# Highlights
## Energy Systems

## New Beam Irradiation Device for Compact Scanning Carbon-Ion Therapy System

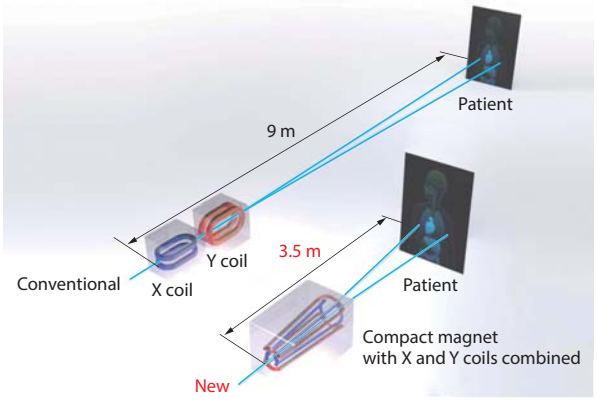
Toshiba Energy Systems & Solutions Corporation developed the world's first rotating gantry system using superconducting magnets for clinical scanning carbon-ion therapy(*). To downsize this rotating gantry, we have developed a new beam irradiation device.

The rotating gantry is highly useful because it can precisely deliver a radiation beam from any direction without the need to tilt the patient, and strong demand has accordingly increased for downsizing of the rotating gantry for carbon-ion therapy.

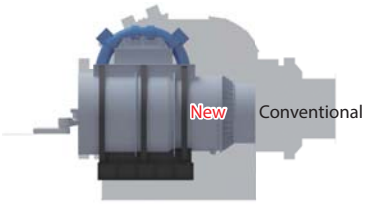
In response, we have developed a compact beam irradiation device by integrating two magnetic coils into a single unit in collaboration with the National Institute of Radiological Sciences (NIRS) and the National Institutes for Quantum and Radiological Science and Technology (QST). The newly developed magnet has made it possible to greatly reduce the length of the beam irradiation device, from 9 m to 3.5 m.

As a result, the length of the rotating gantry is reduced by roughly one-third compared with the previous model. This will contribute to the further dissemination of carbon-ion therapy and downsizing of radiotherapy facilities.

(*) As of November 2017 (as researched by Toshiba Energy Systems & Solutions Corporation)




New beam irradiation device for compact scanning carbon-ion therapy system




Downsizing of superconducting rotating gantry

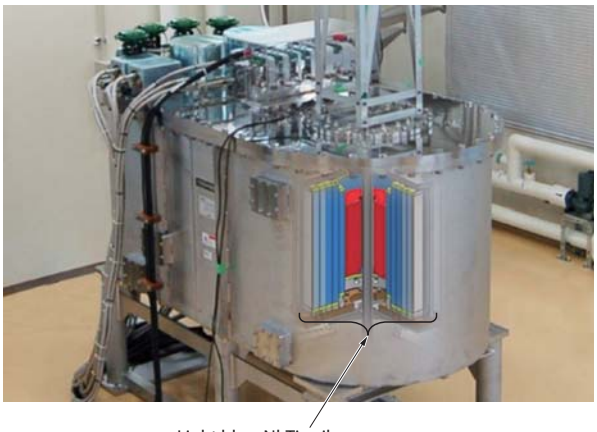
## Cryogen-Free High-Temperature Superconducting Magnet Capable of Generating World's Highest-Class Magnetic Field

Toshiba Energy Systems & Solutions Corporation and Tohoku University have jointly developed a cryogen-free high-temperature superconducting magnet composed of a niobium-titanium (NbTi) coil, a niobium-tin ($Nb_3Sn$) coil, and a bismuth (Bi)-based high-temperature superconducting coil. We have also developed a technology for generating a high magnetic field from the high-temperature superconducting coil. Consequently, we have succeeded in generating a stable magnetic field of 24.6 T, the world's highest class for practical superconducting magnets(*), in a room-temperature space with a diameter of 52 mm.

This superconducting magnet is open to researchers nationwide at a shared-use facility to contribute to the advancement of basic science such as research on physical properties under high magnetic fields and materials development.

The technology acquired by this development work can be expected to find applications in magnetic resonance imaging (MRI), as well as in enhancement of the magnetic field of superconducting magnets for particle accelerators, nuclear fusion equipment, and other devices.

