Energy Solutions

1 Outlook for Energy Solutions Business

Energy is one of the most fundamental and important parts of the social infrastructure. However, factors such as economic progress and the changing nature of society are making the requirements for energy more diverse. The following are five common challenges and customer requirements.

(1) The provision of reliable electric power in response to rising demand, particularly in emerging economies.

(2) Dealing with global warming

(3) Maintaining grid stability despite challenges such as the increased use of renewable energy

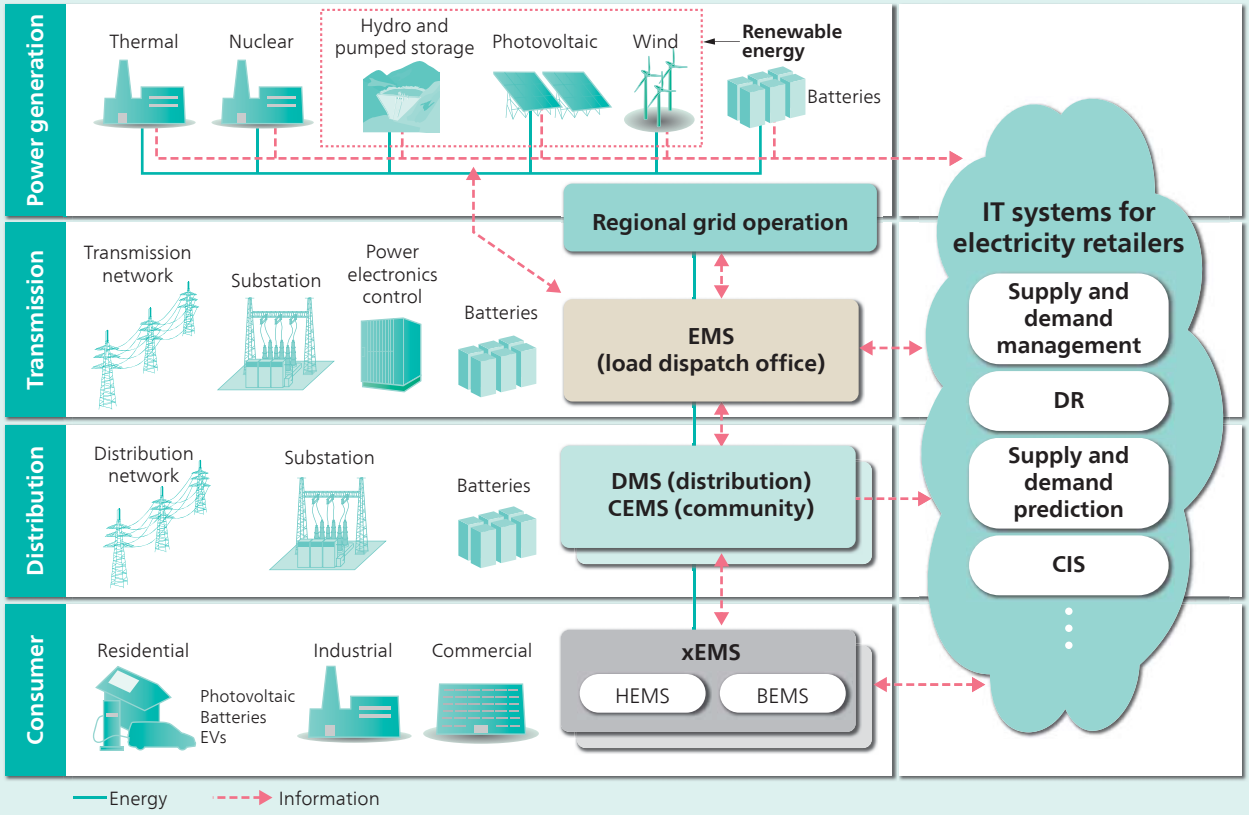
(4) Dealing with aging equipment

(5) Introduction of market principles to reduce electricity prices through competition

As the nature of these challenges and requirements vary widely depending on the customer's circumstances and other factors, the solutions lie not only in past business models based on the supply of equipment, but also demand open innovation involving the collaborative creation with customers and other external stakeholders of solutions to shared challenges, and thinking in terms of total solutions that combine operation technology (OT) with information technology (IT).

Hitachi established its Energy Solutions Company in April 2015 to engage in businesses in the electric power sector alongside its conventional equipment supply business.

Hitachi supplies total solutions from power generation to transmission and distribution as well as IT systems for electricity retailers.



EMS: energy management system, DMS: distribution management system, CEMS: community energy management system, HEMS: home energy management system, BEMS: building energy management system, EV: electric vehicle, DR: demand response, CIS: customer information system

1 Energy solutions from Hitachi

Power Generation Equipment and Systems

1 Chingshan Branch of Taiwan Power Company

1 Replacement of Four 96.13-MW/105-MVA Vertical-shaft Francis Turbines and Generators and Electrical Systems at Chingshan Branch of Taiwan Power Company

The Taiwan Power Company's underground Tachiachi Hydro Power Plant Chingshan Branch Power Plant, which commenced operation in 1973, was completely engulfed by landslides when Taiwan was struck by a devastating typhoon (Typhoon Mindulle) in July 2004. Redevelopment and reconstruction work on the power plant and surrounding area began in 2009, with Hitachi Mitsubishi Hydro Corporation being part of a consortium along with Taiwanese suppliers that won an order and contract in November 2011 for the replacement of four turbine and generator sets, including control and substation equipment. Although on-site work commenced in December 2012, because the plant is located in steep mountainous terrain in central Taiwan, this work was often interrupted due to landslides that made access roads impassable. Despite these very difficult conditions, site installation and commissioning staff worked assiduously and completed on-site testing well ahead of the initial schedule. All four sets completed on-site testing in September 2015 and are sequentially being brought back into commercial operation.

