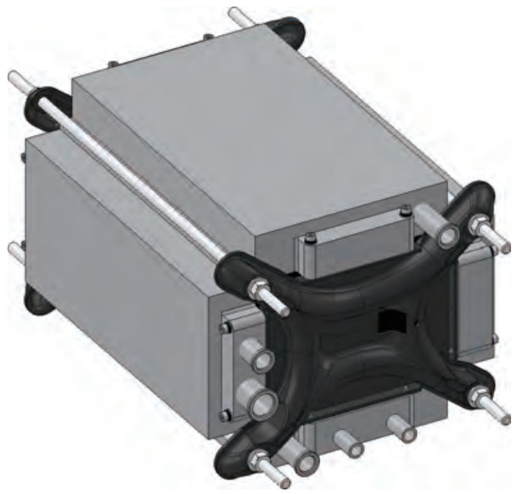
3. Energy Systems

3.1 Cultivation of Overseas Market for Fuel Cell Systems

Base station for 5G mobile communications in Guangzhou, China



Outline of 5 kW fuel cell

The market for the utilization of hydrogen is growing in China as it seeks to shift toward more environmentally friendly energy systems and secure electricity supply for areas where access to grid electricity is limited or unreliable. In October 2019, Toshiba Energy Systems & Solutions Corporation concluded a technical cooperation agreement with More Hydrogen Energy Technology Co., Ltd. (MOH), a startup company in Guangzhou City that is developing reformed methanol fuel cell systems. The purpose of this agreement is to create a power supply market for base stations of the rapidly expanding fifth-generation (5G) mobile networks as well as a market for combined heat and power supplies for residential use. We will combine MOH's methanol-related technology with our fuel cell technology to provide products for the rapidly growing Chinese market.

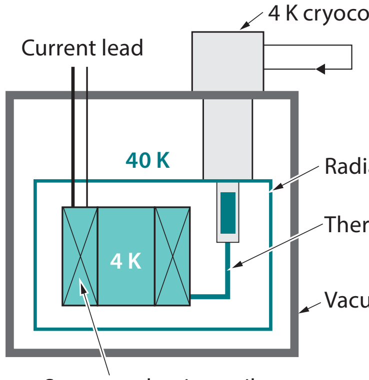
Methanol can be produced from various energy sources and is easily transported and stored. The Chinese government has a vision of converting large amounts of coal resources into methanol as a means of solving environmental problems while achieving cost competitiveness in power supplies through the use of fuel cell systems.

3. Energy Systems

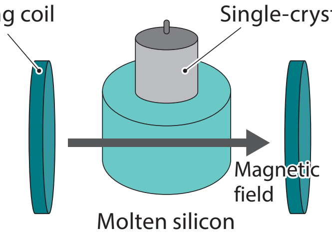
Prior to joint development activities, we developed a prototype 5 kW-class fuel cell stack to satisfy the performance and cost requirements of MOH's system. Then, using its power generation system, MOH confirmed that this fuel cell stack offered superior performance and enhanced applicability. Since the commencement of joint development activities, we have revised the design and manufacturing systems in preparation for volume production. Based on the production plan, we have estimated the sales price, verifying that it satisfies the cost requirement. As global contenders are rushing into the huge Chinese market, we have also confirmed the advantages of our technology.

We will continue development activities to maintain our market position and accelerate the development of distributed power sources, targeting the rapidly expanding communication equipment and services market, particularly 5G base stations for areas without reliable access to grid electricity.

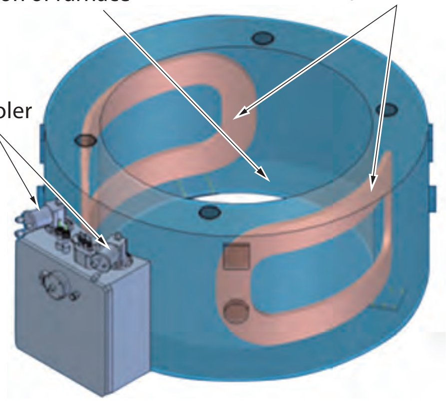
3.2 Liquid Helium-Free Superconducting Magnets and Their Applications



Configuration of liquid helium-free superconducting magnet directly cooled by 4 K cryocooler



High-precision curved, saddle-shaped coil fabricated using 3D winding technology



Superconducting magnet for single-crystal silicon puller

Since superconducting magnets can generate an extremely strong magnetic field in a large space, they have been utilized in the scientific, industrial, and medical fields. However, superconducting coils must be cooled to about 5 K (-268°C) to maintain their superconductivity. Superconducting coils have conventionally been immersed in liquid helium to maintain their temperature at 4.2 K (-269°C), making a continuous supply of liquid helium indispensable. Because helium gas is a scarce resource, liquid helium is expensive. Furthermore, special expertise is necessary to handle liquid helium. These factors act as constraints on the use of superconducting magnets.

Toshiba Energy Systems & Solutions Corporation commenced the development of a liquid helium-free, 4 K-cryocooler-cooled superconducting magnet in the 1980s and commercialized it for the first time in the world in 1995[*1], simplifying the use and reducing the cost of superconducting magnets. The subsequent prevalence of cryocooler-cooled superconducting magnets has contributed to the conservation of helium.

We have also developed a numerically controlled three-dimensional (3D) coil winding technology, making it possible to precisely reproduce complicated coil designs according to diverse customer requirements.

In recent years, we have been leveraging these technologies to apply innovative liquid helium-free superconducting magnets to heavy-ion cancer therapy systems and single-crystal silicon pullers. These superconducting magnets can be utilized simply by turning on a 4 K cryocooler.

Looking toward the future, we are currently working on the development of high-temperature superconducting magnets capable of generating even stronger magnetic fields with lower power consumption. We have now developed an innovative technology to prevent high-temperature superconducting coils from being seriously damaged in the event of a quench(*2) and succeeded in fabricating practical superconducting coils with uniform quality that are of sufficient size for industrial and medical applications.

We will continue to develop easy-to-use and environmentally friendly superconducting magnets to achieve their widespread use in society.

(*1) As researched by Toshiba Energy Systems & Solutions Corporation

(*2) A phenomenon in which a superconducting coil enters the normal (resistive) state

3.3 Contact Made with Deposits Considered to Be Fuel Debris inside PCV of Fukushima Daiichi Nuclear Power Station

In 2018, Toshiba Energy Systems & Solutions Corporation developed a remotely operated observation device to investigate the condition of the deposits inside the primary containment vessel (PCV) of Fukushima Daiichi Nuclear Power Station Unit 2.