(*) As of April 2017 (as researched by Toshiba Energy Systems & Solutions Corporation)



Light blue: NbTi coil
Blue: $Nb_3Sn$ coil
Red: Bi-based high-temperature superconducting coil

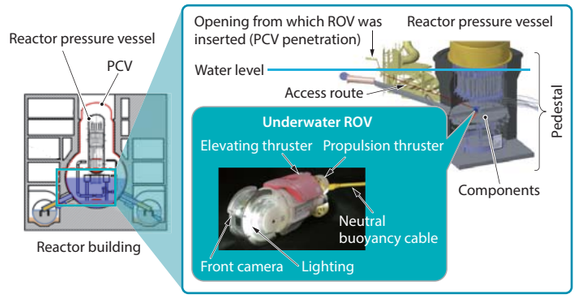
24.6 T cryogen-free superconducting magnet installed at High Field Laboratory for Superconducting Materials (HFLSM)

## Images Inside Pedestal of Fukushima Daiichi Nuclear Power Station Unit 3 Captured Using Underwater Remotely Operated Vehicle

In preparation for the decommissioning of the Fukushima Daiichi Nuclear Power Station, an investigation of the interior of the pedestal in the lower part of the primary containment vessel (PCV) of Unit 3 is currently underway. Since the bottom of the PCV is filled with water, Toshiba Energy Systems & Solutions Corporation has developed a small underwater remotely operated vehicle (ROV) with a diameter of approximately 13 cm in collaboration with the International Research Institute for Nuclear Decommissioning (IRID). The ROV was guided through the PCV penetration opening to capture images inside the pedestal.

In July 2017, we conducted a series of surveys using the ROV and finally succeeded in capturing images of solid substances considered to be fuel debris for the first time since the Fukushima accident. Although the PCV components, which were damaged more severely than expected, lay cramped in a narrow space, we were able to complete the surveys, eventually retrieving the ROV itself.

This work was accomplished as part of the efforts being made under the Decommissioning and Contaminated Water Management Project sponsored by the Ministry of Economy, Trade and Industry (METI) using funds allocated in the 2015 supplementary budget.




Underwater ROV and route of investigation of PCV of Fukushima Daiichi Nuclear Power Station Unit 3

Damaged components



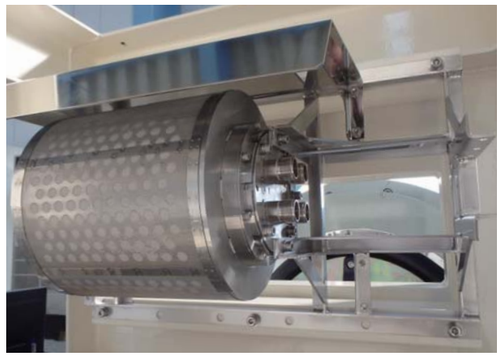
Solid substances considered to be fuel debris

Examples of images captured by survey

## Hydrogen Concentration Detector for Primary Containment Vessel in Event of Severe Accident

Toshiba Energy Systems & Solutions Corporation has developed a prototype hydrogen concentration detector in collaboration with Japanese electric utility companies and METI, which detects hydrogen concentration in a PCV in the event of a severe nuclear accident.

The hydrogen concentration detector has iodine filters and a hydrogen-permeable membrane coating for oxygen segregation. The cylindrical detector provides a high response speed. This detector will be used to enhance the safety of nuclear plants.



Hydrogen concentration detector for PCV in event of severe accident





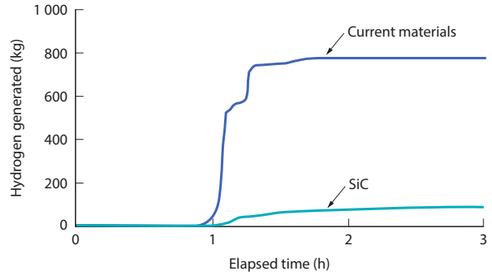
## Analysis of Accident Tolerance of SiC Reactor Core Material in Event of Severe Accident

In conventional nuclear reactor cores, zirconium alloy is used for the fuel claddings and fuel assembly covers, and stainless steel is used for the control rods. However, silicon carbide (SiC) is more resistant to heat and oxidation than these current materials.

In order to prevent or retard the progression of severe accidents leading to reactor core damage, Toshiba Energy Systems & Solutions Corporation has been developing safety analysis technology with the aim of applying SiC as a reactor core material.

We have analyzed the behavior of a nuclear power plant in the event of a severe accident when SiC is used for fuel claddings, fuel assembly covers, and control rods in the reactor core. We evaluated accident scenarios such as loss of reactor coolant, and reactor depressurization and coolant injection failure. The analysis model considered not only the properties of SiC but also the amounts of heat and hydrogen generated in the oxidation reaction between SiC and water, including the effects of the formation and separation of a silicon dioxide ($SiO_2$) layer.

The analysis results showed that the use of SiC slows the rate of temperature rise of fuel claddings after core uncovery and significantly reduces the amount of hydrogen generated. The use of SiC as a reactor core material is expected to mitigate the consequences of severe accidents and enhance the safety of nuclear power plants.



