system reforms and partnering with existing systems it ensures flexible expandability.

One of the obligations of electricity retailers is to ensure that the amount of power they have available for sale is equal to the total amount consumed by their users. Under the new system, providers will be required to avoid imbalances between demand and supply by precisely forecasting the amount of demand up to one hour in advance. Forecasting precision can be improved by creating a forecasting model from demand clusters with different demand patterns.

Supply-demand Management Solution

Hitachi has used demand cluster analysis technology to develop a supply-demand management solution (see Fig. 3). Power demand forecasting is the most difficult task among the supply-demand management tasks, and a task that greatly affects business. Hitachi's supply-demand management solution supports multiple power demand forecasting methods, which can be combined to enable power demand forecasting that is tailored to the characteristics of a provider's users.

For example, the demand cluster analysis technology described in the section above can be used to classify users and to apply a combination of suitable forecasting methods such as multiple regression analysis and time-series analysis to each demand cluster, achieving more finely tuned power demand forecasting.

The power demand forecasting method used is determined by the timing of the forecast (such as one year or one hour beforehand), and by factors in the business environment such as the electricity retailer's number of users or rate of smart meter installation. The approach to power supply and demand forecasting must therefore be varied to fit the situation. Table 1 lists the forecasting methods used by Hitachi's solution. Fig. 4 shows example applications of power demand forecasting methods.

Multiple regression analysis is a method of power demand forecasting that uses empirically set explanatory variables to perform analysis, and is widely used for estimating daily maximum temperatures and maximum demand quantities. It will be used when the full liberalization of the retail power market starts in April 2016, at which time the rate of smart meter installation will be low and there will be little numerical data in 30-minute increments. As more smart meters are subsequently installed and user data accumulates, it will become possible to use the demand cluster analysis described in the section above to make forecasts by extracting and classifying data from similar days.

Once the infrastructure has reached the point where it is possible to gather a large quantity of fresh 30-minute increment data, it will then be possible to use time-series data observed in the previous hour in short-term daily or hourly forecasts, enabling forecasts to account for demand fluctuation processes such as classified demand patterns and attribute information.

TABLE 1. Power Demand Forecasting Methods Available with Hitachi's Solution
Hitachi's solution provides the following power demand forecasting methods, each using its own past performance data or prior investigation approach.

No.	Method	Features
1	Multiple regression analysis	Forecasts using multiple regression model with explanatory variables such as temperature
2	Similar day analysis	Performs cluster analysis of representative days/users from measured demand quantities (meter data), and forecasts in combination with various forecasting methods
3	Time-series analysis	Forecasts future demand (such as demand one hour in the future) from time-series data created from observations of demand quantities over time

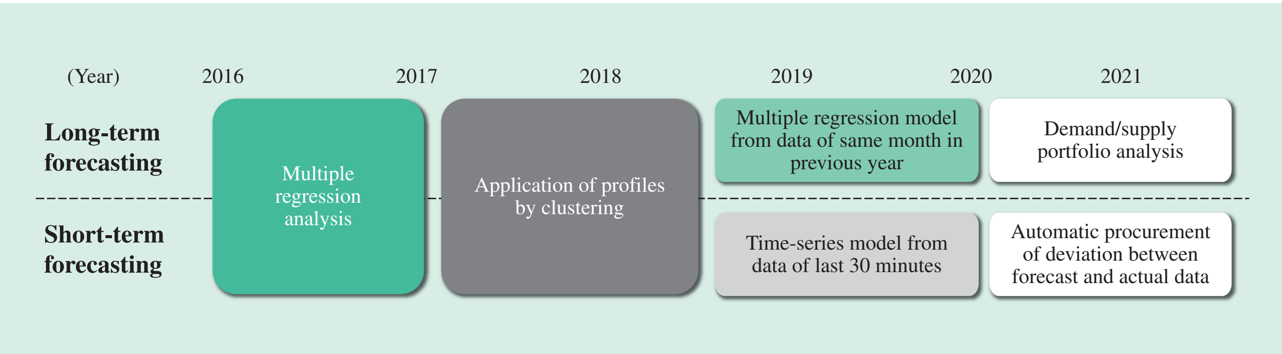

Fig. 4—Example Applications of Power Demand Forecasting Methods.
As the smart meter installation rate and number of users increase in the future, providers will need to use optimal combinations of multiple forecasting methods.

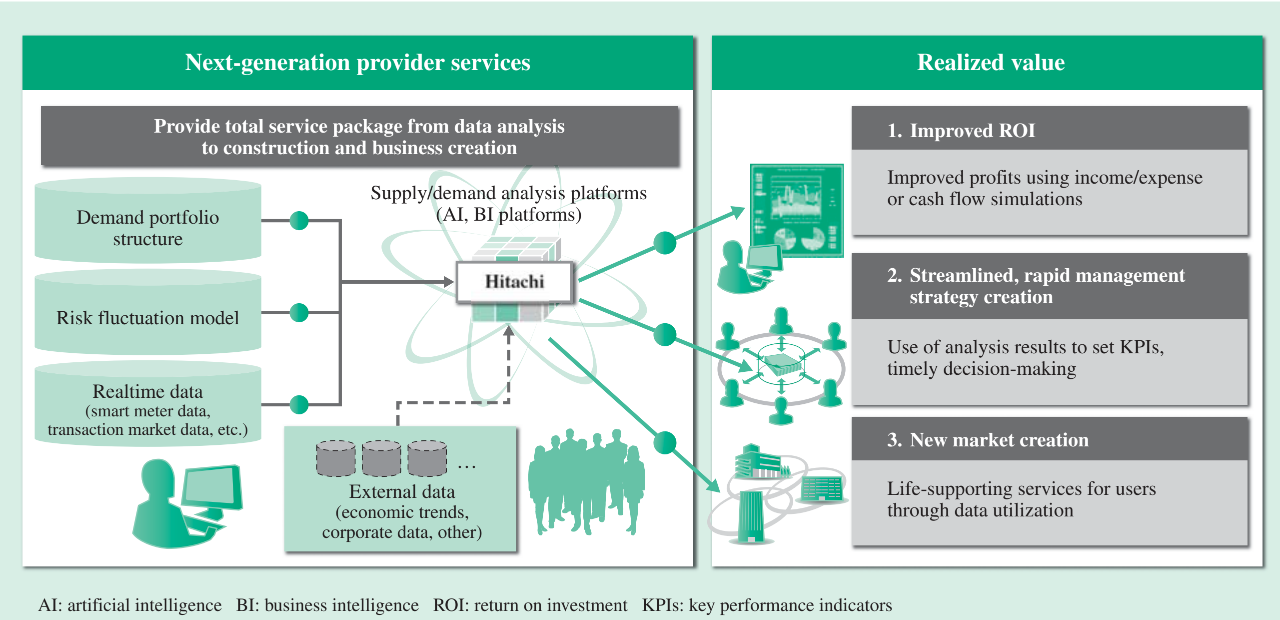

Fig. 5—Next-generation Provider Services Enabled by Large Data Volumes, and Their Value.
In addition to improving ROI, next-generation provider services also pave the way for new user services and innovative management methods by using a variety of connected information to examine complex relationships among stakeholders, and complex correlations.

Effective sales and marketing activities such as pricing options optimized to the characteristics of individual users will be another important challenge in the future, along with improving power demand forecasting precision. Since the demand cluster analysis technology Hitachi has developed will make it possible to identify user characteristics, its use in supply-demand management solutions make it a useful tool for sales and marketing activities.

CONCLUSIONS

This article has described Hitachi's demand cluster analysis technology and its applications. The technology has been designed to promote business success among electricity retailers. As the data-gathering infrastructure becomes more highly developed in the future, this technology should not only help improve forecasting precision, but also boost the effectiveness of marketing activities.

Hitachi plans to analyze massive quantities of data in a wide range of fields in the future to help find ways of improving corporate return on investment (ROI), possibly by drawing on the use of next-generation technologies such as artificial intelligence (AI). It is also looking for ways to assist management strategy proposals in a streamlined and rapid manner, and to help create new markets that cross traditional power market boundaries (see Fig. 5). More than just a provider of individual technologies and solutions, Hitachi is a provider of total service packages for maximizing technology-created value and a leader in Social Innovation.

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Featured Articles

Power System Stabilization Solutions in North America and Future Outlook

Hiroo Horii, P.E.Jp
Nao Saito
Atsushi Honzawa
Kenichirou Beppu
Kenji Takeda
Yutaka Kokai, Ph.D.

OVERVIEW: In recent years the power industry in North America has been characterized by an aging infrastructure of electric power transmission and distribution, with incentives for the development of renewable energy. The electric power exchange market has also become revitalized, giving rise to a variety of challenges for power system operation. In response to these challenges, industry observers have called for system reforms to the electric power exchange market, with regulatory agencies imposing tougher measures on transmission operators to improve electric power system reliability. This article discusses the technologies needed for power system operation in an environment of system reform and stricter regulations. It describes the work being done on power system stabilization solutions technology in the form of electrical energy storage systems for ancillary services and protection and control systems of wide-area power systems. Also discussed is how the creation of these technologies will affect the unbundling of Japan's power generation and transmission businesses (scheduled for 2020), and changes to its energy mix.

INTRODUCTION

LARGE amounts of renewable energy from sources such as photovoltaic power generation and wind power generation are recently being introduced worldwide. Since renewable energy output varies with the weather conditions, it has a large impact on power system stability. Focusing on the leading-edge initiatives underway in North America, this article describes power system stabilization solutions technology and the results it has demonstrated as well as the future outlook for this technology.

POWER ENVIRONMENT AND CHALLENGES IN NORTH AMERICA

North America is ahead of Japan in unbundling its power generation and transmission businesses and introducing renewable energy, and the initiatives being undertaken there are leading the way for the rest of the world.

A report by the U.S. Department of Energy entitled Wind Vision[1] suggests that the penetration of wind power generation could account for 35% of all the energy generated in the US by 2050. However, California has a high rate of photovoltaic power generation, and the guidelines set forth in its Renewables Portfolio Standard[2] call for renewable energy to provide 33% of the state's power demand by 2020.

The large amount of photovoltaic power generation in California has been shown to result in a phenomenon called a 'duck curve,' which is characterized by a rise in photovoltaic power generation during the day, with an apparent decline in power demand. Since renewable energy output is prone to fluctuation, power system stabilization is a problem that needs to be addressed.

One approach to power system stabilization has been the creation of ancillary markets aimed at balancing power supply and demand.

Along with the rise in renewable energy, North America is also grappling with the problem of its aging infrastructure of electric power transmission and distribution. As seen in the example of Hurricane Sandy in 2012, large-scale damage from weather anomalies is also on the rise. In response to the increase in blackouts caused by the aging infrastructure of electric power transmission and distribution and weather anomalies, a growing number of stability control systems such as Remedial Action Schemes

(RAS) are being introduced to prevent large blackouts in wide-area power systems.

In this way, North America is undertaking many leading-edge initiatives with respect to its infrastructure of electric power transmission and distribution. The rest of this article discusses the work that Hitachi is doing on power system stabilization solutions in North America.

ANCILLARY MARKET TRENDS AND WORK ON ELECTRICAL ENERGY STORAGE SYSTEM

Ancillary Market Trends in North America

Power grids aim for frequency stabilization by balancing power supply and demand. A system has been created in North America for coordinating the balance of supply and demand in the form of ancillary services that enable regional system operators to engage in market transactions to procure power. In addition, regulations enacted in October 2010 create incentives by mandating high-priced purchases of power provided by service providers who respond precisely to the command values of system operators. The result has been a growing demand for electrical energy storage systems that enable high-speed response. Electrical energy storage systems with a total capacity numbering in the tens of megawatts were rapidly introduced in 2015.

CrystEna Electrical Energy Storage System and Pilot Project Results

Hitachi has developed an electrical energy storage system called CrystEna (a combination of the words ‘crystal’ and ‘energy’) designed to enable stable power use while maintaining the balance of power supply and demand. It is being introduced to markets in Japan and around the world as one of Hitachi’s solutions businesses.

Developed for the ancillary services market, CrystEna (a 1-MW shipping container-type electrical energy storage system) is a comprehensive package that includes components such as a power conditioning system (PCS), lithium ion battery, and control system mounted in a standard 40 ft-class shipping container (see Fig. 1). CrystEna has been designed to easily handle large-capacity systems by using a package mounting with a single shipping container system configuration along with standardized specifications enabling expansion to a large-capacity system configuration comprising multiple shipping containers[3].

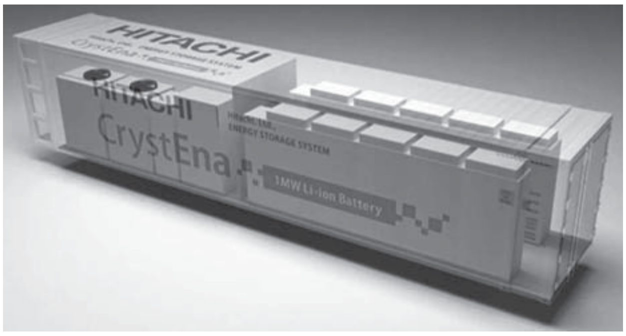

Fig. 1—External Appearance of Shipping Container-type Package.
Components such as a power conditioning system (PCS), lithium ion battery, and control equipment are mounted in a standard 40-ft-class shipping container.

Life management is usually an important requirement for storage batteries since performance drops as the battery is charged and discharged. In conjunction with the development of the CrystEna system, Hitachi has therefore also developed an operational control simulator that estimates CrystEna’s operation performance. Fig. 2 shows how the simulator works. As storage batteries degrade, their performance in areas such as capacity and internal resistance is affected by the voltage, current, and temperature they are used with. For that reason, Hitachi has created a method of predicting battery life under various usage conditions with a high degree of precision, by applying multivariate analysis to the degradation factors for the lithium ion batteries used in containers. The operational control simulator comes with four functions, which are used to (1) set operation strategy by analyzing

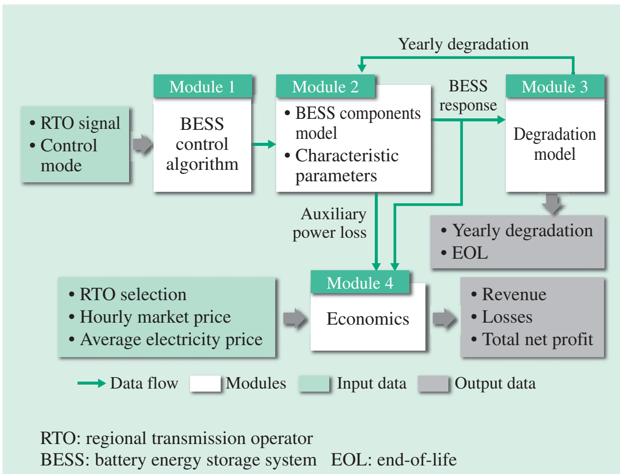

Fig. 2—Operational Control Simulator.
A lithium ion battery degradation model enables estimation of operating revenue when a battery reaches the end of its operating life.

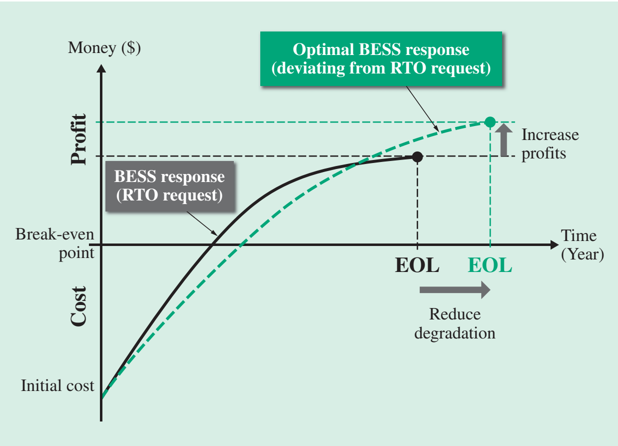

Fig. 3—Illustration of Revenue Maximization by Extending Battery Life.
Moderating storage battery operation can be expected to extend battery life and increase revenue over the lifetime of the battery.

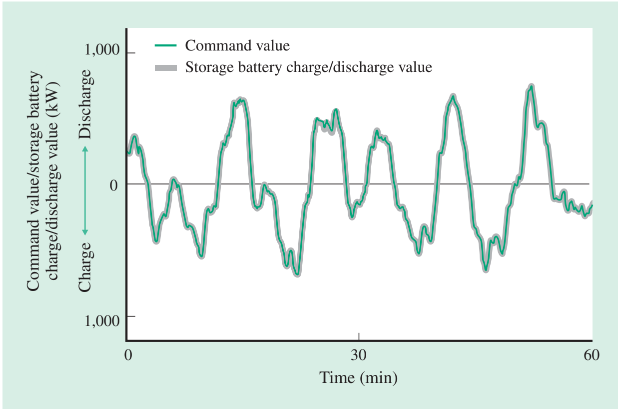

Fig. 4—Electrical Energy Storage System Response to Command Values.
The system responds to system operator commands without delays.

the command values sent from the system operator, (2) select PCS and storage battery combinations, (3) estimate degradation using lifetime prediction, and (4) calculate revenue using market parameters.

The operational control simulator's lifetime prediction function can evaluate operation in terms of the risk to revenue posed by time degradation. It can also suggest operation methods that can extend storage battery life while maintaining the tracking ability to conform to system operator command values, ensuring optimal system configuration proposals in line with the return on investment of various businesses.

Fig. 3 shows how revenue is maximized by increasing storage battery life, comparing the revenues resulting from two operation methods. The first method is a simple response method in which the batteries are charged and discharged in conformance with system operator commands without considering storage battery life. The second method is an output optimization method in which the charge/discharge output is adjusted to account for storage battery life, while still maintaining conformance to command values. By using the output optimization method, storage battery life is extended, and the electrical energy storage system can be operated for a longer period, which increases the amount of total revenue that is ultimately obtained.

In February 2015, Hitachi started a CrystEna pilot project in the US ancillary market. Actual power transactions were used to evaluate the storage system's performance, demonstrate its reliability and effectiveness, and verify its ability to respond well to command values (see Fig. 4).

PROTECTION AND CONTROL SYSTEM OF WIDE-AREA POWER SYSTEM (RAS) OVERVIEW AND FUTURE OUTLOOK

This chapter discusses the challenges facing the US power transmission industry and provides an overview of an R&D project undertaken by Hitachi and the Bonneville Power Administration (BPA) to find solutions for these challenges.

Challenges Facing Power Transmission Industry in North America and How RAS Addresses Them

With blackouts on the rise in North America due to problems such as the aging infrastructure of electric power transmission and distribution and natural disasters, there is a demand for the prevention of large blackouts. The increase of renewable energy is also causing imbalances between supply and demand and inducing voltage fluctuations, making transmission grid operation more complex. Investment in power system analysis is expanding and there is a need for technology to effectively maximize existing facility performance. Other problems facing the industry include operation restrictions that reduce the output of renewable energy. Fig. 5 illustrates the challenges facing the power transmission industry.