It is anticipated that this replacement project will help Taiwan enjoy a more reliable supply of electric power.

The project also won a superior construction quality award at the 15th Public Construction Golden Quality Awards, the highest distinction for public works in Taiwan.

(Hitachi Mitsubishi Hydro Corporation)

2 Commencement of Operation after S&B of 10.9-MW/12-MVA Vertical-shaft Pelton Turbine and Generator at Mibugawa 2 Power Plant of Mibugawa Power Company

A scrap and build (S&B) project for the 10,910-kW vertical-shaft, single-runner, four-jet Pelton turbine and 12,000-kVA synchronous generator at the Mibugawa 2 Power Plant of Mibugawa Electric Power Co., Inc. was completed in December 2014 and the plant is now operating reliably.

Mibugawa 2 is a run-of-the-river power plant located in the Hase district of Ina City in Nagano Prefecture and is powered by water from the headwaters of the Mibugawa River in the Tenryu River system.

The main features are as follows.

(1) The turbine runner is highly efficient, with the latest design.

(2) The vertical shaft of the turbine uses water-lubricated polymer bearings that do not require lubricating oil.

(3) The generator thrust bearing uses polyether ether ketone (PEEK) polymer bearings to reduce bearing losses and eliminate the need for cooling water.

(4) Electric and electromagnetic systems are used to operate the needle, deflector, and brake to eliminate the need for hydraulics.

In future new hydroelectric power plant and S&B projects, Hitachi intends to help take advantage of renewable energy, reduce environmental risks such as oil leaks, and improve maintenance.

(Hitachi Mitsubishi Hydro Corporation)

2 Turbine-generator (barrel type) (top) and electric drive mechanism for needle and deflector (bottom)

3 S&B and Electrics Upgrade to Two 2,860-kW/3,000-kVA Vertical-shaft Francis Turbines at Kakinosawa Power Plant of JX Nippon Mining & Metals Corporation

Hitachi has completed a full upgrade of the turbines, generators, distribution panel switchgear, and substation equipment at the Kakinosawa Power Plant of JX Nippon Mining & Metals Corporation, with the plant resuming commercial operation in June 2015.

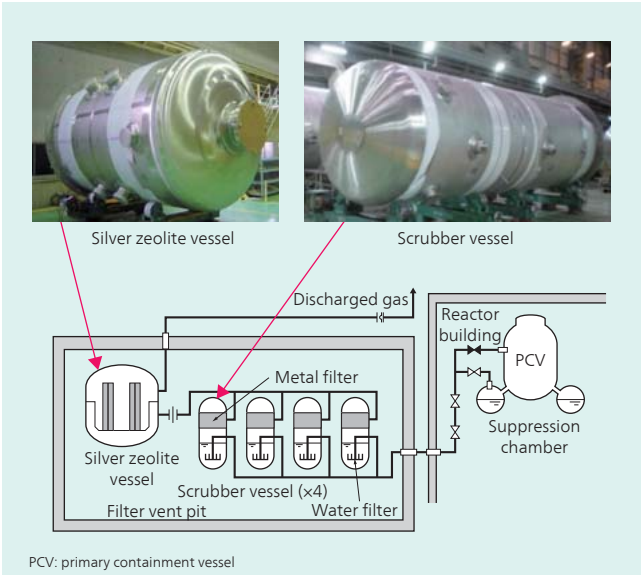
The upgrade of the generation system came roughly 60 years after the plant first commenced operation in 1955.

The upgrade has reduced environmental risks as well as improved maintenance by eliminating hydraulics and other auxiliary equipment using electric servomotors for the turbine hydraulics and air-cooled turbine bearings that do not require a water supply. To control the two turbine/generator units so as to make full use of the precious water energy resource and maximize electric power generation, the two units can be operated alone or together in response to the ever-changing water volume.

On-site work for the two turbine/generator units, which extended from dismantling and removal to assembly, was undertaken in parallel and completed in only 11 months. Hitachi anticipates that the upgrade will enable the plant to continue to operate reliably in the future.

(Hitachi Mitsubishi Hydro Corporation)

3 Kakinosawa Power Plant generator room (top) and turbine room (bottom)



4 Vent filter

4 Development and Deployment of Vent Filter

The purpose of a vent filter is to capture the radioactive material in a gas to prevent it from being released into the environment in large quantities when the gas needs to be vented into the atmosphere from the reactor containment vessel at a nuclear power plant, such as to prevent over-pressure failure of the vessel during a severe accident.

The vent filter for Unit 2 at the Shimane Nuclear Power Station of The Chugoku Electric Power Co., Inc. is made up of a stainless steel scrubber vessel (approximately 2 m in diameter and 8 m in height) and a silver zeolite vessel (approximately 3 m in diameter and 5 m in height). It was designed and developed by Hitachi using filter technology from AREVA GmbH that has already been deployed in Europe, and complies with Japanese standards and satisfies the space constraints for installation.