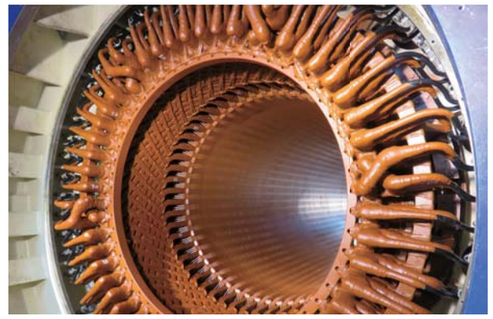

Example of hydrogen generation analysis in event of severe accident (reactor depressurization and coolant injection failure)

## Completion of Eighth Generator Stator Rewind for EDF

In 2008, Toshiba concluded a contract with Électricité de France (EDF) for rewinding the stators of 11 nuclear generators comprising four 1 300 MW stators and seven 900 MW stators.

Toshiba Energy Systems & Solutions Corporation has been engaged in rewinding the eighth generator stator, a task that was commenced by Toshiba in 2016. For this work, we employed a new subcontractor for various reasons. In order to reduce quality risks and avoid schedule delays due to inexperienced workers, we organized elaborate training programs to provide the workers with sufficient knowledge of and skills in our work methods, including leaders' training in Japan, mock-up training, and on-the-job training in France.

As a result of these efforts, the rewinding of the eighth generator stator was successfully completed. In addition, we applied interspersed winding to all of the 900 MW generator stators to reduce the coil-end vibration significantly. EDF expressed its satisfaction with our design and workmanship.



Eighth generator stator rewind for nuclear power plant of EDF

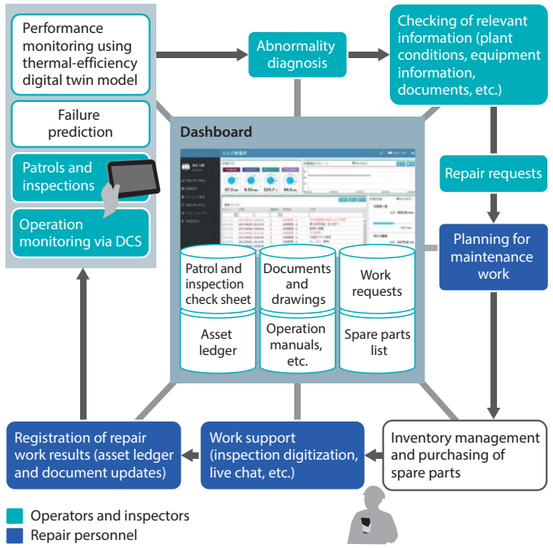
## IoT Solution for Thermal Power Plants

Toshiba Energy Systems & Solutions Corporation has developed an Internet-of-Things (IoT) solution that supports high-availability and high-performance operation of thermal power plants using IoT technologies. This solution was deployed at the Mikawa Power Plant of Sigma Power Ariake Co., Ltd.

The concepts of the new solution are described below.

- Digitalization: A shift from paper-based procedures to digital and data-driven processes is supported.
- Advanced monitoring: Performance analysis and failure prediction/diagnosis functions using a digital twin model allow operators to detect abnormalities early and take remedial action.
- Seamless work processes: The dashboard is configured to seamlessly link the constituents of a thermal power plant's plan-do-check-act (PDCA) cycle, encompassing all elements from the detection of an abnormality through to the completion of repair work.

The newly developed solution can be operated from remote offices and via mobile devices with enhanced security. This solution will be used to accelerate the development of diagnostic technologies and functional improvement measures.




DCS: distributed control system

Seamless PDCA cycle of power plant operation and maintenance (O&M)

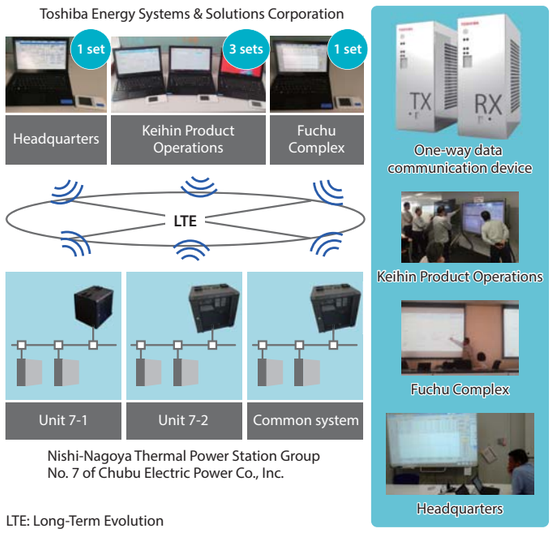
## Control and Monitoring System for Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc.

Nishi-Nagoya Thermal Power Station Group No. 7 consists of a common system and two generating units, each of which is a multishaft combined-cycle power generation system comprising three gas turbines and one steam turbine.

Toshiba Energy Systems & Solutions Corporation has developed a control and monitoring system that provides an overview of the entire plant and allows independent operation of each unit. Since an operator can control and monitor the entire plant from a single operator station (OPS), the central control room has been designed to be compact with a view to fully automating the plant's operations in the future.

Furthermore, this system incorporates one-way data communication and other security technologies, which enabled online plant supervision from our Keihin Product Operations and Fuchu Complex during commissioning tests. This system helps to reduce the time required for analysis of plant data in the event of a problem, facilitating commissioning tests.