In order to reach the bottom of the pedestal(*1), the observation device needed to pass through a penetration hole with a diameter of 10 cm on the hatch of the X-6 penetration point, continue moving into the pedestal for 10 meters, and then descend for 2 to 3 meters. This observation device has a telescopic guiding pipe, whose performance was proven during the previous investigation. With regard to the design of the observation device, it was necessary to downsize the survey unit so that it could fit inside the pipe while having a sufficient range of motion to grab debris.

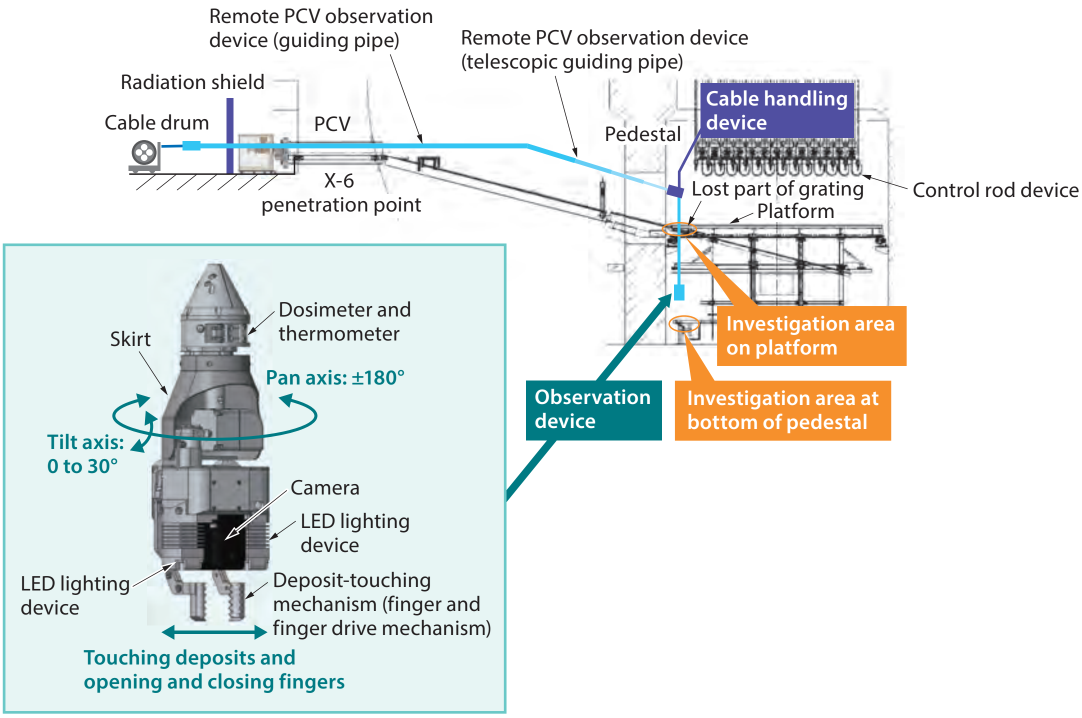
Based on video images, the previous investigation in 2018 found that some deposits were distributed over the bottom of the PCV pedestal, which might be fuel debris caused by the accident that occurred at the Fukushima Daiichi Nuclear Power Station in 2011.

Utilizing the expertise acquired through our past PCV investigations, we have now equipped the survey unit with a two-finger drive mechanism capable of grabbing debris with open-close movements. The purpose of this mechanism is to touch the deposits to examine their condition in order to determine whether they are movable.

In February 2019, the observation device accessed six locations at the bottom of the pedestal and four locations over the platform(*2) frame, successfully making physical contact with the deposits. As a result, it was found that it is possible to grab and pick up some pebble-like deposits and deposits assumed to be part of the fuel assembly. The results of this investigation have provided us with valuable information for reviewing how to remove the fuel debris.

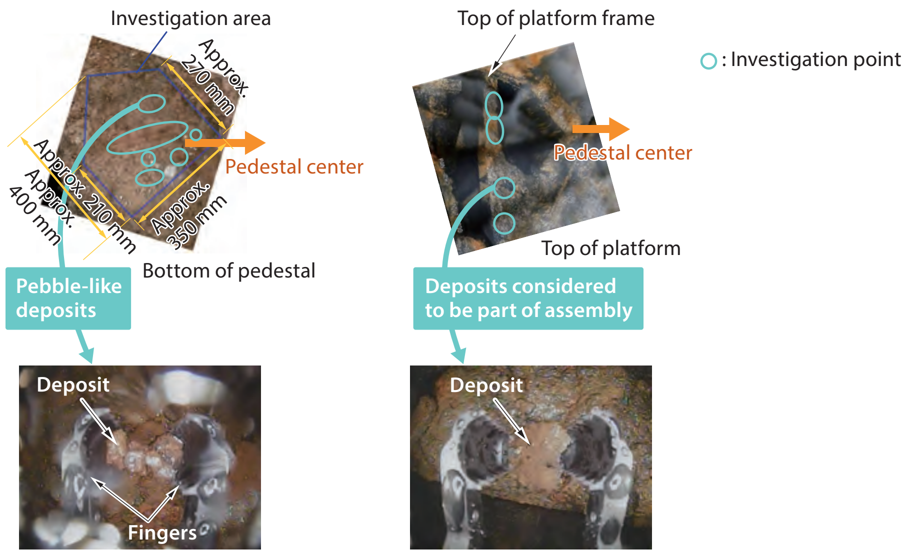
(*1) A concrete cylinder-type component supporting the reactor pressure vessel

(*2) A scaffolding working platform in the pedestal



LED: light-emitting diode

Survey area and observation device for accessing bottom of PCV pedestal of Fukushima Daiichi Nuclear Power Station Unit 2



Source: "Decommissioning and Contaminated Water Management, 63rd Meeting Material No. 3-3," Tokyo Electric Power Company Holdings, Inc.