Work on grid stabilization technology is being done around the world, with advances in power electronics such as static var compensators (SVCs) and high-voltage direct current (HVDC) and the standardization of substation equipment such as phasor measurement units (PMUs) and intelligent electronic devices (IEDs). But development of technology that can

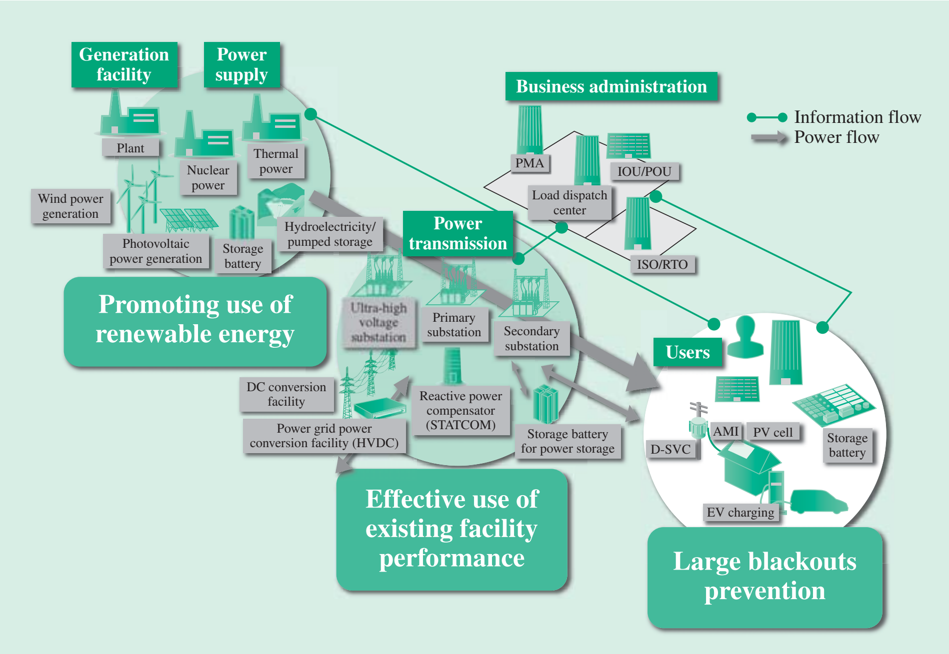

Fig. 5—Challenges Facing Power Transmission Industry.
Various challenges need to be resolved to provide a stable power supply.

provide comprehensive control of these components to enable optimal operation is lagging. Therefore the development of RAS that provide integrated stability control systems for wide-area grids is necessary. RAS is a scheme that automatically performs the correct operation (set beforehand) to maintain the operation standards of the North American Electric Reliability Corporation (NERC) when a predefined failure precursor is detected.

R&D Project with BPA in North America: Overview and Future Outlook

Headquartered in Portland, Oregon, BPA is a nonprofit power system operating body under the control of the U.S. Department of Energy (DOE). BPA currently uses an RAS for grid stabilization.

BPA currently employs an off-line RAS, which gathers offline data before grid faults occur. When the RAS is operated, power system analysis using offline data is performed and the generator shedding amount is calculated under preset conditions.

With the support of BPA, Hitachi is developing an on-line RAS in an R&D project that implements a control function with online data, aiming to optimize the generator shedding amount. Through this project, Hitachi is planning to develop an on-line RAS prototype system that uses actual online grid data to calculate grid protection countermeasures in realtime and to demonstrate its feasibility and benefits in the future. Specifically, by performing parallel computing processing using multiple computers, Hitachi plans to propose and evaluate optimal countermeasures for phenomena such as transmission line overloading, abnormal bus voltages, and generator step-out that occurs when grid faults take place, covering the entire grid area from Canada to the western US. Table 1 lists

TABLE 1. Challenges Facing Power Transmission Industry and How Hitachi's On-line RAS Addresses Them
Hitachi's on-line RAS is solving challenges, to help stabilize power grids.

No.	Challenge	Response
1	Preventing large blackouts	• Detect signs of abnormalities, provide decision support for countermeasures using knowledge gathered in the past and prevent faults • Create wide-area protection and control schemes to localize effects of accidents
2	Making effective use of existing facility performance	• Maximize the performance of existing facilities by operating them at the total transfer capability of the power grid system in its present state instead of at a predefined total transfer capability • Support system operator decision-making that achieves both system stability and cost-effective operation
3	Promoting use of renewable energy	• Precisely identify and reduce operational risks associated with increase of renewable energy interconnection • Address the output fluctuations of renewable energy by making effective use of spinning reserve other than renewable energy

RAS: remedial action scheme

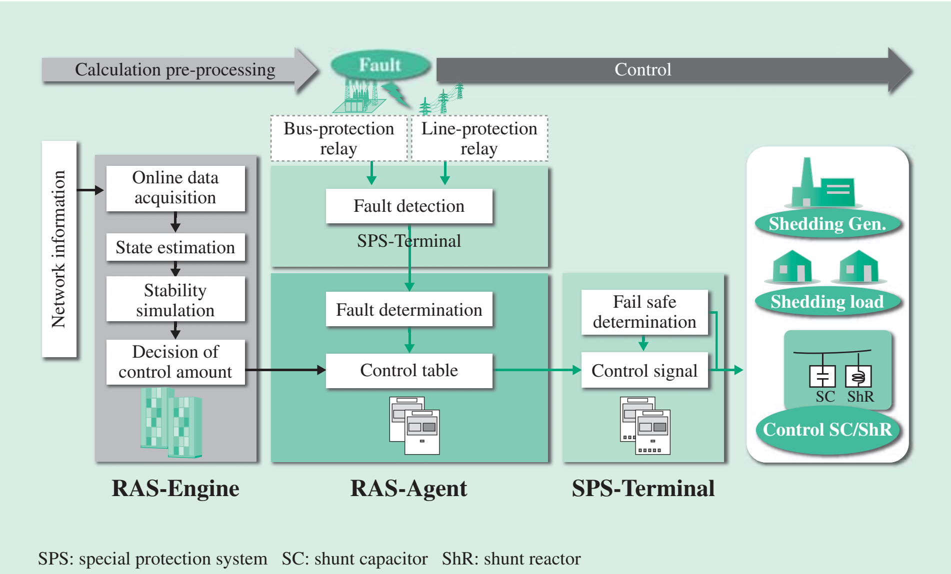

Fig. 6—On-line RAS Control Flow.
Hitachi's on-line RAS has a three-stage configuration for pre-event calculation and post-event control.

the challenges facing the power transmission industry and how Hitachi's on-line RAS addresses them. Fig. 6 illustrates the control flow of the on-line RAS.

CONTRIBUTIONS TO JAPAN'S ELECTRIC POWER INDUSTRY AND FUTURE OUTLOOK

With an increasing share of renewable energy and the upcoming unbundling of the power generation and transmission businesses, Japan's electric power industry is facing a changing environment. The US is ahead of Japan in the use of renewable energy and unbundling, and the work being done by Hitachi as described in this article could be applied to Japan in the future. For example, if wide-area coordination of power grids advances in the future, the knowledge gained from Hitachi's experience supported by BPA could be used to provide solutions that will help stabilize Japan's power grids. Similarly, knowledge gained from projects using electrical energy storage system in the North American ancillary market could be applied to solutions driven by electrical energy storage system designed to reduce sudden output fluctuations from the growing use of renewable energy in Japan.

CONCLUSIONS

This article discussed the work Hitachi is doing on grid stabilization in North America. These efforts will be expanded from North America to Japan and other countries in the future as it works on activities designed to help power system stabilization on a global scale.

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Featured Articles

Overseas Involvement in Smart Energy Solutions

Akira Honma
Takeshi Suzuki
Takayoshi Nishiyama
Isao Kume
Makoto Aikawa

OVERVIEW: Full deregulation of the supply of electric power to households commences in Japan from April 2016. Countries like the UK and Germany deregulated their retail markets in the 1990s, and more than 20 US states have done likewise (this being a decision that is left up each state in the USA). The UK is also pursuing CO_2 emission reductions in the household sector, recognizing the potential for smart energy practices. This article profiles work by Hitachi in leading overseas markets that takes account of local conditions and involves collaboration with local companies and regional governments together with the adoption of common strategies, and describes the IT systems that underpin this work.

INTRODUCTION

SHARING a common cause with the New Energy and Industrial Technology Development Organization (NEDO), and in preparation for the comprehensive liberalization of the retail electricity market in Japan in April 2016, Hitachi is conducting smart energy trials in Europe and North America (where market liberalization has already taken place) that use control technologies for aggregating electric vehicles (EVs) and batteries installed in the home so that they can operate as if they are a single power plant, and use information technology (IT) for systems such as those for coordinating supply and demand that control the operation of heat pumps and other electrical appliances during periods of peak demand. Hitachi is also participating in the provision of high-added-value services for electric power distributors in North America that combine IT and operational technology (OT).

These leading overseas markets are also home to customers who are seeking to move quickly from demonstration projects to full-scale systems.

This article presents examples of Hitachi's overseas activities and describes the Intelligent Operations Suite of IT for expediting their implementation in response to diverse customer challenges and other requirements.

MARKET DEVELOPMENTS IN THE UK AND HITACHI'S ACTIVITIES

Market Developments in the UK

The UK has set a target of reducing carbon dioxide (CO_2) emissions by 34% relative to 1990 by 2020, and reducing them by 80% by 2050. This will require a major reduction in emissions by the electricity and building sectors in particular. The expectation for the electricity sector is that these reductions will be achieved through a combination of nuclear power and fossil fuel power generation with carbon capture and storage (CCS). In the building sector, the focus is on households as well as commercial facilities. The UK has a high demand for heating during winter, with space and water heating accounting for as much as 80% of household energy consumption. It is anticipated that the use of heat pumps and other electrical appliances will reduce CO_2 emissions and these will become the predominant form of heating systems in the future. The use of electrical appliances is not without problems, however. The UK is exposed to a prevailing westerly wind that can bring sudden changes in air temperature, meaning that using electric power to meet the full heating demand during peak cold periods will require a large investment in additional generation and distribution capacity and other infrastructure solely to cover this peak. It will also increase the risk of power outages caused by the sudden loads imposed on aging distribution networks by higher peaks in the demand for electric power or greater use of renewable energy. Overcoming this requires mechanisms and technologies for improving security of supply that control the use of electric power on the supply-side and demand-side, including demand response (DR) and demand-side management (DSM).

Involvement in NEDO Demonstration Project in UK

Under contract to NEDO, a demonstration project in Greater Manchester that combines technologies from Hitachi and Daikin Industries, Ltd. is planned to run from April 2014 to February 2017. The aim of the project is to trial technologies and systems that will help the UK to become a low-carbon society, using Hitachi information and communication technology (ICT) platform and aggregation system technologies and Daikin heat pump and water heating technologies. The project involves replacing gas water heating used for heating public housing with heat pump systems and installing an aggregation system to control the individual heat pumps. Along with adjusting power use by each household, the trial is evaluating the ability to balance supply and demand for small-scale consumers by coordinating these adjustments. It is also evaluating the potential for using aggregation to implement DR without compromising comfort by assessing the extent to which adjustments to power use affect residents, utilizing in-home heat retention together with the hot water tanks installed along with the heat pump systems (see Fig. 1).

In addition to evaluating the effectiveness of Hitachi's ICT platform and household aggregation functions, the project also aims to extend the scope of control by the aggregation function to include large premises such as commercial or industrial facilities, and expand its application to other locations that have a similar climate to the UK and where the same model will be applicable.

A feature of Hitachi's technology used in the project is that the ICT platform consolidates the technologies and services needed to engage in trading on the UK electricity market, combining the distributed power supply to several hundred homes into a bundle large enough to trade on the market. As an aggregation technology, it identifies which orders for the sale or purchase of electric power from aggregators dealing in electricity trading can be accepted and which are most profitable, and calculates and orders trades so that trades do not go unexecuted. It calculates the

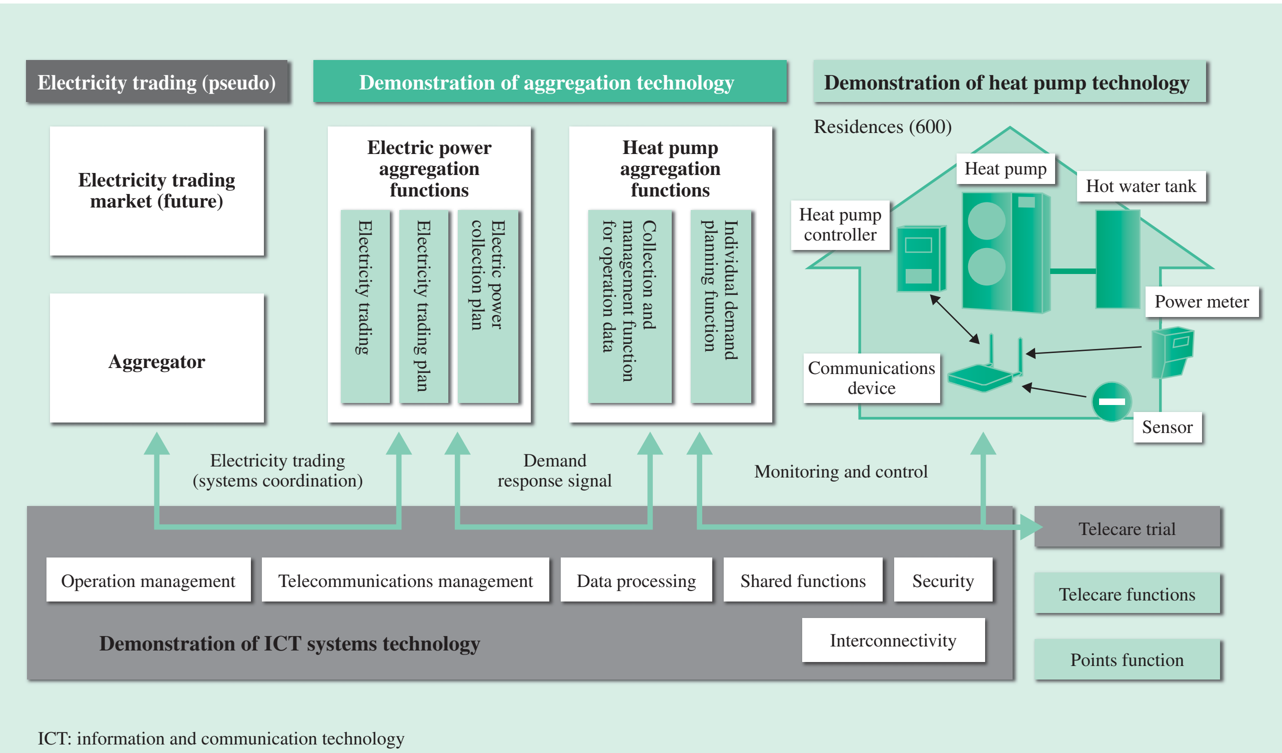

Fig. 1—Block Diagram of UK Demonstration System.
The figure shows an overview of the system to be trialed in Manchester in the UK and its functions.

optimal amount by which to cut consumption based on the future price of electric power. It collects data from the electricity meters installed in each household to implement optimal DR in accordance with the current situation and past performance.

For the ICT platform, technology that is able to provide simple and secure communications with other companies' aggregation systems was reviewed and selected. Communication equipment was also given encryption capabilities in recognition of the potential for data from sensors installed in people's homes to be accessed by third parties.

MARKET DEVELOPMENTS IN THE USA AND HITACHI'S ACTIVITIES

Market Developments in the USA

Investment in power distribution infrastructure in the US market reached 20.8 billion dollars in 2013. It is also anticipated that North American utilities will continue to increase expenditures on both capital (capex) and operation and maintenance for electric power distribution.

This is because power distribution in North America experienced growth in suburban housing driven by population increases in the 1960s and 1970s, together with the installation of distribution infrastructure with a large capacity and geographical scope based on the industrial policy of the time, meaning that this extensive and high-capacity infrastructure is now reaching the end of its life. Furthermore, the maintenance staff recruited to maintain all of this distribution infrastructure when it was first installed is now approaching retirement. This distribution equipment was installed at high cost, and measures for dealing with aging infrastructure are also needed so that it can withstand natural disasters such as the frequent tornados that have been occurring recently as a result of climate change.

Meanwhile, along with interest in installing more renewable energy to diversify the energy supply, reducing CO_2 emissions, introducing EVs and other next-generation vehicles, and encouraging energy savings through more efficient use prompted by rising awareness of global environmental problems, progress is being made on the installation and operation of new distribution systems (commonly referred to as smart grids) in accordance with recent industrial promotion measures. As a result, distribution systems are becoming more diverse and there is a need to establish new maintenance and management practices.

Involvement in NEDO Demonstration Project in Maui

Under contract to NEDO, Hitachi, Ltd., Cyber Defense Institute, Inc., and Mizuho Bank, Ltd. are jointly participating in the Japan-U.S. Island Grid Project in Maui, Hawaii (JUMPSmartMaui), which runs from 2011 to the end of FY2016. Hitachi has been acting as project coordinator, building the NEDO Maui project site in collaboration with the State of Hawaii; County of Maui; Hawaiian Electric Industries, Inc.; The University of Hawaii; and American national research laboratories as well as Cyber Defense Institute and Mizuho Bank.

An EV Energy Control Center was set up at the project site to enable construction of the EV-based island smart grid with the aim of improving usage of renewable energy, and a trial of integrated energy management on the island conducted by coordinating its operation with the distributed management system (DMS) installed in the Kihei district and the energy management system (EMS) that balances supply and demand on the Maui Electric Company grid (see Fig. 2). Through this project, Hitachi is engaging in the construction and maintenance of more diverse electric power distribution systems.

The following are four technical features of Hitachi's participation in the project.

(1) Implementation of advanced load sharing to improve usage of the large installed capacity of renewable energy

(2) Management of electric power use by EV chargers and other home appliances to deal with the sudden fluctuations in supply and demand that are a characteristic of renewable energy

(3) Installation of fast chargers and associated support systems to establish the infrastructure for widespread use of EVs

(4) Cybersecurity to ensure secure system operation

Involvement in North American Power Distribution

One of the challenges for North American electric power distributors regarding the maintenance of distribution equipment installed over a wide area is that the increasing size and diversity of equipment means that a run-to-failure (RTF) policy of reactive maintenance (repairing equipment as it fails) is approaching its limit. For this reason, they are implementing measures for conducting maintenance in ways that do not impact the distribution of electric power by monitoring and managing equipment condition and performing repair or replacement pre-emptively when indicators of a potential fault are present. Use of information and associated operation technologies is seen as having the potential to overcome challenges like this. Hitachi is already working to overcome these challenges in Japan through collaboration with Tokyo Electric Power Co., Inc., which uses advanced maintenance techniques and systems that utilize collected and analyzed data on distribution systems and equipment failures, and THE Power Grid Solution Ltd., a joint venture with Hitachi. Consultations with North American power distribution companies that focused on maintenance services like these for dealing with the aging of distribution equipment, which is the greatest challenge in North America, identified the following problems.

(1) Patrol and inspection

There were inadequate maintenance criteria, variability in the data, and inaccuracies in the collected data.

(2) Responding to outages and other faults

There was inadequate root cause analysis and traceability of data items, and inaccuracies in information on outages and other faults.

(3) Responding to tornados

The prioritization of restoration was unsystematic and lacked clarity.

These problems have resulted in cases where the identification of repeated instances of faults due to the same cause has been inadequate.