Since this system can also be used for IoT-based plant diagnosis, we will provide it as our standard system in the future.




LTE: Long-Term Evolution

Control and monitoring system with one-way data communication technology for Nishi-Nagoya Thermal Power Station Group No. 7 of Chubu Electric Power Co., Inc.

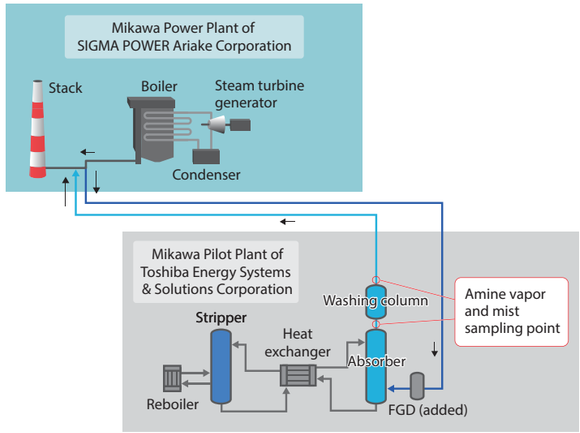




## Quantitative Investigation of Forms of Amine Emissions from Carbon Dioxide Capture Plant

Carbon dioxide capture and storage (CCS) plants capture waste carbon dioxide ($CO_2$) from thermal power plants or other large point sources and store it at storage sites. However, it has been pointed out that small amounts of amines derived from $CO_2$ absorbent in the flue gas that is discharged to the atmosphere after $CO_2$ removal may have a negative impact on the environment.

As part of the Demonstration of Sustainable CCS Technology Project sponsored by Ministry of the Environment (MOE) of Japan, Toshiba Energy Systems & Solutions Corporation evaluated forms of amine emissions at the Mikawa Pilot Plant using actual flue gas from the thermal power plant and an artificial flue gas. As a result, we found that amines are discharged in vapor and mist and measured their composition ratio. Based on this result, we have devised countermeasures for reducing amine mist emissions and are now performing verification using a bench-scale test facility.




FGD: flue gas desulfurization

Overview of verification test to investigate forms of amine emissions from $CO_2$ capture plant using Mikawa Pilot Plant

## Combined-Cycle Power Plant of Chubu Electric Power Co., Inc. Recognized for World's Highest Efficiency

At Unit 7-1 of Nishi-Nagoya Thermal Power Station Group No. 7, Chubu Electric Power Co., Inc. and Toshiba Energy Systems & Solutions Corporation achieved an LHV(*1) efficiency of 63.08%, which has been recognized as the world's highest efficiency for a combined-cycle power plant(*2).

The multishaft combined-cycle power generation unit is composed of three 7HA.01 gas turbines from General Electric and our high-efficiency steam turbine and generator to achieve the optimal overall plant system design.

We will continue to deliver state-of-the-art technologies and systems in order to further expand the efficiency limit of combined-cycle power plants, and will redouble our efforts to realize a low-carbon society and a stable electricity supply.

(*1) Lower heating value, which excludes the heat of vaporization of the water due to fuel combustion

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

Overview of Nishi-Nagoya Thermal Power Station Unit 7-1 of Chubu Electric Power Co., Inc.


Steam turbine and generator


Gas turbine and generator

## Gas Turbine Replacement at Futtsu Thermal Power Station Unit 4-1 of TEPCO Fuel & Power, Inc.

Futtsu Thermal Power Station Unit 4-1 of TEPCO Fuel & Power, Inc. (507 MW) had been out of service following a fire that occurred on August 16, 2015.

Toshiba Energy Systems & Solutions Corporation replaced the damaged gas turbine and the surrounding equipment at Unit 4-1, which resumed commercial operation on September 23, 2017. This project marks the first time that we have installed a General Electric 9HA.01 gas turbine, only a few of which are in operation around the world.

Due to the transition from steam cooling (for the previous 9H model) to air cooling, it was necessary to redesign the turbine pipe system. Furthermore, many constraints imposed by the existing plant specifications and layout complicated the replacement work. All of the stages of construction were systematically planned, encompassing design, manufacture, transportation, construction, and test run, and completed successfully. As a result, Futtsu Thermal Power Station Unit 4-1 restarted commercial operation six days earlier than scheduled.

Renewed gas turbine enclosure and fuel gas skid at Futtsu Thermal Power Station Unit 4-1 of TEPCO Fuel & Power, Inc.

## Shipment of Double-End Drive Indirectly Hydrogen-Cooled Generator for Ishikariwan Shinko Thermal Power Station Unit 1 of Hokkaido Electric Power Co., Inc.

Toshiba Energy Systems & Solutions Corporation shipped a 650 MVA double-end drive indirectly hydrogen-cooled generator for Ishikariwan Shinko Thermal Power Station Unit 1 of Hokkaido Electric Power Co., Inc. (HEPCO) in July 2017.

