2. Energy Systems

2.1 Third-Generation 100 kW H2Rex™ Model and Multi-MW Model

In the coming hydrogen economy, it will be important to utilize fuel cell systems capable of converting hydrogen into electricity with high efficiency. Toshiba Energy Systems & Solutions Corporation provides the H2Rex™ series of stationary fuel cell systems. The first-generation 100 kW model was commercialized in FY2016, followed by the second-generation model in FY2018.

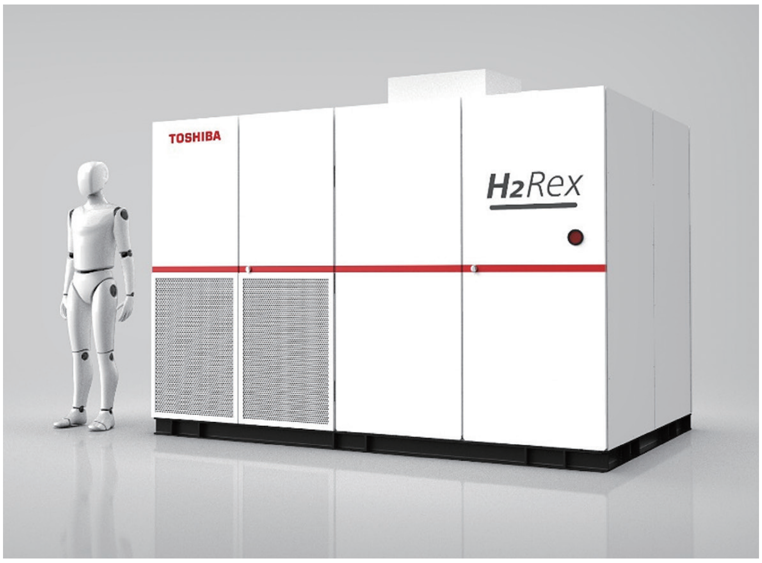
We have now developed the third-generation model, which features a new cell stack with high power density and a simplified design, making it more compact and less costly than the second-generation model. The third-generation model has an overall CHP(*1) efficiency of 95% and the world's highest-class durability of 80 000 hours of operation(*2). With a width of 2.8 m, a depth of 2.0 m, a height of 1.9 m, and a weight of about 4.5 tons, the third-generation model is 22% smaller and 22% lighter than the second-generation model. The third-generation model also features a volume of 0.1 m^3 per kW output, the world's smallest level for stationary fuel cell systems(*2). It was commercialized in April 2022.

In addition to the third-generation 100 kW model, we have developed a 1 MW unit consisting of ten 100 kW modules, each of which is controlled by an energy management system (EMS). Its operation is optimized in terms of CHP according to the electricity and heat demands. In addition, the EMS schedules the operation of each module, taking the number of operating hours and the conditions of each module into consideration.

Furthermore, we are developing a multi-MW model that consists of multiple 1 MW units. The upper-level EMS monitors and controls the EMS of each 1 MW unit via a network to achieve efficient operation as a multi-MW model. This system structure provides high efficiency over a wide range of output power and helps to reduce system shutdowns during maintenance, increasing system utilization.

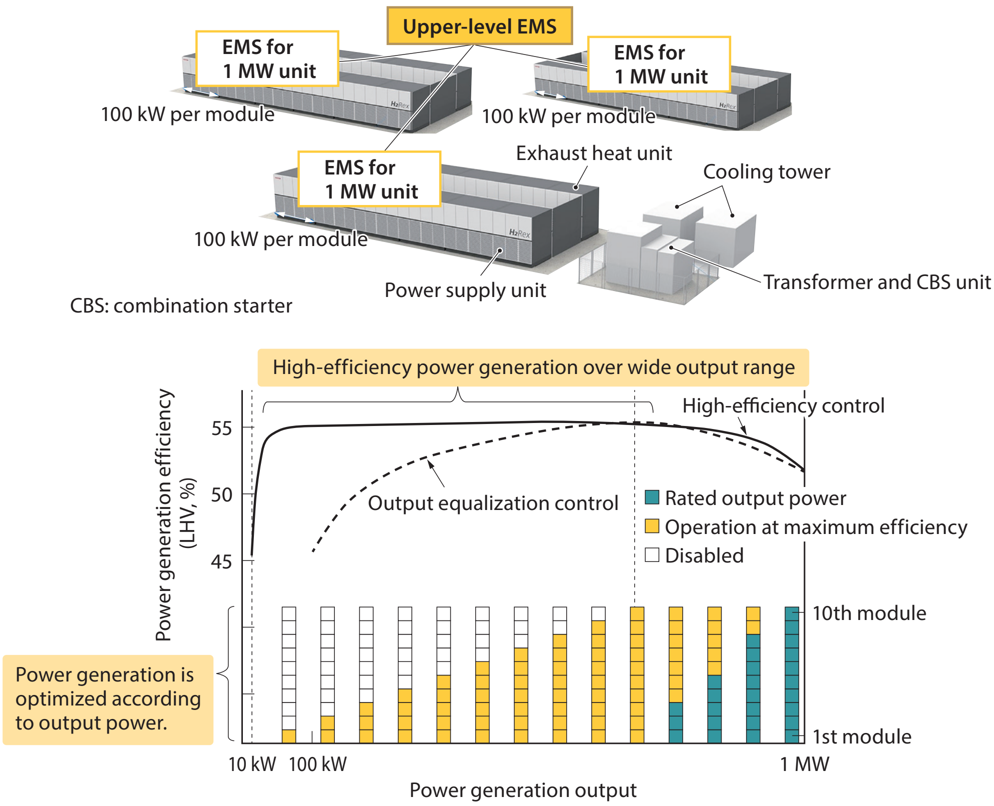
(*1) Combined heat and power

(*2) As of April 2022 (as researched by Toshiba Energy Systems & Solutions Corporation)



* Humanoid figure is 170 cm tall.