Hitachi has collated use cases that are useful for the steps from identifying to resolving workplace problems like these, and believes it is possible to combine them with decision support systems (DSSs) and other IT to establish OT that is tailored to the characteristics of particular regions. Hitachi also believes that machine learning techniques are useful for further tuning of the knowledge required for such

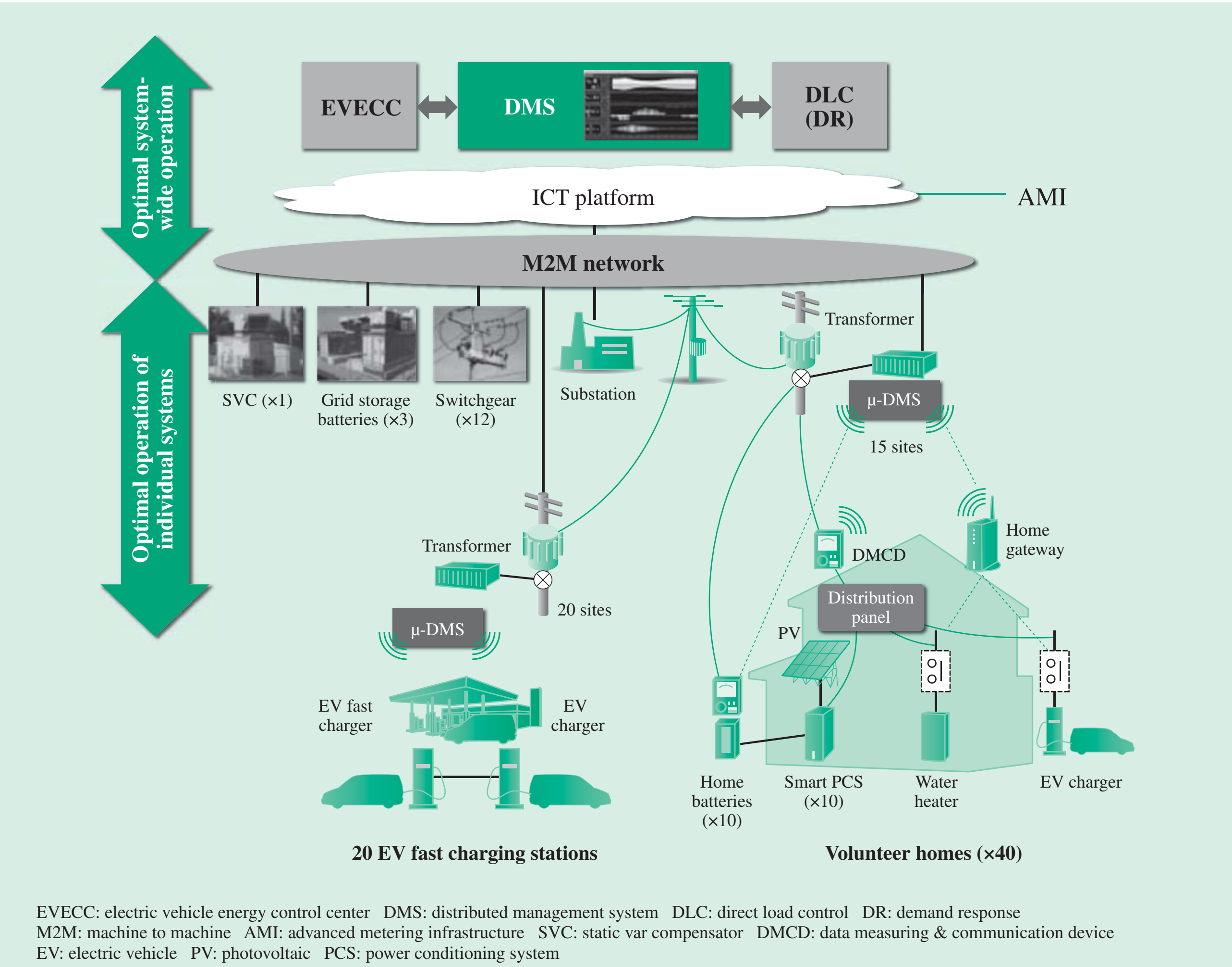

Fig. 2—Block Diagram of Demonstration System in Maui.
The trial is evaluating the ability to maintain grid stability using a tiered control architecture that combines a DMS for optimal system-wide operation with μ-DMSs for optimal operation of individual systems.

initiatives. Hitachi is currently deploying these in North America, including a consultation service that extends as far as management decision-making on measures for resolving problems, and is working on things like building smart grids and activities aimed at ensuring the secure supply of electric power.

IT SYSTEMS FOR SUPPORTING ENERGY SOLUTIONS

As noted in the above overseas examples, supplying energy solutions to customers requires both a high level of control technology for the stable operation of power systems and advanced IT for the optimal exchange of information between energy suppliers and consumers. This section presents an overview of Hitachi's IT system technologies for energy solutions.

IT System Requirements

Hitachi has collated IT system requirements through the demonstration projects described above. The main requirements are as follows.

(1) Dealing with diversity (interoperability)

The capability is required to link together the varied equipment and diverse information and control systems belonging to energy suppliers and consumers, and to supply users with integrated services.

(2) Dealing with reliability

There is a need to implement systems that can be used safely and securely so that services are not interrupted during emergencies and are trouble-free during normal operation, and also a high level of security so that information can be shared and used safely and securely.

(3) Dealing with ongoing growth (sustainability)

The capability is required to supply services over the long term in step with the incremental growth of systems, while also being able to maintain harmony even when additions or repairs are made to parts of the system.

(4) Dealing with system-wide optimization (total optimality)

So that the different systems used by energy users and suppliers can coexist, there is a need for mechanisms that are aimed at optimizing the overall system by having individual systems interoperate and resolve their respective issues by having a positive impact on each other.

IT Systems for Energy Solutions

Hitachi is making progress on putting together its Intelligent Operations Suite of ideal IT system "patterns" that draw on its past experience supplying IT systems to customers and its knowledge of how to use various different solutions to provide total support across the customer's system life cycle, from planning through to design, implementation, operation, and maintenance. To satisfy the IT requirements described above, Hitachi is also working on the deployment of symbiotic autonomous decentralized system platforms

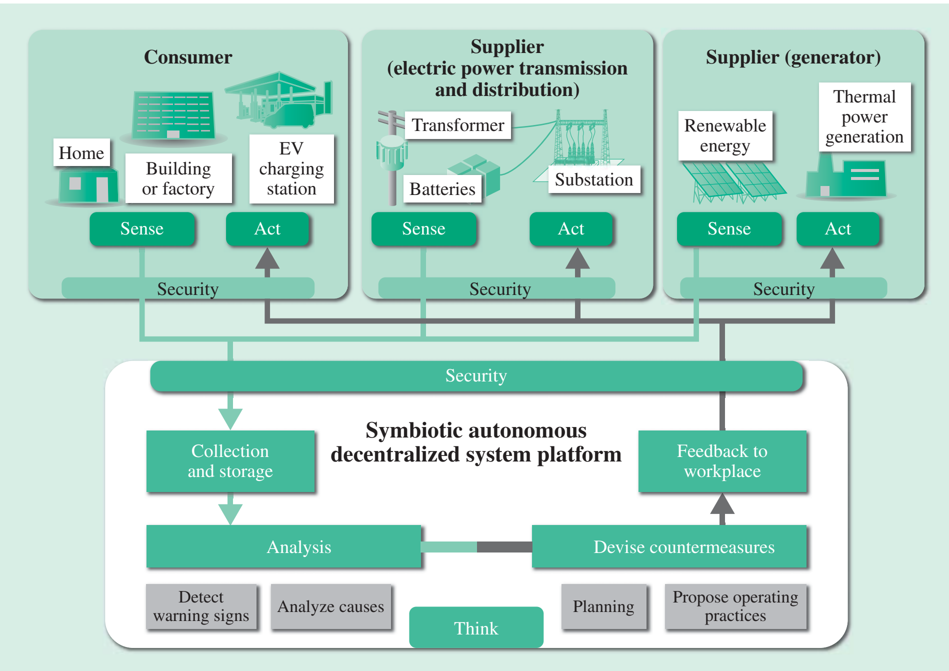

Fig. 3—Block Diagram of Symbiotic Autonomous Decentralized System Platform.
The aim is to achieve system-wide optimization by linking a number of independent systems together so that they can interoperate via a hub for inter-system data sharing.

that seek to provide system-wide optimization by linking a number of independent field control systems in such a way that the systems can interoperate via a common hub for data sharing (see Fig. 3). These symbiotic autonomous decentralized system platforms collect and store different types of data from the systems, and analyze the collected data to obtain status information. They also devise ways of overcoming the challenges faced by each system and provide the results of this back to the workplace as feedback in order to optimize key performance indicators (KPIs) across all systems, not just individual systems.

By using loose coupling to enable field systems to interoperate smoothly, symbiotic autonomous decentralized system platforms provide an environment in which individual systems can coexist while still remaining independent of each other. Furthermore, combined with the security, network, and other solutions collected together in the Intelligent Operations Suite, they maintain the security of the systems, machinery, and equipment belonging to customers and enable highly reliable communication and interoperation between different systems, machinery, and equipment.

CONCLUSIONS

As noted in this article, Hitachi is helping make energy smarter through the implementation of demonstration projects and commercial systems, not only in Japan, but also in the countries of Europe and North America where energy deregulation is well-advanced. Hitachi's IT covers a wide range, of which the examples in this article have only touched on a small part. By combining this IT, the OT of partners, and other elements, Hitachi intends to continue contributing to the realization of a global low-carbon society.

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Featured Articles

Development of 5-MW Downwind Turbine and Floating Substation Facility for Offshore Wind Power

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Kiyoshi Sakamoto, Dr. Eng.
Shingo Inamura, Dr. Eng.
Ikuo Tobinaga
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OVERVIEW: To meet the societal demand for greater use of renewable energy, Hitachi is working on developing equipment that can be used in offshore wind farms. In terms of wind turbines, up to now Hitachi has developed 2-MW downwind turbines, and it is drawing on this experience to develop a more reliable 5-MW downwind turbine. A prototype turbine is currently being moved into commercial operation. This article describes the performance/function testing carried out during trial operation, and the test results. Since Japan has few areas of shallow coastal water, floating offshore wind farms are promising, so this article also describes the development of the floating substation facilities these wind farms will require.

INTRODUCTION

FOSSIL fuel depletion, global warming, and concern for the energy mix are resulting in rising societal demand for renewable energy sources. Wind power is one of the more cost-competitive renewables, and its use is being promoted worldwide. Offshore wind farms offer benefits such as a reduction in land-based sites, high or stable wind speeds, and low incidence of environmental problems such as noise. Many such sites are being planned inside and outside of Japan.

Hitachi has developed wind turbines to meet the societal demand for renewables. It installed a 2-MW downwind turbine prototype (model HTW2.0-80) in 2005, with 96 units of this model installed in Japan so far. In 2010, Hitachi installed seven units of the same model in the open ocean (a first in Japan), and added eight more units in 2013. Also in 2013, the company installed a floating offshore wind turbine off the coast of Nagasaki, and another off the coast of Fukushima[1]. These facilities are the first of their kind in Japan, and only the third of their kind worldwide.

Hitachi is currently developing a more cost-effective 5-MW downwind turbine (model HTW5.0-126). A prototype turbine was constructed in March 2015 on coastal land in Kamisu, Ibaraki Prefecture, and began commercial operation in September 2015. The development concept[1] and development process[2] have been discussed in previous articles. This article will discuss the performance/function testing done on the prototype turbine.

Since Japan has few areas of shallow coastal water, floating wind turbines and substations are needed. The development of the world's first floating offshore substation is discussed below.

HTW5.0-126: BASIC SPECIFICATIONS, FEATURES

To withstand the typhoons that strike Japan and neighboring regions, the HTW5.0-126 was designed for an extreme wind speed of 55 m/s, in excess of the Class I standard specified by the International Electrotechnical Commission (IEC). Drawing

TABLE 1. HTW5.0-126 Basic Specifications
An output voltage of 33 kV was selected due to the cost effectiveness of using undersea cable for connecting to the land-based grid.

Rated output	5,000 kW
Rotor diameter	126 m
Number of blades	3
Rotor orientation	Downwind
Tilt angle	–8 deg
Output control	Pitch, variable speeds
Coning angle	5 deg
Extreme wind speed	55 m/s
Average wind speed	10 m/s
Turbulence category	A
Speedup ratio	1:40 (approx.)
Generator	Permanent magnet synchronous generator
Power conditioning system (PCS)	Full converter

Fig. 1—Photograph of the HTW5.0-126 Prototype Turbine.
The prototype turbine was installed in March 2015 in Kamisu, Ibaraki Prefecture, and is undergoing various types of performance/function testing.

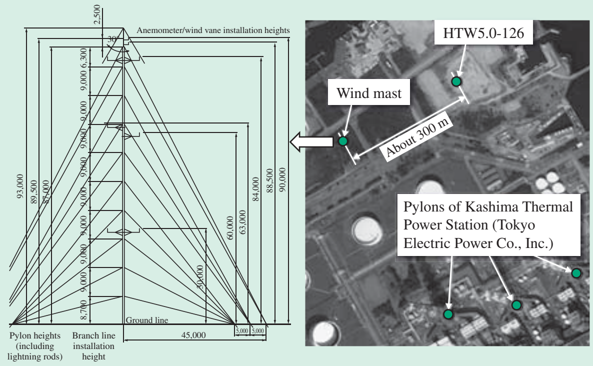
on Hitachi's previous wind turbine development experience, a downwind turbine rotor position was selected, providing superior performance during power failures in high winds and ensuring easy tower clearance. Table 1 lists the basic specifications of the HTW5.0-126, and Fig. 1 shows a photograph of it.

To increase reliability, the unit's structure features a medium-speed gear drive system, a shaft driven by dual-bearing outer ring drive, and passive cooling system.

HTW5.0-126 TRIAL OPERATION

Power Generation Performance Testing

In the vicinity of the HTW5.0-126 prototype turbine, Hitachi has installed a wind mast at the same 90-m height as the wind turbine's hub, and is evaluating the power curve. Fig. 2 shows an aerial photograph of the site, and the side view of the wind mast. The wind mast is installed about 300 m west-southwest of the wind turbine, wind speed and the wind direction



* Google Maps is a trademark of Google Inc.

Fig. 2—Aerial Photograph of the HTW5.0-126 Prototype Turbine Site and Side View of the Wind Mast.
To determine the prototype turbine's generation performance, a wind mast was constructed near it to measure parameters such as wind speed. The aerial photograph of the prototype turbine site is from Google Maps(3).*

height distribution, air pressure, temperature, and humidity are being measured.

Fig. 3 shows the measured power curve. Since there are pylons belonging to the Kashima Thermal Power Station (owned by the Tokyo Electric Power Co., Inc.) located on the south side of the wind turbine, the data for the southern wind direction has been omitted from the analysis. Although the wind turbine's method of operation is currently being adjusted,

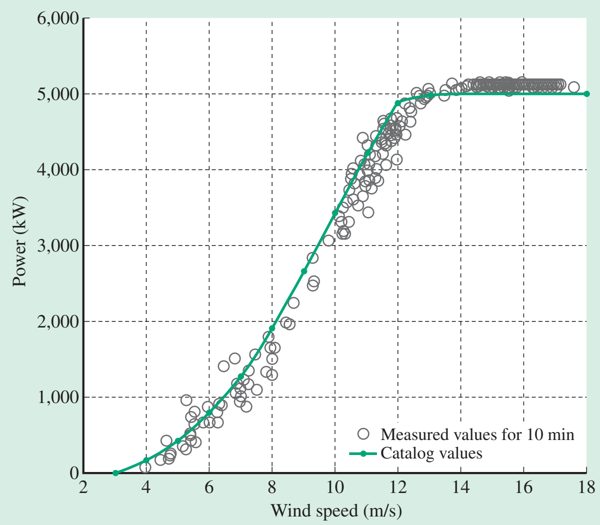


Fig. 3—Measured Power Curve Values.
The curve shows the correlation between the power and the wind speed measured by the wind mast at the height of the wind turbine hub. The performance obtained closely resembles the anticipated catalog values.

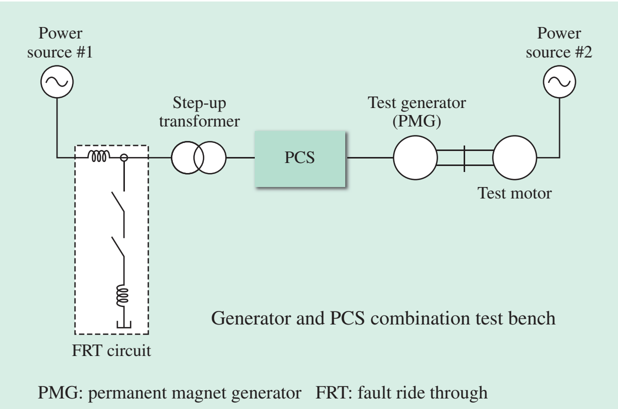


Fig. 4—Factory Testing Configuration (FRT Function Verification).
The generator to be tested was driven by a test motor, and an FRT circuit simulating a voltage drop was installed on the grid output side of the PCS.

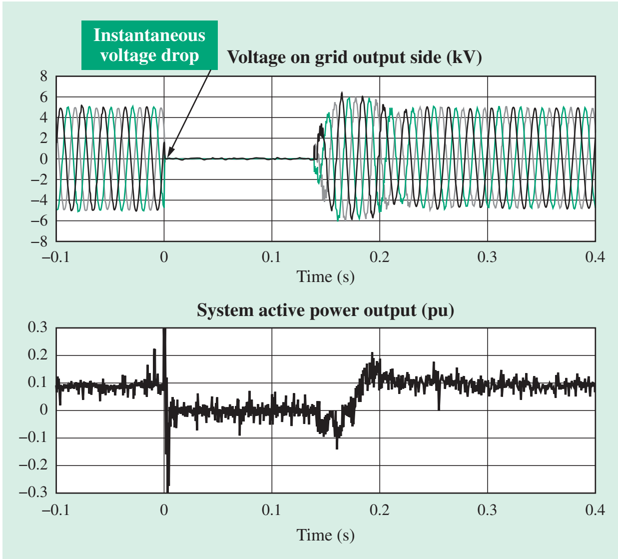


Fig. 5—Example FRT Function Test Waveforms.
This example shows that output continued during the 0.15-second interval in which the power voltage dropped to 0 V. Generation output recovered within 0.1 seconds after the voltage was restored.

Hitachi has verified that performance similar to the expected values can be obtained.

Test of Continuous Operation during Grid Faults

The HTW5.0-126 downwind wind power generation system comes with an fault ride through (FRT) function provided as a standard feature. When an instantaneous voltage drop occurs due to a grid fault, the FRT function allows the system to continue operating without taking the turbine offline as long as the grid voltage drop level and voltage drop time are within the specified ranges. Factory testing of a combination of the generator and power conditioning system (PCS) has verified that this function meets the specification requirements. Fig. 4 shows the factory test configuration. The FRT circuit simulates a voltage drop during a grid fault. Fig. 5 shows an example factory test waveform. Hitachi has verified that the generation output was covered within the time specified by the Japanese standard(4) after the grid voltage was restored.

Hitachi is also conducting grid fault continuous operation testing on the HTW5.0-126 prototype turbine. This verification testing is done by inserting an FRT circuit between the wind turbine and the network substation used for connecting to the power company, and checking the behavior of the entire wind power generation system. It is scheduled to be completed within FY2015.

Cooling Performance Testing

To cool the nacelle and tower, the HTW5.0-126 uses a passive cooling system that has no fan for the radiator. Computational fluid dynamics was used to design the nacelle shape and radiator placement to obtain the air flow needed for cooling.

For the nacelle cooling system and tower cooling system during operation of the prototype turbine under load, Fig. 6 shows the correlation between the temperature of the cooling water (relative to the outside air) after passing through the radiator and the nacelle wind speed. The diagram shows that the cooling water temperature is low when the nacelle wind speed is high, resulting in higher cooling efficiency, and verifying the validity of the cooling system design.

Load Evaluation Testing

When designing the wind turbine, the loads on various turbine parts and cross-sections were calculated using aeroelastic analysis. These loads were used as input conditions to evaluate strength by calculating stresses on detailed models using methods such as the finite element method (FEM). Verifying upstream loads is important when evaluating the structural soundness of wind turbines(5).

The loads on the wind turbine parts are currently being verified. The results of verification of the flapwise bending moment (‘flap bend’) on the blade roots are presented here. Measurement was done using strain gauges installed on the positive and negative pressure sides in the flapwise. The difference between the two measurements was divided by 2 to remove

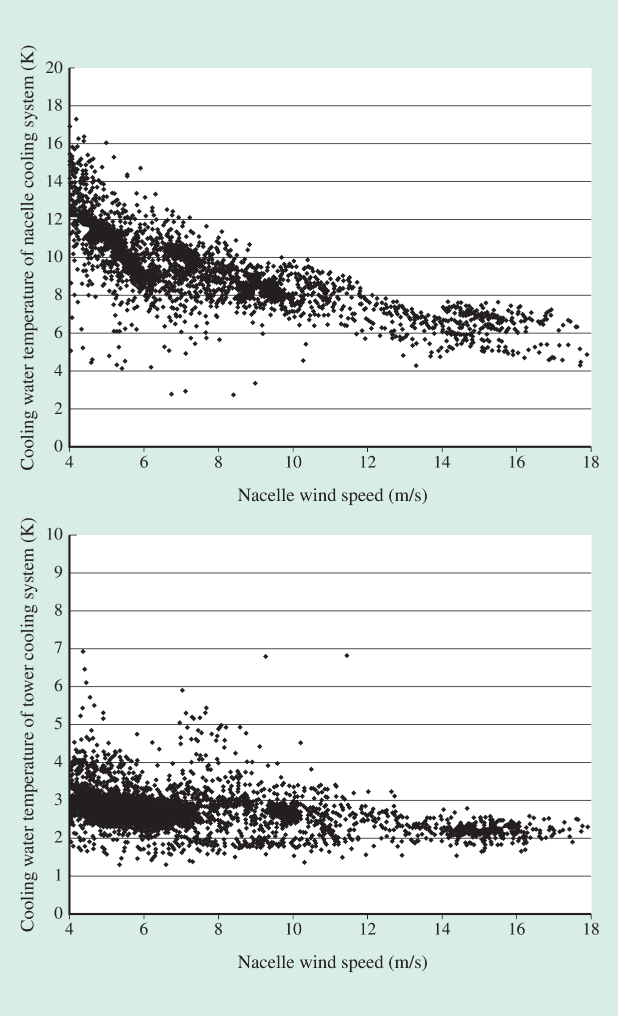


Fig. 6—Correlation between Cooling Water Temperature and Nacelle Wind Speed.
In the nacelle cooling system and tower cooling system, cooling water temperature is low when nacelle wind speed is high, resulting in higher cooling efficiency.

effects such as the equivalently applied centrifugal force, and then multiplied by a conversion factor to calculate the bending moment.

