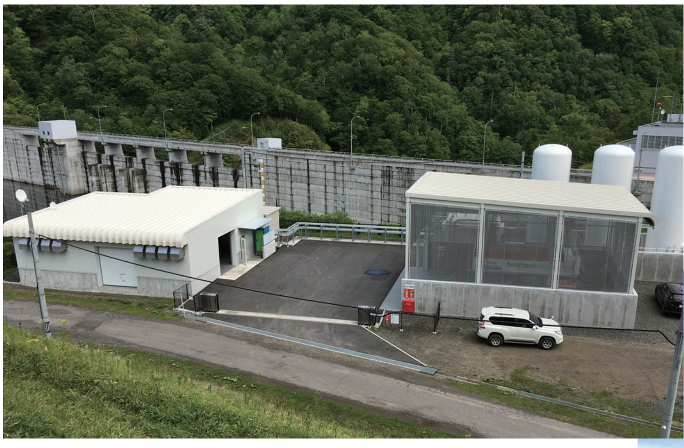
Energy Systems

Commencement of Demonstration Project to Establish Low-Carbon Hydrogen Supply Chain in Hokkaido



Hydrogen production facility installed at Shoro Dam in Hokkaido, Japan

Hydrogen application facility installed at heated pool

As part of the Low-Carbon Hydrogen Supply Chain Demonstration Project sponsored by the Ministry of the Environment of Japan, Toshiba Energy Systems & Solutions Corporation has initiated a project to establish a hydrogen utilization model suitable for the local characteristics of Hokkaido, using electricity produced by a small hydroelectric power plant.

For this project, we have constructed a small hydroelectric power plant with a capacity of 200 kW at the Shoro Dam in Shiranuka Town. Electricity from the hydroelectric power plant is used to electrolyze water and separate hydrogen at a hydrogen production facility, which produces roughly 35 $Nm^{3(*)}$ of hydrogen per hour. Pressurized to 19.6 MPa for transportation, the produced hydrogen is used to generate electricity by means of pure hydrogen fuel cell systems installed at dairy farms and indoor swimming pools in Shiranuka Town and at welfare and health centers in Kushiro City. It is also used as a fuel for fuel cell vehicles.

Through this project, we have demonstrated a low-carbon hydrogen supply chain encompassing all processes from hydrogen production using renewable energy to the transportation and utilization of the hydrogen.

We have also developed a hydrogen supply chain management system to maximize the efficiency of the fuel cell operation and transportation plans and to minimize carbon dioxide (CO_2) emissions from the hydrogen supply chain.

Through this project, we will collect data on the production, transportation, and utilization of hydrogen, which will be used to evaluate the reduction of CO_2 emissions and study the composition of a hydrogen supply chain.

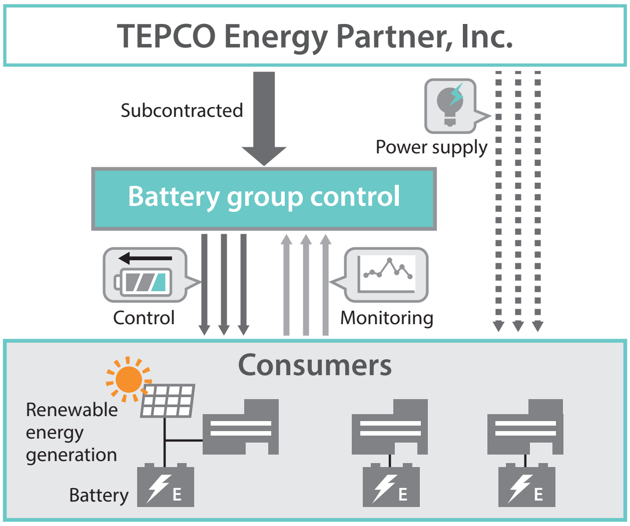
(∗) Nm^3: normal cubic meter, defined here as one cubic meter of gas at 0°C and 1 atm

Launch of Virtual Power Plant Service Utilizing Storage Batteries

In January 2019, Toshiba Energy Systems & Solutions Corporation launched a service for the operation of a virtual power plant (VPP) using storage batteries.

A VPP is a distributed power plant that aggregates distributed energy sources under integrated control. It is expected to be used as a power source for supply-demand balancing as the amount of installed renewable energy capacity increases. We conducted a two-year demonstration project from 2016 to 2017 in collaboration with the City of Yokohama and TEPCO Energy Partner, Inc., aiming to commercialize a VPP utilizing storage batteries.

Based on the results of this demonstration project, we considered the economical use of storage batteries and their use as an emergency power source and consequently launched a VPP service incorporating newly developed storage battery group control technology. In this service, we are handling the remote control and maintenance of storage batteries for 11 elementary schools in the City of Yokohama while TEPCO Energy Partner supplies the electricity. This service provides the schools with a number of benefits including emergency power supply, peak shaving, and demand response.



Service scheme of VPP using storage battery control technology

We will combine storage batteries with various energy resources to develop new technologies and services in preparation for the balancing energy market that will be established in 2021.

Commencement of Commercial Operation of Minamisoma Mano-Migita-Ebi Solar Power Plant and Minamisoma Haramachi-Higashi Solar Power Plant in Fukushima

The Minamisoma Mano-Migita-Ebi Solar Plant (photovoltaic module capacity: 59.9 MW) and the Minamisoma Haramachi-Higashi Solar Power Plant (photovoltaic module capacity: 32.3 MW) have commenced commercial operation.

These plants were constructed in the city of Minamisoma, Fukushima Prefecture, for economic reconstruction and regional revitalization following the Great East Japan Earthquake of March 2011. Although both plants are located on soft ground that was originally paddy field, Toshiba Energy Systems & Solutions Corporation has successfully completed their construction in cooperation with the joint venture partner and subcontractors. The main features of the plants are as follows:

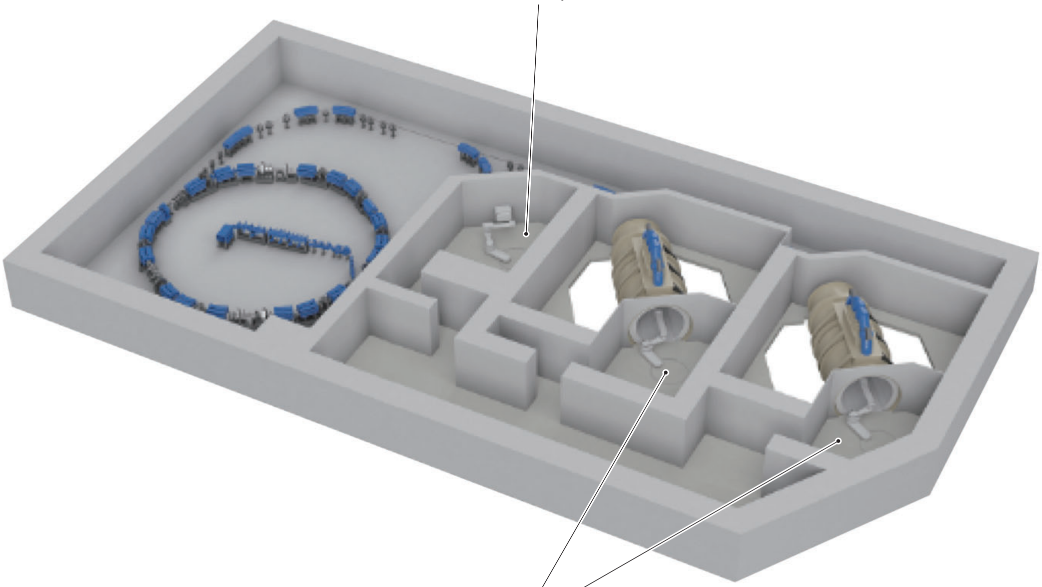
- high-quality polycrystalline 270 W photovoltaic modules
- simplified oblique pile foundation method for soft ground
- private transmission line from Minamisoma Haramachi-Higashi through a tunnel under a railway line, a national road, and a river.