100D third-generation model of H2Rex™ stationary pure hydrogen fuel cell system

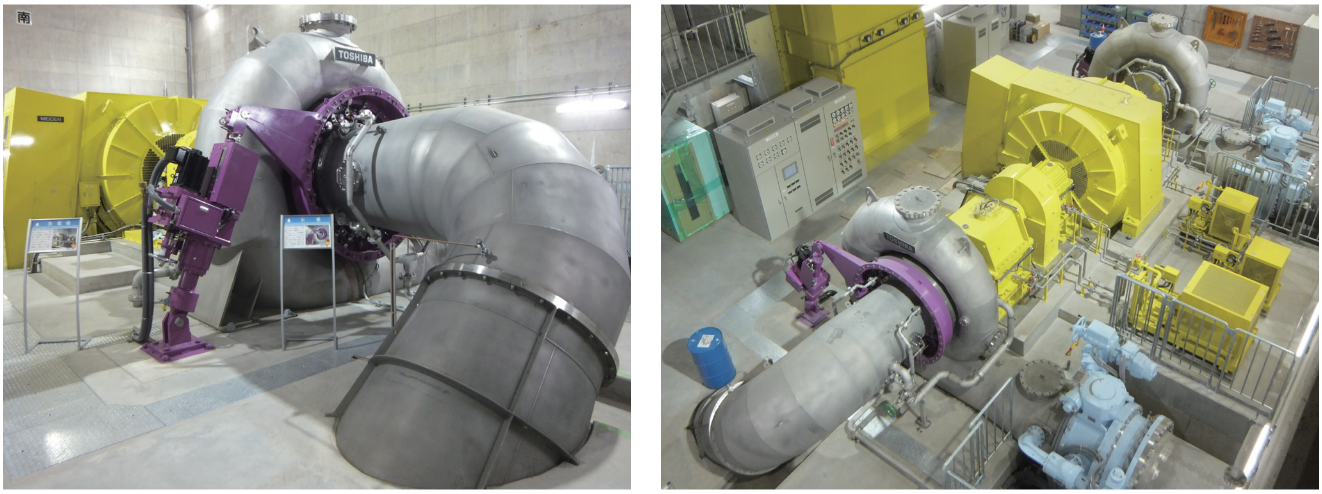


LHV: lower heating value, which excludes the heat of vaporization of the water due to fuel combustion

Megawatt-class stationary pure hydrogen fuel cell system employing integrated management of multiple 1 MW units

2. Energy Systems

2.2 Commencement of Commercial Operation of Yanba Power Plant in Gunma Prefecture, Japan



Hydraulic turbine (left) and hydraulic turbine generator (right) for Yanba Power Plant, Gunma Prefecture

Constructed in conjunction with a new dam, the Yanba Power Plant in Gunma Prefecture is a hydroelectric power generation facility that commenced commercial operation in April 2021. Toshiba Energy Systems & Solutions Corporation was awarded a contract in June 2016 for the design and manufacture of its hydraulic turbine.

Although the Yanba Dam is a multipurpose dam, it was built mainly for flood control with a flood control capacity of 65 million m^3, larger than its water utilization capacity of 25 million m^3. Therefore, the water level of the Yanba Dam is lowered considerably during the flood season, causing the effective water head of the hydraulic turbine to vary by more than 40 m from 105.8 m to 62.08 m. The hydraulic turbine is also designed to allow flow rate variations from 13.6 m^3/s to 2.4 m^3/s. In order to achieve high turbine efficiency and a wide operating range, we employed a horizontal-shaft Francis turbine with double runners and a T-Blade™ runner while optimizing their design.

As the Agatsuma River, the primary source of water for the Yanba Power Plant, is an acidic river, we used stainless steel for all of the parts that come into contact with river water including the draft tube and the spiral casing. For the runner and the guide vane, we chose SCS6 stainless cast steel based on our experience.

When the hydraulic turbine is in single-runner mode, the idling runner requires cooling. For the hydraulic turbine at the Yanba Power Plant, we improved the performance of air cooling via open-close control of a motor-operated valve installed in the drainage pipe of the turbine, eliminating the need for cooling water. In addition, we utilized an electric servomotor for the guide vane to eliminate the need for the use of hydraulic oil and the related maintenance.

The type and the ratings of the turbine are as follows:

- Horizontal-shaft Francis turbine with double discharge runners and spiral casings, 12.6 MW, 105.8 m, 600 min^{-1}.

2.3 Completion of Major Refurbishment of Hydroelectric Generators at Blue Mesa Powerplant in U.S.A.

Installation of generator stator at Blue Mesa Powerplant, U.S.A.

Units 1 and 2 of the Blue Mesa Powerplant in Colorado, U.S.A., resumed commercial operation in September 2020 and May 2021, respectively, after a major refurbishment of their generators.

Toshiba America Energy Systems Corporation received a contract for this project as the main contractor in May 2016. Toshiba Energy Systems and Solutions Corporation acted as its subcontractor responsible for the design and manufacture of the generator stators. Toshiba America Energy Systems took charge of on-site assembly of the generator stators, repair of the parts to be reused, procurement of the excitation equipment, and reassembly of the units.

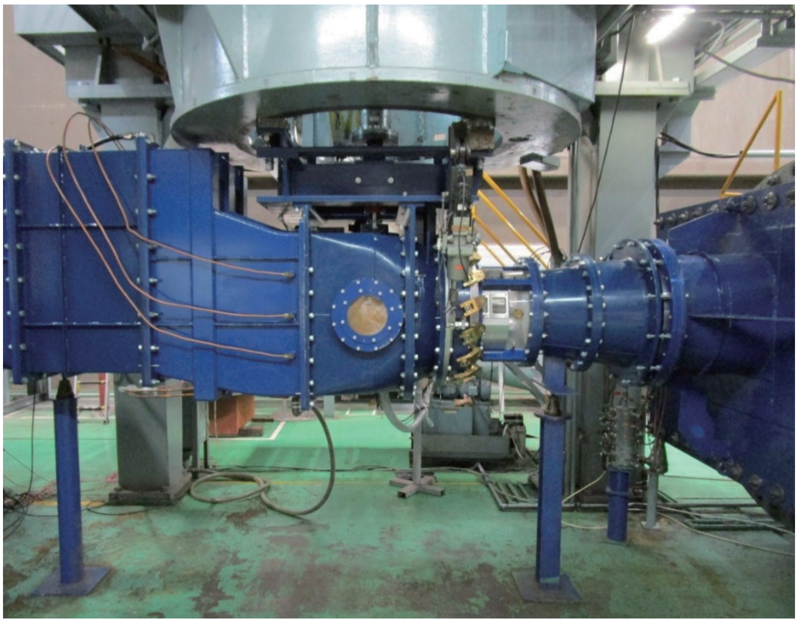
The purpose of this project was to modernize and restore the reliability of the generators. The previous generators had issues concerning rises in the temperature of the stator windings. In the beginning, we did not have sufficient data required for design improvement since these generators were originally fabricated by another manufacturer. To overcome this problem, we collected necessary information through on-site generator operation tests. The stators were assembled outside the generator pit to improve work efficiency and shorten the outage period.