Fig. 7 and Fig. 8 show the flap bend evaluation results while generating power. Fig. 7 shows the average, maximum, minimum, and standard deviation values for 10 minutes of data. Fig. 8 shows the damage equivalent load (DEL). Values labeled 'measured' in the diagrams are actual measurement values, and values labeled 'design' are design values obtained using an aeroelastic analysis software application called Bladed[6]. The values are ratios to the DEL design value at 10 m/s.

DEL was calculated using the following formula.

$$R_{eq} = (\Sigma R_i^m \cdot n_i / n_{eq})^{1/m} \quad (1)$$

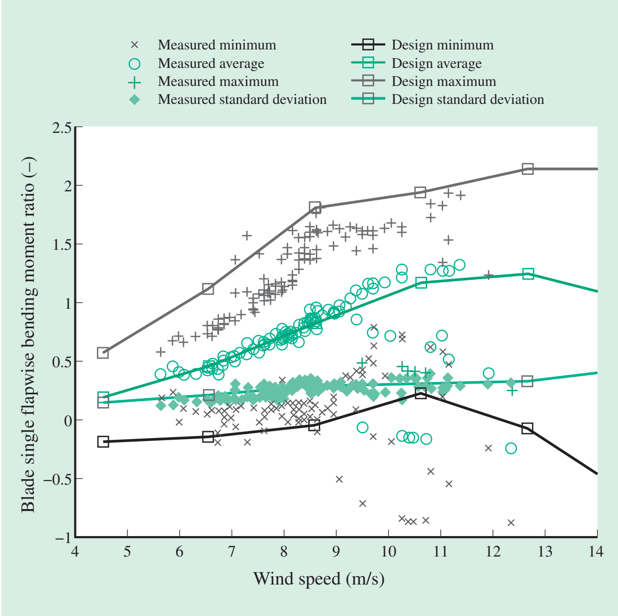


Fig. 7—Statistical Values of Flapwise Bending Moment at Blade Roots.
The graph shows 10 minutes of statistical values for blade flap bend relative to the average wind speed over a 10-minute period.

Where R_{eq} is the DEL, R_i is the load range of the ith bin in the fatigue load spectrum, n_i is the repetition count of the ith bin in the fatigue load spectrum, n_{eq} is the equivalent repetition count (600), and m is the slope of the stress-number of cycles to failure (S-N) curve of the material.

The measured average values and design average values in Fig. 7 are closely matched, indicating that the aeroelastic analysis faithfully reproduced the static behavior of the equipment. The measured maximum values are smaller than the design maximum values, and the measured minimum values larger than the design minimum values, resulting in the fatigue load of Fig. 8 also having smaller measured values than design values. Flap bend DEL is dominant during power generation, indicating that fatigue in parts greatly affected by flap bend is unlikely to be a problem.

VERIFICATION TESTING OF FLOATING SUBSTATION FOR OFFSHORE WIND POWER

Unlike the North Sea in Europe, Japan's coastal waters have few shallow areas, making floaters the best approach to offshore power generation. This chapter describes the Fukushima Floating Offshore Wind Farm Demonstration Project implemented as a

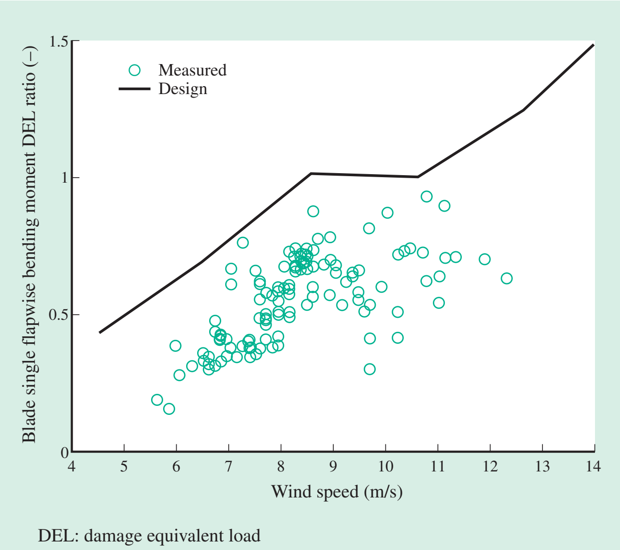


Fig. 8—Flapwise Bending Moment Fatigue Load at Blade Roots.
The graph shows 10 minutes of fatigue equivalent load values for blade flap bend relative to the average wind speed over a 10-minute period.

Fig. 9—Photograph of Exterior of Offshore Substation.
The substation has one 66-kV incoming line and transformer output of 25 MVA. Its equipment is housed within the upper deck. This photograph was taken off the coast of Onahama, Fukushima Prefecture. The substation is shown in the foreground, with a 2-MW Hitachi wind turbine in the background (photo courtesy of the Fukushima Offshore Wind Consortium).

demonstration project in FY2011 by Japan's Agency for Natural Resources and Energy. Fig. 9 shows a photograph of the offshore substation.

Offshore Substation Equipment Vibration Testing

Drawing on the experiences of past major earthquakes, substations produced in recent years are highly seismic-resistant products. Floaters need to withstand normal ocean rolling as well as the extreme rolling produced by typhoons that occur once every few decades. To verify rolling resistance, extensive study was done during the design phase of the Fukushima project, and the performance of switches (66-kV gas insulated switchgears and 24-kV vacuum insulated switchgears) was verified by placing them on vibration generators for testing. Since the main transformer (66 kV, 25 MVA) weighs more than 50 t, there were very few vibration generators that could handle its weight. Its performance was therefore verified by simulating the acceleration produced by rolling by tilting the transformer instead (see Fig. 10).

In addition to rolling, other concerns for ocean-based facilities are rust and damage caused by sea salt. Serviceability is different from land-based facilities. Creating an environment that enables optimum paint refinishing and service work is easy for land-based facilities, but there are limitations for ocean-based facilities that must be considered during design. Although the only equipment actually located outside is the transformer, radiators made of thin sheet material are galvanized or zinc-sprayed to ensure low maintenance.

Verification Testing

Since coming online in October 2013, the project has accumulated nearly two years' worth of performance data. It has experienced several major typhoons, but has continued to operate without problems from rolling or other causes. The effects of salt damage to

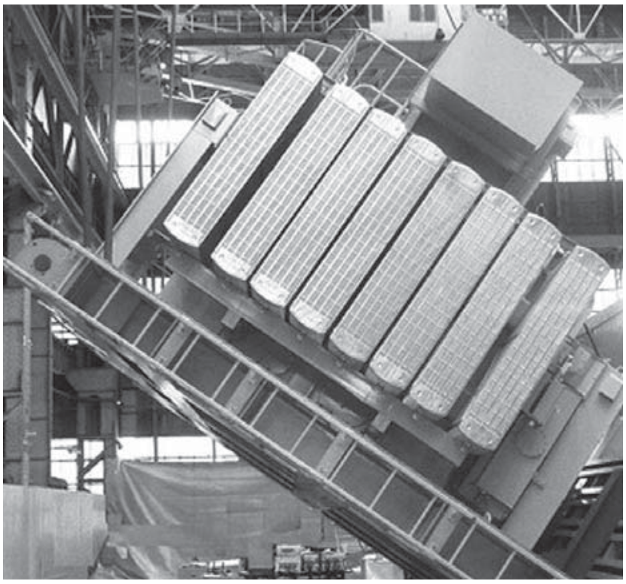


Fig. 10—Transformer Tilt Test.
The photo shows the transformer tilt test done at a test facility in Kokubu Works of Hitachi, Ltd.

the transformer exposed to the outdoor environment are within the expected severity level. Going forward, Hitachi plans to implement cost reduction/design evaluations for the future.

CONCLUSIONS

This article has described the performance/function testing carried out on Hitachi's HTW5.0-126 downwind turbine, the test results, and the development of a floating substation.

In the future, Hitachi will carry out further performance/function testing in areas such as noise, identifying and improving the equipment characteristics. It will also work on the verification of new control methods. These activities will enable Hitachi to offer high-performance/high-reliability equipment to society.

ACKNOWLEDGMENTS

We would like to express our appreciation to the New Energy and Industrial Technology Development Organization (NEDO) for its assistance in the development of the HTW5.0-126 5-MW downwind turbine.

We would also like to express our appreciation to the members of the Fukushima Offshore Wind Consortium for their assistance in the Fukushima Floating Offshore Wind Farm Demonstration Project.

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Featured Articles

Technologies for Improving Safety of Nuclear Power Generation

Koji Nishida, Dr. Eng.
Hirokazu Adachi
Hirofumi Kinoshita
Noriaki Takeshi
Takao Kurihara
Kazuhiro Yoshikawa
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OVERVIEW: This article describes work Hitachi has done in terms of nuclear power generation in regard to safety improvement technologies that are under development or in the process of being implemented. This includes the work on decommissioning of the Fukushima Daiichi Nuclear Power Station being undertaken in Japan, the GDA being undertaken by the Office for Nuclear Regulation on an ABWR that is planned for construction in the UK, and a new nuclear reactor that reduces the load on the environment by cutting the quantity of nuclear waste and serves as an example of progress being made on the development of a next-generation reactor.

INTRODUCTION

SINCE the accident at the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Co., Inc. (TEPCO), Hitachi has been providing full-scale cooperation with the recovery and reconstruction of the affected areas and the plant itself, assisting in ways that include surveying the damaged nuclear reactors and treating the contaminated water. In preparation for restarting plants in Japan, Hitachi is also working on the development of safety improvement technologies that further increase safety margins in accordance with the new regulatory standards introduced in July 2013 based on the lessons learned from the Fukushima accident, including measures for dealing with major accidents, natural disasters, and deliberate attacks (terrorism).

Overseas, meanwhile, there is rising demand for the construction of new nuclear power plants, particularly from emerging nations, due to the potential for nuclear power generation to provide a reliable source of energy in response to rising global energy demands, and its characteristic of not emitting greenhouse gases in the generation process. In response to this international need, Hitachi is preparing for the construction of new nuclear power plants in places like the UK and Lithuania based on a strategy of supplying its advanced boiling water reactor (ABWR) design, which features a high level of safety performance and an extensive track record. In a new initiative, Hitachi is proceeding with the development of a next-generation light water reactor that is based on proven BWR technology and can reduce the load placed on the environment by high-level waste.

This article focuses in particular on Hitachi's work on the decommissioning of the Fukushima Daiichi Nuclear Power Station, the construction of new nuclear power plants in Europe, and the progress of development of the next-generation light water reactor.

WORK ON DECOMMISSIONING OF THE FUKUSHIMA DAIICHI NUCLEAR POWER STATION

Removal of Spent Fuel from Unit 4

The underlying functions of Units 1 to 4 of the Fukushima Daiichi Nuclear Power Station were disabled by the tsunami that accompanied the Great East Japan Earthquake of March 2011 and the subsequent hydrogen explosions. As the spent fuel pool (SFP) in the Unit 4 reactor building contained 1,535 rods, more than in Units 1 to 3, there was a need to start removing fuel as soon as possible, and this was one of the completion requirements for Phase 1 of the Mid-and-long-Term Roadmap towards the Decommissioning of TEPCO's Fukushima Daiichi Nuclear Power Station Units 1–4 to which Tokyo Electric Power Co., Inc. has publically committed.

The steps taken to achieve this unprecedented task of removing spent fuel from a reactor building that has lost its underlying functions consisted of:

(1) Removing debris from the top of the existing reactor building

(2) Selecting or designing and building the machinery needed for fuel removal
(3) Designing the structure of a cover to enable fuel removal to be performed without placing a load on the damaged reactor building and planning the installation of machinery
(4) Installing and commissioning of the cover and machinery
(5) Removing debris from the SFP and transporting fuel (performed underwater by remote control)

The on-site work for steps (1), (4), and (5) in particular involved working under the unprecedentedly high level of radiation present after the earthquake.

Fig. 1 shows the cover and machinery installation for Unit 4.

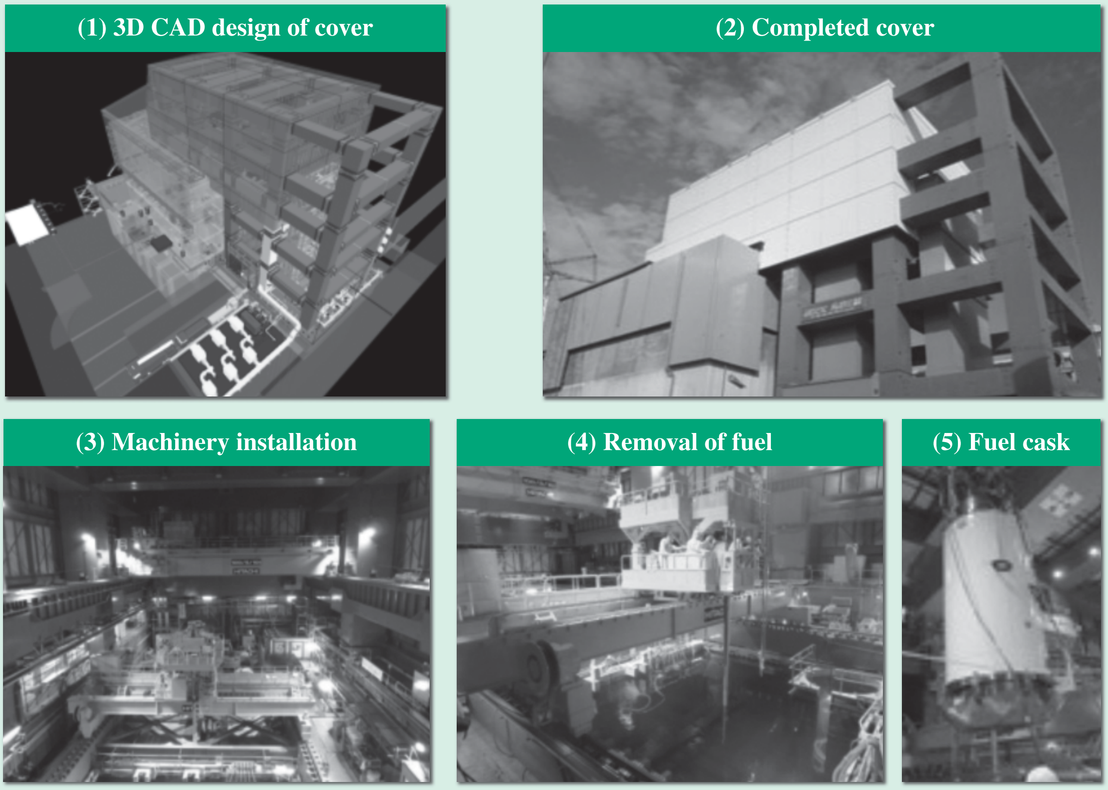
(1) Removing rubble from the top of the existing reactor building

The hydrogen explosion that occurred in the aftermath of the earthquake left the Unit 4 reactor building with parts of the roof, walls, and floor at the top of the building blown out and with damage to the remaining structure. There was also considerable debris piled up on top of the fuel removal equipment and the lids of the containers that had been left out on the fifth floor due to the periodic inspection in progress at the time of the disaster.

This debris was broken up and craned to the ground using a large crawler crane that was positioned on the west side of the reactor building from October 2011 to October 2012 for this purpose. The removal of debris from the roof, walls, and other structural parts of the building was undertaken by Takenaka Corporation, and the removal of damaged machinery by Hitachi-GE Nuclear Energy, Ltd. (Hitachi-GE).

(2) Design, fabrication, and installation of machinery needed for fuel removal

As the atmospheric radiation level on the operation floor of the Unit 4 reactor building was low enough for workers to enter (lower than the other units), a study of the fuel removal equipment was undertaken to look at using the conventional manual procedure whereby casks would be placed in the SFP, loaded with fuel using the fuel removal system, and transported out of the building using the overhead crane. A study of



3D: three-dimensional CAD: computer-aided design

Fig. 1—Cover and Machinery Installation for Unit 4.
The images show (1) the 3D CAD design of the cover, (2) the completed cover, (3) a view of the machinery (fuel removal system and overhead crane), (4) fuel removal in progress (using the fuel removal system), and (5) a fuel cask (being used to transport spent fuel).

the installation of equipment for removing the debris collected in the SFP was undertaken along with planning for minimizing the dispersal or scattering of radioactive material, and how to install ventilation and air conditioning systems to maintain an environment under the cover suitable for human workers and equipment for supplying the water, air, electric power, and other utilities required for the work.

An investigation into the cover intended to provide support for the fuel removal equipment and to prevent dispersal or scattering was considered in cooperation with Takenaka Corporation, and a cantilevered structure was chosen whereby the cover would be supported by newly constructed foundations on the south side of the reactor building in order to avoid placing a load on the building, which had been damaged by the hydrogen explosion. The plan also succeeded in reducing the quantity of ducting and amount of on-site installation work by using part of the cover structure (box shape with 3-m-long sides) as ventilation ducting.

On-site installation of the cover and machinery took place from August 2012 to October 2013. To reduce exposure to radiation, the cover was installed by performing the initial assembly of pillars and beams away from the Fukushima Daiichi Nuclear Power Station site and then performing on-site assembly by having workers bolt the structure together from the inside (with steel plate thickness of approximately 30 mm). Similarly, the amount of machinery installation work inside the reactor building was minimized by initially assembling the machinery into units at an area with a low level of radiation, and then progressively transporting them into the cover for assembly.

(3) Preparing for fuel removal

To prepare for fuel removal, the debris was cleared from the SFP.