Results of investigation of deposits at bottom of pedestal and on platform

3.4 Commencement of Operation of New Simplified Active Water Retrieval and Recovery System at Fukushima Daiichi Nuclear Power Station

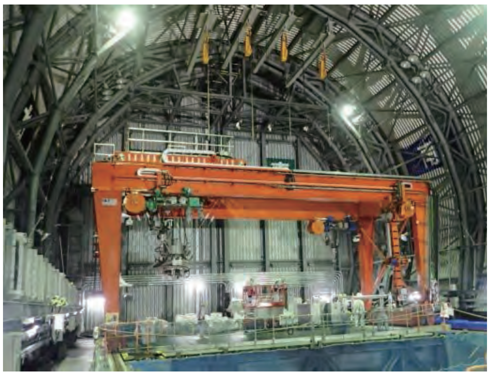
Two filtration filters and four adsorption towers of SARRY II

Since 2011, a large water treatment loop named SARRY (Simplified Active Water Retrieval and Recovery System) and two units of a system called MRRS (Multi-Radionuclide Removal System) developed by Toshiba Energy Systems & Solutions Corporation have been utilized to treat more than one million tons of contaminated water at the Fukushima Daiichi Nuclear Power Station.

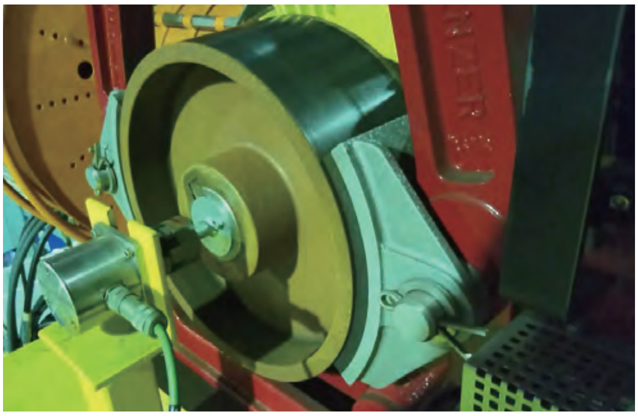
In order to complete the treatment of the remaining contaminated water by 2020 according to the mid- to long-term roadmap for decommissioning of the Fukushima Daiichi Nuclear Power Station, we have added SARRY II, which commenced operation in July 2019. SARRY II consists of two filtration filters and four adsorption towers to remove cesium (Cs) and strontium (Sr) from highly contaminated water. We developed a new adsorbent in the adsorption towers to reduce secondary waste.

We will continue to develop new technologies to contribute to the decommissioning of the Fukushima Daiichi Nuclear Power Station.

3.5 Wearable Camera System Used for Fuel Removal from Unit 3 Spent Fuel Pool of Fukushima Daiichi Nuclear Power Station



Fuel handling machine installed at Fukushima Daiichi Nuclear Power Station Unit 3



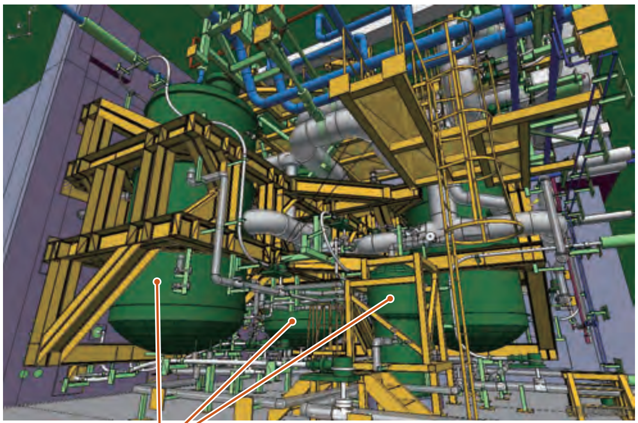
Remote visual inspection of crane brake by means of wearable camera system

The installation of spent fuel removal systems is currently in progress for fuel removal from the Unit 3 spent fuel pool of the Fukushima Daiichi Nuclear Power Station. Because of the high levels of radiation exposure and contamination in the work environment, site workers are required to wear full-face masks and protective clothing. In addition, workers are not permitted to spend more than 10 hours per day in radiation-controlled areas. In the past, a considerable amount of time was required for the design personnel of Toshiba Energy Systems & Solutions Corporation to travel to Fukushima in order to confirm equipment conditions and perform investigations as well as to make trips back and forth between their office and Fukushima to report the investigation results and discuss actions to take. Because of the time constraints, it was sometimes difficult to complete a series of actions in one day.

To resolve these issues, we employed a wearable camera system to allow the design personnel to check the conditions at the site remotely. The design personnel received images from site workers via the wearable camera to grasp the on-site conditions while checking drawings at a well-equipped office. The wearable camera system allowed the design personnel to provide instructions to the site workers in a timely manner, thereby reducing repetitive tasks.

The use of a wearable camera system with a large crane significantly facilitated the installation of a fuel handling machine.

3.6 Application of Spatial Arrangement Method to Precisely Install FCVS in Reactor Building of Onagawa Nuclear Power Station Unit 2



Venturi scrubber vessels

Layout planning of built-in FCVS in reactor building of Onagawa Nuclear Power Station Unit 2

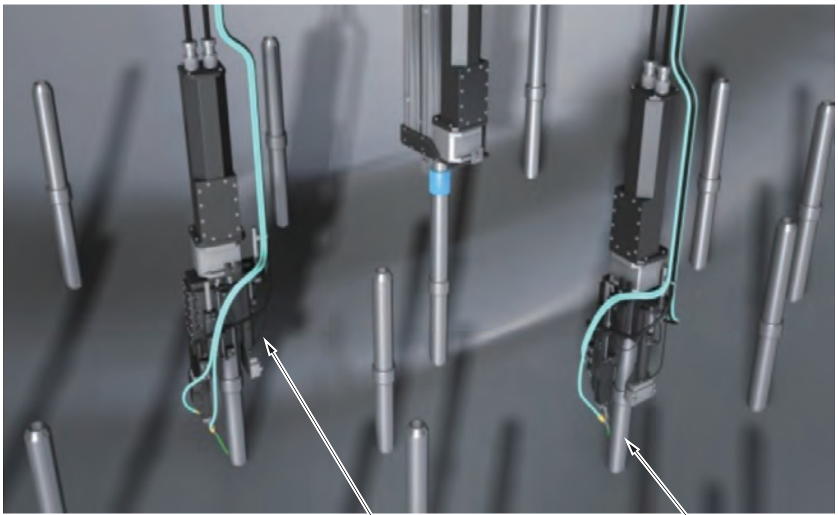
FCVS after installation

The electric power industry is installing filtered containment venting systems (FCVS) at nuclear power plants to protect primary containment vessels from excessive pressure in the event of a severe accident.