Although we encountered some unexpected events and circumstances such as interruption of the work due to the COVID-19 pandemic, the repair and renovation of the generators were completed as scheduled.

The generator ratings are as follows:

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

2.4 Completion of Model Tests of Hydraulic Turbine for Hubei Xinji Hydropower Plant in China



Verification of hydraulic turbine performance by model tests

In August 2021, Toshiba Energy Systems & Solutions Corporation completed model tests of the hydraulic turbine for the Hubei Xinji Hydropower Plant in China. Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC) received an order for four sets of this hydraulic turbine because of its extensive experience in the design and manufacturing of bulb turbine-generators.

Since we already had a turbine model that satisfied the customer's specifications, no development time was required to meet the required performance.

The COVID-19 pandemic made it difficult for the customer to come to Japan, so we performed the model tests of the hydraulic turbine while the customer was present remotely online. As a result of the tests, we confirmed that the hydraulic turbine satisfies the performance requirements.

THPC is currently designing and manufacturing the power generation equipment for the Hubei Xinji Hydropower Plant. Its shipment will begin in October 2022, and installation and commissioning tests will be completed in May 2023, followed by the commencement of commercial operation.

The ratings of the hydraulic turbine are as follows:

- 30.77 MW, 8.6 m, 78.95 min^{-1}.

2.5 Commencement of Commercial Operation of Goto-Hassakubana Wind Power Plant

Wind turbine for Goto-Hassakubana Wind Power Plant of Cosmo Eco Power Co., Ltd.

In March 2021, Cosmo Eco Power Co., Ltd. completed construction of the Goto-Hassakubana Wind Power Plant (1 200 kW × 1 unit) located in Goto City, Nagasaki Prefecture, and commenced commercial operation. Toshiba Energy Systems & Solutions Corporation supplied wind turbine equipment, dispatched technical advisors to the site, and conducted site acceptance tests for the wind turbine as required by the Ministry of Economy, Trade and Industry (METI) of Japan. We are now responsible for the maintenance of the wind turbine.

The features of this project include the following:

(1) Under this project, we received NK certification (Japanese Marine Standards) from Nippon Kaiji Kyokai (NK) for the first time.

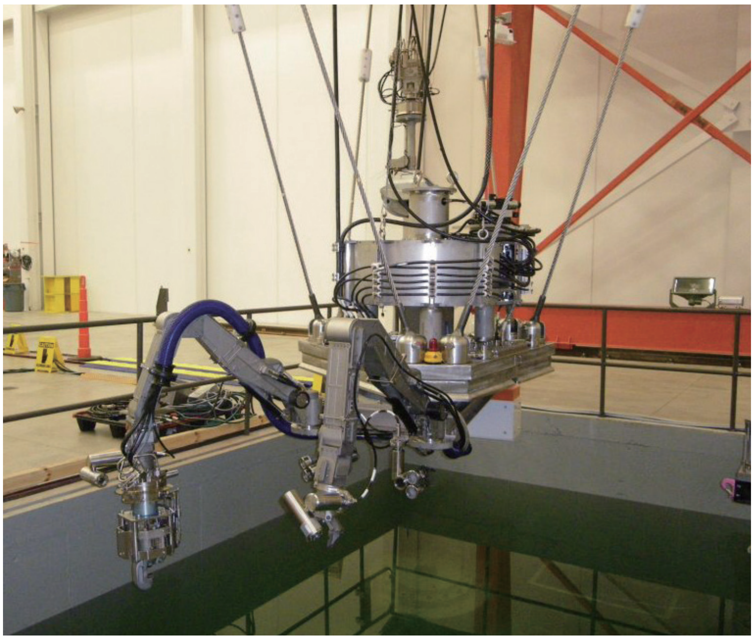
(2) The wind turbine is located in an area where the utility grid voltage is unstable.

(3) We developed and supplied a new online output control device to meet the requirements of electric power companies.

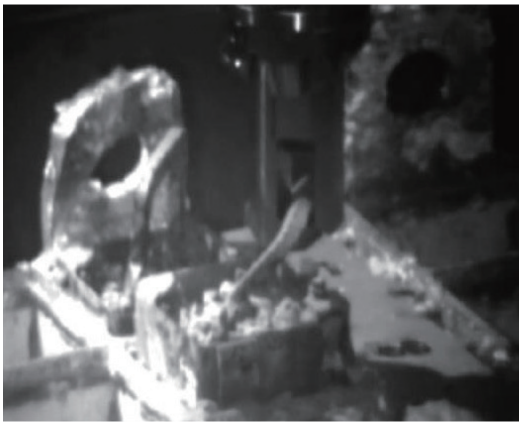
The COVID-19 pandemic spread during the construction work, causing a delay in the arrival of technical advisors from abroad. However, we cooperated with the project contractor and implemented thorough infection control measures. As a result, construction work was completed as originally scheduled.

We will apply the knowledge and expertise acquired through our experience in this project to future wind turbine construction projects in order to expand our wind power business and further promote technological development.

2.6 Completion of Nuclear Fuel Removal from Unit 3 Spent Fuel Pool of Fukushima Daiichi Nuclear Power Station



TensileTruss™ and manipulators of fuel handling machine installed at Fukushima Daiichi Nuclear Power Station Unit 3



Scene of removal of fuel with deformed handle

The reactor building of Fukushima Daiichi Nuclear Power Station Unit 3 was severely damaged by a hydrogen explosion triggered by the Great East Japan Earthquake. As a result, building rubble and a refueling machine fell into the spent fuel pool. Since the spent fuel pool contained 566 fuel assemblies, it was necessary to remove them from the pool for transportation to a safe repository as soon as possible.

In 2011, Toshiba Energy Systems & Solutions Corporation commenced the design of a fuel and rubble removal system. To reduce radiation exposure, it was necessary to remotely operate the fuel handling machine as well as a crane for transporting fuel transport containers. For removal of the rubble, the fuel handling machine was equipped with two manipulators attached to a TensileTruss™ structure with sufficient tensile strength to bear the horizontal load. In 2019, we assembled the fuel removal system at Fukushima Daiichi Nuclear Power Station Unit 3 and began the removal of the fuel assemblies.