The on-site work was not started until adequate preparations had been made by formulating a recovery plan for each item of debris, the nature and size of which had been determined by a preliminary survey conducted using an underwater camera and other

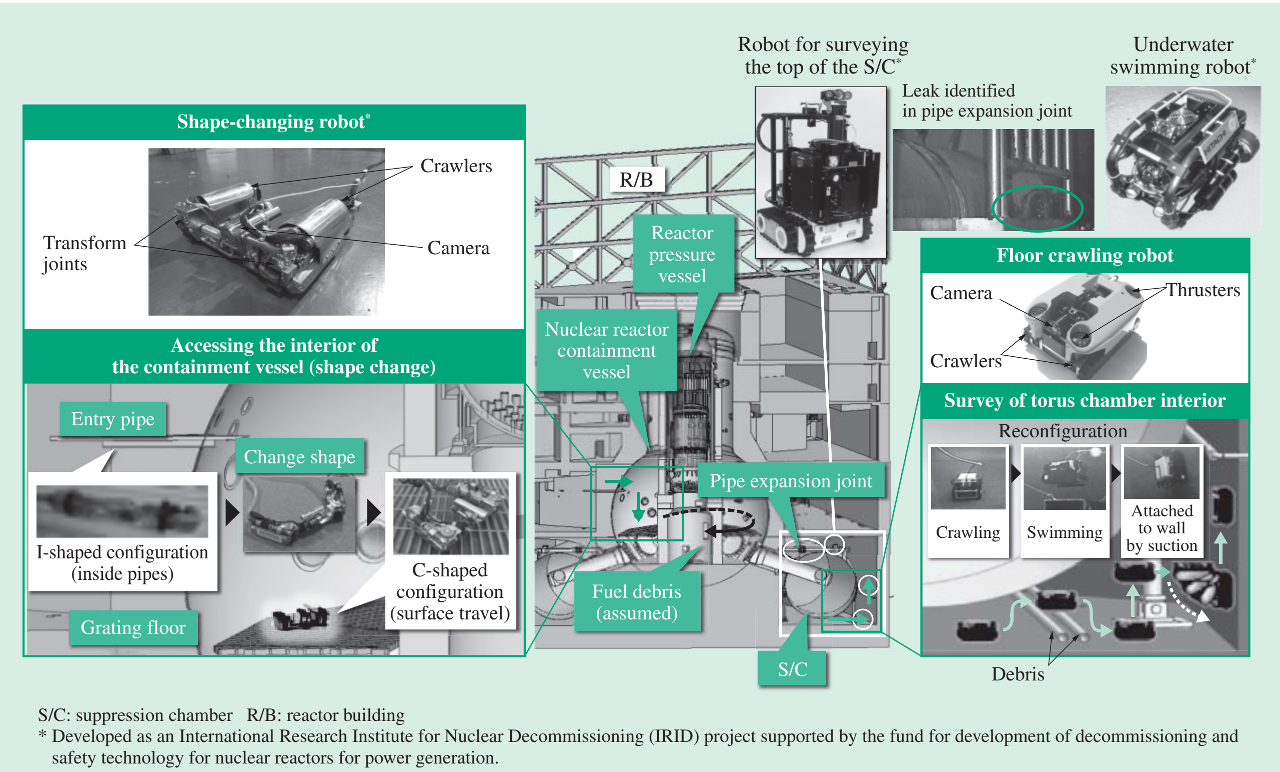


Fig. 2—Robots for Surveying the Interior of a Reactor Building.
To survey the interior of a reactor building, Hitachi developed and conducted on-site trials of three robots for surveying the basement and a shape-changing robot for surveying the interior of the containment vessel. In the survey of the torus chamber in the basement of Unit 1, the robot surveying the top of the S/C found leaks in pipe expansion joints and collected valuable information for repair planning. In the survey of the interior of the containment vessel, the robot traveled about two-thirds of the way around the floor collecting information, including the distribution of temperatures and radiation levels, the condition of equipment, and access routes to the underground floor.

equipment, and obtaining the required gripping and suction equipment. As a result, removal of large items of debris was completed without problems in October 2013, and removal of small items of debris was completed from October 2013 to March 2014.

(4) Fuel removal

After work on the cover was completed in November 2013, fuel removal by Tokyo Electric Power Co., Inc. commenced from November 18. Because of the risk that small pieces of debris might fall through the gap between the fuel and storage racks, the work was undertaken with great care, including a preliminary check using an underwater camera and by paying attention to the load while lifting it using the fuel removal system. As a result, the removal of all spent fuel (1,331 rods) was completed on November 5, 2014 and all fuel removal work was finished by December 22.

Development of Robot for Surveying Reactor Building Interior

A buildup of water occurred at Fukushima Daiichi Nuclear Power Station due to cooling water that had leaked into the basement and other parts of the reactor buildings. To reduce the quantity of this water, it was necessary to find and plug the leaks. Also needed was to work out how to survey and remove the fuel debris that was assumed to have been scattered around the underground parts of the containment vessel.

In response, Hitachi developed a survey robot for finding leaks both underwater and in the air, and another robot for surveying the interior of the nuclear reactor containment vessel, and used them to survey the buildings.

These robots were the subject of an on-site trial funded by the Agency for Natural Resources and Energy for developing technology to use in fuel removal at Fukushima Daiichi Nuclear Power Station.

Fig. 2 shows the survey robots.

(1) Survey robots for reactor building basement

The survey robots for the reactor building basement included a robot for surveying the top of the suppression chamber (S/C) to look for pipes or other leaks, and floor crawling and underwater swimming robots for finding underwater leaks. In particular,

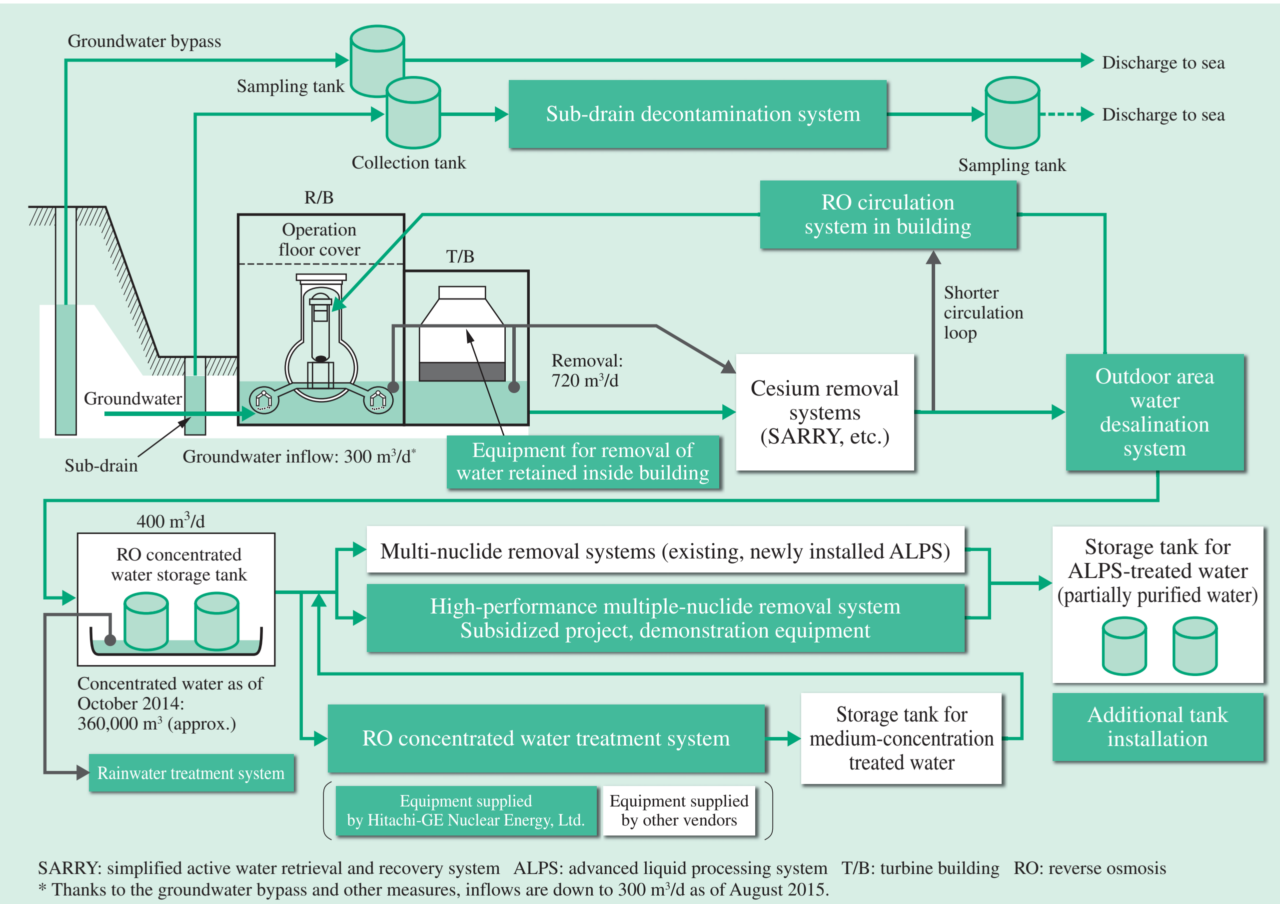


Fig. 3—Overview of Systems for Dealing with Contaminated Water.

Hitachi-GE supplies a large number of key systems for treating contaminated water.

the floor crawling robot for finding underwater leaks was equipped with a pair of crawler mechanisms and six propellers for thrust in the vertical and horizontal directions that gave it the ability to swim around obstacles or reorient itself to move along walls.

When trialed on site, these robots found leaks in expansion joints in piping exposed to the air at Unit 1, providing valuable information for planning how to plug the leaks.

(2) Robot for surveying inside nuclear reactor containment vessel

The challenge for enabling the survey robot to gain access to the interior of the nuclear reactor containment vessel was that it needed both to move through piping with an entrance diameter of only 100 mm and to be able to move reliably over floors. To achieve this, Hitachi changed the propulsion mechanism and developed a shape-changing robot that could switch between an I-shaped configuration for traveling through confined spaces and a C-shaped configuration for reliable travel over floors. This shape-changing robot conducted a survey of the grating on the first floor of the Unit 1 nuclear reactor containment vessel and provided valuable information for assessing the spread of fuel debris in the basement.

Measures for Dealing with Contaminated Water

Fig. 3 shows the progress made by Hitachi-GE on dealing with contaminated water at the Fukushima Daiichi Nuclear Power Station and in the main treatment systems. The underground parts of the buildings at the site still retained water contaminated with radioactive material, made up of seawater from the inundation of the building by the post-earthquake tsunami in 2011 and the injection water used for cooling the reactor cores of Units 1 to 3.

Furthermore, the inflow of groundwater into the buildings meant that the total amount of contaminated water was increasing by 400 t each day. To deal with this, purification equipment was installed and decontamination was performed by circulating the water in a loop. Meanwhile, to minimize the ever-growing quantity of contaminated water (due to the inflow of groundwater and so on), work commenced on minimizing groundwater inflow by pumping out the accumulated water from the buildings to lower the water level, shortening the circulation loop to reduce the risk of leaks, and removing the accumulated water and drying out the buildings. The main equipment supplied for this purpose was as follows.

- Sub-drain decontamination system (see Fig. 4, left)
- High-performance multiple-nuclide removal system (see Fig. 4, right)
- Reverse osmosis (RO) concentrated water treatment system
- In-building RO circulation system
- In-building retained water pumping system
- Storage tanks (63 × 1,000 t)

(1) Overview of main equipment and current situation

(a) Sub-drain decontamination system

The sub-drain decontamination system draws lightly contaminated groundwater from the numerous sub-drain pits located around facilities such as the

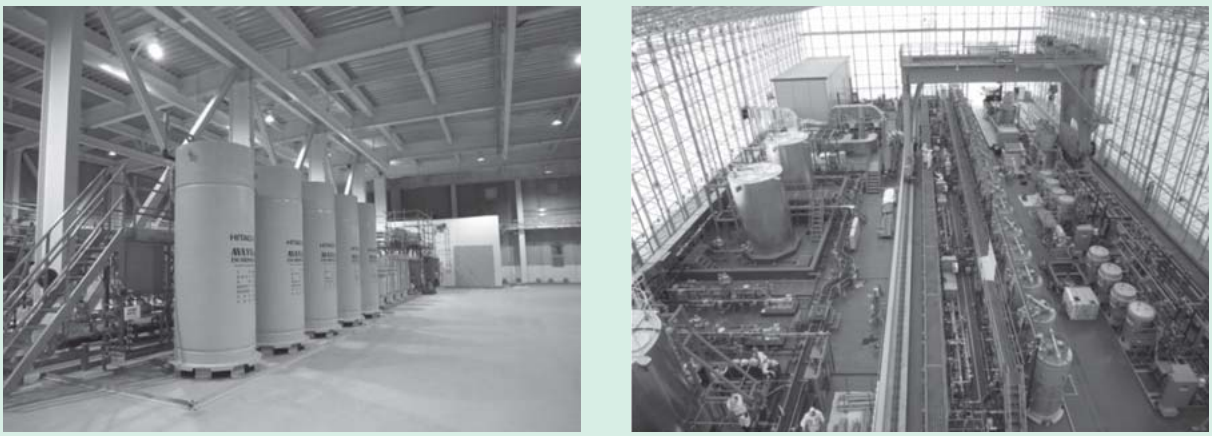


Fig. 4—Sub-drain Decontamination System and High-performance Multiple-nuclide Removal System.
The sub-drain decontamination system and high-performance multiple-nuclide removal system shown here were provided to deal with the contaminated water.

turbine rooms in Units 1 to 4 and separates out the radioactive isotopes. It is essential for limiting the inflow of groundwater into the buildings, and for reducing the level of contaminated water retained in the buildings in the future.

Hitachi-GE undertook the design and fabrication through a joint venture with AVANTech, Inc. of the USA, and completed the installation in only six months, an exceptionally short time for nuclear power equipment (see Fig. 4, left). In preparation for full-scale operation, treatment commenced in September 2015, with the discharge of water into the ocean beginning on September 14.

(b) High-performance multi-nuclide removal equipment

Intended for use on the approximately 360,000 t of heavily contaminated water stored at the Fukushima Daiichi Nuclear Power Station site, this system is able to reduce 62 different nuclides (not including tritium) to below detectable levels (and reduce strontium-90 to one part in 100 million; project funded by the Agency for Natural Resources and Energy). As of the end of August 2015, it had treated approximately 90,000 m^3 of contaminated water (see Fig. 4, right).

(2) Future work

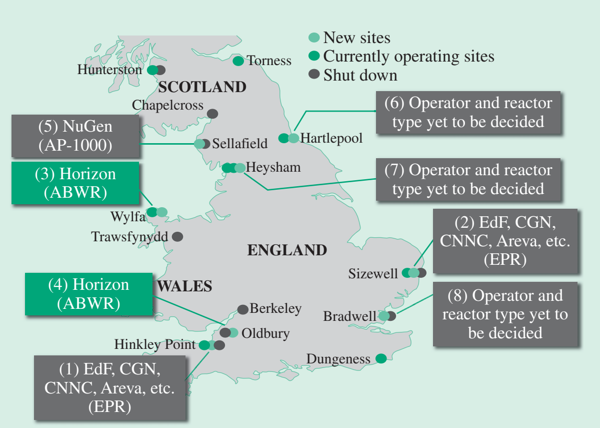
As described above, Hitachi-GE is working on a variety of ways of dealing with contaminated water to help with the Fukushima recovery.

Fukushima recovery poses major challenges, including rethinking the nuclear power industry to improve the energy situation. In response to these challenges, Hitachi-GE is taking steps to contribute through its work on the treatment of contaminated water, which represents one type of measure. In the four years since the 2011 earthquake, Hitachi-GE believes that steady progress has been made. Hitachi-GE intends to continue working on measures for the recovery through a variety of future initiatives.

NEW CONSTRUCTION OF NUCLEAR POWER PLANTS IN EUROPE

UK

The UK government has since 2007 supported the construction of nuclear power plants with the aim of creating a low-carbon society. While the UK currently has 16 operating nuclear power plants that together supply about 20% of the nation's electric power, the plants are aging and coming due for reconstruction. As a result, there has been growing activity directed toward new construction.



Prepared from Department of Energy & Climate Change documents

EPR: European pressurized reactor
ABWR: advanced boiling water reactor

Fig. 5—Planned New Nuclear Power Plants in the UK.
Plans for new plants in the UK include the Horizon projects at Wylfa and Oldbury [(3) and (4) in the figure].

Hitachi, Ltd. acquired Horizon Nuclear Power Limited, a UK company involved in the development of nuclear power generation, in November 2012, and has formulated a plan to build two or three 1,300-MW-class nuclear power plants at each of Horizon's two sites in the UK (at Wylfa and Oldbury) (see Fig. 5). Hitachi, Ltd. intends to obtain all of the licenses and permissions required for the initial project at Wylfa Newydd from the UK government by 2018 and to have the first reactor in service during the first half of the 2020s (see Fig. 6). The four-step approval procedure for the generic design assessment (GDA) of the UK ABWR design has been in progress since April 2013, with all steps to be completed by December 2017. In

Fig. 6—Planned Construction Site at Wylfa Newydd.
The Wylfa Newydd Nuclear Power Plant is planned for construction at this site.

Fig. 7—Cutaway Diagram of UK ABWR.
The UK ABWR, shown here as a cutaway diagram, is scheduled to commence operation in the first half of the 2020s.

the GDA, the ABWR is expected to achieve higher safety due to lessons learned from the accident at the Fukushima Daiichi Nuclear Power Station as well as from the experience of building and operating four reactors operating at three sites in Japan.

The UK ABWR design currently going through the GDA approval process is essentially based on the same plant concept as the ABWRs in Japan, which are currently undergoing safety enhancements for compliance with new Japanese regulations (see Fig. 7). The greatest strength of the ABWR design is that examples have already been built and operated in Japan. The following design optimizations and site adaptations are being undertaken using this design as a base.

(1) Safety enhancements based on experience from the accident at Fukushima Daiichi Nuclear Power Station

Based on lessons from the accident, the design includes measures for dealing with hazards that exceed design assumptions. In addition to improving measures for dealing with flooding of important buildings and providing portable equipment that will be made available for use if a serious accident occurs, these measures also include constructing a new backup building located some distance from the reactor building that can hold equipment such as an alternative water injection system or backup alternating current (AC) power supply to enable functions such as reactor core cooling to be performed even during a serious accident. The concept is the same as that for the measures for dealing with major accidents or other incidents at ABWRs that comply with the new Japanese regulations.

(2) Design changes for compliance with national regulations and standards

In addition to compliance with UK regulations and standards, the design also takes account of factors such as the design concepts used in existing reactors. For example, because the practical effect of the safety assessment criteria in the UK nuclear power regulations is to prohibit the installation of equipment with a high fire risk in the reactor building, the intention is to build a separate dedicated building to house the emergency diesel generator. There is also a need to comply with requirements relating to the diversity of electrical systems and instrumentation and control systems that are unique to the UK.

(3) Adaption to different site conditions to those in Japan

When building overseas, it is necessary to consider the different weather conditions as well as different seismic conditions. For example, due to the high latitude of the UK, the ventilation and air conditioning systems and heating equipment are designed to take account of more severe low winter temperatures than assumed in Japanese designs.

Lithuania

One of the three Baltic states, Lithuania is dependent on Russia for approximately 80% of its domestic energy consumption (when gas imports are included). With the aim of resolving energy security concerns of this nature, Estonia, Latvia, and Lithuania agreed in 2006 to the construction of the Visaginas Nuclear Power Plant in anticipation of future energy market integration (see Fig. 8). The Visaginas Nuclear Power Plant is included in the Baltic Energy Market Interconnection Plan (BEMIP) agreed to in 2009 by the eight nations fronting onto the Baltic Sea. In the 2011

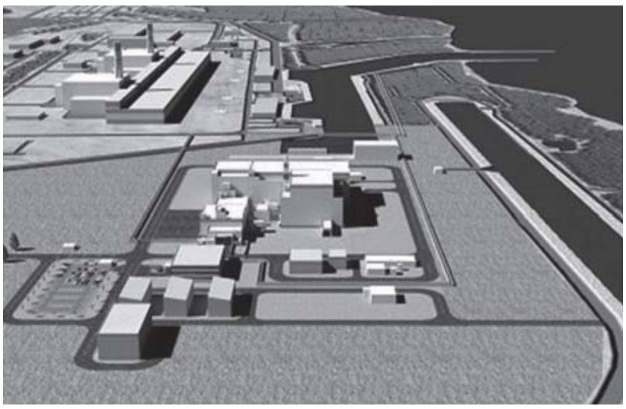


Fig. 8—Conceptual Drawing of Completed Visaginas Nuclear Power Plant.
The drawing shows the completed Visaginas Nuclear Power Plant.

tender for selection of a strategic investor (SI), Hitachi proposed a 1,300-MW-class ABWR with safety that would be further enhanced by measures taken in response to the Fukushima Daiichi Nuclear Power Station accident, and was granted preferred bidder status. Subsequently, the plan became the subject of a transfer of business rights contract between the government of Lithuania and Hitachi, Ltd. (in March 2012), and was approved in June of that year at the conclusion of a parliamentary debate together with the related laws. Following a change of government and the result of a national referendum, however, a special committee of the Lithuanian parliament was requested in October 2012 to undertake a review of energy strategy. Currently, Lithuania is still working on its national energy strategy, with the status of the Visaginas Nuclear Power Plant construction expected to be clarified during 2016. Meanwhile, a joint committee of the three Baltic states undertook a study of the technical issues associated with connecting the Visaginas plant to the transmission network and found no problems. Furthermore, the viability of the project is being enhanced by a training program for nuclear industry personnel that is proceeding with assistance from the Japanese government and elsewhere and by incorporating features from the Horizon project in the UK (which has an earlier timeframe).