The Ishikariwan Shinko Thermal Power Station is a uniaxial gas turbine combined-cycle plant in which the generator is installed between a gas turbine and a steam turbine and driven from both ends. In the future, the double-end drive configuration will become standard for uniaxial gas turbine combined-cycle systems because it reduces plant startup time and improves operability. Since conventional generators are driven only from one end, we developed a new shaft structure with sufficient strength for double-end drive. In addition, the indirectly hydrogen-cooled system provides a generator efficiency of more than 99.1%. We will proceed with installation, commissioning, and calibration, moving toward commercial operation of the plant.

650 MVA double-end drive indirectly hydrogen-cooled generator for Ishikariwan Shinko Thermal Power Station Unit 1 of HEPCO





## Successful Completion of Rotation Test for 700°C-Class A-USC Steam Turbines

To realize advanced ultra-supercritical (A-USC) power plants, Toshiba Energy Systems & Solutions Corporation has been focusing on the development of turbine material and manufacturing technologies. The rotation test of a turbine rotor conducted in 2017 represented the culmination of our efforts for A-USC turbine development.

We manufactured a full-scale rotor and performed a 50-hour rotation test at a maximum temperature of 700°C or higher and at a rotation speed of 3 600 revolutions per minute (rpm). During the testing, the turbine rotor exhibited no excessive vibration or any other problem. The inspection following the rotation test also revealed no cracks or other defects.

The successful completion of this test and subsequent inspection is a major step forward for the commercialization of A-USC steam turbines.

This study is being sponsored by METI and the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

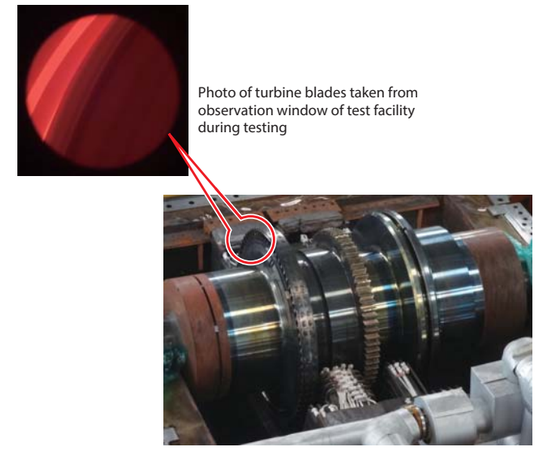


Photo of turbine blades taken from observation window of test facility during testing

Prototype turbine rotor for A-USC power plants

## Shipment of Unit 1 Generator to Jimah East Coal-Fired Power Plant, Malaysia

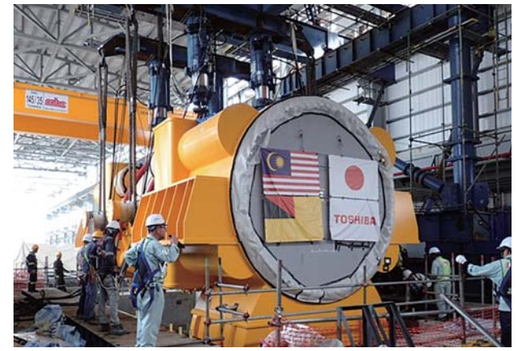
Toshiba Energy Systems & Solutions Corporation shipped a 1 270 MVA generator for Unit 1 of the Jimah East Coal-Fired Power Plant in Malaysia and completed the installation of its stator in October 2017.

We will supply two sets of 1 000 MW ultra-supercritical steam turbine-generators to the Jimah East Coal-Fired Power Plant. Unit 1 and Unit 2, including the largest two-pole generators in our manufacturing experience, are scheduled to commence commercial operation in June 2019 and December 2019, respectively. These generators use direct water cooling for the stator windings.

We shipped the generator for Unit 1 from the factory after it had passed a performance test in May 2017.

The ratings of the generator are as follows:

- 1 270 MVA-26 kV-0.85 PF-50 Hz-2 P
  -600 kPa (gauge) $H_2$ gas pressure.




Generator stator for Jimah East Coal-Fired Power Plant Unit 1, Malaysia

## Reduction of Outage Duration at Callide C Power Plant Unit 4 in Australia Using 3D Laser Measuring Instrument

In August 2017, an outage was implemented at Unit 4 of CS Energy's Callide Power Plant (Callide C) in Australia, to replace low-pressure (LP) nozzle diaphragms.

Conventionally, piano wires have been used to measure the changes in the diaphragm positions between the upper-half casing unmounted and mounted states in order to correctly adjust the turbine clearances. This task has generally required a period of roughly seven days per turbine casing.

In order to reduce the outage period of Unit 4, Toshiba Energy Systems & Solutions Corporation employed a three-dimensional (3D) laser measuring instrument instead of piano wires for measurement of the half-joint level of the upper- and lower-half casings. We then used our proprietary algorithm to estimate the positions of the diaphragms before mounting the upper-half casing.