We will also undertake operation and maintenance (O&M) of the plants for 20 years. Drawing on the expertise acquired from this construction project, we will contribute to the further development and dissemination of renewable energy.

Minamisoma Mano-Migita-Ebi Solar Power Plant (59.9 MW DC)

Minamisoma Haramachi-Higashi Solar Power Plant (32.3 MW DC)

Toshiba's First Overseas Contract for Heavy-Ion Radiotherapy System Concluded with Yonsei University Health System



Outline of heavy-ion radiotherapy facility for Yonsei University Health System, Korea

In March 2018, Toshiba Energy Systems & Solutions Corporation, in collaboration with DK Medical Solutions, a leading Korean medical company, was awarded a contract to supply a heavy-ion radiotherapy system to Yonsei University Health System (YUHS), one of the major providers of medical services in Korea. The highly advanced technologies of our heavy-ion radiotherapy system and our contributions to several heavy-ion radiotherapy facilities in Japan were positively evaluated by YUHS, leading to the awarding of the contract. This was our first overseas contract for a heavy-ion radiotherapy system.

Heavy-ion radiotherapy uses particles such as carbon ions to generate a high-energy beam that irradiates cancerous tissues. The system accelerates a beam of carbon ions to as much as 70% of the speed of light and delivers a concentrated dose of radiation to the targeted part. This ensures the efficient pinpoint application of lethal irradiation to cancerous tissues, with minimum damage to surrounding healthy tissues and fewer fractions compared with other radiotherapies.

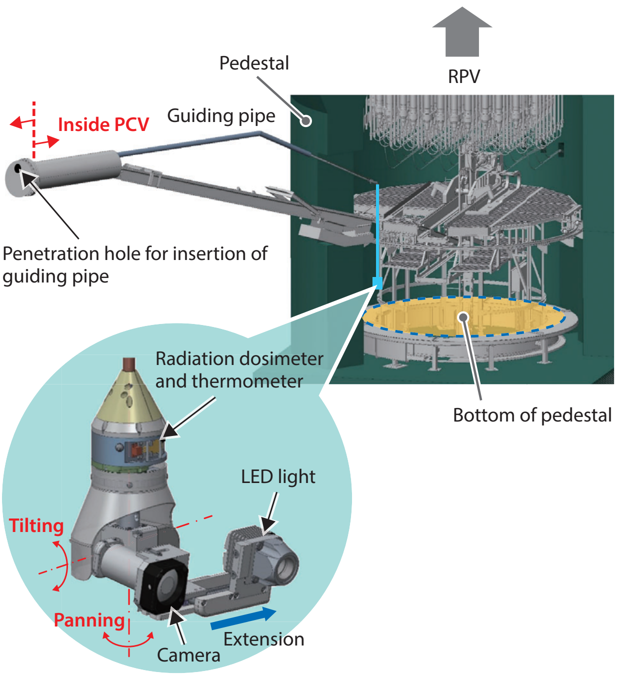
The heavy-ion therapy system supplied under this contract will be equipped with one horizontally fixed beam treatment room and two rotating gantry treatment rooms. This will be the world's first system with two rotating gantry treatment rooms(*), making it possible to provide more patients with advanced cancer treatment with very short waiting times.

We have been developing heavy-ion therapy systems in collaboration with the former National Institute of Radiological Sciences (NIRS) and the present-day National Institutes for Quantum and Radiological Science and Technology (QST). In October 2015, we developed the world's first downsized rotating gantry using superconducting magnets for the then NIRS. The rotating gantry is highly useful because it can precisely irradiate a beam from any direction without the need to tilt the patient. This helps to improve the treatment efficiency, minimizing the side effects of radiation and improving patients' quality of life.

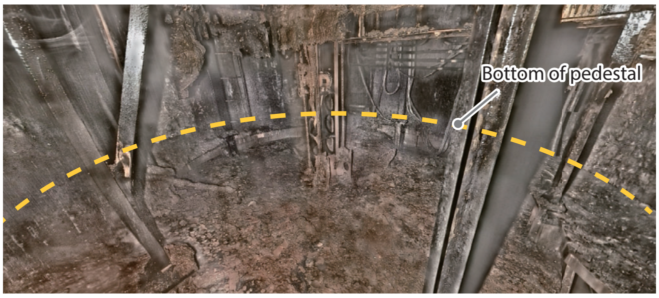
We intend to use this radiotherapy system with world-leading performance as a starting point for the global expansion of our business in this field.

(*) As of March 2018 (as researched by Toshiba Energy Systems & Solutions Corporation)

Image Capture Using Remotely Operated Robot inside PCV of Fukushima Daiichi Nuclear Power Station Unit 2

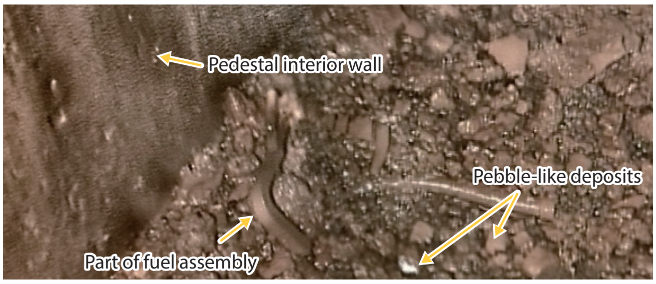


Remotely operated robotic device for Investigation inside PCV of Fukushima Daiichi Nuclear Power Station Unit 2



Source: "Decommissioning and Contaminated Water Management, 53rd Meeting Material No. 3-3," Tokyo Electric Power Company Holdings, Inc.

Part of omnidirectional image of bottom of PCV pedestal



Source: "Decommissioning and Contaminated Water Management, 53rd Meeting Material No. 3-3," Tokyo Electric Power Company Holdings, Inc.

Part of fuel assembly accumulated at bottom of PCV pedestal

It was assumed that, during the accident that occurred at Fukushima Daiichi Nuclear Power Station in 2011, the nuclear fuel that melted in Unit 2 had become fuel debris, fallen from the reactor pressure vessel (RPV), and been deposited at the bottom of the primary containment vessel (PCV). In order to determine the procedures for fuel debris removal, it is critical to identify where such debris is located.

Toshiba Energy Systems & Solutions Corporation investigated the bottom of the pedestal—a cylindrical component supporting the RPV—in January 2018. For this investigation, we employed a remotely operated robotic device developed as part of the "Development of Technology for Investigation inside PCV" project implemented by the International Research Institute for Nuclear Decommissioning (IRID) of Japan. From images captured by the robotic device, it was confirmed for the first time since the 2011 accident that part of the fuel assembly had actually fallen off.

With regard to the design of the robotic device, the survey unit needed to be downsized in order to pass through a penetration hole with a diameter of 10 cm, continue moving into the pedestal for 10 meters, and then descend for 2 meters to reach the bottom area. Therefore, the survey unit was attached to the top of a guiding pipe so that the unit could pass into the PCV through the opening and then be lowered to the bottom using a cable transfer mechanism. The survey unit was equipped with a light-emitting diode (LED) light, a thermometer, a dosimeter, and a camera with a pan-tilt mechanism that could provide wide-angle images of the interior of the pedestal.