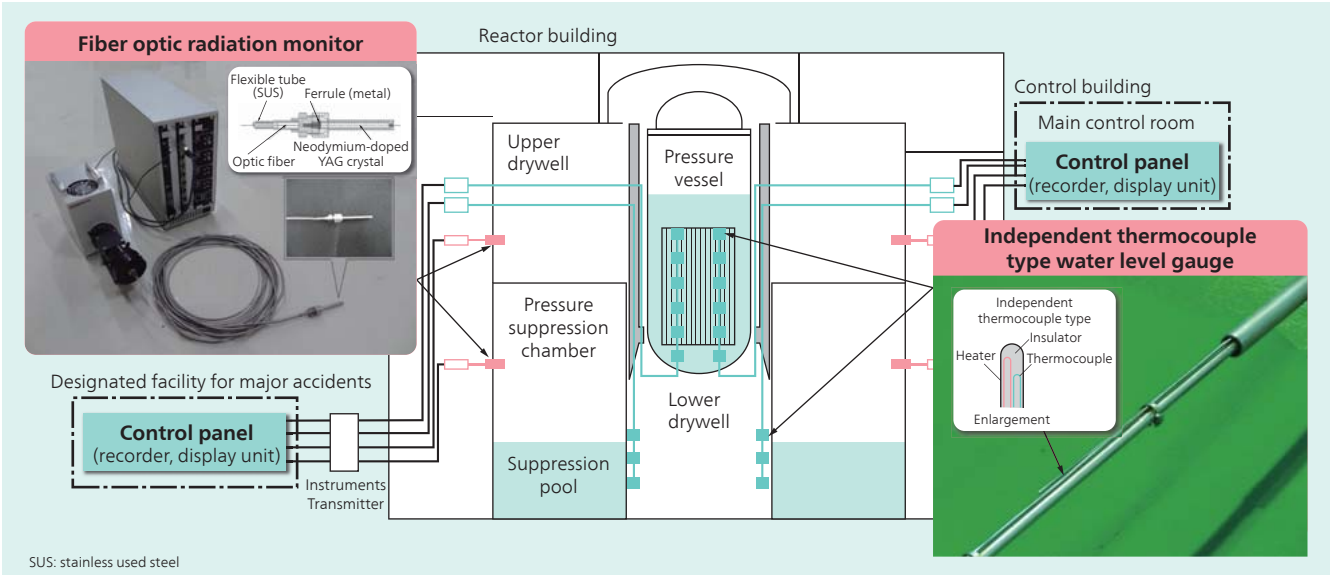
The scrubber vessel uses a water filter and metal filter to remove radioactive particles and inorganic iodine, and the silver zeolite vessel uses a silver zeolite filter to remove organic iodine.

[Installation: August 2014 (scrubber vessel) and April 2015 (silver zeolite vessel)]

5 Instrumentation System for Severe Accidents

To provide information about plant status in the event of a severe accident, Hitachi has developed an independent thermocouple type reactor water level gauge and a fiber optic radiation monitor that are able to operate under such conditions.

Unlike conventional water level gauges that use differential pressure, the thermocouple type reactor water level gauge (nuclear reactor, lower drywell) has a heated thermocouple arranged in a vertical direction (a thermocouple and a heater wire positioned inside the tip of a metal sheath) that detects the temperature rise in the sensor tip when a current is applied to the heater wire. From the temperature rise, whether the thermocouple is immersed in



5 Example of new instrumentation system able to operate during severe accidents

water or steam is detected and the water level is determined. In addition to water level, the gauge can also measure the temperature at the location of the thermocouple. The fiber optic radiation monitor works on a different principle to the ionization chambers used in the past. The radiation level is determined using a neodymium-doped yttrium aluminum garnet (YAG) crystal that serves as a long-wavelength light-emitting element, emitting light in proportion to the strength of incident radiation. This light passes along an optic fiber cable and is measured by an optical sensor.

Both systems have been tested to confirm their ability to operate under the harsh environmental conditions present during a severe accident and Hitachi intends to contribute to improving safety measures at nuclear power plants by installing them in the future.

The research results described in this article are a part of the results of research undertaken jointly by 11 Japanese electric power companies (Hokkaido Electric Power Co., Inc.; Tohoku Electric Power Co., Inc.; Tokyo Electric Power Co., Inc.; Chubu Electric Power Co., Inc.; Hokuriku Electric Power Company; The Kansai Electric Power Co., Inc.; The Chugoku Electric Power Co., Inc.; Shikoku Electric Power Co., Inc.; Kyushu Electric Power Co., Inc.; The Japan Atomic Power Company; and Electric Power Development Co., Ltd.) and three Japanese equipment suppliers and the research was undertaken as a project of the Agency for Natural Resources and Energy in the Ministry of Economy, Trade and Industry to develop safety technology for power-generating nuclear reactors and other plants.