As a result, these activities during the outage were completed in a single day, six days faster than the period required when using the conventional method.

LP turbine half-joint level measurements using 3D laser measuring instrument at Callide C Power Plant Unit 4, Australia

## Retrofitting of Steam Turbine at Yanaizu-Nishiyama Geothermal Power Station of Tohoku Electric Power Co., Inc. to Reduce Steam Consumption Rate

The Yanaizu-Nishiyama Geothermal Power Station of Tohoku Electric Power Co., Inc. used to be the largest geothermal power plant in Japan, with a power output of 65 MWe. However, the steam mass flow rate gradually deteriorated over time, and the generator output has been only about 20 MWe in recent years. Furthermore, the need arose at this power plant for countermeasures against corrosion, erosion, stress corrosion cracking, corrosion fatigue, and scale deposition caused by the characteristics of the geothermal steam.

In 2017, Toshiba Energy Systems & Solutions Corporation replaced the steam turbine and optimized the steam path according to the current operating conditions. Consequently, the steam consumption rate has been reduced by roughly 20%.

Steam turbine rotor optimized for Yanaizu-Nishiyama Geothermal Power Station of Tohoku Electric Power Co., Inc.





## Commencement of Commercial Operation of All Four Units at Trung Son Hydropower Plant in Vietnam

The Trung Son Hydropower Plant in Vietnam commenced commercial operation in August 2017. Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC), a Chinese subsidiary of Toshiba Energy Systems & Solutions Corporation, supplied all four turbine-generator units for this project. This is the first hydroelectric project in Vietnam financed by the World Bank, and THPC was contracted by Hydrochina Corporation as a consortium partner in August 2013.

The turbines were designed for relatively lower-head sites. Toshiba Energy Systems & Solutions Corporation developed a turbine performance model using computational fluid dynamics (CFD) analysis and performed a model test. THPC designed and manufactured the turbines and generators. The hydraulic pressure was increased to 14 MPa to achieve the downsizing of turbine auxiliaries.

The Trung Son Hydropower Plant has been in stable operation and is highly evaluated by its owner, Vietnam Electricity (EVN). Its ratings are as follows:

- Turbines: 66.6 MW–70.02 m–166.7 $min^{-1}$
- Generators: 76.5 MVA–13.8 kV–166.7 $min^{-1}$–PF 0.85.


Turbine runner with shaft

Generator rotor

## Commencement of Commercial Operation of Two Vertical Bulb Turbines at Kanose Hydroelectric Power Station of Tohoku Electric Power Co., Inc.

Toshiba Energy Systems & Solutions Corporation completed the replacement of two generating units at the Kanose Hydroelectric Power Station of Tohoku Electric Power Co., Inc., and the new units commenced commercial operation in September 2017.

To reduce the system and civil engineering costs, six vertical Francis turbines were replaced by two vertical bulb turbines, which are more effective for low-head facilities such as the Kanose Hydroelectric Power Station. For Toshiba, this was the second application of vertical bulb turbines, which are in operation at only a few power plants around the world.

The new vertical bulb turbines provide an increase of about 10% in the power output without any change in the flow rate. We also adopted our proprietary water-lubricated turbine guide bearing for environmental conservation.

The ratings of the turbines and generators are as follows:

- Turbines: 27.7 MW-22.53 m-167 $min^{-1}$, 2 units
- Generators: 28.6 MVA-11 kV-167 $min^{-1}$, 2 units.

Kanose Hydroelectric Power Station of Tohoku Electric Power Co., Inc.


Installation of rotor in pit

# Completion of Model Test of Francis Turbine for Malea 1 Hydropower Plant in Indonesia

In August 2017, Toshiba successfully completed the model acceptance test of a Francis turbine at the model test stand of THPC. This Francis turbine was designed for and supplied to the Malea 1 Hydropower Plant in Indonesia.

This is the first non-Chinese hydroelectric project for which we performed a turbine model acceptance test using THPC's model test stand.

The ratings of the turbine and generator are as follows:

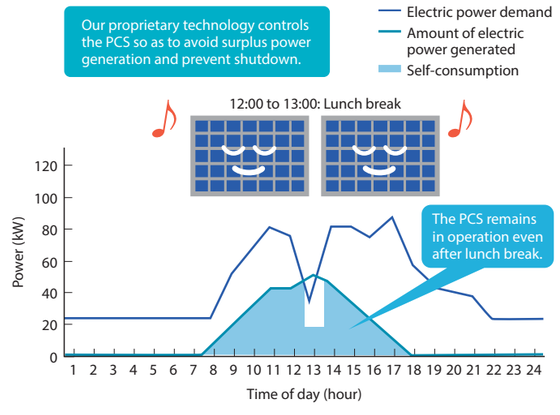
- Turbine: 49.5 MW-417.02 m-600 $min^{-1}$, 2 units
- Generator: 45 MVA-11 kV-600 $min^{-1}$-50 Hz, 2 units


Model test of Francis turbine for Malea 1 Hydropower Plant, Indonesia

# Calendar Type Continuous Power Generation Function for Self-Consumption Photovoltaic Power Generation Systems

A self-consumption photovoltaic (PV) power generation system produces a surplus of electricity when electricity demand drops below the amount of power being generated. To avoid a surplus of electricity, the PV system trips a protective relay so that the power conditioning system (PCS) stops power generation.