From the data obtained, spherical images were created to better grasp the overall spatial conditions inside the pedestal. In addition, the LED light was equipped with a telescoping mechanism that made it possible to adjust the distance between the camera and the light source, which prevented halation and greatly improved the visibility inside the PCV. In particular, it was a major accomplishment to simultaneously achieve both the downsizing of the robotic device and an improvement in distant visibility under dark and hazy conditions.

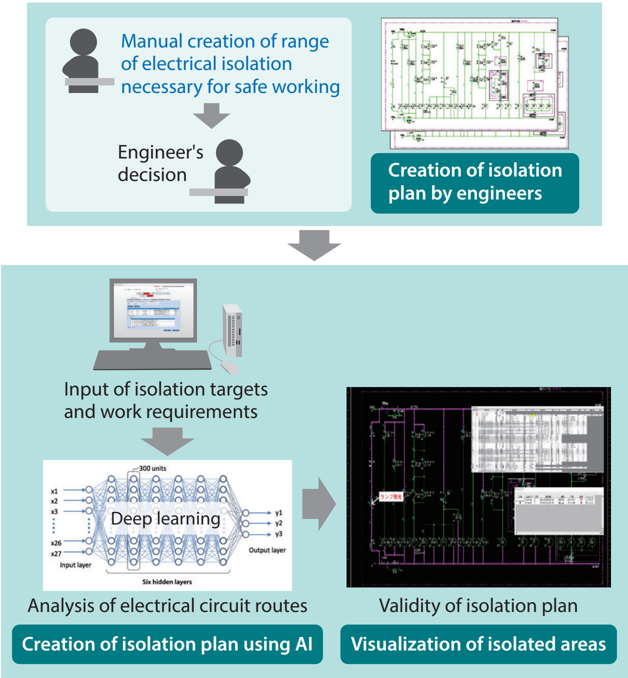
This investigation revealed that pebble- and clay-like deposits had accumulated over the entire bottom of the pedestal, and part of the fuel assembly was identified lying at the bottom. The information and data gathered through the investigation will significantly help those involved in the planning of the upcoming fuel debris removal. This work was subsidized by the Ministry of Economy, Trade and Industry (METI) under the "Decommissioning and Contaminated Water Management" project.

Electrical Isolation Planning System for Nuclear Power Plants

Electrical isolation is an important task in the construction and inspection of nuclear power plants so as to secure a safe working environment. A large amount of time is usually required for skilled engineers to create an electrical isolation plan based on hundreds of circuit diagrams.

To automate the planning of electrical isolation and evaluate its effects on the behavior of a plant, Toshiba Energy Systems & Solutions Corporation is currently developing an electrical isolation planning system using artificial intelligence (AI). Once the isolation targets and work requirements are entered, this system analyzes electrical circuit routes at high speed based on wiring diagrams using deep-learning algorithms. We have also developed a system that automatically visualizes the energization state on the wiring diagrams, allowing engineers to evaluate the validity of the electrical isolation plan via a graphical user interface.

The newly developed electrical isolation planning system reduces the planning time from as much as several days to about 10 minutes and simplifies the validation of the plan.



Flow of planning for electrical isolation at nuclear power plants using AI

Electrolysis-Based Technologies to Recover Long-Lived Fission Products from High-Level Radioactive Liquid Waste

In order to reduce the radiation levels of radioactive waste generated by the nuclear fuel cycle, Toshiba Energy Systems & Solutions Corporation is developing technologies to separate, recover, and transmute long-lived fission products (LLFPs) included in high-level waste.

As part of this research, we have developed a technology to separate and recover four elements—palladium (Pd), selenium (Se), cesium (Cs), and zirconium (Zr)—from high-level radioactive liquid waste generated during the reprocessing of spent fuel, including radioactive isotopes with half-lives of hundreds of thousands of years.

This technology eliminates the need for additives by combining adsorption and solvent extraction processes with an electrolytic process, minimizing the quantity of secondary waste with little change in the properties of the liquid. The radioactive elements are recovered in the form of metals suitable for nuclear transmutation, storage, and reuse.

In an experiment using simulated high-level radioactive liquid waste, 92% of Pd and 90% of Cs were recovered. We will continue our research to increase the Se recovery rate from 65% to more than 90%.

This research was funded by the ImPACT Program of the Council for Science, Technology and Innovation under the Cabinet Office of the Government of Japan.

Electrolysis of simulated high-level liquid radioactive waste

Stainless steel cathode with deposited Pd and Se after electrolysis

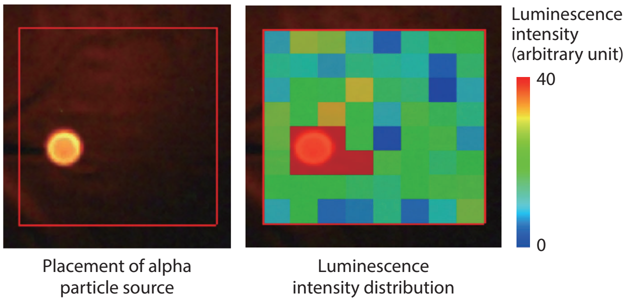
ImPACT: Impulsing Paradigm Change through Disruptive Technologies

Technique to Monitor Radioactive Alpha Aerosols in High-Dose Environments

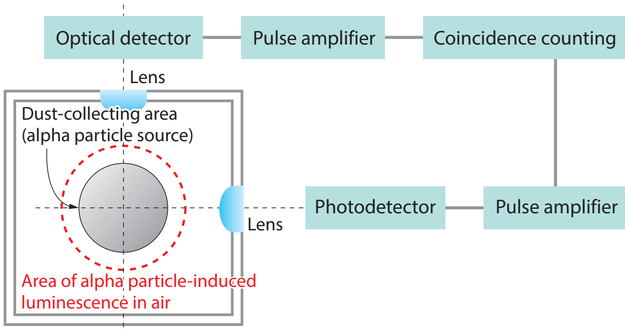
Inhaling even a trace amount of alpha-emitting radionuclides has negative effects on human health. Airborne alpha-radioactivity concentration in a workplace is typically evaluated by collecting aerosols on filter paper and measuring the alpha radiation with a solid-state radiation detector. However, solid-state radiation detectors are highly sensitive to gamma rays and if the workplace has a high gamma dose of several mSv/h, the filter paper must be brought to a low-dose environment in order to measure low alpha-radioactivity concentrations.

To simplify the measurement of alpha-radioactivity concentrations, Toshiba Energy Systems & Solutions Corporation has developed a new measuring technique based on the principle of a gas radiation detector, which measures the luminescence of gas excited by alpha particles. This technique removes the interference of luminescence in the lens excited by gamma radiation by counting the number of coincidence outputs from two photodetectors. This makes it possible to measure low-concentration alpha-radioactive aerosols in an area with a gamma dose level as high as 3 mSv/h, roughly 10 times the dose limit of conventional monitors.

We will further improve this technique for application to the gas management systems used in the decommissioning of the Fukushima Daiichi Nuclear Power Station and other nuclear power plants.