Hitachi has extensive construction experience and believes it can contribute to the development of social infrastructure in different countries and to the creation of low-carbon societies by building nuclear power plants that are safer, more secure, and that incorporate lessons learned from the Fukushima Daiichi Nuclear Power Station.

DEVELOPMENT OF NEXT-GENERATION LIGHT WATER REACTOR

Range of Reactors that Match the Market

Hitachi has taken advantage of the generation of steam (voids) due to the boiling of water, a feature of the boiling water reactors (BWRs) it has developed, to develop a new type of reactor that matches market needs (see Fig. 9).

Large reactors are suitable for regions with transmission networks designed to cope with high demand for electric power, where they offer a centralized source of power that benefits from economies of scale and other improvements in economic performance. Hitachi is working on developing a next-generation BWR with hybrid safety systems that combine active and passive safety, and the economic simplified BWR (ESBWR) with natural circulation that takes advantage of the voids that occur in the reactor and utilizes enhancements to the ABWR, which has a history of use in Japan.

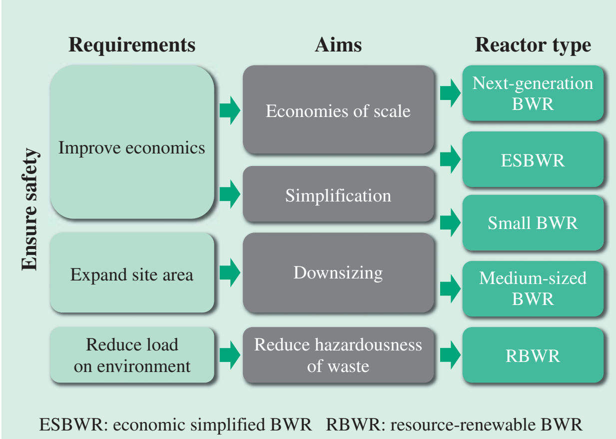


Fig. 9—Development of New Reactor Types to Suit Diverse Needs.
The development of reactors is continuing with the aim of satisfying various requirements.

Hitachi is also developing medium- and small-size BWRs that can adapt flexibly to the needs of regions with limited transmission capacity or users who want to minimize their initial investment. Rather than just being a downsized version of the ABWR, the medium-size BWR also features system simplifications while still maintaining adequate safety. The small-size BWR provides further simplifications by taking advantage of the voids that occur in the reactor to achieve natural circulation. Another development is the resource-renewable BWR (RBWR) that is based on proven BWR technology and reduces the load on the environment by reducing the hazardousness of high-level waste.

The following section describes the progress of development of the RBWR that can reduce the load on the environment.

TRU Burner Reactor

Hitachi is working on the development of an RBWR[1] that is fueled by long-lived transuranium elements (TRUs). The accumulation of the TRU waste produced as a byproduct of burning uranium fuel is a problem for nuclear power generation. TRU-containing waste is so hazardous that it takes approximately 100,000 years for it to attenuate to about the same degree of hazard as natural uranium. However, if these TRUs can be burned up and eliminated from the nuclear waste, that time can be reduced to a few hundred years.

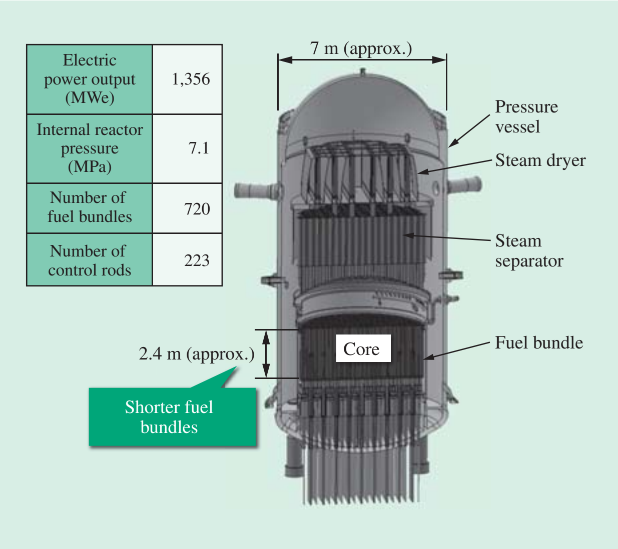


Fig. 10—Internal Reactor Equipment for RBWR Designed to Reduce Load on the Environment.
The plant concept and design use proven ABWR technology to reduce the load on the environment by minimizing the hazardousness of high-level waste while still maintaining safety.

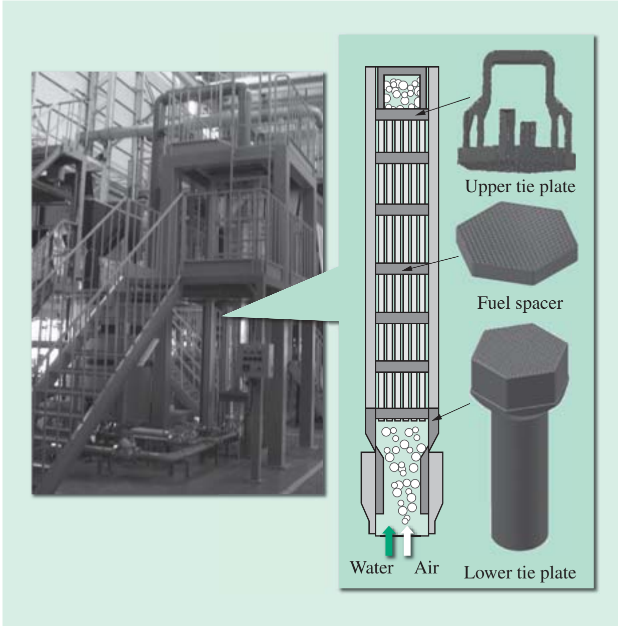


Fig. 12—Flow Vibration Testing of RBWR Fuel Bundles.
The robustness of the small-diameter fuel rods packed into RBWR fuel bundles with respect to fluid vibration was confirmed by conducting tests that simulated the flow at the plant.

The RBWR is based on BWR technology and, apart from the use of a reactor core with shorter fuel rods and fuel bundles, uses the same internal reactor equipment (including steam dryer, steam separator, and recirculation pumps) and safety systems as the latest ABWR (see Fig. 10). The operating conditions (such as electric power output and internal reactor pressure) are similar to the ABWR. To lower the amount of coolant relative to fuel in the core in order to achieve an efficient TRU burn, the fuel bundles are larger than in an ABWR, and small-diameter fuel rods are packed into hexagonal channel boxes and narrower gaps between the channel boxes (see Fig. 11).

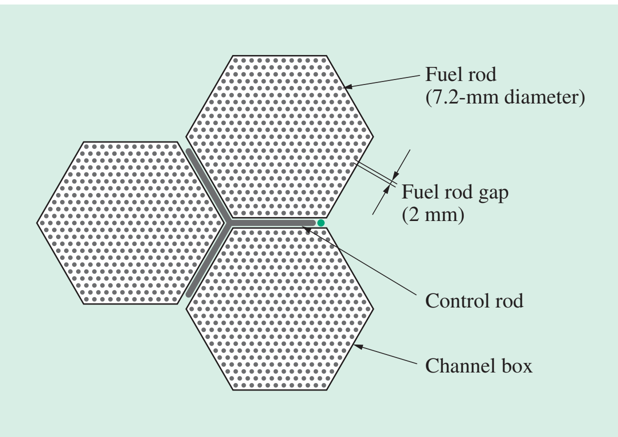


Fig. 11—Fuel Bundles.
To lower the amount of coolant relative to fuel in the core in order to achieve an efficient TRU burn, while still maintaining safety, small-diameter fuel rods are packed into hexagonal channel boxes with narrower gaps between the channel boxes.

While the fact that the RBWR is based on the same equipment concepts as the ABWR means there are few technical issues, there remains a need to demonstrate the viability of the newly developed fuel bundles and core equipment.

As the RBWR fuel bundles are made from tightly-packed small-diameter fuel rods with the possibility of different flow-induced vibration characteristics, testing of the vibration integrity of the fuel rods was conducted using an air-water test apparatus at ambient temperature and pressure (see Fig. 12). The experiment was conducted using model fuel rods fitted with accelerometers, upper tie plate, fuel spacers, and lower tie plate.

The upper tie plate was designed to provide adequate strength while also presenting a low resistance to the two-phase flow of coolant. The fuel spacers have a cell structure to ensure fuel bundle heat removal performance and to reduce flow resistance. The top surface of the lower tie plate includes fuel rod support holes and flow channel holes to allow the coolant access to the packed fuel rods. The lower part of the lower tie plate is fitted with a connecting pipe that inserts into the fuel support to provide independent support for the fuel bundle.

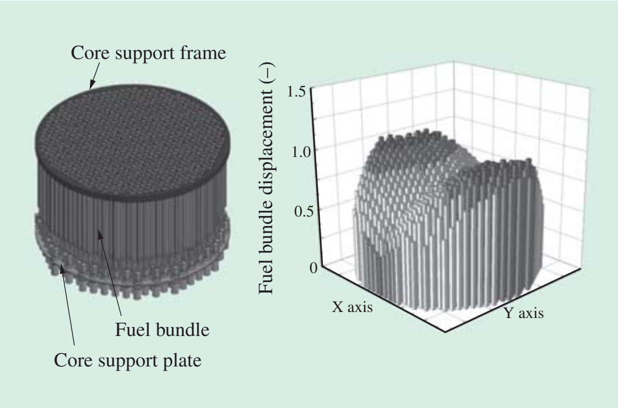


Fig. 13—Seismic Analysis of Core Structure.
Soundness during an earthquake was confirmed by developing a vibration analysis model to simulate the RBWR fuel bundle and core support structures.

Air-water testing at ambient temperature and pressure found that the maximum fuel rod vibration amplitude was equal or less than that of the ABWR and was sufficiently less than the gap between fuel rods to not pose any viability problems(2).

The top of an RBWR fuel bundle is in contact with the adjacent fuel bundles, and the fuel bundles on the circumference of the core are supported by the core support frame (see Fig. 13). The bottom ends of the rods are held up by the fuel supports on the core support plate. As the means of supporting the tops of the fuel bundles is different from other ABWRs, a vibration analysis of the fuel bundles during an earthquake was performed to assess their integrity. A total of 720 fuel bundles were modeled as beams and the extent to which the fuel bundles influenced each other by way of the coolant was modeled in terms of the imposed hydrodynamic load. To simulate how fuel bundles come into contact with each other, adjacent fuel bundles were linked using gap elements.

An analysis of the vibration response when the fuel bundles were subjected to artificial seismic waves was conducted and found that the maximum displacement of the fuel bundles occurred on the edges of the core due to the influence of the core support frame, as shown in Fig. 13. Testing also found that the maximum bending moment in the fuel bundles was similar to the ABWR(3). In the future, Hitachi intends to make improvements to this analysis technique and use it to study control rod insertion performance.

In research undertaken under contract with the Electric Power Research Institute (EPRI), Hitachi requested a US university to conduct studies from 2007 to 2011 that included TRU fission performance and safety. These studies found no fatal flaws that would prevent the design from being implemented(4). Subsequently, Hitachi embarked on joint research using a more accurate analysis technique developed by the US university(5). Hitachi also intends to participate in ongoing study of the nuclear and thermal viability of the RBWR and to work on improving the accuracy of techniques for predicting the critical power of fuel bundle(6).

This section has presented an overview of the RBWR and recent development progress. In the future, Hitachi hopes to establish technology for reducing the load on the environment by conducting further studies on reducing the hazardousness of high-level waste.

CONCLUSIONS

This article has described the status of some of the work done by Hitachi on technology for improving the safety of nuclear power generation. While the situation surrounding nuclear power generation has changed significantly since the accident at the Fukushima Daiichi Nuclear Power Station, Hitachi will continue striving to restore faith in nuclear power through ongoing work to make the industry even safer while drawing on the lessons learned from the accident.

Hitachi also intends to make an active contribution in response to increasing international demand for energy by applying the results of this work to nuclear power generation in Japan and other countries, and by supplying it in the form of safe and reliable technology.

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Featured Articles

Development of IT Facility Advanced Management & Maintenance System Solution for Power and Energy System Service Businesses

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OVERVIEW: With terms such as Industrie 4.0 and the Industrial Internet (1) trending in the market, there has been a rise in demand for advanced facility management and maintenance systems that use IT to maintain corporate production facilities and energy facilities, predict failures from online monitoring or data acquisition, and undertake preventive measures. Hitachi has responded to this demand by using the IoT to develop an advanced maintenance system platform, and by providing actual advanced maintenance services including failure prediction. This platform is called CMMS. This article provides an overview of CMMS and discusses examples of its application to maintenance services in the form of gas engine generation equipment, high-voltage motors, and photovoltaic equipment.

INTRODUCTION

THE power and energy sectors are attempting to connect the information technology (IT) known as the Internet of things (IoT) to maintenance services. While the equipment in these sectors use large numbers of sensors to monitor conditions remotely, it also needs failure prediction capability. A shortage of experienced maintenance technicians is creating growing demand for maintenance assistance systems that can enable maintenance work by less-experienced maintenance technicians.

With attitudes toward maintenance changing, one trend that has arisen is the division of maintenance approaches into after-the-fact maintenance, time-based maintenance (TBM), and condition-based maintenance (CBM) approaches in accordance with equipment performance and maintenance cost. After-the-fact maintenance is maintenance that is done to repair failed parts or broken equipment after problems arise. TBM is maintenance that is done to repair/replace old or malfunctioning parts discovered during periodic inspections. CBM is maintenance that is done by detecting failures, errors or other condition changes before emergency stops are generated.

Power Systems Company, Hitachi, Ltd. and Hitachi Power Solutions Co., Ltd. (Hitachi Power) have provided maintenance services to the power and energy sectors for many years. In response to the maintenance environment described above, both companies together have spent about three years developing an advanced IoT-driven maintenance system platform, and have been using it to provide advanced equipment maintenance services. This article provides an overview of these activities, and presents some example applications of the platform developed.

OVERALL CONCEPT OF CMMS

Hitachi's computerized maintenance management system (CMMS) is an IT platform that enables advanced facility maintenance. Fig. 1 illustrates its overall concept. CMMS assists CBM by providing early detection of changes in facility conditions. When condition changes are difficult to assess, experienced maintenance technicians from multiple maintenance sites provide logistical support that ensures high-quality maintenance work.

CMMS Software Configuration and Features

This software is an IT platform that provides eight functions to assist in all areas of maintenance work. The eight functions are used for (1) equipment management for managing equipment installation locations, configurations, and failure histories, (2) document management for managing documents

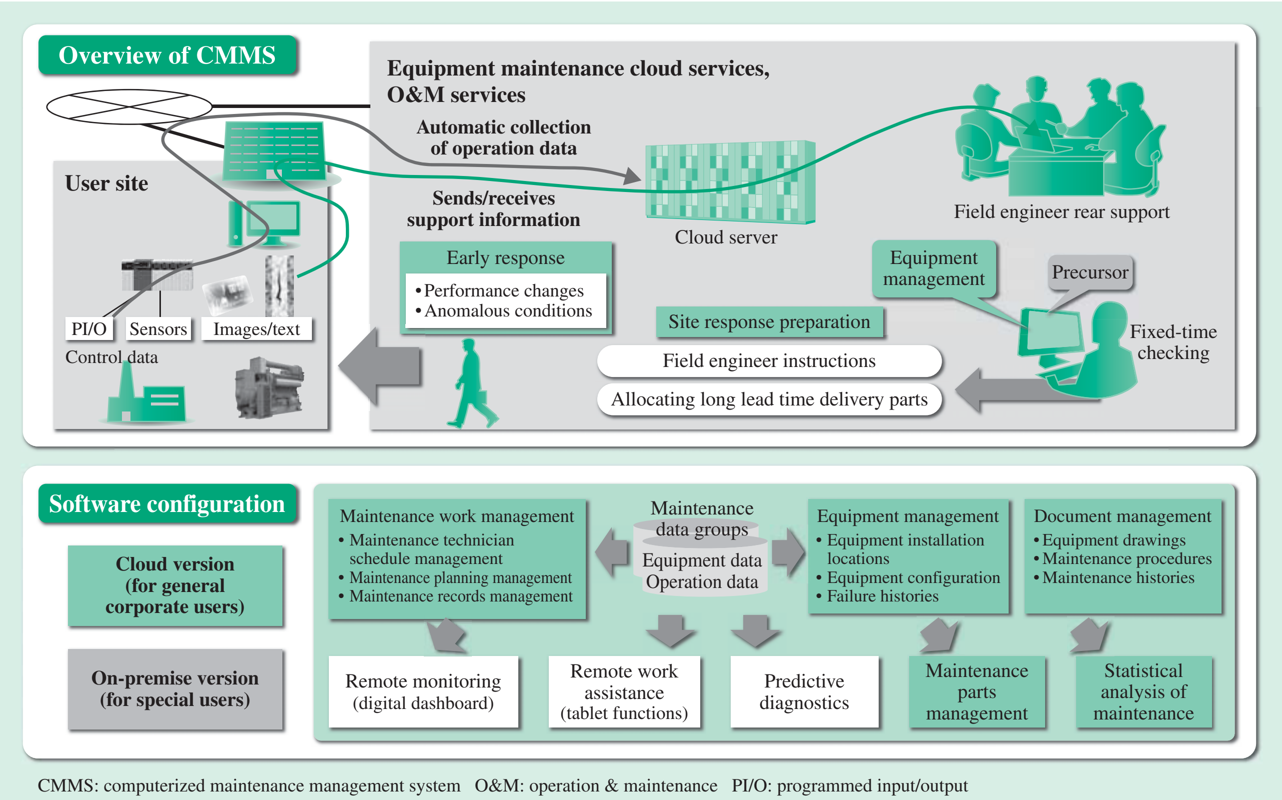

Fig. 1—Overall Concept of CMMS.
The illustration shows the concept of the CMMS platform, which provides services such as remote monitoring, remote work assistance, predictive diagnostics, equipment management and document management and assists with advanced maintenance work.

such as equipment drawings and maintenance procedures, (3) maintenance work management that assists with work such as maintenance planning and maintenance technician scheduling, (4) maintenance part management for managing the inventory of replacement parts and storage locations, (5) remote monitoring using digital dashboard technology, (6) remote work assistance using tablets or mobile terminals, (7) predictive diagnostics to notify of changes in equipment conditions, and (8) statistical maintenance analysis to statistically analyze gathered data.

This system is available in two formats tailored to different user characteristics (such as whether the user permits data removal) and equipment characteristics (geographical distribution). For general users, the cloud-based version provides it as a service. For special users, the on-premise version provides as a system.

The sections below provide a detailed look at three characteristic functions among the eight functions provided by CMMS—the functions for predictive diagnostics, remote monitoring, and remote work assistance.

Predictive Diagnostics System

The Hitachi Power Anomaly Measure Pickup System provides early detection of unusual conditions in equipment by combining the maintenance service expertise that has accumulated over many years with information and communications technology (ICT) and data mining technology (see Fig. 2).

This system detects a variety of abnormal conditions such as failure precursors that can superficially resemble normal operation, parameters set incorrectly due to human error, and differences in input materials or material quality. Early detection and remediation of these abnormal conditions can prevent sudden equipment shutdowns or drops in quality.

Anomaly detection is done by using data mining technology for vector quantization clustering (VQC) or local subspace classifiers (LSCs). Since both of these methods are nonparametric algorithms, their statistical effects are low, and they enable rapid system configuration since no model construction is required (see Fig. 3). In addition to these benefits, the processing needed to output results can be done rapidly, making these methods good at detecting anomalies in transient conditions.