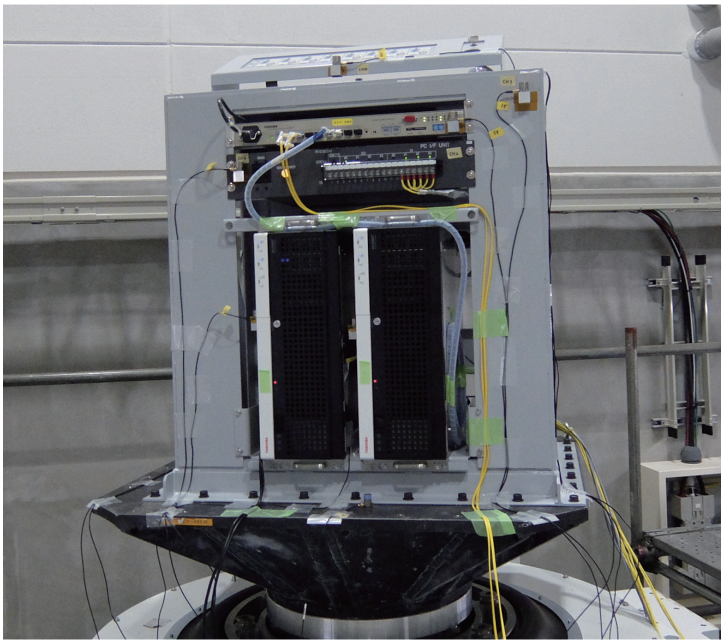
After fuel removal started, it was found that the handles of 18 fuel assemblies were so deformed that it was impossible to grasp them with the existing fuel grasping tool. To remove these fuel assemblies, we developed a new grasping tool. Since the handles were deformed in different ways and had only narrow areas to grip, we reduced the size of the tool and used a high-strength material.

This was our first experience of designing and manufacturing a fuel removal system for a spent fuel pool strewn with rubble. Drawing on our experience in the operation of nuclear power plants and leveraging a new technology introduced from an overseas company, we completed the removal of the 566 fuel assemblies in February 2021.

Although some problems occurred during system operation, we acquired valuable experience investigating, solving, and taking countermeasures against such problems. We will draw on this experience when removing fuel assemblies from Unit 2.

TensileTruss is a registered trademark of PaR Systems, LLC.

2.7 Seismic Qualification of Toshiba Digital Control System for Rokkasho Reprocessing Plant



CIEMAC™-DS/nv digital control system undergoing seismic qualification test

The safety control systems at the Rokkasho Reprocessing Plant of Japan Nuclear Fuel Limited are required to meet the regulatory seismic requirements related to basic earthquake ground motion.

Conventional nuclear safety control systems use hardwired components, including indicators and relays, to satisfy the seismic requirements. In contrast, digital systems with multiplexed signal transmission capability are expected to provide many benefits for the reduction of system installation costs, including cable costs.

Toshiba Energy Systems & Solutions Corporation has well-proven experience in applying the CIEMAC™-DS/nv, an industrial digital control system from Toshiba Infrastructure Systems & Solutions Corporation, to the production control system of the Rokkasho Reprocessing Plant. However, the CIEMAC™-DS/nv did not meet the seismic requirements for nuclear safety systems since it was originally designed for general-purpose industrial digital control applications. We therefore improved its structural design to meet the nuclear seismic requirements.

Seismic qualification tests showed that, as a result of this improvement, the CIEMAC™-DS/nv now withstands a horizontal acceleration of 5G and a vertical acceleration of 3G, as specified by the seismic requirements. We are confident that the new variant of the CIEMAC™-DS/nv can be applied to the safety systems of the Rokkasho Reprocessing Plant.

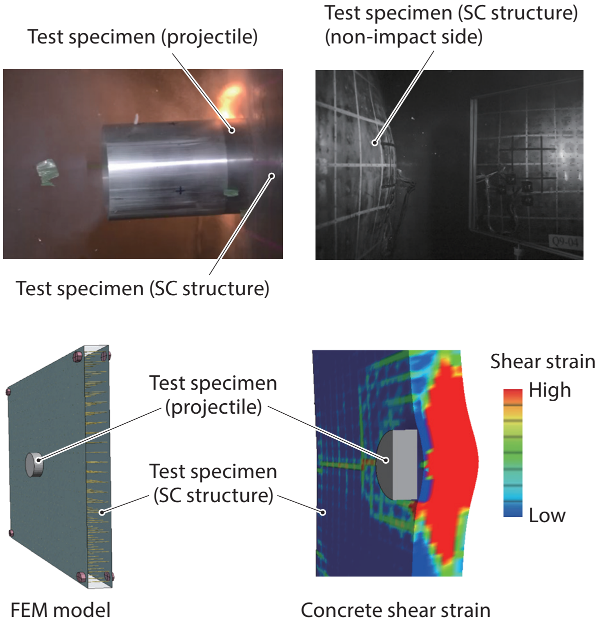
2.8 Commencement of Commercial Operation of Barakah Nuclear Energy Plant with High-Capacity Steam Turbine Generators

Barakah Nuclear Energy Plant, UAE

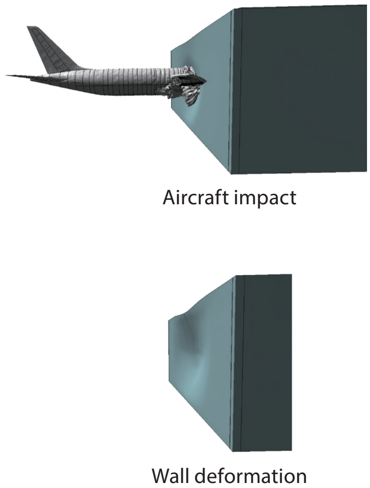
Toshiba Energy Systems & Solutions Corporation has delivered steam turbine generators (STGs) to the Barakah Nuclear Energy Plant (Barakah NEP) through Doosan Enerbility Co., Ltd., which is a subcontractor to Korea Electric Power Corporation, the prime contractor of the Barakah NEP project. The first-ever nuclear power plant in the United Arab Emirates (UAE) and the whole Arab region, the Barakah NEP consists of four APR-1400 nuclear reactor units. As a result of on-site tests, we successfully verified the performance of the STG components that we delivered to the Barakah NEP. Unit 1 commenced commercial operation in April 2021, followed by Unit 2 in March 2022.

STGs are the main components of the secondary circuit of a nuclear power plant for generating electricity from the steam produced by heat from the nuclear chain reaction. We designed and manufactured the STGs using the latest technology developed through our R&D initiatives for increasing STG capacity. The last-stage blade of the steam turbine is 52 inches long, exceeding the 48-inch length of our previously largest last-stage steam turbine blade. The generator has a capacity of 1 690 MVA, the largest among the generators that we have supplied to date to nuclear power plants.