Radioluminescence induced by alpha particles in air



Configuration of newly developed radioactive alpha aerosol monitoring system

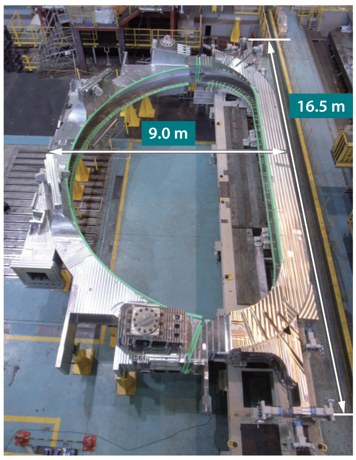
Completion of Production of First ITER TF Coil Case for EU

The International Thermonuclear Experimental Reactor (ITER), which is being constructed in France to demonstrate the technological feasibility of fusion energy, contains 18 D-shaped superconducting toroidal field (TF) coils to confine high-temperature plasma.

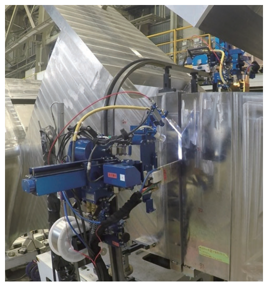
Toshiba Energy Systems & Solutions Corporation has received orders for four TF coils and six TF coil cases for the European Union from the National Institutes for Quantum and Radiological Science and Technology of Japan.

Each TF coil case consists of four welded structures and contains a single superconducting coil forming a TF coil. For the coil case structures, high dimensional accuracy is required to achieve a groove gap tolerance of 0.5 ± 0.25 mm and a linear misalignment of 0.3 mm or less for proper integration with a TF coil.

To satisfy these requirements, we have introduced new manufacturing techniques designed to correct thermal deformation that might occur during processing and to control machining processes according to the three-dimensional (3D) groove shape of the counterpart structure to be welded. As a result, an assembly test of the first TF coil case conducted in Japan successfully confirmed that it conforms to the groove alignment accuracy requirement. We will continue manufacturing the remaining TF coil cases and TF coils.

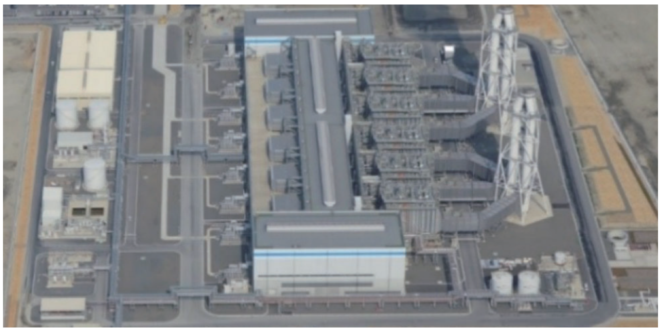


Coil case of ITER TF coil assembly

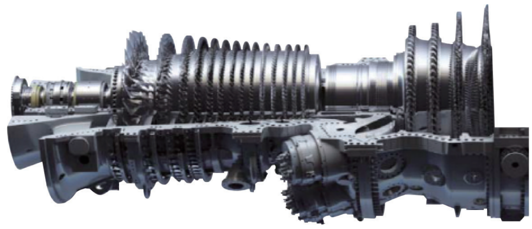


Welding of TF coil case while maintaining high dimensional accuracy

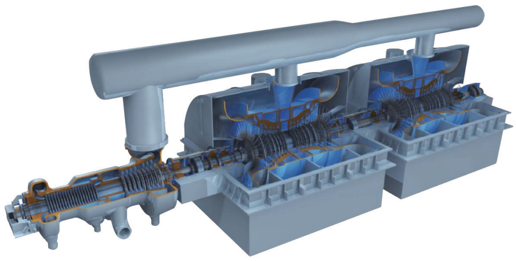
Both Units of Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc. Now in Commercial Operation, Achieving World's Highest Efficiency



Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc.



HA gas turbine manufactured by General Electric Company



Steam turbine for multishaft combined-cycle systems

Overall view of heat recovery steam generator

Unit 7-2, the second of the two units comprising Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc., commenced commercial operation in March 2018 following the commencement of operation of Unit 7-1 in September 2017. Group No. 7 has achieved the world's highest demonstrated efficiency of 63.08% LHV(*1), (*2). Toshiba Energy Systems & Solutions Corporation contributed to this achievement.

Group No. 7 consists of two multishaft combined-cycle blocks, Unit 7-1 and Unit 7-2, each with a generating capacity of 1 188.2 MW. Each block has three gas turbines and one steam turbine.

We have achieved high power generation performance by employing the latest four-stage HA gas turbines from General Electric Company, which use a 14-stage high-efficiency compressor with a pressure ratio of about 21:1 that is equipped with advanced 3D aerodynamic foils and incorporates state-of-the art sealing technology.

The steam turbine is equipped with an optimally designed reaction blade to improve the stage efficiency, and its high-pressure section has a multistage configuration with a drum rotor and the world's longest last-stage blade(*2) to improve efficiency. The heat recovery steam generator also provides improved heat recovery performance by adopting a high main steam and reheated steam temperature of 590°C.

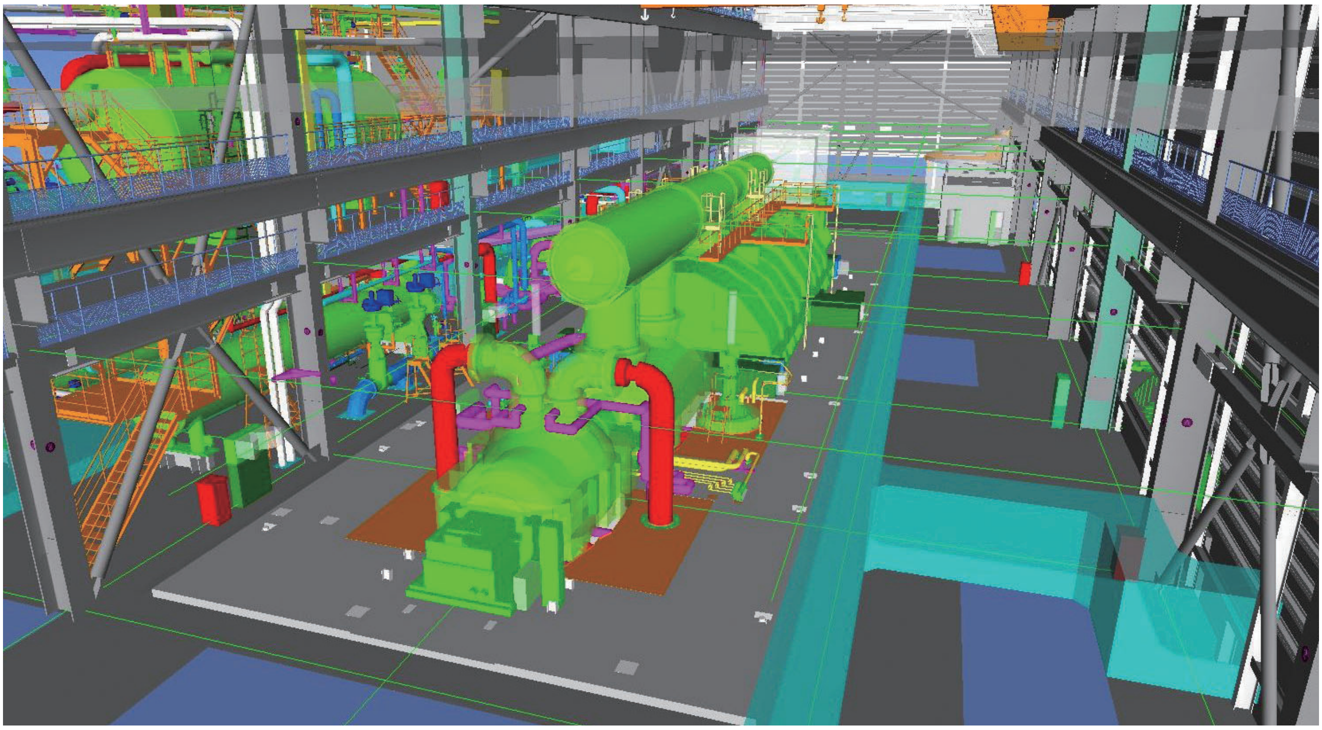
The application of these technologies and system configuration has contributed not only to the achievement of the world's highest efficiency but also to enhanced operability and a reduction in environmental impact.