To address this problem, Toshiba Energy Systems & Solutions Corporation has developed a calendar type continuous power generation function for self-consumption PV systems. The new function incorporates our proprietary technology to predict the minimum power demand based on data collected every 30 minutes for a certain period and accordingly schedule the PCS so as to avoid generating a surplus. Whereas the power generation capacity of a conventional PV system is determined according to the minimum electric power demand, the continuous power generation function makes it possible to construct PV systems with larger capacities. Following pilot operation at a power plant installed in December 2016, we released this function in November 2017.

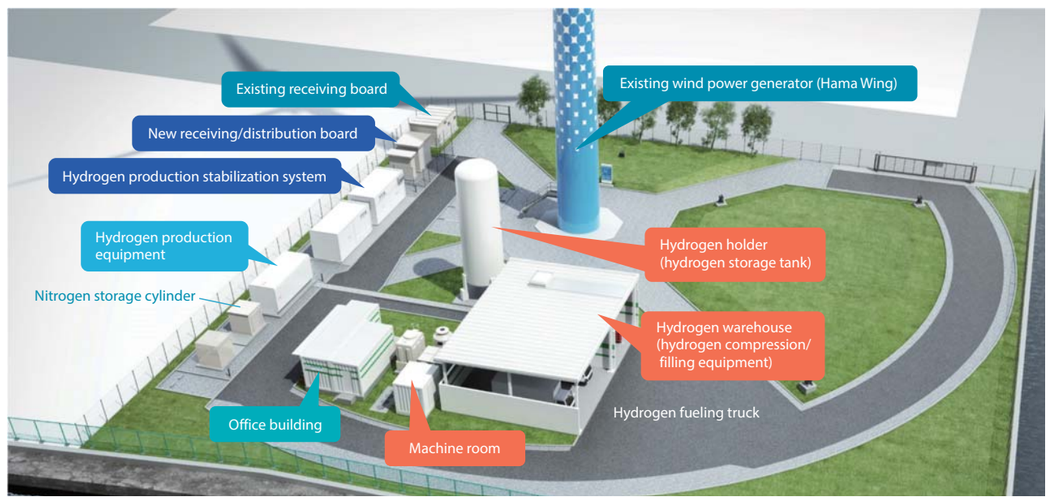



Continuous power generation function





# Introduction of Fuel-Cell Forklifts and Demonstration of Clean Hydrogen Utilization Model




* Based on "Low-Carbon Hydrogen Technology Demonstration Project Using Hama Wing in the Keihin Coastal Area" by MOE

Demonstration facility for supplying hydrogen produced using wind power to fuel-cell forklifts

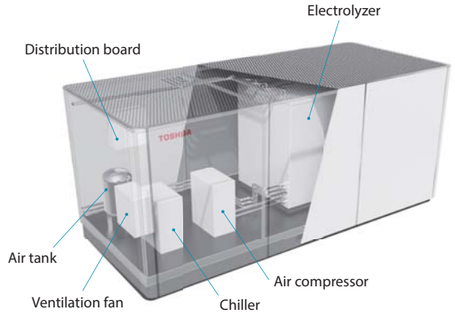
In July 2017, headed by Toyota Motor Corporation, a group of nine organizations including two municipal governments and Toshiba commenced a demonstration project for the introduction of fuel-cell forklifts and clean hydrogen utilization commissioned by the Ministry of the Environment (MOE) of Japan.

In this project, clean hydrogen produced using wind power is being supplied to fuel-cell forklifts at factories, warehouses, and a fruit and vegetable market in the Keihin waterfront area.

Toshiba Energy Systems & Solutions Corporation is providing water electrolysis hydrogen production equipment and a hydrogen energy management system (EMS) that monitors the wind power generated and hydrogen demand in order to efficiently control the hydrogen facilities.

Renewables such as wind power have relatively low $CO_2$ and other environmental impacts. However, many energy consumers consider renewable energy to be costly and unstable even though active utilization of renewable energy is socially required. Therefore, the goal of this project is to establish a hydrogen supply chain and analyze market-acceptable costs.

This project supplies forklift users with hydrogen produced using wind power every day except on holidays. Its aim is to reduce $CO_2$ emissions and hydrogen prices through efficient facility management and realize a society where hydrogen is widely used.