6 300-kW Photovoltaic PCS for Medium-scale Photovoltaic Power Generation

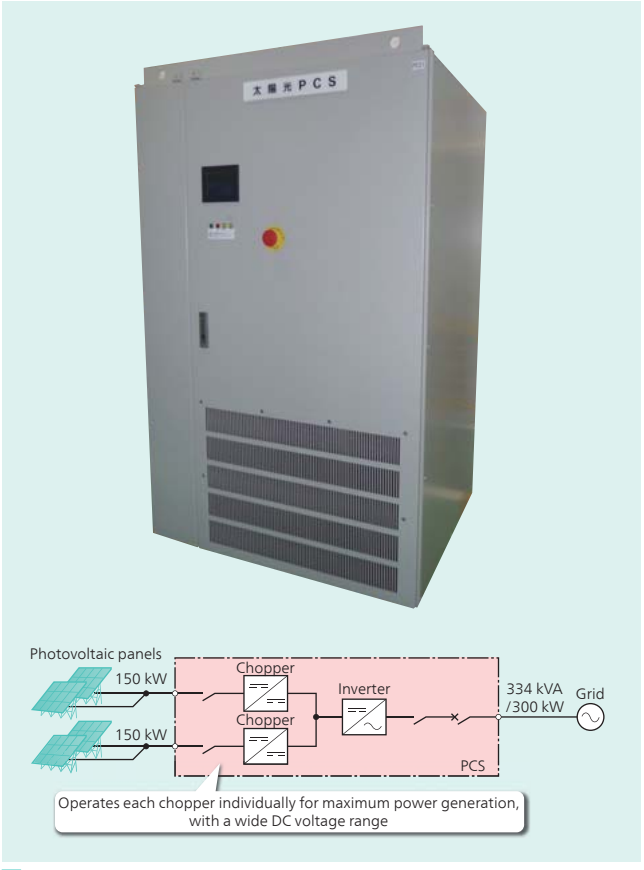
As part of the growing market for photovoltaic power generation systems in recent years due to rising environmental awareness, medium-scale systems intended to take advantage of roofs or unused land at shopping centers, factories, and schools are becoming more common. In response to the rising demand for such systems, Hitachi has developed a 300-kW power conditioning system (PCS) for medium-scale photovoltaic power generation to add to its existing 500-kW and 660-kW models for large-scale photovoltaic power generation.

The features of the 300-kW model are as follows.

(1) This model has two chopper circuits for boosting the direct current (DC) voltage from the photovoltaic panels. Having two such circuits maximizes the power from each chopper and expands the range of panel voltages at which power can be generated. That is, power can be generated even when the DC voltage is low due to low levels of sunlight.

(2) It achieves high power conversion efficiency (97.5% max.).

In the future, Hitachi intends to contribute to the building of photovoltaic power generation systems that meet customer needs by expanding its range of PCS products with high efficiency and wide operating range.



6 300-kW photovoltaic PCS (top) and photovoltaic PCS circuit diagram (bottom)

Parameter	Value	Notes
Rated capacity	630 kW	
Number of DC inputs	1	
Max. DC input	1,000 VDC	Over-voltage detection level
Rated AC voltage	300 VAC	50 Hz
Control functions	MPPT, FRT, islanding detection, etc.	FRT function complies with PEA requirements.

AC: alternating current, VDC: voltage direct current, VAC: volts alternating current, MPPT: maximum power point tracking, FRT: fault ride through

7 630-kW photovoltaic PCS for Thailand (top) and photovoltaic inverter specifications (bottom)

7 630-kW Photovoltaic PCS for Thailand

The installation of renewable energy sources such as wind and photovoltaic power is not limited only to Europe and America, these systems are also becoming increasingly prevalent in China and other parts of Asia. The photovoltaic power generation business in Thailand was expected to get underway in earnest during FY2015, underpinned by a new energy efficiency policy.

Hitachi has developed a PCS for photovoltaic power generation in Thailand and had it certified by that nation's Provincial Electricity Authority (PEA).

The main features are as follows.

(1) It achieves high power conversion efficiency (98.8% max.).

(2) It can operate with a wide range of panel voltages (520 to 900 V).

(3) It has environmental specifications that are suitable for installation in Thailand (upper limit on ambient temperature: 50°C).

Hitachi intends to use this development as a starting point for helping to build photovoltaic power generation systems that meet the needs of customers around the world by accelerating overseas deployment of PCS technology developed in Japan for achieving high efficiency and a wide operating range.