2.9 Technology to Create Robust Reactor Building Design for Protection against Crash Impact of Large Aircraft



Example of high-speed impact test and impact resistance analysis of steel-plate reinforced concrete (SC) structures



Example of impact resistance analysis of reactor building structure in case of large-aircraft impact

In Japan, as in other countries, the reactor buildings of nuclear power plants are required to be designed to withstand an intentional crash of a large aircraft and to be prepared for a severe accident resulting from an act of terrorism.

In order to enhance the safety of nuclear power plants, Toshiba Energy Systems & Solutions Corporation has developed a technology to improve the robustness of reactor buildings against the crash impact of a large aircraft. The robustness of a reactor building can be improved by increasing the thickness of the reinforced concrete (RC) structure that makes up its outer shell, but its seismic stability will be affected if the overall weight and the wall thickness are unbalanced.

We determined the basic specifications for a steel-plate reinforced concrete (SC) structure with excellent impact resistance through experiments and analyses. We also applied a three-dimensional (3D) finite element method (FEM) model of the SC structure to part of a reactor building in order to evaluate the strain of the building structure under high-speed deformation. As a result, it was confirmed that the reactor building wall can be more than 50% thinner than that required for an RC structure if the overall building structure is optimized according to the strain.

We will continue to enhance the value of our energy solutions by further improving the safety and reliability of nuclear power plants.

2.10 Wireless Communication Technologies for Operation and Maintenance of Nuclear Power Plants

Scene of data transmission field test using tablet

Nuclear power plants are expected to benefit greatly from the use of wireless technologies. For example, mobile devices will help improve the efficiency of fieldwork. The use of wireless Internet-of-Things (IoT) sensors will contribute to the enhancement of plant diagnosis while eliminating the need for cables, reducing the cost and construction period of new nuclear power plants.

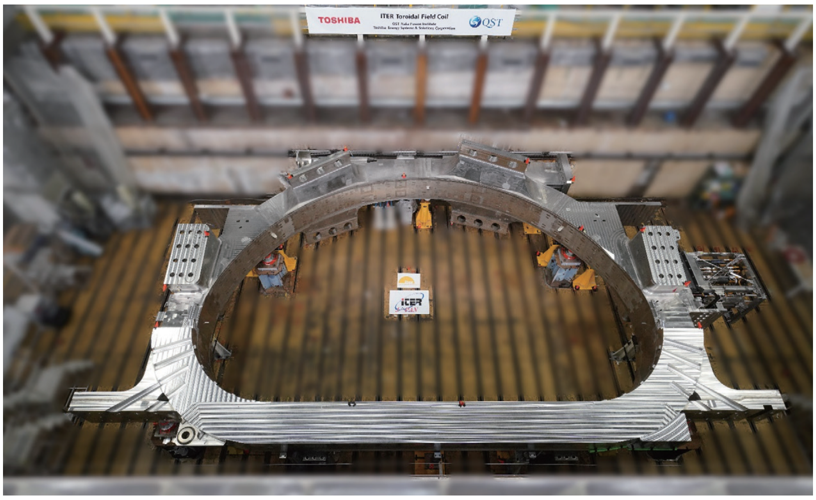
However, wireless systems might expose power generation facilities to electromagnetic interference (EMI). In addition, wireless communication poses concerns with regard to cyber-security.

In response to these issues, Toshiba Energy Systems & Solutions Corporation has been developing highly secure wireless communication technologies. Areas where radio emissions are controlled are designated to protect EMI-sensitive facilities. Wireless devices communicate with a security algorithm that executes data encryption, data tampering detection, and authentication of transmitting devices.

As a result of field tests at a biomass power plant, we confirmed that a regular inspection record with a size of 10 Mbytes can be transmitted in approximately 20 seconds and simulated plant performance data with a size of 1 kbyte can be transmitted in 1 second. Stored on a maintenance management server, these data can be used for plant life management.

We are planning to improve the transmission speed to expand the areas of application of wireless technologies.

2.11 Completion of Manufacturing of ITER TF Coil



Completed TF coil for ITER thermonuclear experimental reactor

Nuclear fusion generation is one of the power generation methods that is expected to contribute to carbon neutrality, a state of net-zero carbon dioxide (CO_2) emissions to alleviate global warming. ITER is a thermonuclear experimental reactor, and the ITER project is currently underway in France with the participation of seven member parties including Japan and the European Union (EU).

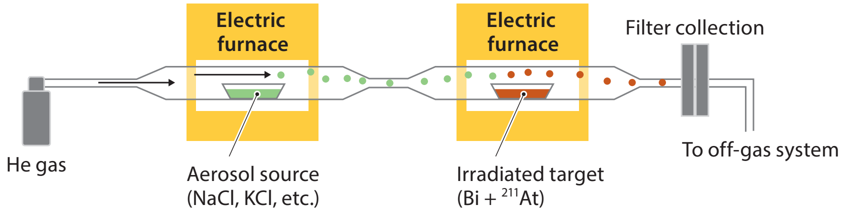
In 2013, Toshiba Energy Systems & Solutions Corporation received an order from the National Institutes for Quantum Science and Technology (QST) of Japan for four toroidal field (TF) coils, which are key devices for generating a strong magnetic field to confine high-temperature, high-density plasma in order to produce a fusion reaction. We manufactured and shipped the first of the four TF coils in July 2021.

The TF coil is the world's largest superconducting coil(*) with a length of 17 m, a width of 9 m, and a weight of 320 tons. It consists of a winding pack (WP) in which a superconducting conductor is wound and insulated, and a coil case that houses the WP. In order to secure the positioning accuracy required to align the coil's current center line (CCL) with the cross section of the WP, the WP is installed in the coil case with an error of less than 1 mm. The case closure welding is followed by a gap impregnation process and machining work. In each process of WP-case integration, the assembly error and the amount of deformation due to the welding heat and the weight of the WP itself are measured with high precision using a 3D measuring instrument. Since the deformation due to the weight of the WP must be corrected prior to the impregnation process, we established a dimension control method to correct the position of the WP's CCL.