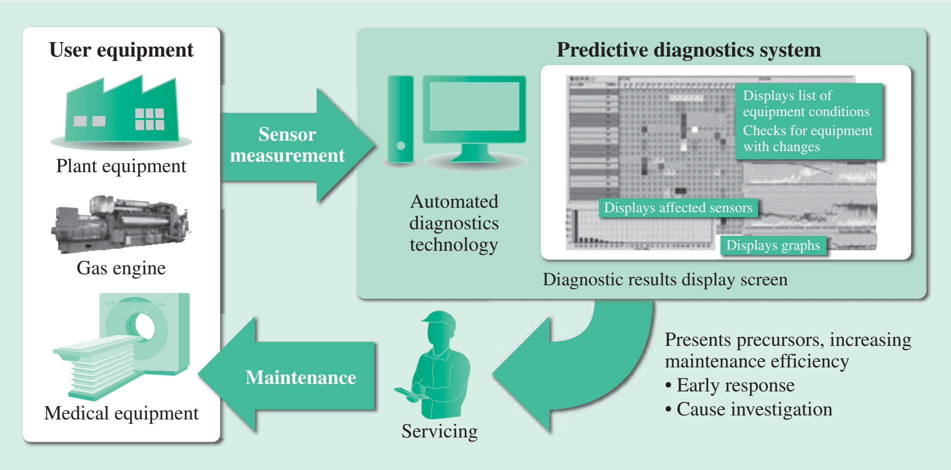

Fig. 2—Predictive Diagnostics System.
The predictive diagnostics system provides data-gathering/storage, diagnostic processing and display of results, as well as early detection of changes in conditions to help infer causes.

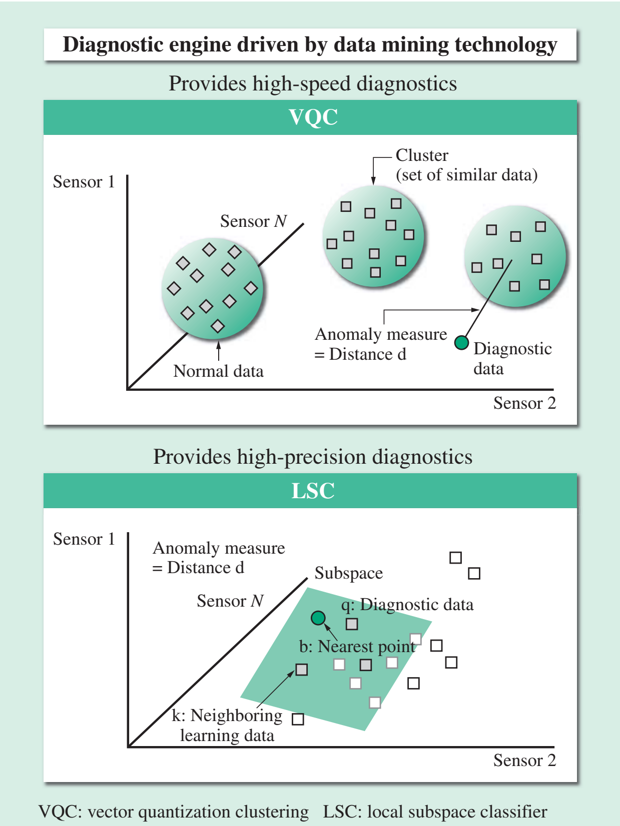

Fig. 3—Diagnostic Engine.
The diagnostic engine uses equipment operating conditions and sensor signal movements to select optimal diagnostic algorithm and implements it in the system.

This system applies machine learning to data gathered from equipment sensors to learn the normal (usual) data patterns, and to evaluate whether anomalies are present by analyzing the degree of deviation between the routinely gathered data and learned data. If an anomaly is detected, the cause can be surmised from the types of sensors that have the greatest impact on the deviation, and the degree of deviation detected. The criticality level can then be assessed.

By giving maintenance technicians early notice of unusual condition information, this system can prevent failures and ensure replacement part lead times.

Hitachi is planning to enhance this system by adding to its predictive detection ability with a function that will surmise failure causes by comparing the results of past failure analysis with predictive analysis results.

Remote Monitoring (Digital Dashboard)

The remote monitoring function uses digital dashboard technology to provide centralized round-the-clock monitoring of equipment warnings, sending equipment operation statuses to the user. The function provides timely response instructions to maintenance technicians, and maintenance information in cooperation with design department technical support.

This digital dashboard assists with remote monitoring of equipment and machinery, enabling the optimal display for unified management of the operation statuses of multiple pieces of equipment.

One feature of the remote monitoring function is the method for gathering and sending data. Output values from equipment or machinery sensors are sent to a server with unique IDs identifying each sensor value. Each user terminal can specify these sensor value IDs to display the desired values, then the server can use them as keys so that only the sensor values that need to be displayed are sent to the user terminals. This method ensures that information is sent in realtime with no lags caused by drift between the database information storage cycle and the cycle in which the database is referenced by the user terminals (see Fig. 4).

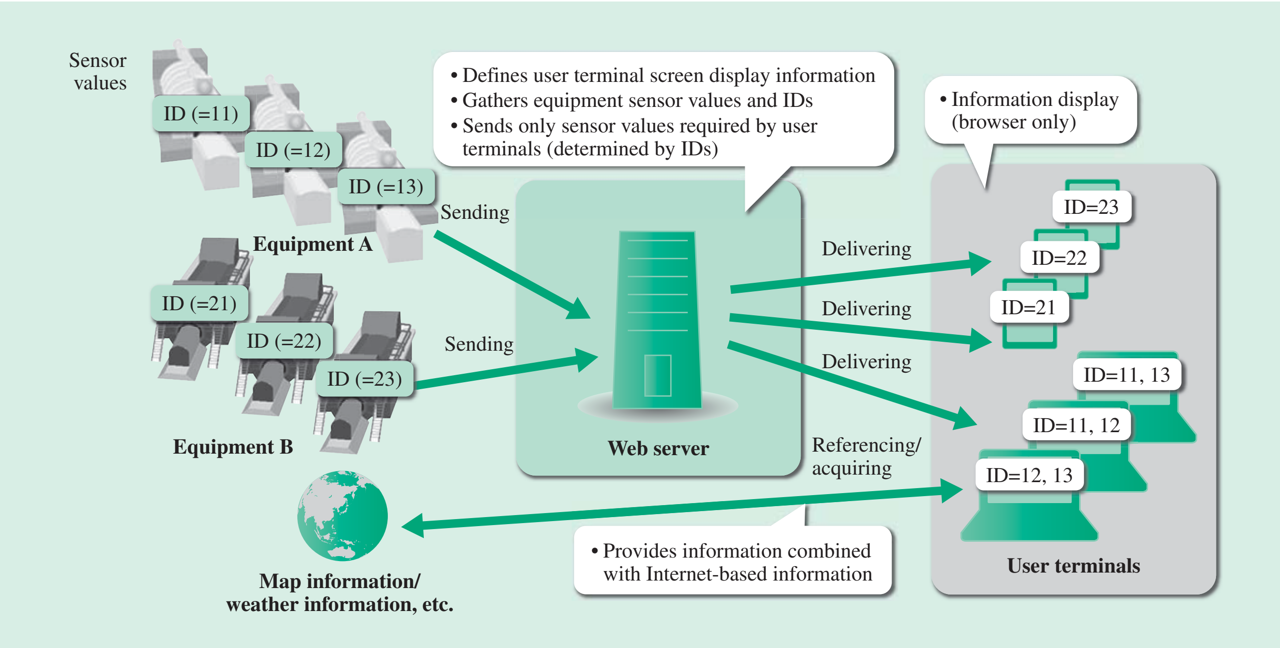

Fig. 4—Digital Dashboard Configuration Example.
The digital dashboard provides unified management of multiple facility operation conditions, enabling optimal display.

When sensors are added or changed as equipment is upgraded or expanded, the function can be flexibly adapted just by reworking the user terminal screen design, with no need to revise the data-gathering and distribution processes or the database structure.

Trend graphs, bar graphs, lists, image information, and other information elements on the user terminal display screens are implemented as modules, which makes it easy to change screen layouts and enable or disable the display of particular elements. The user terminals also provide map information(2), weather information(3), and other information combined with information from the Internet. These features enable the screen design and the information provided to be tailored to the user's needs (see Fig. 5).

Fig. 5—Output Screen Example.
Screens can display sensor information in forms such as images, trend graphs, and bar graphs.

Remote Work Assistance

The remote work assistance function seamlessly links the tablet terminals of maintenance technicians on sites to the logistical support environment at the center. It enables the proper work instructions to be provided in the form of videos, images, recordings, and written documents to assist with the safety and precision of site work (see Fig. 6).

In the future, Hitachi intends to draw on its many years of accumulated maintenance service expertise to make further refinements to the IT platform, helping create more advanced maintenance technologies. This will create and expand advanced maintenance business opportunities, providing maintenance services and remote monitoring systems for power generation equipment and other key infrastructure equipment.

APPLICATIONS

Applications for Gas Engine Power Generators

The Ohnuma Works, Hitachi Power (located in Hitachi, Ibaraki Prefecture) provides maintenance services for small gas engine power generators throughout Japan. To enable predictive diagnostics for these small gas engine power generators, the factory started developing a predictive diagnostics system in 2008. Actual equipment use and operation testing/

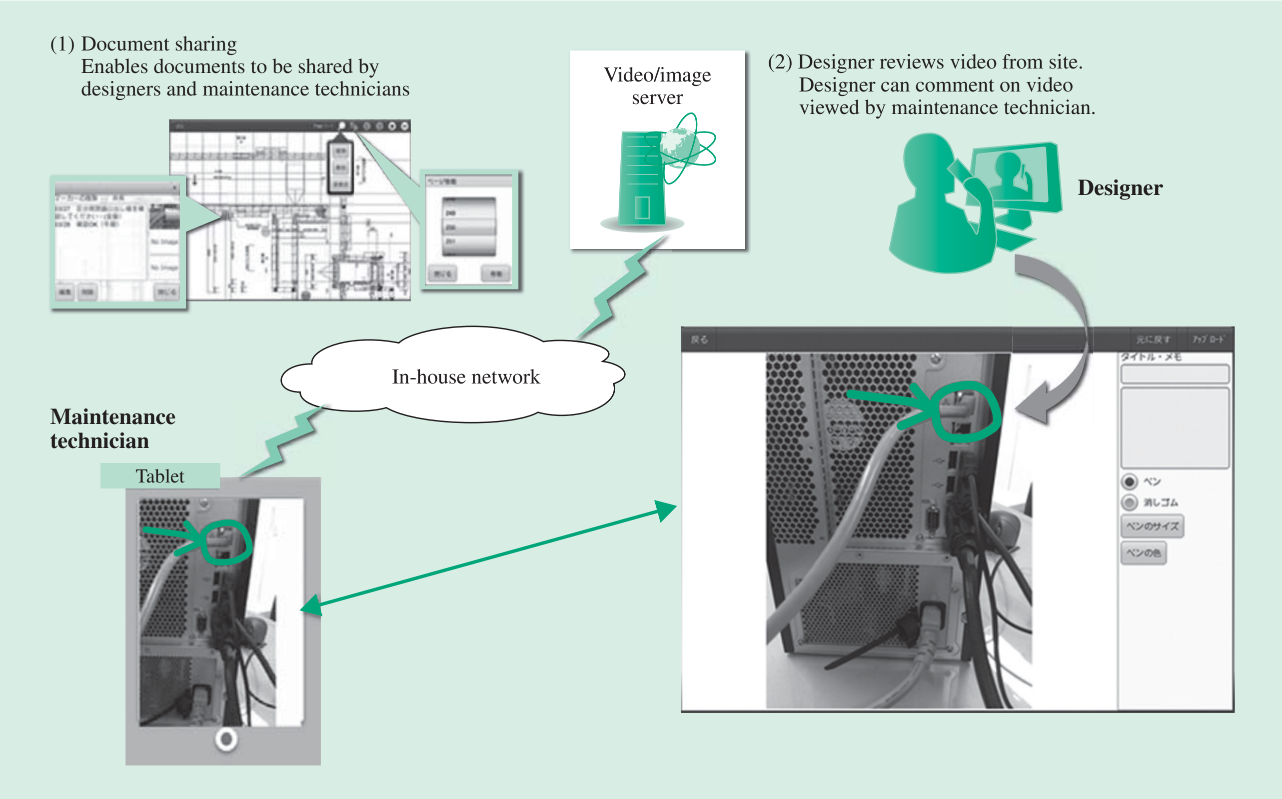

Fig. 6—Remote Work Assistance Function.
The remote work assistance function seamlessly connects the site terminals to the logistical support environment, providing the proper instructions to assist with the safety and precision of site work.

evaluation started in FY2011, and this system is now being used in 160 generators.

Specifically, about 30 sensor signals measured in 30-second cycles are diagnosed daily. The system has shown positive results, detecting up to about 70% of failure causes (see Fig. 7).

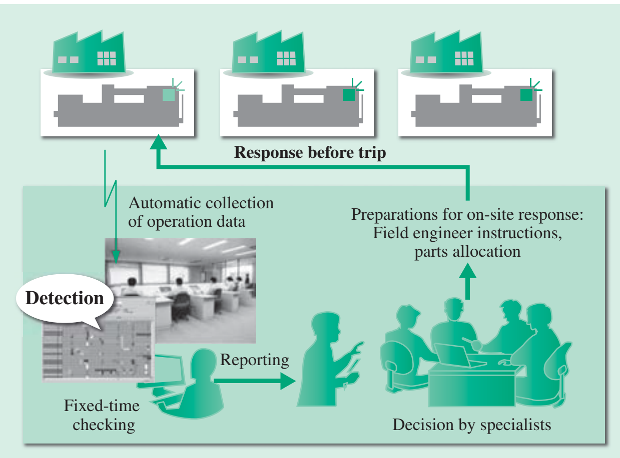

Fig. 7—Operation of Predictive Diagnostics System.
Predictive diagnostics system results are checked daily, enabling response before problems arise.

Anomalies have traditionally been evaluated using threshold values, but the effects of individual unit characteristics and seasonal changes in installation environments result in inadequate detection precision. The use of Hitachi's predictive diagnostics system is now providing benefits and enabling the detection rate stated above.

Motor Maintenance Service

The mainstream approach to motor maintenance has always consisted of routine inspections combined with after-the-fact maintenance in the form of response measures taken when signs of problems arise. When these signs arise, technicians have traditionally made assessments based on sensory evidence—measuring parameters such as vibrations to manage absolute values, listening for abnormal sounds, and taking similar steps. Routine inspection management has also largely consisted of recording daily inspection items and speaking to users, which is a method that is not well adapted to trend management with a time-series axis. Hitachi has improved this approach using trend management that incorporates predictive diagnostic technology.

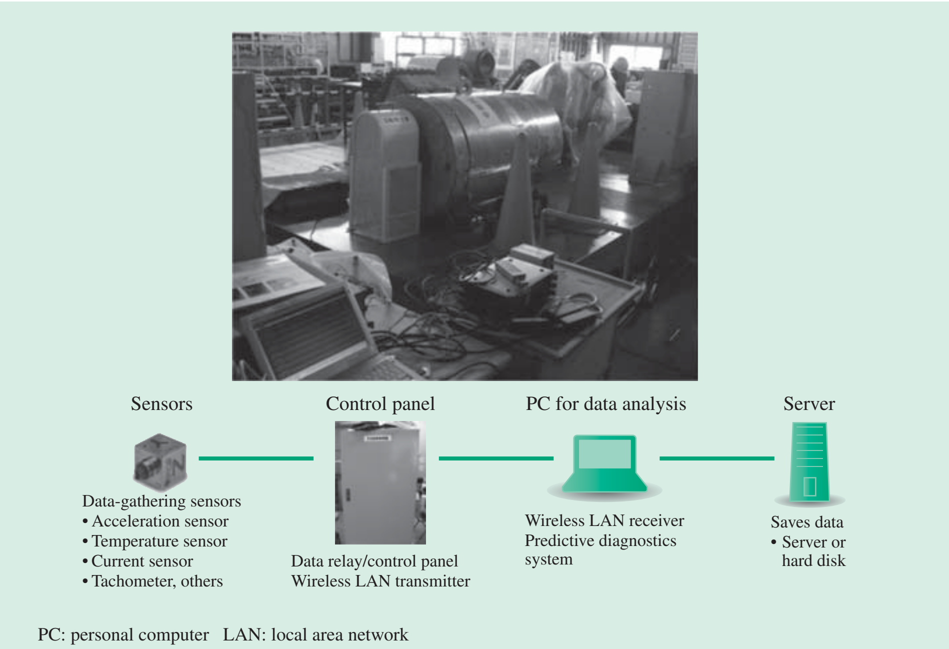

Fig. 8—In-house Verification Testing and Test Configuration.
To verify the accuracy of the analysis/precursors, continuous operational testing is performed on aging motors up to the point of motor bearing burnout.

As shown in Fig. 8, Hitachi's predictive diagnostics service for motors is provided by repeatedly performing in-house verification testing while using this system as a uniform integrated tool to handle processes ranging from data-gathering to analysis and diagnoses of degradation trends and failure precursors.

The features of Hitachi's predictive diagnostics system for motors include:

(1) 24-hour automated data-gathering and analysis
(2) Hitachi's 24-hour monitoring service
(3) Threshold value management (conventional)
(4) Trend management
(5) Expandability to all equipment that include motors

In addition to conventional threshold value management, signs of problems are also detected by comparing process trends using Hitachi's predictive diagnostics technology. This approach is highly effective for equipment that makes it difficult to analyze data under uniform conditions due to a changing ambient environment or changing loads. Moreover, the system's automated gathering and storage of maintenance and management information is beneficial since it lets equipment maintenance staff devote themselves to the work needed for other equipment or production. Hitachi also has a remote monitoring center, and can provide 24-hour monitoring of equipment statuses at the user's request.

O&M Service for Photovoltaic Equipment

Japan's photovoltaic market has expanded greatly since the start of a feed-in tariff (FIT) system in July 2012. It is important to minimize drops in the utilization factors of constructed photovoltaic power generation equipment through early detection of failures and rapid repairs, and there is a growing demand for high-quality operation and maintenance (O&M) services.

This section looks at the solar panel failure diagnostics service Hitachi has developed independently.

Solar panel failure diagnostics is generally conducted using string monitors (a string is a unit consisting of multiple photovoltaic modules connected in a series). This method requires sensitivity to be set low to prevent false-positives since anomalies are assessed by relative comparisons to adjacent strings or average values. To solve this problem, Hitachi has developed a failure diagnostic model that uses the physics of semiconductor devices to enable high-precision diagnoses by comparison with theoretical values(4).

Fig. 9 illustrates an example application of this diagnostic model for a typical string monitor. In this example, a crack has occurred in the glass of a single solar panel—a problem difficult for a string monitor to detect but clearly detected using Hitachi's failure diagnostic model.

In addition to strings, this diagnostic model can also be applied to sensing targets such as connection boxes or power conditioning systems (PCSs) according to the customer's needs.