8 Increasingly Advanced Large-scale Photovoltaic Power Generation System

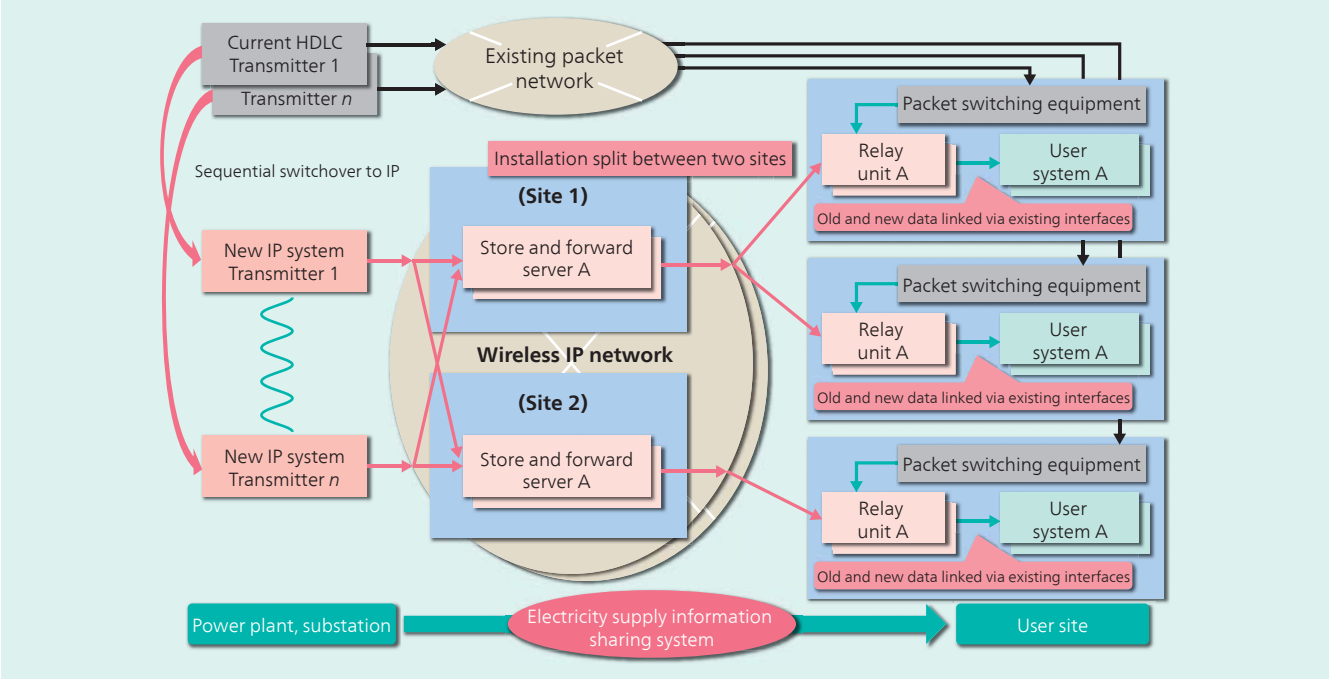
The Eurus Tenmyo Solar Park of Eurus Energy Group (rated output of photovoltaic modules: 18,757 kW, rated output of power conditioners: 14,000 kW) commenced operation in March 2015. The project, which commenced in March 2014 and was completed in 12 months, involved Hitachi working with new technologies. It included construction at a mountain golf course site (approximately 0.8 km^2), use of pile foundations to cope with upswelling due to frost, the construction of a regulating reservoir with a capacity of 35,000 m^3 of water, and the running of private transmission lines with a mix of pylons and undergrounding along municipal roads.

The 73,566 photovoltaic panels were installed along the centers of the fairways and located so as to leave the off-course topography unchanged as much as possible. The system has performed well, with power generation in April 2015 totaling 123 MWh and a capacity factor of 17%. Total annual power generation at the site will be equivalent to the consumption of approximately 5,000 households, representing an annual reduction in carbon dioxide (CO_2) emissions of 9,200 t. On the basis of each tree absorbing 14 kg of CO_2 each year, this is equivalent to a plantation of 660,000 Japanese cedar trees.

Photograph courtesy of Eurus Energy Holdings Corporation

8 Eurus Tenmyo Solar Park (top) and panel installations (with pile foundations) (bottom)

Electric Power Transmission Equipment and Systems



1 Configuration of electricity supply information sharing system

1 The Kansai Electric Power Co., Inc. Electricity Supply Information Sharing System

As part of an upgrade to communication equipment in its automatic electricity supply system, The Kansai Electric Power Co., Inc. converted its online electricity supply information network to support the Internet protocol (IP) in place of the previous system, which ran on packet switching equipment and used high-level data link control (HDLC) with a switched network on leased lines. However, because the system must be capable of remaining in operation during an earthquake or other emergency, the adoption of the existing IP system needed to be accompanied by a high degree of reliability.

Achieving this high reliability by incorporating the following technologies, Hitachi developed the electricity supply information sharing system in a way that facilitated migration.

(1) The previous packet switching functions were consolidated into dual store and forward servers with installation split between two sites, and a wireless IP network with dual communication links was adopted to improve the disaster-tolerance of the network, to ensure that store and forward processing of electricity supply information functioned reliably, and to improve maintenance.

(2) The network was designed to facilitate migration, including avoiding the need to upgrade existing systems by installing relay units at each user site that can handle both old and new data and perform conversion and transmission of existing protocols and data formats.