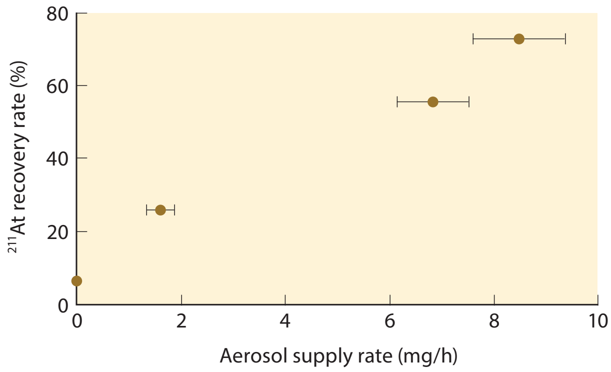
With the completion of the first TF coil, we have been able to demonstrate our technological capabilities for the fabrication of superconducting coils, representing a further step toward achieving carbon neutrality through energy technologies for decarbonization.

(*) As of April 2022 (as researched by Toshiba Energy Systems & Solutions Corporation)

2.12 Technology for Separation and Recovery of Alpha-Ray Nuclides Effective for Cancer Treatment



Outline of aerosol-based astatine-211 (^{211}At) recovery system



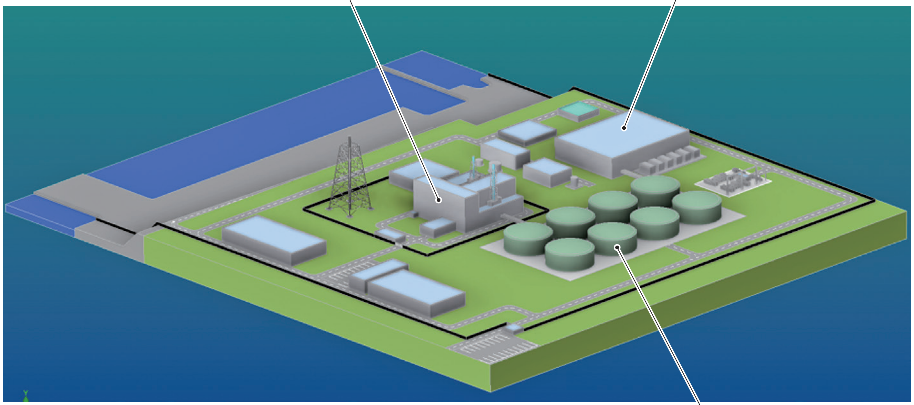
Relationship between aerosol supply rate and ^{211}At recovery rate

Radiopharmaceutical therapy for cancer is currently under development around the world using various radionuclides. Astatine-211 (^{211}At), an alpha-ray nuclide, is a promising candidate for cancer treatment. As ^{211}At does not exist in nature, it is produced by bombarding bismuth (Bi) with helium (He) atoms accelerated by a particle accelerator. In order to use ^{211}At as a radiopharmaceutical, it is necessary to separate and recover ^{211}At produced in a target Bi material.

Against this background, Toshiba Energy Systems & Solutions Corporation has developed an ^{211}At separation and recovery system using an aerosol method. Since there is a difference in boiling point between Bi and ^{211}At, the target Bi material is heated to vaporize and separate ^{211}At. The separated ^{211}At is introduced into an aerosol chamber so that it is attached to the aerosol particles, which are then collected with a filter.

In 2021, we conducted a separation and recovery test, successfully verifying the principle of the newly developed system. Our next step is to create a model that represents interactions between ^{211}At and an aerosol, and to design an ^{211}At separation and recovery system that can be used for practical clinical trials.

2.13 Small Modular High-Temperature Gas-Cooled Reactor with Inherent Safety



Bird's-eye view of small modular high-temperature gas-cooled reactor power plant

High-temperature gas-cooled reactors (HTGRs) are significantly contributing to public acceptance because they provide inherent safety characteristics including confinement of radioactive materials, and passive cooling and shutdown in the event of an accident.

Toshiba Energy Systems & Solutions Corporation and Fuji Electric Co., Ltd. have developed a small modular HTGR with high economic performance, aiming for early commercialization. This HTGR has a simplified confinement system based on the concept of inherent safety. Housing four 600 MW modules, it provides a total thermal power output equivalent to that of a large light-water reactor (LWR) and improved economic performance. To achieve early development, the newly developed HTGR uses a steam turbine since steam turbines are mature technology.

This HTGR can supply heat at a temperature of more than 700°C, which can be used not only for power generation but also for various other purposes. We are exploring an optional heat storage system to accommodate the inherent intermittency of renewable energy such as solar and wind power. The generated heat can also be used for hydrogen production and chemical plants. In addition, the HTGR contributes to a reduction of CO_2 emissions.

This work was partially supported by METI of Japan through the Nuclear Energy × Innovation Promotion (NEXIP) program.

2.14 CO_2 Capture Test Facility for Carbon Capture and Utilization

CO_2 capture test facility for carbon capture and utilization (CCU) installed at site of Sekisui Chemical Co., Ltd.

In recent years, it has become imperative to reduce CO_2 emissions from industry in order to mitigate global warming. With the progress of CO_2 capture technology, carbon capture and utilization (CCU) for the recycling of CO_2 is gaining greater attention than carbon capture and storage (CCS).

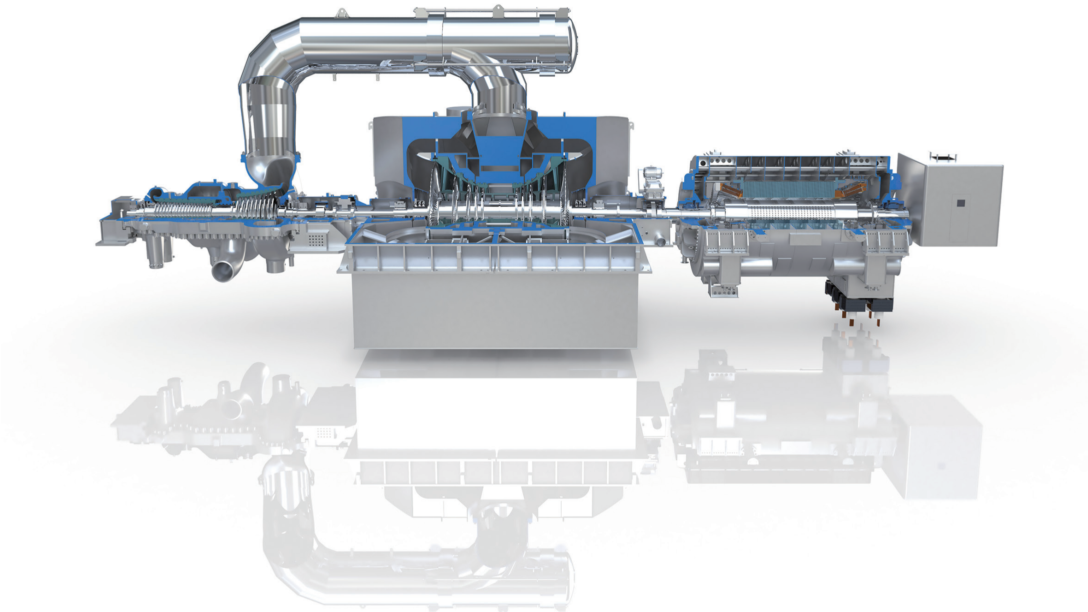
Sekisui Chemical Co., Ltd. has been conducting a CCU demonstration project as part of the FY2021 Project to Promote the Creation of Circular Carbon Society Model through CO_2 Recycling being implemented by the Ministry of the Environment of Japan. In the CCU demonstration project, Sekisui Chemical will convert CO_2 into carbon monoxide (CO) to synthesize ethanol.