Toshiba Energy Systems & Solutions Corporation has installed three venturi scrubber vessels, i.e., the filtration stages of the FCVS, in the reactor building of Onagawa Nuclear Power Station Unit 2. Each of these venturi scrubber vessels measures approximately 2.6 m in diameter and 6 m in height. Because of the constrained installation space in the reactor building, there was a clearance of as little as a few millimeters between the vessels and the surrounding equipment. Therefore, a highly accurate operation was necessary to avoid interference during the installation of the vessels. We performed simulations using a 3D computer-aided design (3D-CAD) model for the planning of the installation process, including the entry, erection, and fixing of the vessels, in order to examine the available clearance at each step of the installation.

We also held a number of meetings and discussions with the on-site operators to resolve issues identified by the simulations, so that we could begin the installation without concern. As a result, we completed the installation safely and efficiently, contributing to a reduction in the installation period.

3.7 Completion of Preventive Maintenance Work at Arkansas Nuclear One Unit 1 in United States Using Laser Peening



Implementation of LP for BMI nozzle welds

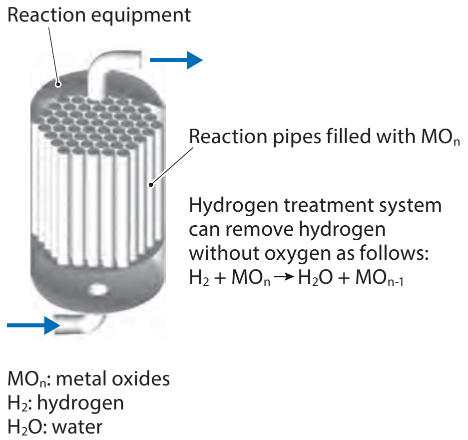
Laser peening (LP) is a preventive maintenance technology to mitigate the initiation and progress of stress corrosion cracking (SCC) by transforming tensile residual stress into compressive residual stress on the metal surface. Applicable to narrow areas, LP provides greater flexibility than other peening technologies.

Toshiba Energy Systems & Solutions Corporation has extensive experience in the implementation of LP for boiling water reactors (BWRs) and pressurized water reactors (PWRs) in Japan.

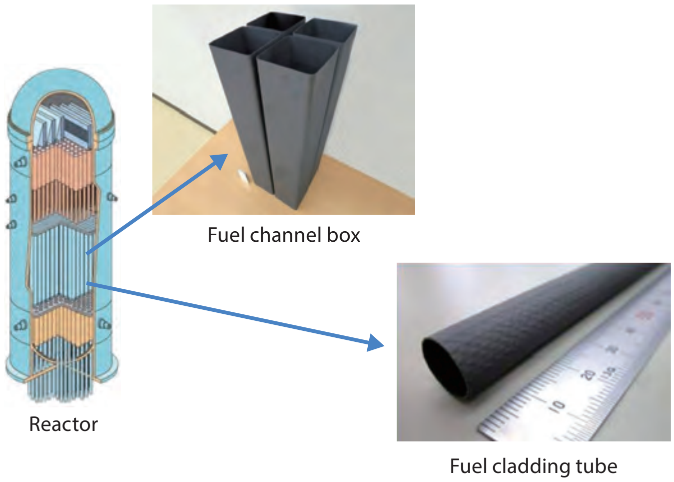
In October 2019, as a subcontractor of Westinghouse Electric Corporation, the prime contractor, we completed the implementation of LP on the reactor vessel bottom-mounted instrumentation (BMI) nozzle welds of Unit 1 of the Arkansas Nuclear One power plant operated by Entergy Arkansas, LLC, which had concerns over SCC on the nozzle welds.

For this project, we developed a new air-transportable LP system and operated multiple units of this system simultaneously. As a result, we completed the project ahead of schedule despite the fact that this was our first experience of this type of project for an overseas customer.

3.8 Development of Safety Enhancement Technologies for Nuclear Power Plants



Outline of hydrogen treatment system



Prototype fuel components fabricated with SiC composite ceramics

Toshiba Energy Systems & Solutions Corporation is developing various technologies to contribute to enhancement of the safety of nuclear power plants. Two major examples are given below.

The first example is a new hydrogen treatment system, which is expected to be one of the most significant and innovative technologies to remove hydrogen from the PCV in the event of a severe accident. When combined with other safety systems, this system eliminates the need to vent the PCV to control a severe accident condition. Although the existing hydrogen treatment systems require oxygen, the newly developed system is operable with metal oxides instead of oxygen. An examination of the key properties of metal oxide materials such as strength and disintegration after use indicates that they can be used for hydrogen treatment. As the next step, we are currently improving the reaction analysis model to achieve early deployment of the hydrogen treatment system at actual nuclear power plants.

The second example is silicon carbide (SiC), which has high acid resistance, a high melting point, and low neutron absorption. The use of SiC as a reactor core material helps to reduce the amount of hydrogen generated in the event of a severe accident and increase the seismic resistance and economic efficiency of nuclear fuel. We completed development of the basic technologies necessary to manufacture SiC fuel rods in 2019. Our next steps include verification of the irradiation performance of SiC and development of technologies to produce SiC fuel rods in large quantities.

We will continue the development of technologies to meet social demand, including further improvement of the safety of nuclear power plants.

3.9 Application of IoT Platform and Digital Services for Energy Systems to Mikawa Power Plant

Mikawa Power Plant of SIGMA POWER Ariake Corporation

With the aim of becoming one of the world's leading cyber-physical system (CPS) technology enterprises, the Toshiba Group has worked to establish the Toshiba IoT Reference Architecture (TIRA) as a common framework to support the development and operation of industrial Internet of Things (IoT) services.