2 Tohoku Electric Power Co., Inc. Regional NW Distribution Network Monitoring and Control System

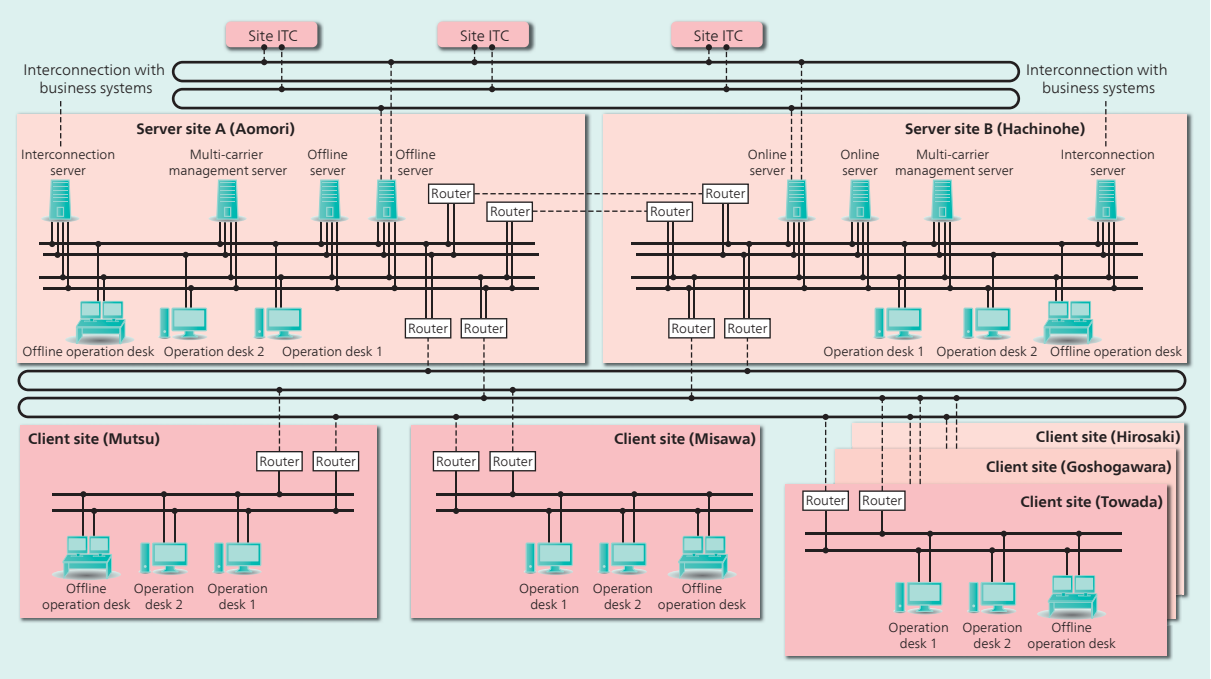
In an upgrade to the distribution automation system for the region administered by the Aomori Branch Office of Tohoku Electric Power Co., Inc., Hitachi has replaced an existing system made up of a single configuration spread across seven sites with an integrated system based on a redundant configuration.

The distribution network monitoring and control system for the regional network (NW) was implemented by splitting the sites into server and client sites, with active and backup servers located at the server sites (Aomori and Hachinohe) and thin client operation desks installed at the client sites.

The main features are as follows.

(1) By installing the active and backup servers remotely from each other and using thin clients for the operation desks at each site, sites can switch to backup operation in the event of a disaster. This is the first time a Hitachi distribution network monitoring and control system has been integrated at the site level.

(2) Whereas, in the past, each distribution automation system had its own grid and there was no automatic operation of the grids at the boundaries between sites, integration has enabled automation and improved security of supply.



2 Block diagram of regional NW distribution network monitoring and control system of Tohoku Electric Power

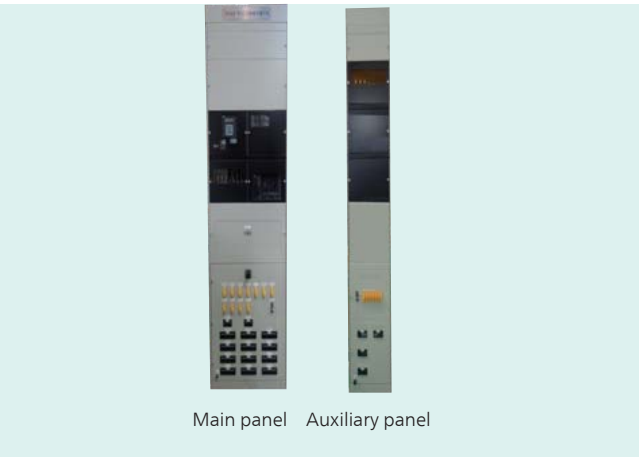
(3) Use of a virtualization operating system (OS) for the servers and thin clients for the operation desks reduced hardware requirements, minimizing installation space requirements and cutting the cost of hardware and software maintenance.

[Commencement of operation (five sites): March 2015 (the remaining two sites were integrated later during FY2015)]

3 Tokyo Electric Power Co., Inc. 500-kV Busbar Protection System Using Process Bus

In extra-high-voltage power systems of 275 kV or higher, standard practice in the past for busbar protection systems for double busbars has been a dual-panel configuration made up of check zone and discriminating zone protection. Hitachi has now developed a 500-kV busbar protection system using Process Bus that reduces the number of panels and facilitates the retrofitting of lines by using a shared central processing unit (CPU) for both check zone and discriminating zone protection.

The main features are as follows.



3 Busbar protection system using Process Bus

(1) Check zone and discriminating zone protection use the same CPU.

(2) Use of Process Bus enables precise synchronization of sampling across distributed panels and high-speed transmission (sampling synchronization error: 1 μs or less).

(3) Faster operation through direct control of auxiliary panel input/output (I/O) from main panel CPU.

Following acceptance testing of the main and auxiliary panel configurations involving type testing by Tokyo Electric Power Co., Inc., only the main panel configuration was supplied and is currently operating reliably.