We will continue to contribute to society by securing reliable and stable energy supplies and delivering technologies to realize environmentally friendly operation.

(*1) lower heating value

(*2) As of March 2018 for combined-cycle power plants (as researched by Toshiba Energy Systems & Solutions Corporation)

Shipment of Steam Turbine for Takehara Thermal Power Plant Unit 1 of Electric Power Development Co., Ltd.



3D model of turbine building operating floor at Takehara Thermal Power Plant Unit 1

Toshiba Energy Systems & Solutions Corporation has completed the plant design and the production of main equipment for Takehara Thermal Power Plant Unit 1 in the city of Takehara, located in Hiroshima Prefecture, of Electric Power Development Co., Ltd. (J-POWER). In December 2018, we shipped the IP turbine outer casing integrated with reheat steam stop valves.

The Takehara Thermal Power Plant is a highly efficient state-of-the-art coal-fired plant with a reheat steam temperature of 630°C, the first unit in Japan with such a high reheat steam temperature(*). Unit 1 has a main steam pressure of 27 MPa (gauge) and a main steam temperature of 600°C. We are undertaking the engineering, procurement, and construction (EPC) of the turbine island, including the supply of a steam turbine generator.

The steam turbine is a tandem-compound, single-reheat, four-flow exhaust condensing unit with four casings (HP, IP, and two LP casings) equipped with a proven 40-inch steel moving blade for the final stage. The steam turbine incorporates various high-temperature technologies including dual-structure steam inlet and rotor-cooling systems as well as performance improvement technologies such as high-efficiency blade cascades and low-resistance bearings.

To deal with future fluctuations of grid demand caused by the increasing supply of renewable energy, the plant is designed to be highly responsive to high load change rates and provide a low minimum load limit.

In addition, auxiliary power has been reduced over a wide range of operating loads by adopting an inverter-controlled condensate booster pump and a water circulation pump with variable-pitch blades.

We are now transporting and constructing the new unit in parallel with the demolition of existing thermal power generation facilities being implemented by J-POWER, while paying attention to the environment of the Seto Inland Sea as well as taking into consideration the local community. We are planning to ship the equipment and construct the turbine island in line with the targeted commencement of commercial operation of the unit in June 2020.

HP: high pressure
IP: intermediate pressure
LP: low pressure

(*) As of March 2019 (as researched by Toshiba Energy Systems & Solutions Corporation)

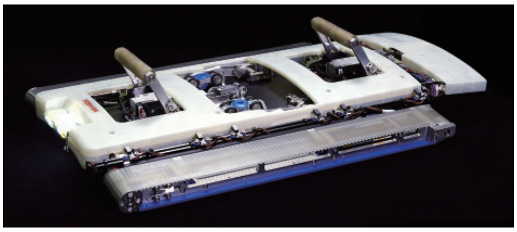
Development of Inspection Robot for Turbine Generators

Toshiba Energy Systems & Solutions Corporation has developed a robot that can perform inspections on turbine generators in a short period of time. The robot can inspect generators equipped with segregating baffles(*1), which have previously been an obstacle to the robotic inspection of turbine generators. It can complete detailed inspections of a rotor and a stator without rotor removal in around 12 days(*2) (including the period required to partially disassemble and reassemble the turbine generator), about half the time required by a conventional detailed inspection with rotor removal.

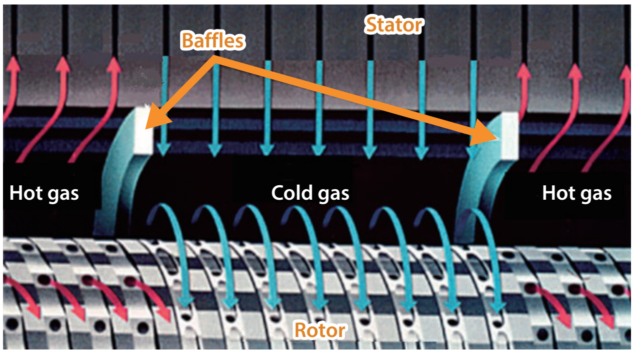
At present, we are performing a final verification test on actual turbine generators with the aim of launching robotic inspection services in 2019. We will enhance our inspection services for existing power plants using this robot both in Japan and abroad, including in North America and Southeast Asia, to maximize the benefit to our customers.

(*1) Partitions built into a stator for rectification of the internal ventilation

(*2) Since different types of generators have different numbers of inspection points, the number of days needed for the inspection may vary.



Turbine generator inspection robot



Structure of generator equipped with baffles

Completion of High-Efficiency 700 MVA-Class Indirectly Hydrogen-Cooled Turbine Generator

Demand has been growing in recent years for thermal power generators with higher efficiency in order to reduce CO_2 emissions.

Toshiba Energy Systems & Solutions Corporation has been developing high-efficiency, high-capacity indirectly hydrogen-cooled turbine generators since 1998. In 2000, we developed TOSλ, a high-thermal-conductivity insulation system to realize high-efficiency, high-capacity turbine generators. Since then, we have manufactured many generators equipped with TOSλ.

We have now manufactured a 716.667 MVA indirectly hydrogen-cooled turbine generator that incorporates various technologies to further increase efficiency and capacity, thereby achieving an efficiency of more than 99.1%. The stator winding loss of the new turbine generator is roughly 40% lower than that of a conventional directly water-cooled system. This reduction in stator winding loss has been achieved by increasing the cross-sectional copper area of the stator winding through the use of TOSλ for the main insulation and by paralleling multiple stator coil connections. The rotor winding loss has also been reduced by optimizing the ventilation path and maximizing the cross-sectional area of the rotor winding.

We will continue to apply these technologies to further increase the efficiency and capacity of indirectly hydrogen-cooled turbine generators.

Parameter		Specification
Capacity		716.667 MVA
Voltage		19.5 kV
Power factor		0.9
Rotational speed		3 000 rpm
Frequency		50 Hz
Standard		JEC-2130-2000
Cooling system	Rotor winding	Direct cooling by hydrogen
	Stator winding	Indirect cooling by hydrogen
Temperature rise		Class F with B rise
Short-circuit ratio		≥ 0.556
Hydrogen pressure (gauge pressure)		0.52 MPa

JEC: Japanese Electrotechnical Committee

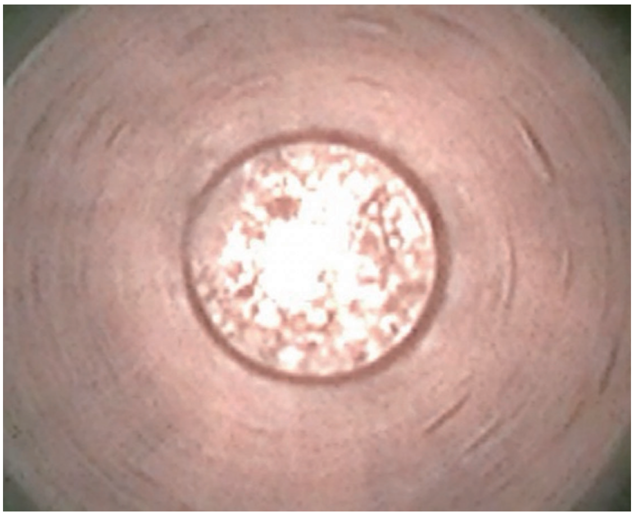
Specifications and scene of shop test of 716.667 MVA indirectly hydrogen-cooled generator

Validation Test of Combustor for Supercritical CO_2 Cycle Demonstration System

In August 2018, Toshiba Energy Systems & Solutions Corporation completed the validation test of a combustor that comprises one of the key components of a supercritical CO_2 cycle demonstration system. The combustion test was conducted at a test rig constructed at a demonstration plant of NET Power, LLC in the United States that provides integrated operation of the full supercritical CO_2 process of NET Power.