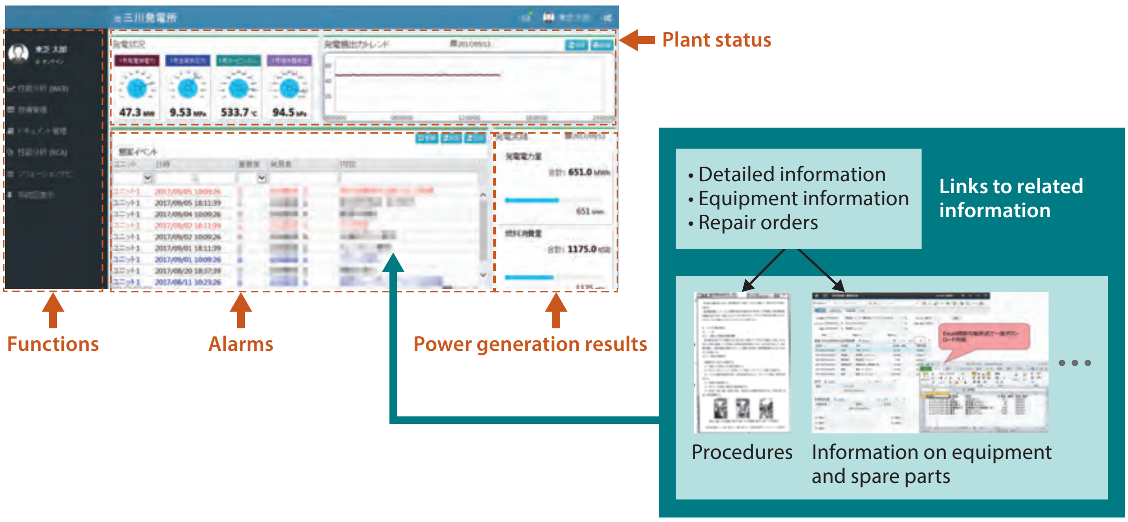
In the energy system domain, Toshiba Energy Systems & Solutions Corporation has developed an IoT platform for energy systems compliant with TIRA. We have applied the following four digital services available with this platform to the Mikawa Power Plant in Omuta City, Fukuoka Prefecture, operated by SIGMA POWER Ariake Corporation: (1) real-time plant efficiency monitoring using a heat balance model, (2) failure prediction using plant data, (3) linkage of design and maintenance data between documents, and (4) a dashboard that integrates all information necessary for plant operation and maintenance (O&M).

In 2018 we completed a joint study on real-time plant efficiency monitoring and failure prediction with Tohoku Electric Power Co., Inc., which has been using these services since that time for all of its thermal power plants to improve their availability.

All of the above four digital services are linked with one another. The dashboard seamlessly provides information about O&M operations, including failure detection, document checking, plant inspection rounds, and surveys on spare parts.

We will apply the new IoT platform and digital services to various energy systems such as thermal, hydroelectric, and wind power systems as well as to substations. By means of this platform, we will continue to deploy digital services jointly developed with customers and partners to resolve energy-related issues.

Example of plant performance monitoring display



Example of dashboard display

3.10 Commencement of Demonstration Operation of Supercritical CO_2 Turbine and Combustor in U.S.A.

Courtesy NET Power, LLC and McDermott International Inc.

Pilot supercritical CO_2 cycle power plant, U.S.A.

Toshiba Energy Systems & Solutions Corporation has commenced the demonstration operation of a turbine and a combustor at a pilot supercritical carbon dioxide (CO_2) power plant of NET Power, LLC in Texas, U.S.A. We designed and manufactured the turbine and combustor, which are key components of the pilot supercritical CO_2 cycle power plant. This pilot plant has approximately one-tenth the output capacity of, and the same system configuration as, an actual 300 MW-class commercial plant.

The supercritical CO_2 cycle power plant is a new environment-friendly solution that separates and collects CO_2 without releasing it into the atmosphere while generating electricity with fossil fuel. To date, we accomplished one-fifth-scale combustion in 2013 and real-scale 50 MWt(*) combustion in 2018, verifying the results of our consistent development efforts.

We are currently verifying the performance, combustion characteristics, and operability of the turbine and combustor at the pilot plant. As of October 2019, the total operating time exceeded 250 hours. We will continue to verify their reliability and durability through the demonstration operation and reflect the results in the design of commercial products.

(*) The watt thermal, Wt, is a unit of thermal output.

3.11 Commencement of Commercial Operation of Wasabizawa Geothermal Power Plant of Yuzawa Geothermal Power Generation Corporation

Courtesy Yuzawa Geothermal Power Generation Corp.

Overall view of Wasabizawa Geothermal Power Plant of Yuzawa Geothermal Power Generation Corp.

In May 2019, Yuzawa Geothermal Power Generation Corporation commenced commercial operation of the Wasabizawa Geothermal Power Plant with a capacity of 46.199 MW, the fourth largest in Japan, marking the inauguration of Japan's first large-scale geothermal power plant with a capacity exceeding 10 MW since 1996.

Toshiba Energy Systems & Solutions Corporation manufactured and installed equipment including the steam turbine, generator, condenser, flasher for low-pressure steam, and remote monitoring system for this power plant.

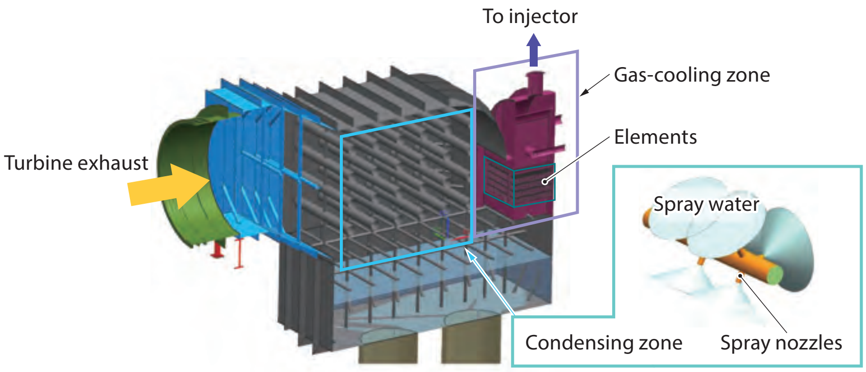
The steam turbine is a single-flow axial exhaust unit with a 40-inch last-stage blade. The air-cooled generator has a capacity of 52 MVA. The central control room at the power plant is connected to a remote monitoring room at the foot of the mountain on which the plant is located via an optical fiber cable, so that the plant can be monitored and shut down remotely.

The electric motors of the circulating water pumps and cooling tower fans are operated with inverters. Optimization of the conditions of the circulating water according to the weather conditions minimizes the electric power consumed by the power plant, maximizing the amount of electric power transmitted. A benefit of geothermal energy is that it is not intermittent like other renewable energy sources that are affected by natural conditions such as the weather and daytime/nighttime conditions.

Our product lineup supports not only large-scale geothermal power plants but also small plants with a capacity of less than 10 MW. We will continue our efforts to contribute to the expansion of renewable energy.