In May 2021, Toshiba Energy Systems & Solutions Corporation delivered a CO_2 capture test facility to Sekisui Chemical, which is designed to absorb CO_2 in exhaust gas into an aqueous amine solution. The purity of the recovered CO_2 is 99% or more on a dry volume basis. This test facility can capture up to 10 kg of CO_2 per day.

There are concerns about short-term and long-term changes in the amount of CO_2 captured from waste incineration facilities due to exhaust gas fluctuations and amine solution degradation. In order to keep the amount of CO_2 capture constant, we introduced equipment and a control technology to measure the amount of CO_2 capture in real time and adjust the process conditions accordingly. In addition, this equipment maintains CO_2 gas at a stable pressure so as to supply an exact amount of CO_2 gas.

We will continue to work on technological development for the realization of a carbon-neutral society.

2.15 Delivery of Steam Turbine Generator to Montgomery County Power Station, U.S.A.



Steam turbine generator for Montgomery County Power Station, U.S.A.

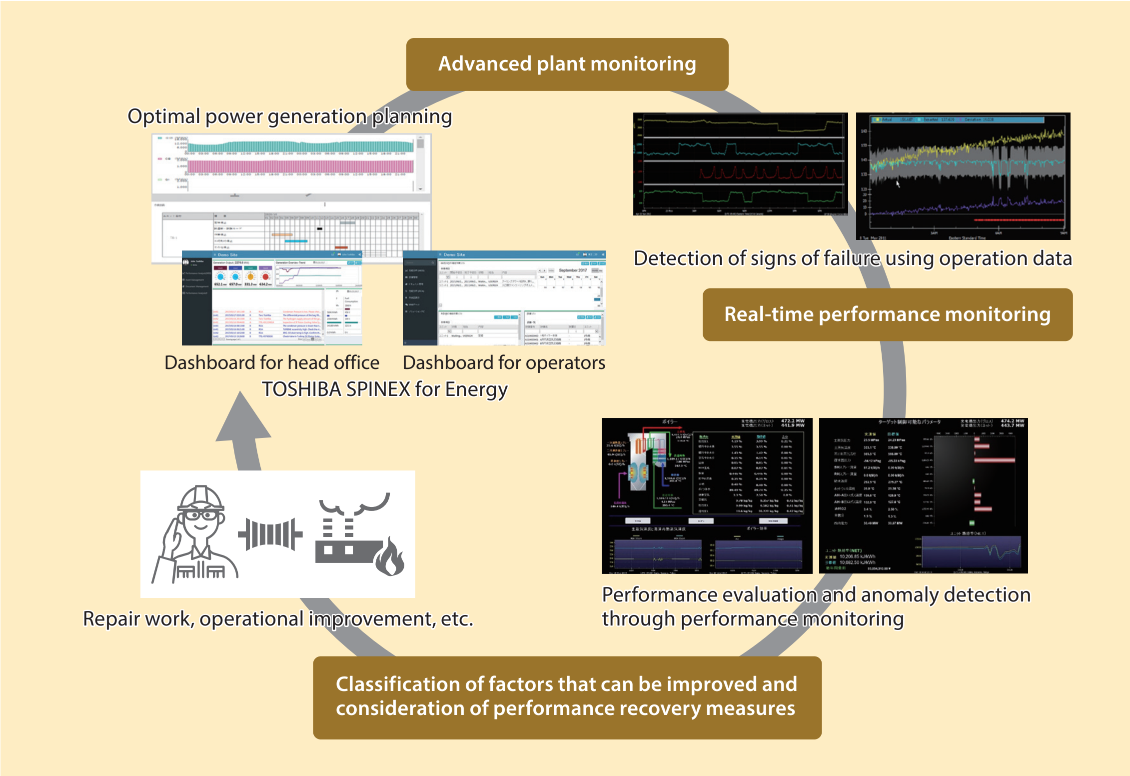
In the midst of the shrinking coal-fired power generation market, the replacement of aging coal-fired power plants with gas-fired power plants, including combined-cycle thermal power plants, is attracting attention.

In 2018, Toshiba Energy Systems & Solutions Corporation received an order for a 450 MW steam turbine generator (STG) from McDermott International, Ltd., a major U.S. engineering company, for the Montgomery County Power Station in Texas. Shipped from Japan in September 2019, it commenced commercial operation in January 2021, four months earlier than originally scheduled, even though we needed to take countermeasures against COVID-19 during the installation period.

We had previously received orders for STGs from McDermott for two other power stations in the U.S.A., the J. Wayne Leonard Power Station in 2016 and the Lake Charles Power Station in 2017, both of which were also installed successfully.

While adapting to the changing energy market, we will continue to provide high-efficiency STGs and other value-added products to meet customers' increasingly diverse requirements for power plant construction and services.

2.16 TOSHIBA SPINEX for Energy for Japanese Electric Power Companies



Overview of TOSHIBA SPINEX for Energy services for Japanese electric power companies

In the energy field, there is a growing need for services that solve the issues faced by electric power companies through digital transformation (DX).

In response, Toshiba Energy Systems & Solutions Corporation offers TOSHIBA SPINEX for Energy, a collection of IoT microservices for Japanese electric power companies. These microservices include optimal power generation planning, plant performance monitoring, anomaly detection using IoT, and predictive failure detection using operation data.

We have combined these microservices according to customers' requirements and deployed them in multiple power plants. The management and visualization of these microservices are consolidated on a dashboard.

We will continue to improve and provide various microservices to help solve power plant issues according to customers' requirements.