In NET Power's supercritical CO_2 power cycle system, the combustion gas consisting of high-pressure natural gas and oxygen in a CO_2 atmosphere is supplied to the turbine. The exhaust gas returns to the combustor inlet in a semi-closed cycle, ensuring that little of the fuel gas and oxygen mixture remains unburned. Since the mechanism of the supercritical CO_2 combustor differs greatly from that of a conventional power gas turbine combustor, we conducted a validation test of the combustor prior to the demonstration of power generation in combination with a turbine.

The results of the validation test, which brought the combustor from ignition to a supercritical condition, indicate that the combustor exhibits almost 100% combustion efficiency while providing high operability and stable combustion.



Flame inside combustor of supercritical CO_2 cycle demonstration system undergoing combustion test

The next phase is to integrate the combustor with a turbine to efficiently utilize high-pressure, high-temperature CO_2 for demonstration of the system's power generation performance.

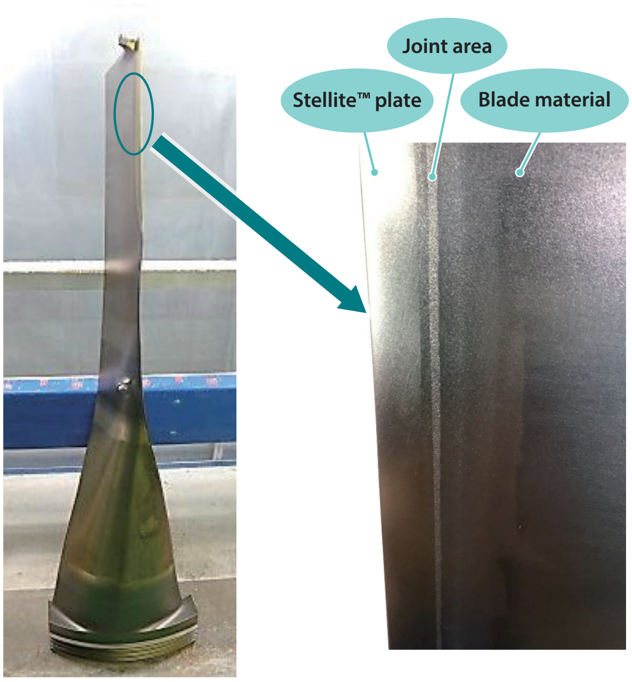
Welding of Stellite™ Plate to Precipitation-Hardened Stainless Steel Last-Stage Blades of Steam Turbines

To prevent erosion of the tip of the last-stage blades of a steam turbine due to droplets of steam, Stellite™ plate is sometimes joined to the blades using electron-beam welding (EBW). However, EBW subjects the blade body to considerable heat, reducing the strength of even the high-strength precipitation-hardened stainless steel used in the latest last-stage long blades.

To address this problem, Toshiba Energy Systems & Solutions Corporation has developed a new welding method to reduce the welding heat to a level that does not affect the blade material. In this method, a nickel alloy is first joined to the blade using buildup welding with low heat input then Stellite™ plate is joined to the nickel alloy using EBW.

We have employed this method at power plants in Italy. Inspections after six months of operation confirmed the soundness of the weld joints. We will continue monitoring the weld joints.

We have also established a repair technology using this method to re-weld Stellite™ erosion shields to eroded conventional last-stage blades.



48-inch last-stage long blade and detail of Stellite™ plate bonded portion

Stellite is a trademark of Kennametal Inc.

Completion of Trial Runs of Talin Power Plant New Units 1 and 2 of Taiwan Power Company

Taiwan is fostering renewable energy projects in order to meet its increasing electricity demand and support economic growth under its policy of promoting nuclear-free electricity. On the other hand, high-efficiency ultra-supercritical coal-fired power plants are being constructed, expanded, and renovated to save energy resources and reduce the environmental load while a shift is taking place in the fuel for thermal power generation from coal to natural gas.

Under these circumstances, Toshiba Energy Systems & Solutions Corporation has been participating in a project to build a 1 600 MW ultra-supercritical coal-fired power plant, scrapping the antiquated portion of the existing Talin Power Plant of Taiwan Power Company.

There were several challenges for us, including the first adoption of a separate-bed condensate polishing system and an Emerson's distributed control system. However, we successfully overcame these challenges, drawing on the expertise acquired through our experience in engineering and construction in Taiwan. Although unexpected events occurred including typhoon-related flooding, the project team resolved all of these difficulties and finally completed a trial run of Unit 1 in April 2018, followed by a trial run of Unit 2 in August 2018.

Overall view of Talin Power Plant New Units 1 and 2

Steam turbine generator

We are currently finalizing the project toward the handing over of the plant in the summer of 2019.

Commencement of Commercial Operation of Hayakawa No. 3 Hydroelectric Power Station Unit 2 of Tokyo Electric Power Company Holdings, Inc.

Hayakawa No. 3 Hydroelectric Power Station Unit 2 commenced commercial operation in March 2018. Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC) manufactured a new turbine and generator for this facility, and Toshiba Energy Systems & Solutions Corporation replaced the antiquated turbine, generator, and control system with new ones.

We employed computational fluid dynamics (CFD) to design the turbine and utilized the state-of-the-art T-Blade runner, thereby increasing turbine efficiency by more than 5%. The turbine incorporates water-lubricated guide bearings. The guide-vane control system is equipped with a hybrid servo-motor system that directly pressurizes a closed oil-supply loop with a two-way oil pump. In addition, the inlet valve is electrically operated by a DC motor in order to reduce the amount of oil used and to simplify the facility.

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

- Turbine: 21.0 MW, 149.90 m, 500 min^{-1}
- Generator: 22.0 MVA, 11 kV, 500 min^{-1}, 50 Hz.

Hydraulic runner

Hydraulic turbine generator

Completion of Shipment of Large-Scale Components for Major Overhaul of Ludington Pumped Storage Plant, U.S.A.

Sixth pump-turbine runner on arrival at Ludington Pumped Storage Plant

Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC) in China has manufactured large-scale components for a major overhaul of all six units of the Ludington Pumped Storage Plant in the United States, including pump-turbine runners and the stator frames for generator-motors, completing shipment in March 2018.

The pump-turbine runners are each approximately 270 tons in weight and 8.4 m in outside diameter, among the largest in the world(*), and the generator-motor stator frames are approximately 17.1 m in outside diameter. Both components were subjected to stringent qualification tests and inspections during and after manufacturing.