3.12 Newly Developed Spray and Element Type Direct-Contact Condenser for Geothermal Power Plants

Newly developed spray and element type direct-contact condenser



Internal structure of condenser

Conventional geothermal power plants are generally equipped with a direct-contact condenser in which hot steam and cooling water are allowed to mix directly.

Toshiba Energy Systems & Solutions Corporation has now developed a unique spray and element type direct-contact condenser that combines two types of cooling systems, one providing low-pressure-loss steam condensation using spray nozzles and the other providing heat transfer enhancement for gas cooling using elements.

We have installed this condenser at a geothermal power plant in Japan. In order to optimize the amount of power generated, we also added an operation-switching function that varies the flow rate of the cooling water in summer and winter by about 20%. This function makes it possible to change the heat exchanging area of the condenser and improve the plant's operating efficiency by conserving the amount of power consumed by the plant while maintaining the turbine exhaust vacuum pressure. During commercial operation, it was confirmed that the new direct-contact condenser achieves high heat exchange efficiency as planned and that the operation-switching function operates properly.

We will continue to provide highly efficient condensers that make effective use of geothermal energy for power generation.

3.13 Commencement of Commercial Operation of Jimah East Power Plant in Malaysia

Panoramic view of Jimah East Power Plant, Malaysia

The Jimah East Power Plant (2 × 1 000 MW) in Malaysia is a state-of-the-art high-efficiency ultra-supercritical coal-fired power plant with a main steam pressure of 27 MPaG, a main steam temperature of 600°C, and a reheat steam temperature of 610°C. This power plant is equipped with a rapid extraction steam control system as required by the Malaysian Grid Code in order to respond to instantaneous load changes. The plant is also equipped with a desuperheater to increase the final feedwater temperature in order to achieve higher turbine efficiency than conventional supercritical power plants.

Toshiba Energy Systems & Solutions Corporation provided substation facilities, offshore civil engineering work, and turbine island systems for this project, including the steam turbines, generators, and heat exchangers. We achieved commercial operation of Unit 1 in August 2019, followed by Unit 2 in December 2019.

In addition to large capacity and high efficiency, this power plant provides the capability to respond to sudden load fluctuations, greatly contributing to stable and reliable power supply in Malaysia.

3.14 Completion of Turbine Rehabilitation Project with Short Outage Time for Shin-Onoda Thermal Power Station Unit 2 of The Chugoku Electric Power Co., Inc.

HIP turbine under assembly for Shin-Onoda Thermal Power Station Unit 2 of The Chugoku Electric Power Co., Inc.

Improvement of the availability factor and reduction of CO_2 emissions are important management issues for any electric utility company that operates coal-fired thermal power plants. At Shin-Onoda Thermal Power Station Unit 2 operated by The Chugoku Electric Power Co., Inc., the horizontal flange surface of the high- and intermediate-pressure (HIP) turbine casing was found to be distorted because of the aging of its material. It was planned to be replaced during the periodic outage in 2019. The outage period, including the time required for pipe welding and adjustments between the new and reused components, was initially estimated to be 135 days. However, in order to maintain the high availability of the plant, the operator requested an outage period 50 days shorter than the previous outage required for similar rehabilitation work on Unit 1.

While maintaining the same scope of rehabilitation for Unit 2 as had earlier been carried out for Unit 1, Toshiba Energy Systems & Solutions Corporation adopted a laser tracker measurement method to eliminate the need for temporary assembly, thereby reducing the outage period and cost of the work and improving the availability of Unit 2. We also proposed performance recovery measures such as the use of a spring-back tip seal. As a result, we completed the rehabilitation project in June 2019 with an outage period 67 days shorter than the initial estimation while exceeding the performance improvement target.

3.15 Refurbishment of Hydroelectric Power Equipment at Three Power Plants in U.S.A.

Installation of third Kaplan turbine runner at Wells Hydroelectric Power Plant, U.S.A.

Installation of first generator stator at Blue Mesa Power Plant, U.S.A.

Many hydroelectric power plants were constructed in the U.S.A. in the 1960s and 1970s. In addition to the overhaul of aging facilities, the refurbishment and modernization of these plants entailing the renewal of equipment have been actively implemented in order to solve operational issues and improve performance.

Toshiba Energy Systems & Solutions Corporation is currently working on the refurbishment of existing equipment manufactured by other manufacturers at three power plants in the U.S.A.; namely, the Ludington Pumped Storage Plant, Wells Hydroelectric Power Plant, and Blue Mesa Power Plant.

To achieve the refurbishment of equipment made by other manufacturers, it is crucial to collect information necessary for reverse engineering and design. However, some of the necessary information could not be obtained from the existing documents. To solve this problem, we conducted on-site surveys and field tests.

Toshiba Hydro Power (Hangzhou) Co., Ltd. manufactured some of the major refurbishment components, satisfying the strict quality requirements of the U.S.A.

An overview of the refurbishment work on the three power plants is given below.

(1) Ludington Pumped Storage Plant

The main scope of the work is the replacement of all six pump-turbine runners, generator-motor stators, and thrust bearings to improve the operating performance and reliability of the plant. The fifth unit commenced commercial operation in June 2019. The ratings of the pump-turbines and generator-motors are as follows:

- Pump-turbines: 359 MW/398 MW, 98 m/111 m, 112.5 min^{-1}
- Generator-motors: 455 MVA/455 MVA, 20.0 kV, 112.5 min^{-1}, 60 Hz.

(2) Wells Hydroelectric Power Plant

The main scope of the work here is the replacement of nine generator stators and the overhaul of 10 Kaplan turbines to improve the plant's operating reliability. The third unit commenced commercial operation in May 2019. The ratings of the turbines and generators are as follows:

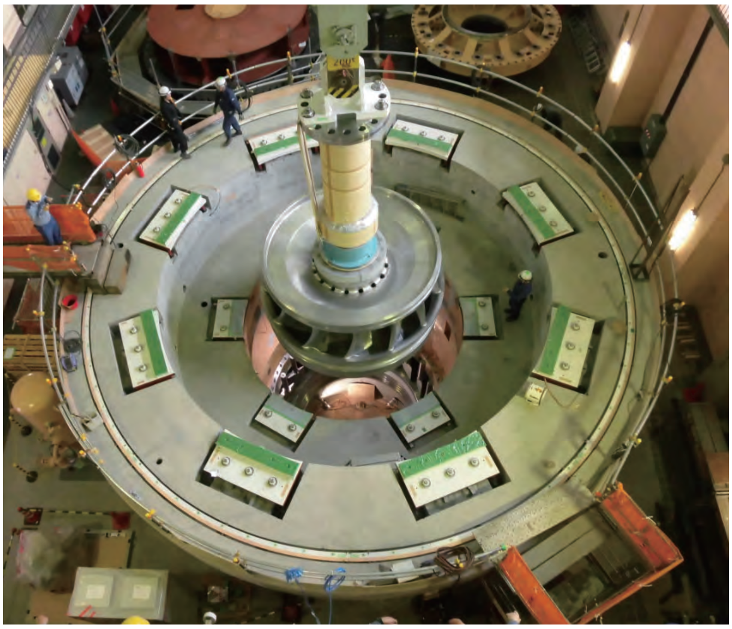
- Turbines: 96.9 MW, 22.9 m, 85.7 min^{-1}
- Generators: 93.7 MVA, 14.4 kV, 85.7 min^{-1}, 60 Hz.