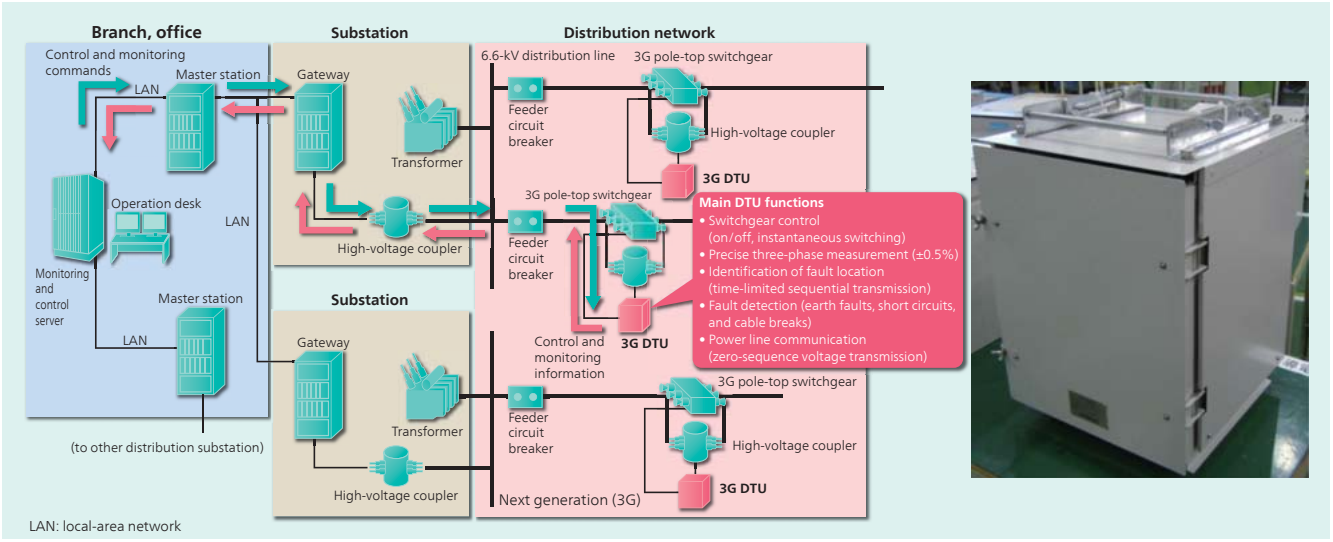
In the future, Hitachi intends to continue utilizing Process Bus technology to develop highly reliable products that meet diverse requirements.

(Commencement of operation: March 2015)

4 Shikoku Electric Power Co., Inc. Next-generation Distribution Terminal Unit (3G DTU)

Growth in the installation of renewable energy has been accompanied by a degradation of power quality, with electric power distribution networks suffering problems such as voltage fluctuations and voltage imbalances. It is anticipated that maintaining power quality using existing electric power distribution systems will be difficult. To overcome these problems, Hitachi is working on functional enhancements to distribution automation systems and has developed a next-generation distribution terminal unit (DTU) [third generation (3G) DTU] that is compatible with these new features.

Enhancements to the 3G DTU include precise three-phase measurement of various electrical quantities (±0.5% for voltage and current), better fault detection (detection of earth faults, short circuits, and cable breaks and recording of fault waveforms), and support for switchgear with instantaneous excitation (instanta-



4 Block diagram of distribution automation system (using power line communications) (left) and next-generation distribution terminal unit (right)

neous switching function). To allow for compatibility with existing equipment, the 3G DTU also uses an existing transmission method (zero-sequence voltage transmission).

The new DTU is expected to facilitate sophisticated power quality management by distribution automation systems and help improve maintenance efficiency.
(Commencement of deliveries: September 2015)

5 300-kV Standalone Gas DSs

The electric power distribution industry in Japan has been experiencing growing demand in recent years for the replacement of aging equipment. Experience with disasters that cause equipment damage or long-duration outages at open-air substations equipped with standalone equipment, in particular, has prompted calls for also making improvements to earthquake strength, reliability, and ease-of-maintenance when equipment is replaced. In response, Hitachi has developed a 300-kV standalone gas disconnecting switch (DS) to replace the air-insulated DSs with porcelain insulators used at open-air substations. The new DSs use tough lightweight composite insulator to improve seismic performance and feature reliability and ease-of-maintenance equivalent to gas-insulated switchgear (GIS).

Not only do the new gas DSs satisfy Japanese standards of JEC-2350 and JEC-2310 performance requirement (for insulation, conduction, seismic, and switching performance), but also their bus-transfer current switching performance gives them a recovery voltage of 600 V (JEC requirement is for a maximum of 300 V), meaning they can be used as busbar DSs at open-air substations with long busbars. This is anticipated to increase demand for upgrades because, if the feeder-side equipment is simultaneously replaced with an integrated GIS that combines gas circuit breakers, DSs, earthing switches, voltage transformers, current transformers, and lightning arresters, it provides a quick path for upgrading open-air substations using equipment that features earthquake strength, reliability, and ease-of-maintenance equivalent to a full-GIS installation.

Rated voltage	300 kV
Rated current	4,000 A
Rated short-duration current	50 kA for 2 s
Rated lightning voltage impulse	1,050 kV
Rated frequency	50/60 Hz
Rated gas pressure (guaranteed minimum pressure)	0.5 MPa (0.45 MPa)
Operation	Electrically-operated spring (coupled three-phase operation)
Standards	JEC-2350, JEC-2310
Bus-transfer current switching capacity	Switching current: 4,000 A Recovery voltage: 600 V Number of switching operations: 100

5 300-kV standalone gas DS (top) and target specifications and performance (bottom)

6 First Transformers Built by HFT

The factory of Hitachi Fortune Transformer, Inc. (HFT) commenced production in Taiwan in May 2015, making it the first facility outside of Japan for Hitachi's transformer business. HFT is a joint venture between Hitachi and Fortune Electric Co., Ltd. of Taiwan and was established on the basis of their strong existing relationship, the two companies having had technical collaboration since 1990.