The previous type of pump-turbine runner at the Ludington Pumped Storage Plant was divided into two structures, whereas the new type is fabricated as a single structure. Because of this structural change, the transportation of the pump-turbine runners was a challenging task as it was necessary to rebuild bridges and investigate the water levels of the rivers along the transportation route from Fuchunjiang, where THPC is located, to the Port of Shanghai. In the U.S., the components were transported from the Port of New Orleans on the Mississippi River to the shore of Lake Michigan, where the Ludington Pumped Storage Plant is located.

This overhaul considerably improves the efficiency, output, pumping discharge, and cavitation performance of the pump-turbines and increases the capacity of the generator-motors. The new generator-motors improve the plant's reliability as they solve problems that occurred with the previous generator-motors such as stator core buckling and frequent thrust bearing failures.

Toshiba America Energy Systems Corporation received an order for this project from Consumers Energy Co. and DTE Energy Co. in January 2011. The overhaul of the first unit was completed in March 2015, followed by the overhaul of three more units, which have already resumed commercial operation. The overhaul of the fifth unit is currently underway.

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.

(*) As of November 2018 (as researched by Toshiba Energy Systems & Solutions Corporation)

Completion of Overhaul of Pump-Turbine and Generator-Motor of Purulia Pumped Storage Power Station Unit 1 in India

Toshiba Energy Systems & Solutions Corporation has completed an overhaul of the pump-turbine and generator-motor of Purulia Pumped Storage Power Station Unit 1 in the state of West Bengal, India, which resumed commercial operation in February 2018. Since this power station is one of the main electricity sources for West Bengal, we had to limit its outage period to within three months in order to minimize power shortage in the state.

The main purpose of this overhaul was to inspect the stator wedge, the runner, and the sealing liners at both the runner outlet and the rear of the head cover.

To minimize disassembly work, we lifted the head cover and placed it safely in the pit, then inspected the runner and the liner in the pit while keeping the turbine shaft and the runner suspended together. As a result, the overhaul was completed in 84 days.

Engineers of TPSC (India) Private Limited were dispatched as supervisors for the overhaul to reinforce the construction support capability in India and to reduce the number of supervisors sent from Japan.

The specifications of the pump-turbine and the generator-motor are as follows:

Installation of turbine guide ring during overhaul of Purulia Pumped Storage Power Station Unit 1

- Pump-turbine: 259.3 MW, 214.5 m, 250 min^{-1}, 4 units
- Generator-motor: 250.0 MVA, 16.5 kV, 250 min^{-1}, 50 Hz, 4 units.

Completion of Overhaul of Bakaru Hydro Power Plant Unit 1 in Indonesia

In October 2018, Toshiba Energy Systems & Solutions Corporation completed an overhaul of the inlet valve of Bakaru Hydro Power Plant Unit 1 in Indonesia, which is a major source of electricity supply for Sulawesi Island. The two units of this power station have been in full-power operation for almost 24 hours a day since its commissioning in 1991. The upstream valve disc of the inlet valve had become heavily damaged because of long-term soil erosion, resulting in an increase in water leakage.

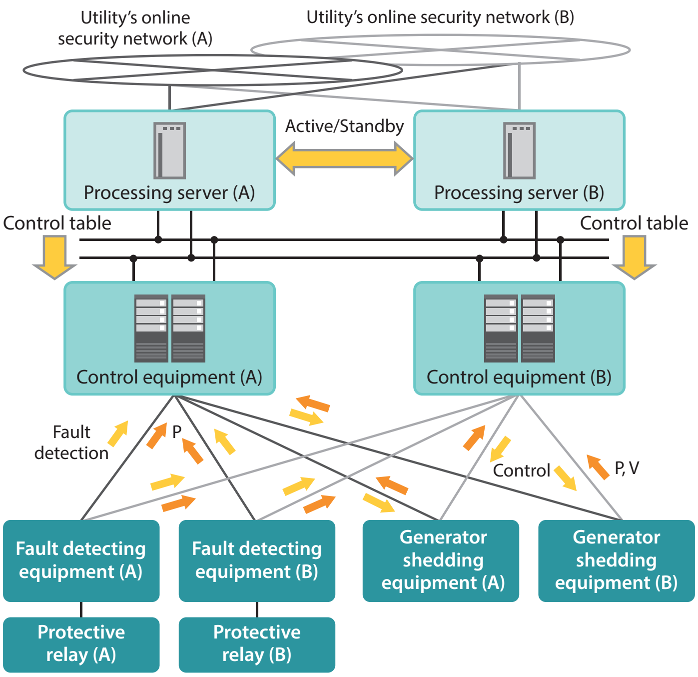
To solve this problem, we overhauled the inlet valve to improve its sealing performance. For the overhaul of the inlet valve, both units of the power station had to be shut down. In order to shorten the shutdown period to ensure stable electricity supply on Sulawesi Island, we devised an overhaul plan to reuse the existing downstream valve disc and avoid local machining. As a result, the overhaul was completed in only 26 days. The main seal of the inlet valve successfully passed a sealing performance test.

The ratings of the turbine and the inlet valve are as follows:

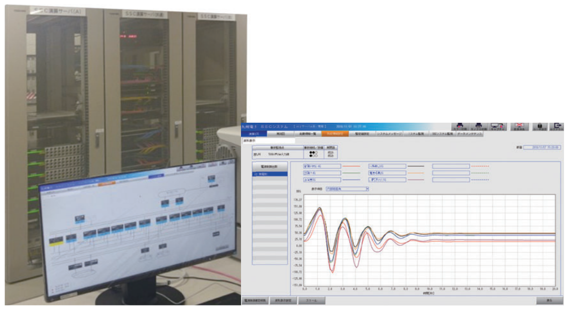
- Turbine: 65.7 MW, 320.6 m, 500 min^{-1}
- Inlet valve: Spherical valve with a diameter of 1.5 m and an operating pressure of 4 MPa.

View of inlet valve during overhaul of Bakaru Hydro Power Plant Unit 1

System Stabilizing Controller for Kyushu Electric Power Co., Inc.



Configuration of online pre-calculating system stabilizing controller of Kyushu Electric Power Co., Inc.



Processing server (computers)

Control equipment (digital protective relays)

Kyushu Electric Power Co., Inc. is currently using an offline pre-calculating system stabilizing controller (SSC) to prevent extremely rare incidents that would affect stable electricity supply to the entire Kyushu region. However, grid conditions have changed considerably since the offline SSC was developed because of the increasing uptake of renewable energy systems, which are frequently connected and disconnected from the grid and cause unanticipated changes in the power flow.

In order to achieve optimal grid stabilization control with highly reliable responsiveness to changes in grid conditions, Toshiba Energy Systems & Solutions Corporation is developing an online pre-calculating SSC for Kyushu Electric Power Co., Inc., the first such system to be operated by Kyushu Electric Power.

The online SSC, which comprises processing servers (computers), control equipment, fault detecting equipment, and generator shedding equipment (digital protective relays), provides functions to maintain grid stability and frequency and prevent overloading of the grid. The processing server periodically simulates multiple postulated grid fault scenarios at high speed based on the latest information, including the grid configuration and electricity flow. Based on the results of this simulation, the processing server selects systems to be controlled and determines the control level, enabling optimal grid control according to the actual grid conditions.

The electricity flow might change sharply in the course of several tens of seconds during an interval between calculation periods because of a sudden change in renewable energy output. To cope with this situation, the online SSC incorporates an auxiliary control function that determines the necessity for additional control based on the actual post-control grid conditions. Furthermore, in the event of a communication failure between a processing server and the control equipment, the online SSC is capable of backup mode operation that is equivalent to the stabilization control of the conventional offline SSC.