(3) Blue Mesa Power Plant

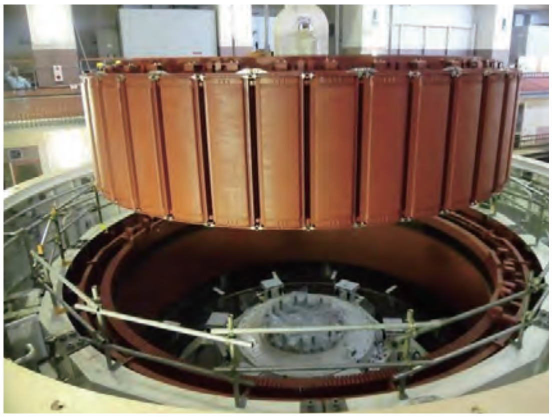
The main scope of the work in this case is the replacement of both of the two generator stators and the excitation systems to improve the operating reliability of the plant. The overhaul of the first unit is underway, with commercial operation scheduled for 2020. The ratings of the generators are as follows:

- Generators: 48.0 MVA, 11.5 kV, 200 min^{-1}, 60 Hz.

3.16 Commencement of Commercial Operation of Maruyama Hydroelectric Power Station Unit 2 of The Kansai Electric Power Co., Inc.



Installation of hydraulic runner at Maruyama Power Station Unit 2 of The Kansai Electric Power Co., Inc.



Installation of generator rotor

Following its renewal, Maruyama Hydroelectric Power Station Unit 2 commenced commercial operation in June 2019.

When the Maruyama Hydroelectric Power Station began operation in 1954 to secure electricity supply for postwar reconstruction, it boasted the largest hydroelectric generating capacity in Japan(*). However, renewal work became necessary due to the aging of its two units after more than 60 years of operation.

Of the two units, Toshiba Energy Systems & Solutions Corporation replaced Unit 2 first. For the hydraulic design of the turbine, we developed the optimum flow passage through computational fluid dynamics (CFD) and a model test, adopting the shape of the existing draft tube to be reused. The use of our advanced hydraulic runner enhanced the turbine performance to an average of 0.72% higher than the guaranteed efficiency. Furthermore, in order to reduce the size and improve the maintainability of the equipment, we increased the hydraulic control oil pressure of the guide vane servo motor and employed a brushless exciter instead of a static exciter. The turbine and the generator were manufactured by Toshiba Hydro Power (Hangzhou) Co., Ltd. in China. The ratings of the turbine and generator are as follows:

- Turbine: 76.0 MW, 87.44 m, 180 min^{-1}
- Generator: 85.0 MVA, 13.2 kV, 180 min^{-1}, 60 Hz.

The replacement of Unit 1, the second unit targeted in this renovation project, is currently underway with commercial operation scheduled for March 2021. The renovation of the Maruyama Dam, which supplies the water to the Maruyama Hydroelectric Power Station, is also in progress to raise the water level by 6.5 m in order to improve its flood control capacity. The ratings of the turbine and generator were determined in consideration of the planned increase in the water level of the Maruyama Dam.

(*) As researched by Toshiba Energy Systems & Solutions Corporation

3.17 Completion of Partially Renewed Main Control Boards for River Bed Pumped Storage Power Station in India

Partially renewed main control board

Toshiba Energy Systems & Solutions Corporation has completed upgrading of the main control boards for all six units of the River Bed Pumped Storage Power Station in India, which resumed commercial operation in July 2019. After more than 13 years of operation since June 2006, two of the six controllers in the main control boards were not working because of age deterioration. Early restoration of the controllers was also required so as to alleviate the tight supply-demand balance.

In order to upgrade the main control boards in a short time, we maximized the reuse of hardware circuits in the existing control boards and carefully selected the field tests to be performed in order to shorten the outage period. As a result, the field work to upgrade the main control boards for the six units was completed in only 53 days.

Toshiba India Private Limited handled the field work and dispatched a site manager to coordinate the project.

3.18 Shipment of First Unit of Qianwei Power Station in China

Installation of first generator rotor at Qianwei Power Station, China

The Qianwei Power Station is expected to contribute to the economic development of Leshan City in China's Sichuan Province. This power station will have nine large-capacity bulb turbine-generator units, each with a capacity of 63.32 MW. Awarded a contract to supply four of the nine turbine-generator units, Toshiba Hydro Power (Hangzhou) Co., Ltd. completed the shipment of the first unit in September 2019.

The rotor spokes of the generator are designed with a π-shaped cross-sectional structure to increase strength, and the air cooler is arranged in the circumferential direction of the inner wall taking the limited space inside the unit into consideration. Furthermore, the stator coil is designed in such a manner as to eliminate the need for a side spacer. The boss in the turbine runner is arranged and structured to provide high reliability, taking into consideration the small boss ratio, high runaway speed, and weight of the runner vanes to be supported. The load of the bearing in the radial direction is 180 t, which is the largest in our experience. The bulb turbine bracket is provided with additional horizontal supports in order to improve the stability of the overall turbine-generator.