Diagnostic ability varies according to the sensing target and failure mode, but power generation capacity

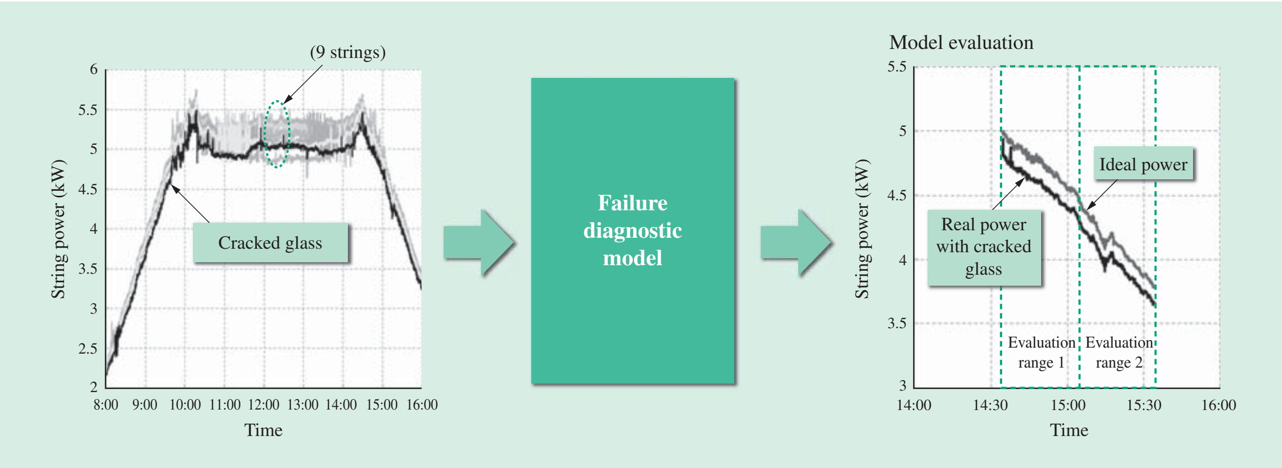

Fig. 9—Failure Detection Example.
A single cracked solar panel undetectable with a string monitor can be detected using Hitachi's failure diagnostic model.

drops of 2.5% or more are generally detectable. Providing online monitoring over a cloud environment enables early failure detection and a reduction in equipment investment.

CONCLUSIONS

Hitachi's advanced IT facility maintenance system has been used for maintenance of gas engine power generation equipment, large motors, photovoltaic power generation equipment, and other power and energy products to improve the added value of equipment maintenance/remote monitoring services.

In the future, Hitachi plans to refine the functions of this system as an equipment maintenance platform to expand its application to products in other fields, and to help provide services tailored to the needs of customers.

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Featured Articles

Development of IT-driven Power Plant Engineering Work Support Systems

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Noriaki Yamamoto
Kenji Oya
Atsuko Enomoto, Dr. Eng.
Hiroshi Seki

OVERVIEW: Rapid and detailed estimates for planning installation or replacement of equipment, or maintenance work are key requirements for meeting the demands for greater power plant reliability and lower costs, and for maintaining safe and secure operation. Hitachi has addressed these demands by developing technology driven by the latest IT. When replacing equipment at complex power plants with high equipment density, the existing state of the installation locations and transportation routes for old and new equipment need to be properly measured. Hitachi has met this need by developing parts recognition technology based on 3D measurement. When decommissioning nuclear power plants, work needs to be done safely and efficiently, minimizing exposure caused by handling of radioactive waste. Hitachi has met this need by developing a technology that applies estimated dose rate to 3D models to enable high-speed calculation of optimal routes for carrying materials in/out. This article provides an overview of these development projects.

INTRODUCTION

SATISFYING the complex web of client requirements and site conditions when constructing a new facility such as a power plant, steel mill, chemical plant or oil refinery requires a wide variety of engineering work. This includes environmental assessment, civil engineering/construction, equipment design, equipment procurement, installation, and trial operation/handover. Plant maintenance also requires advanced and detailed engineering work to diagnose component equipment, machinery, and devices, and to repair/replace them as needed to maintain safe and stable operation. When providing engineering services to clients for new plant construction or maintenance, detailed and rapid estimates of costs and work schedules need to be created. To meet these needs, Hitachi has developed several technologies designed to enable more advanced engineering work through use of the latest information technology (IT).

This article looks at plant maintenance and replacement. Plants of between 30 and 50 years old sometimes only have original design drawings in two dimensions (2D), or have undergone so much maintenance over the years that their plumbing or equipment systems have become unrecognizable from the original drawings. Basing a project plan on the existing state of the plant is an important requirement in these cases.

Hitachi has met this requirement by developing an ‘as-built’ modeling technology based on three-dimensional (3D) measurement and a technology for planning approaches to plant construction/decommissioning based on 3D models (described in the following chapters).

EFFORT TO IMPROVE EFFICIENCY OF SITE STUDIES

Power plant replacement projects consist mainly of removing the items that need to be upgraded, and installing the new equipment. When planning each operation, a key requirement for large plants is to identify the actual state of the surrounding environment to answer questions such as whether there are any obstacles in the transportation routes for removal and installation, or whether reliable connections can be made to existing equipment items. Specifically, the site is surveyed to identify locations to be added or moved, locations that have been transformed by many years of operation, and other site-specific issues. The results of these studies are then used to create

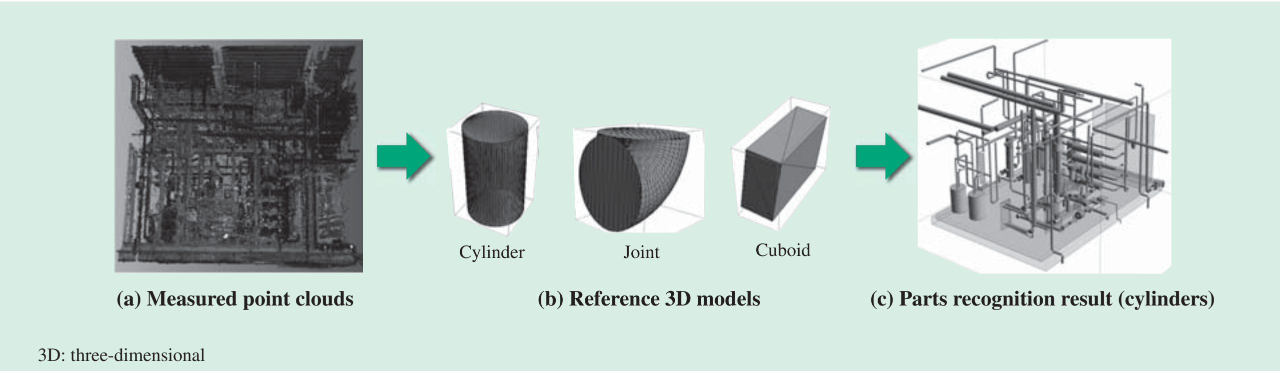


Fig. 1—Parts Recognition from Measured Point Clouds.
(a) Shows measured point clouds for pipe equipment (25 measurement locations, 250 million point clouds). (b) Shows some of the basic-shape reference 3D models (cylinder, joint, and cuboid). (c) Shows an example of cylinders recognized automatically from the measured point clouds.

structural designs and process designs. To increase the efficiency of processes ranging from design to installation, and to eliminate the need for skill in site studies, Hitachi has worked on using 3D measurement by long-distance contact-free laser scanners to enable rapid measurement of existing site conditions.

Laser scanners have recently come into wide use in fields such as civil engineering, construction, and surveying. But measured point clouds contain noise, and since point cloud data is massive, generating as-built models requires extensive manual labor. This chapter discusses technology for recognizing parts from measured point clouds, and reverse engineering technology used to generate data for 3D printing from measured point clouds. These technologies are designed to reduce the lead time from site study to client design proposal.

Technology for As-built Modeling from Measured Point Clouds

Hitachi has developed technology that detects the deviation between a measured point cloud and reference 3D model, and automatically generates an as-built model that reproduces the actual shape(1). Specifically, the technology involves the following three steps.

First, a preprocess is performed in which the 3D model is transformed into polygons, and the polygons are divided into triangular meshes. The divided triangular mesh connections are then transformed into a graph network model. Finally, network analysis is used to recognize basic shapes such as cylinders, joints and cuboids, and the distance between each recognized basic shape and the measured information is minimized to generate an as-built model.

Hitachi has verified the developed technology using measured point clouds of piping equipment (25 measurement locations, 250 million measured point clouds) and reference 3D models (cylinders, joints, cuboids). The parts recognition processing time was 315 minutes, and the recognition rate was 95%, with 440 out of 463 parts successfully recognized (see Fig. 1).

These study results come from joint research done with the Hungarian Academy of Sciences(1).

Measured Point Cloud-based Data Compensation Technology

To 3D-print a measured point cloud, surface information must be added to it. One method of doing so is to generate triangular meshes. But when the point cloud data volume is large, the computational complexity increases to immense proportions. Another problem is the effect of noise contained in measured point clouds, which can result in generated surface information that does not conform to the original shapes. And, because there are blank spots in the 3D measurements of one location when there are complex irregularities, it is necessary to integrate the point clouds for 3D measurements in multiple locations.

Hitachi has developed technology that uses point clouds measured in 3D with a laser scanner to generate 3D printing data for a plant facility of about 5.1 (W) × 3.3 (H) × 20.0 (D) meters in size. The measured point clouds are a combination of measurement results from 11 locations around the facility, made up of point cloud data of about 1 billion points.

Although combining measured point cloud data from multiple locations can reduce the number of blind spots, acquiring point clouds without any

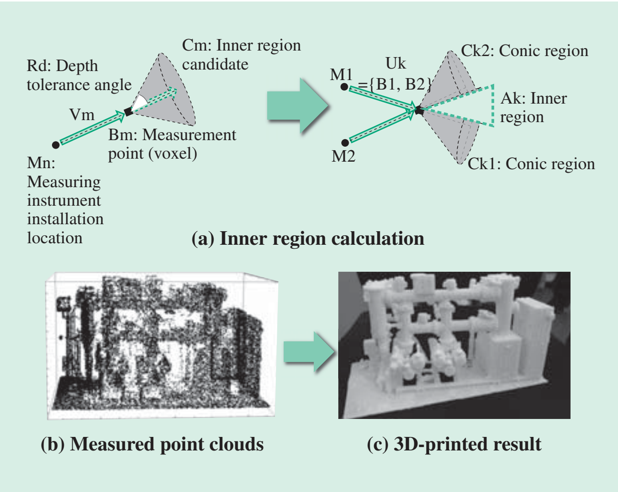


Fig. 2—Measured Point Cloud-based Data Compensation Technology.
(a) The inner regions were calculated using measured point clouds from the locations at which the measuring instruments were installed. The 3D-printed result (c) shows that the technology can compensate for omissions in the measured point clouds (b).

structural omissions whatsoever is difficult in practice. Hitachi has addressed this problem by developing technology that can handle measured point clouds that contain omissions by compensating for the structural discontinuities when generating the 3D printing data.

Specifically, the technology works using the following four steps. First, the point cloud data is transformed into unit lattice (voxel) data of specific dimensions. Only the voxels that contain the set number of point cloud data points are then extracted. For each voxel, the measurement angle is then determined from the position of the laser scanner during 3D measurement, and this measurement angle is used to calculate the inner region of the object [see Fig. 2 (a)]. Finally, the voxels inside the object are compensated for.

3D printing of the measured point clouds for the plant facility demonstrated that this development method can compensate for the data of omitted locations inside of objects [see Fig. 2 (b) and (c)].

Models of the 3D printing results before and after the application of this technology were used to study the locations of structural discontinuities. It was found that the 120 discontinuities that existed before application of the technology were reduced to just 20 discontinuities afterward, demonstrating that the technology could automatically compensate for omissions.

Conventional data compensation processing takes about one month. The usual method is to generate triangular meshes from measured point clouds, visually check parts that vary from the as-built information by taking photographs, and then make revisions manually. Hitachi's 3D print data generation technology has been able to reduce the time required to about seven minutes.

EFFORT TO ENABLE MORE ADVANCED CONSTRUCTION/DECOMMISSIONING PLANNING

Installation Work Planning Simulator

When constructing or replacing substation equipment, a large amount of plant-assembled and plant-inspected equipment items are successively installed at the site. The equipment items are heavy, so they are lifted by crane for transport, positioning, and connection work. These processes require studying the installation sequence and creating work plans after taking into account difficulties in making equipment parts fit each other in three dimensions, and the temporary placement of equipment delivered to the site. It is difficult to visualize with 2D drawings. Besides, the process of planning the installation of substation equipment items requires a lot of experience and specialized knowledge (see Fig. 3). Therefore, Hitachi

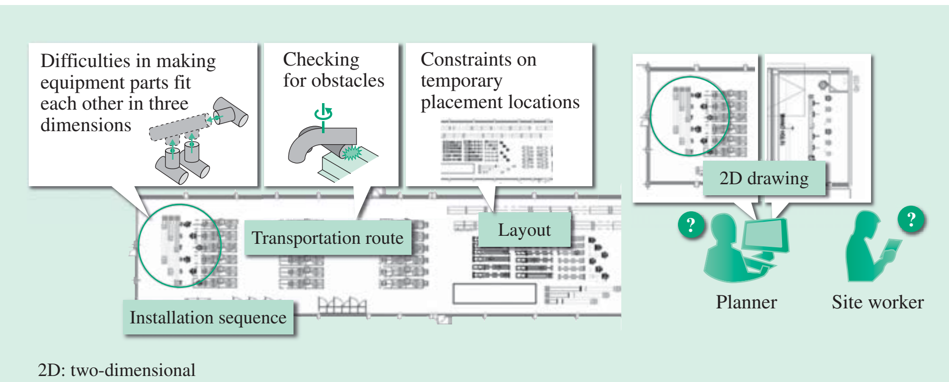


Fig. 3—Installation Work Planning Challenges.
Preliminary studies are required for various cases, such as difficulties in making equipment parts fit each other in three dimensions, obstacles to work operations, and temporary placement layout.

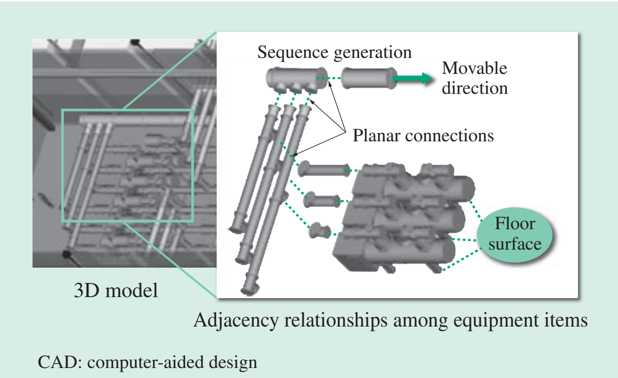


Fig. 4—Automated Generation of Installation Sequence from 3D Model Adjacency Relationships.
The results of analysis of adjacency relationships are used to derive the directions in which the equipment to transport can be disassembled, to derive the disassembly sequence, and to convert this information into an installation sequence.

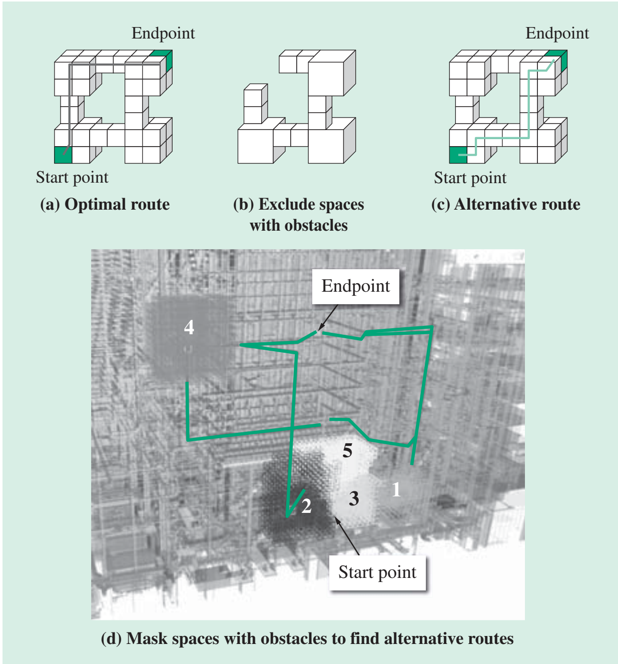


Fig. 5—Method of Suggesting Alternative Routes.
(a) Shows the optimal route. (b) Shows the spaces excluding spaces with obstacles. (c) Shows an alternative route. (d) Shows the obstacle spaces that were excluded for alternative route finding.

has developed technology for generating installation work instructions represented by 3D animations[2].

Specifically, this technology automatically analyzes the geometrical adjacency relationships among equipment items in 3D models, and derives the direction normal to two adjacent surfaces in which disassembly operation is possible. It also uses the layout positions of partially installed or temporarily placed equipment items to detect obstructions on operation routes and to generate the installation sequence (see Fig. 4). The generated sequence is used to create 3D animations showing the site transportation sequence, temporary placement layout, and overhead traveling crane operation. The animations can be used to study the work beforehand, enabling safe, high-quality installation work.

Large Equipment Carry In/out Simulator

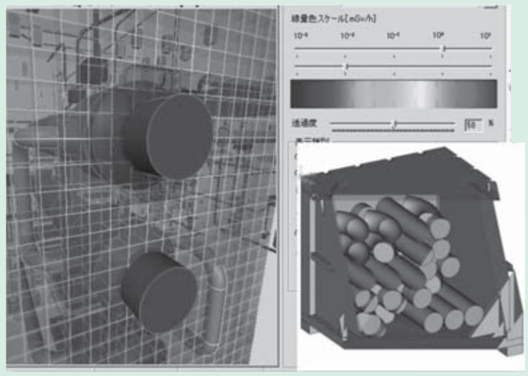
It is difficult to estimate the man-hours required for carrying large equipment in/out of nuclear power plants in maintenance and decommissioning. Therefore, it becomes one of the important factors that cause schedule delays. To protect from radiation exposure, nuclear reactor buildings have complex and cramped spaces. Besides that, the location differential between computer-aided design (CAD) models and real buildings can result in unexpected collisions when carrying equipment in/out. To overcome these issues, Hitachi has developed an alternative route finding method that can flexibly adapt to the real site situation[3].

Fig. 5 illustrates the method developed to find some alternative routes. First, a 3D space with building facets is finely divided into cuboids. Dijkstra's algorithm is then used to find the optimal route passing through cuboids not containing building facets, having the fewest number of turns, and with the most spare room. If there are any obstacles in the real building along the calculated optimal route, then the respective cuboids located on the obstacle are deleted. Then, another optimal route is searched for as an alternative.

The locations of obstacles are acquired from point cloud data measured at the real building over the Internet. A high-speed route finding technique is required to enable alternative route suggestions to be fed back to the site immediately. Facet data of plant buildings can be as much as 10 Gbyte. Developed technology is implemented using parallel computing on a graphics processing unit (GPU), achieving a high processing speed. It can output one route in 1 minute or less, which is about 200 times faster than a single-core CPU.

Automation of Large-scale Waste Quantity Estimation

To calculate the quantity of radioactive waste generated when decommissioning nuclear power plants, Hitachi has used 3D models to create a database for spatial distributions of dose rate. Spatial dose rates are calculated using the Particle and Heavy Ion Transport



CAD: computer-aided design

Fig. 6—Example of Spatial Dose Rates and Visual Representation of Waste Containers.
The spatial dose rate calculation results are loaded into a 3D CAD system, and a visual representation of the work environment is created. A model is created to represent the state of the cut waste items stored in the containers.

Code System (PHITS)[4] in the database for later use. Then, intelligent 3D models are created using a CAD system to create a visual representation of the calculated doses, creating a function for filtering the display to show spatial ranges with doses rates above a specific level[5].

Fig. 6 shows the spatial dose rates and results for storage of cut pipes in a container. The CAD system is used to create a visual representation of the spatial dose rate calculation results, and has shown that it can be used to calculate changes in the number of containers resulting from changes in the dimensions the pipes were cut to. Radioactive waste quantities that have previously been calculated by weight can now also be calculated by volume or number of containers. Waste that has a high radioactivity level is managed by burying it underground for 300 years. By fitting waste items with tags for individual item management and dosimeters for measuring radioactivity near containers, waste can be managed for long periods using the Internet of things (IoT).

CONCLUSIONS

This article has looked at some of the plant maintenance and replacement technologies Hitachi has developed that are driven by the latest IT. These technologies are used for reverse engineering plant construction in conformance with site surveys, and for preliminary engineering done for construction work using plant models. These technologies are now being applied to thermal power plants in other countries, and trial use has started for substation replacement projects in Japan. For nuclear plant decommissioning applications, Hitachi has started detailed studies with engineering work using specific plant data. As IT functions become more advanced, recognizing worker behaviors in addition to objects will become practical, and it will be important to manage the progress of complex maintenance/replacement projects in realtime with IT systems. These advances will enable higher plant utilization rates and longer equipment life, enabling highly efficient construction and maintenance of safe and reliable social infrastructure platforms. Hitachi will continue to develop technologies to meet this objective.

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