Kyushu Electric Power will commence the operation of a large-scale power supply system in 2019. In Phase 1, we will gradually replace the current offline SCC with the online SSC to contribute to grid stabilization in the Kyushu region.

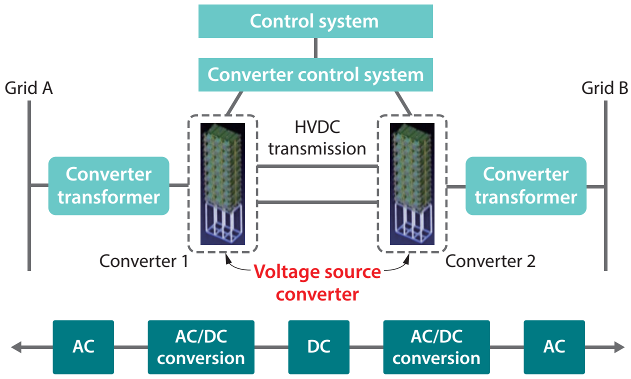
Demonstration of Voltage Source Converters for HVDC Systems

Toshiba Energy Systems & Solutions Corporation has completed the demonstration of voltage source converters (VSCs) for high-voltage direct-current (HVDC) systems at the research facility of the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA).

These VSCs incorporate modular multilevel converter (MMC) technology for AC/DC conversion. One of the advantages of the MMC is its negligible harmonics output, which makes it possible to eliminate the need for AC filters and thus reduce the footprint of the converter station. We have succeeded in the demonstration of AC/DC conversion using scaled 10 kV VSC models.

A number of HVDC systems are expected to be introduced for large-capacity power transmission over long distances, frequency conversion, and power transmission from offshore wind farms. We will provide VSC systems to contribute to the stabilization of electricity supplies.

This work was undertaken under the "International Demonstration Project of Voltage Source Converter for High Voltage Direct Current System in Italy" commissioned by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.



Example of HVDC system applying VSCs

VSCs used in demonstration tests

Training Simulators for National Transmission & Despatch Company in Pakistan

Power grids are expanding rapidly in developing countries. To ensure the stable operation of these grids, it is essential to train skilled system operators within a short period of time.

To meet this requirement, Toshiba Energy Systems & Solutions Corporation has delivered two types of power grid operation training simulators to National Transmission & Despatch Company in Pakistan, which began using them for operator training in October 2018.

The substation operation training simulator provides realistic operation training under normal and emergency conditions using power flow and frequency calculations as well as relay response emulation, while the protection relay operation training simulator provides practical training for relay operations in response to various power system faults using real protection relays with a real-time digital simulator (RTDS).

These simulators are useful for enhancing operators' capabilities. They are expected to help improve the reliability of the power supply in Pakistan and thereby contribute to further economic growth of the country. We are also planning to provide this solution to other developing countries.

Substation operation training simulator

Protection relay operation training simulator

Power grid operation training simulators of National Transmission & Despatch Company

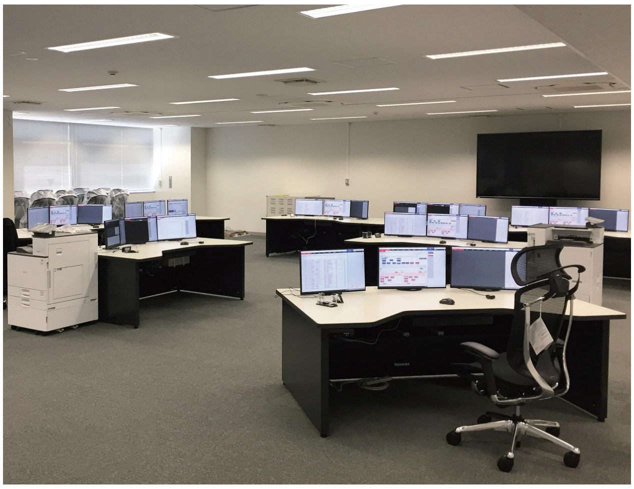
Commencement of Operation of SCADA System for Hydroelectric Power Stations of TEPCO Holdings, Inc.

Toshiba Energy Systems & Solutions Corporation has delivered a new supervisory control and data acquisition (SCADA) system for hydroelectric power stations to Tokyo Electric Power Company Holdings, Inc. (TEPCO Holdings, Inc.), which commenced its operation in July 2018.

This SCADA system provides efficient centralized control over the operations of multiple hydroelectric power stations. TEPCO Holdings, Inc. will transition to the new SCADA system step by step.

The new SCADA system is a wide-area distributed system designed to provide stable continuous operation combined with high availability and security. In addition, the long-life servers of this SCADA system will contribute to a reduction in the system life cycle cost.

The new SCADA system uses a dedicated mathematical model for river water management to achieve maximum power generation by making optimal use of river water under the conditions of government regulations and local agreements. In addition, the new SCADA system provides a monitoring function capable of predicting the states of river water and power stations' equipment. The monitoring function detects signs of system failure, making it possible for operators to deal with such problems at an early stage and thus minimize their impact.



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

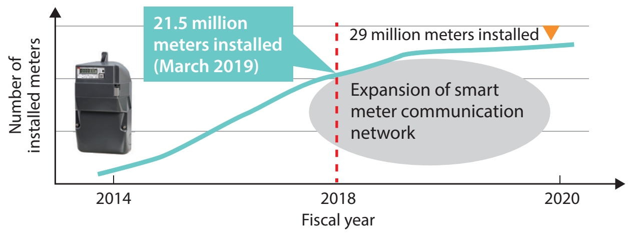
Application of Advanced Technology for Stable Operation of Smart Meter Communication System

In the service area of TEPCO Power Grid, Inc., 21.5 million smart meters had been installed as of March 2019, roughly 75% of the target of 29 million units to be installed by the end of 2020. To maintain the stability of the smart meter communication system, even with the rapid expansion of the network, TEPCO has introduced a cellular phone network for 1:N type meters(*1) and increased the density of the 920 MHz multi-hop network for 920 MHz meters(*2). Currently, TEPCO's smart meter communication system provides a network connection rate of 99.6%.

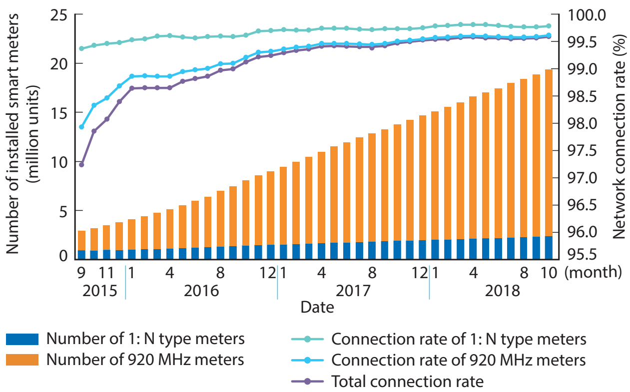
Toshiba Energy Systems & Solutions Corporation has contributed to this achievement through its systems and system integration technology. We will make efforts to further improve the stability and reliability of the smart meter communication system by means of our advanced network security solutions and 3D simulation techniques for optimal network design using AI and robotic process automation (RPA) technologies.

(*1) Meters communicating via the cellular phone network

(*2) Meters communicating via the 920 MHz low-power wireless network



Projected number of smart meters installed in service area of TEPCO Power Grid, Inc.



Changes in number of smart meters and network connection rate