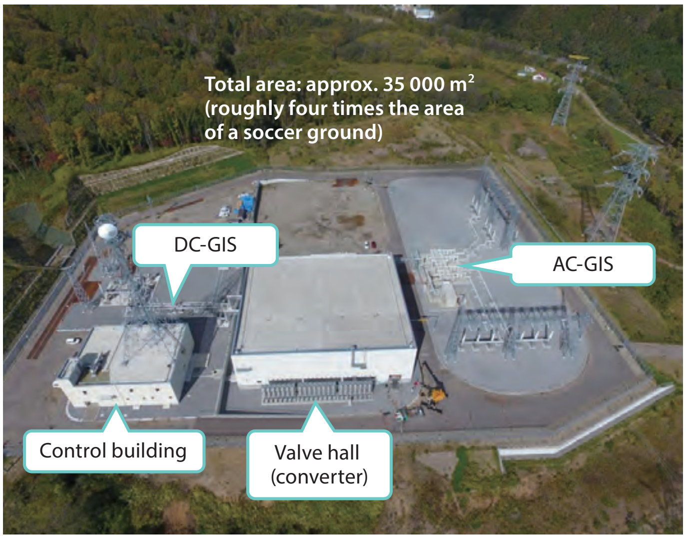
The completion of the first unit demonstrates our capabilities in the design and manufacturing of bulb turbine-generators.

The turbine and generator ratings are as follows:

- Turbine: 63.32 MW/10.00 MW, 17.4 m/4.0 m, 83.3 min^{-1}
- Generator: 61.78 MVA, 10.5 kV, 83.3 min^{-1}, 50 Hz.

3.19 Commencement of Commercial Operation of New Hokkaido-Honshu HVDC Link of Hokkaido Electric Power Co., Inc.

Voltage-source converters for New Hokkaido-Honshu HVDC Link



Hokuto Converter Station

The New Hokkaido-Honshu High-Voltage DC (HVDC) Link constructed by Hokkaido Electric Power Co., Inc. commenced commercial operation in March 2019, enhancing the security of the power supply to both Hokkaido and Honshu (the main island of Japan). This HVDC link is rated at 300 MW ±100 Mvar, 250 kVDC, and 1 200 A.

Toshiba Energy Systems & Solutions Corporation supplied the main equipment for the converter stations of the HVDC link, including the AC-DC converters, converter transformers, DC gas-insulated switchgears (GIS), control and protection systems, and valve cooling systems. We utilized modular multilevel voltage-source converters (VSCs), eliminating the need for such equipment as reactive power plants and harmonic filters that are normally required by conventional line-commutated converters (LCCs) and thereby reducing the area and initial construction cost of the converter stations.

In addition to the conventional functions such as active power transmission and frequency control, the New Hokkaido-Honshu HVDC Link provides functions unique to VSCs, including AC voltage control (reactive power control) and black start (a function to restore the electricity grid in Hokkaido using active power from Honshu in the event of a blackout occurring in Hokkaido), contributing to improved reliability of the Hokkaido grid.

From October 2018 to March 2019, we performed system tests to verify all of these functions of the HVDC link after it was connected with the actual AC grid. In particular, we prepared a special test grid configuration to simulate a blackout situation in order to demonstrate the black-start capability of the HVDC link, successfully starting an adjacent generator connected to the Hokkaido grid.

Large-capacity VSC HVDC links are expected to be introduced for various purposes such as long-distance electricity transmission, frequency conversion, and electricity transmission from offshore wind farms. We will continue to further expand the applications of VSC HVDC links.

3.20 Energization of Gas-Insulated Transformers (110 kV–130 MVA) at Copeland Station of Toronto Hydro-Electric System Ltd. in Canada

GITs installed at underground substation of Toronto Hydro-Electric System Ltd., Canada

In April 2019, Toronto Hydro-Electric System Ltd. (Toronto Hydro) successfully energized two gas-insulated transformers (GITs) at the Copeland Station that were manufactured by Toshiba Energy Systems & Solutions Corporation. Installed in 2016, these GITs were connected to the grid in June 2019, following additional interface connection and commissioning work.

The Copeland Station, the first substation built in downtown Toronto since the 1960s, provides electricity to buildings and neighborhoods in the central-southwest area of the city. It is the second underground substation in Canada and the first to utilize large-capacity GITs.

As the result of detailed consideration, Toronto Hydro selected our unique high-gas-pressure GITs taking into account the fact that conventional oil-immersed transformers have potential safety risks such as explosion and fire hazards, as well as environmental risks. GIT technology dramatically reduces these risks because there is no possibility of explosion, fire, and oil leakage. These safety features, together with the greater compactness of GITs, make them ideal for application to underground substations.

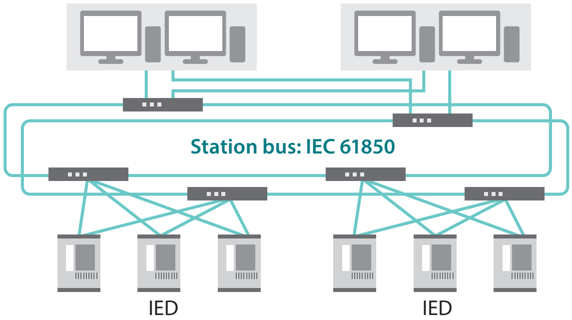
We are honored to have been given this opportunity to provide our GITs to Canada for the first time, and are confident that our technology will contribute to the safety, stability, and reliability of the power grid there.

The ratings of the GITs are as follows:

- Gas directed air forced cooling (GDAF), 60 Hz, 130 MVA, 110 kVΔ, 2 × 14.2 kV ±20% (23P) Y.

3.21 GRE200 Series Intelligent Electronic Devices for MV Power Distribution Systems

GRE200 series IED for MV power distribution systems



＊Redundant communication links are available with PRP, High-availability Seamless Redundancy (HSR), or Rapid Spanning Tree Protocol (RSTP).

Example of application of GRE200 series to substation network system

Toshiba Energy Systems & Solutions Corporation has developed the GRE200 series of intelligent electronic devices (IEDs) for medium-voltage (MV) power distribution systems. The GRE200 series has the following functions and features:

- Multi-function protection and control
  Directional overcurrent, reverse power, voltage, frequency, overload, and motor protection; on-off control function
- Network communication
  Dual LAN port for substation automation systems compliant with the International Electrotechnical Commission (IEC) 61850 standard; support for Parallel Redundancy Protocol (PRP), etc.
- Compact size and draw-out structure
  149 mm (width) × 177 mm (height) × 211 mm (depth); draw-out structure for embedding in MV switchgear panels
- User-friendly interface on the front panel
  21-character, 8-line liquid-crystal display (LCD) with backlight; 14 LEDs (two LEDs for fixed indications and 12 user-configurable LEDs).

The GRE200 series is targeted at not only power utilities but also general industries.