2.17 Completion of Commissioning of Microgrid in Maldives

µEMS™ system

SCiB™ system

Rising environmental concerns are driving the development of renewable energy worldwide. However, weather conditions affect renewable energy generation, causing power grid instability, particularly on remote islands. Although diesel generators are commonly used in remote island communities, they incur high fuel costs and produce CO_2 emissions. Therefore, a microgrid system and an EMS for efficiently controlling generators and battery systems provide an attractive solution for the problems of fuel costs and CO_2 emissions.

Toshiba Energy Systems & Solutions Corporation has delivered a microgrid system to Addu City in the Republic of Maldives. This is the first CO_2 reduction project funded by the Japan Fund for the Joint Crediting Mechanism (JFJCM), one of the trust funds of the Asian Development Bank (ADB). The project organizer is the Ministry of Environment, Climate Change and Technology (MOECCT) of the Maldives. Since the electricity demand of Addu City, the second-largest city in the Maldives, is growing every year, it is essential to operate the power grid efficiently using an EMS and a battery system.

The project site is located in the Central Power Station where 15 diesel generators are running to supply electricity to four islands. There are also five solar photovoltaic (PV) sites with a total capacity of 1.6 MW as against a demand of 6 to 7 MW.

We installed a µEMS™ energy management system for microgrid systems and an SCiB™ rechargeable battery energy storage system with a rated capacity of 1 MW at 333 kWh. The battery system helps to reduce fluctuations of the PV output and therefore the burden on the diesel generators because of the reduced need to change their output. In addition, the µEMS™ system improves the fuel economy of the diesel generators by applying our proprietary optimization algorithm. This microgrid system using a combination of the µEMS™ and SCiB™ systems thus reduces fuel costs and CO_2 emissions.

Following a commissioning test in 2021, we are currently preparing for commercial operation with MOECCT.

2.18 Commencement of Commercial Operation of 900 MW Hida-Shinano Bipolar HVDC Link in March 2021

HVDC thyristor valve installed at Shin-Shinano Substation of TEPCO Power Grid, Inc.

Following commissioning tests and trial operations, the Hida-Shinano high-voltage DC (HVDC) link interconnecting the prefectures of Nagano (50 Hz) and Gifu (60 Hz) commenced commercial operation in March 2021. An additional frequency conversion (FC) system (450 MW × 2, ±200 kVDC, 2 250 A) is installed at the Shin-Shinano Substation of TEPCO Power Grid, Inc. (hereafter "TEPCO PG"), in which it is connected to the 50 Hz end of the HVDC link.

Toshiba Energy Systems & Solutions Corporation supplied the entire equipment required by the Shin-Shinano Substation for the HVDC link including AC/DC converters, transformers, circuit breakers, and control and protection systems. With the commencement of operation of the 900 MW Hida-Shinano HVDC link, the total interconnection capacity of the Shin-Shinano Substation increased from 600 MW to 1 500 MW.

Proven line-commutated current-source converters (LCCs) were chosen for the HVDC link. However, since two sets of 300 MW FC systems, FC1 and FC2, had already been installed there, our main concerns were the limited installation space and interference with the existing transmission system. To solve the installation space problem, we reduced the size of the thyristor valve by reducing the number of series-connected thyristor elements per arm from 36 to 32 (a reduction of approximately 10%). This was achieved by (1) increasing the withstand voltage of the thyristor elements, (2) reducing the protection level of the valve lightning arresters, and

(3) reducing the rated voltage of the converter transformer valve winding. To solve electrical problems such as low-order frequency resonance and temporary overvoltage (TOV), we cooperated with TEPCO PG in various system studies, including stability and transient response analyses taking FC1 and FC2 into consideration. Based on the results of these studies, we introduced a circuit breaker with a damped harmonic filter and a controlled switching device (Toshiba Controlled Switching System: TCSS).

The FC systems at the 50 Hz end that we delivered have been operating normally since the commencement of commercial operation, and the first periodic maintenance conducted in November 2021 found no problems. We will continue to cooperate with TEPCO PG on the maintenance of the HVDC facility in order to ensure a stable electricity supply.

2.19 Energization of Four New 400 kV Substations of Ministry of Electricity of Iraq

Completed 400 kV substation located in Al-Muthanna, Iraq

132 kV GIS installed at Al-Muthanna Substation

Toshiba Energy Systems & Solutions Corporation delivered 400 kV gas-insulated switchgears (GIS), 132 kV GIS, and 400 kV oil-immersed transformers to four new 400 kV substations of the Ministry of Electricity of Iraq, all of which were energized in July 2021. As part of Iraq's power grid development plan formulated after the end of the Iraq War, we received an order in 2017 from Toyota Tsusho Corporation, the main contractor for this project, for the switchgears and transformers as well as support services for on-site installation and testing.

Since Iraq is one of the countries on the travel warning list of the Ministry of Foreign Affairs of Japan, it was difficult to dispatch our engineers there. Therefore, we had to provide remote support for on-site installation and testing. Since we had not had such experience before, we provided a six-month prior training at our factory for the engineers of the Egyptian engineering, procurement, and construction (EPC) company appointed by the main contractor. They performed installation and testing while using an online tool to facilitate communication with the technical advisors of our UAE office, the representative office for the Middle East.

Toshiba Transmission and Distribution Systems (India) Private Limited manufactured the 132 kV GIS, which were our first GIS to be installed in the Middle East. We succeeded in demonstrating our comprehensive technological capabilities through this project. Our achievements in this project will help to optimize our resources for future projects and expand our sales.

2.20 Completion of Transition to New SCADA System for Hydroelectric Power Stations of TEPCO Renewable Power, Inc.

Central SCADA system for hydroelectric power stations of TEPCO Renewable Power, Inc.

Toshiba Energy Systems & Solutions Corporation has delivered a new supervisory control and data acquisition (SCADA) system for hydroelectric power stations to TEPCO Renewable Power, Inc.

This SCADA system is a wide-area distributed system based on a thin client-server architecture designed to provide stable continuous operation combined with high availability and security. The new SCADA system supports safe and efficient operations even under changing weather conditions. It uses a dedicated mathematical model for river water management to achieve maximum power generation by making optimal use of river water. In addition, the new SCADA system provides a long-term logging function to monitor the states of river water and power stations' equipment, making it possible to predict abnormal conditions and thereby minimize the risk of damage.

We have succeeded in making a smooth transition to the new system without interrupting plant operations. TEPCO Renewable Power commenced a gradual transition to the new system in July 2018, completing the full transition in February 2021.