The main features are as follows.

(1) Location

6 345-kV/265-MVA power plant transformer

Located in the Taichung Port Free Trade Zone, the factory is eligible for preferential customs treatment from Taiwan and the site is well placed for the maritime shipment of transformers for export.

(2) Factory equipment

Equipped with new production and testing equipment, the factory provides a highly efficient work environment with low labor requirements. Moreover, adoption of a one-way production line provides process directionality.

(3) Human resources

The factory, equipment, and products were commissioned by staff seconded from the two parent companies and recruited by HFT. Despite being a greenfields site, the factory satisfies Hitachi's technical standards.

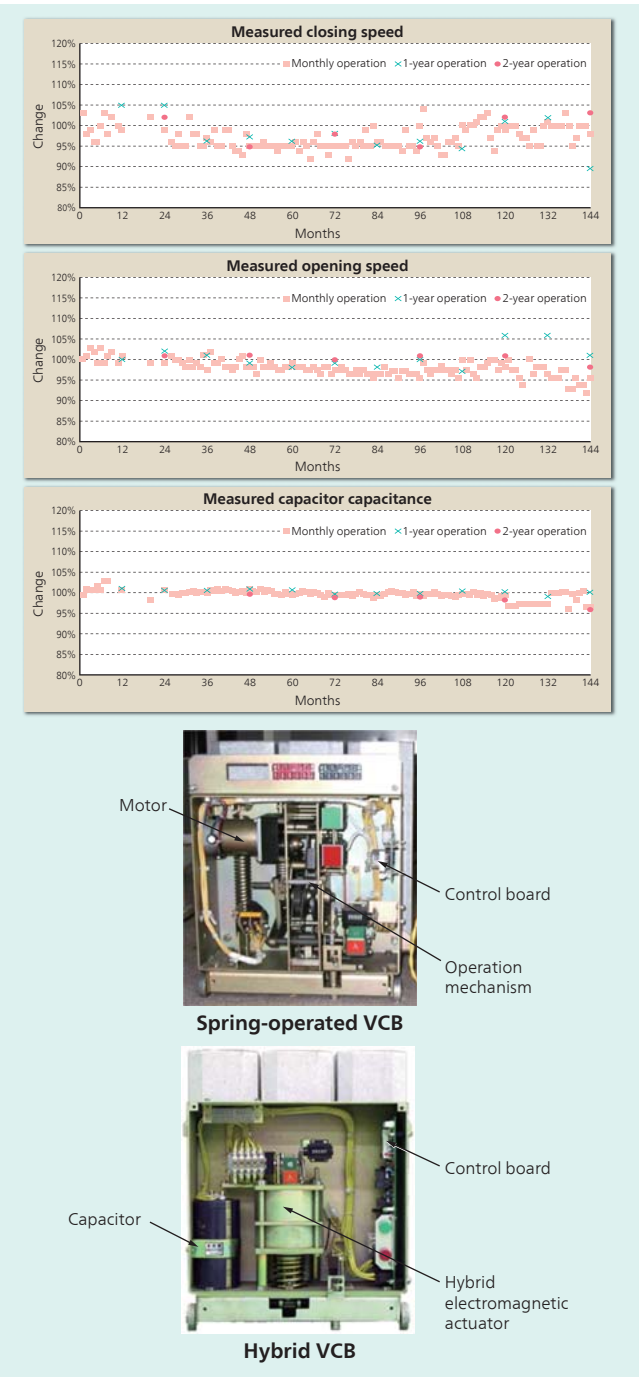
The first orders, for two 345-kV/265-MVA and two 415-MVA transformers, were received from Grand River Dam Authority (GRDA) in the USA in December 2014. They were completed in December 2015 and shipped to the USA from Port of Taichung.

7 Hybrid VCB Infrequent Operation Endurance Test Results

Hybrid vacuum circuit breakers (VCBs) have a simple mechanism and solid-lubricated bearings to enable them to operate without lubrication oil. By not using lubrication oil, hybrid VCBs remain free from mechanical defects caused by the drying out of grease, which are inevitable in spring-operated VCBs without maintenance. Moreover, as they do not need regular lubrication with grease, their maintenance interval is doubled compared to conventional VCBs. As a result, they have an advantage, not only in their reliability, but also in their maintenance cost. Since the product first went on sale in 2003, Hitachi has been conducting ongoing endurance testing (infrequent operation testing), one of the aims of which is to verify the longer inspection interval. The results for the 12-year mark (when a detailed inspection is due), are as follows.

Three test VCBs are being used in infrequent operation testing. Each unit is operated once only every one-month, one-year, and two-year interval, and its speed and other characteristics are being measured. No maintenance is performed on the VCBs during the period of the infrequent operation test.

The test results for the 12-year mark indicate no faults in the operation mechanism or elsewhere, with all measurements being within the criteria and varying by no more than 10% since testing started. These results verify that performance is maintained during the 12-year period, after which a detailed inspection is due. Hitachi intends to continue with infrequent operation testing up to the VCBs' intended product life of 20 years.



7 Overview of infrequent operation endurance test results (change in closing speed, change in opening speed, change in capacitor capacitance) (top) and photograph of the VCB (bottom)