Water electrolysis system

## Successful Completion of On-Site Dielectric Test on 420 kV GIS for Switchyard of Barakah Nuclear Power Station Units 3 and 4, UAE

The Barakah Nuclear Power Station (1 400 MW × 4 units) is the first nuclear power plant in the United Arab Emirates (UAE). For this construction project, Toshiba Energy Systems & Solutions Corporation received a semi-turnkey contract for 400 kV switchyard equipment in February 2012 from Korea Electric Power Corporation, the engineering, procurement, and construction (EPC) contractor for the power station. As main equipment for the switchyard, we supplied a gas-insulated switchgear (GIS) with a rated short-circuit breaking current of 80 kA, the latest GR200 series protection relay in conjunction with a substation automation system, and other devices. We tailored these systems according to the particular specifications of the UAE for the first time.

In the construction of a nuclear power plant, there are stringent requirements for quality control of equipment and safety management of installation work. We employed our substation project management techniques cultivated over 30 years of experience in the Middle East to fulfill these requirements.

Following energization of the stage 1 switchyard equipment for the Unit 1 and 2 generators in January 2016, we completed the on-site dielectric test of a 420 kV GIS, the main equipment of the stage 2 switchyard for the Unit 3 and 4 generators, in October 2017. The stage 2 switchyard is currently in the final stage of its commissioning test and will be ready for energization upon completion of the test.

Switchyard of Barakah Nuclear Power Station Units 3 and 4, UAE

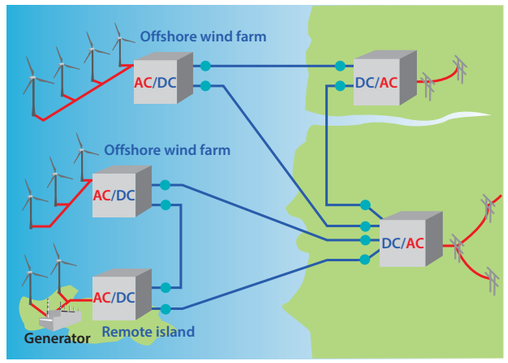
## Large-Capacity DC Circuit Breaker

Toshiba Energy Systems & Solutions Corporation is developing a large-capacity DC circuit breaker (DCCB) under the Next Generation Offshore HVDC System Research and Development Project of NEDO.

We have determined the requirements for DCCBs for a multi-terminal high-voltage DC (HVDC) system in which three or more AC grids are connected by one DC system. The DCCB specifications have been developed in such a manner as to break a large current quickly in the event of a fault in the HVDC system so that the healthy section can continue operation.

We have developed a unique circuit topology to minimize losses and enable rapid removal of a faulty section. This topology consists of a mechanical switch that causes almost no losses and a semiconductor breaker that can break a DC current quickly. Consequently, we have succeeded in breaking an 8 kA current with a 10 kV experimental model.

We will work on a higher-voltage experimental model to achieve commercial application of the DCCB in order to contribute to enhancement of the reliability of multi-terminal HVDC systems.




Example of multi-terminal HVDC transmission system applying large-capacity DCCBs





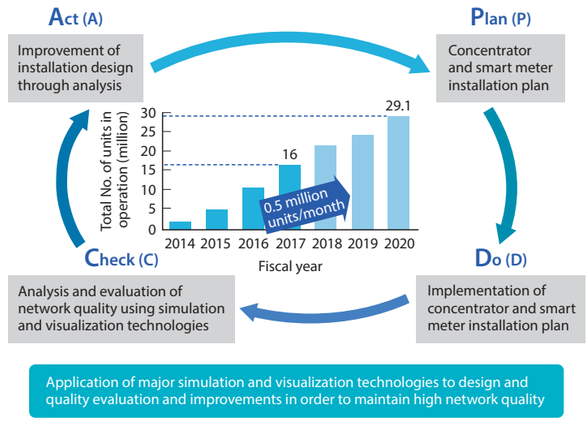
## Stable Operation of Smart Meter Communication System of TEPCO Power Grid, Inc.

Since TEPCO Power Grid, Inc. commenced operation of a smart meter communication system in July 2015, the number of smart meters installed has increased at a pace of 500 000 units per month and reached 16 million in 2017.

One of the world's largest wireless multi-hop networking systems, TEPCO's smart metering infrastructure, which monitors 30-minute meter readings, has maintained stable operation and high network quality with a 99.9% data collection rate.

Toward the full installation of 29.1 million smart meters by fiscal 2020, Toshiba Energy Systems & Solutions Corporation is continuously working to improve the reliability and stability of the system through the implementation of a PDCA cycle.

Our next objective is to further expand this business domain, drawing on the expertise cultivated through this experience with system construction.




Communication system for smart meters of TEPCO Power Grid, Inc. to maintain network quality by implementing PDCA cycle

## Commencement of Operation of Trunk Transmission ISC System in Western Service Area of Chubu Electric Power Co., Inc.

In May 2017, Chubu Electric Power Co., Inc. commenced the operation of a trunk transmission integrated stability control (ISC) system for the 500 kV and lower-voltage grids in its western service area(*) in order to accommodate grid fluctuations caused by the connection of many distributed power supplies to the grids.

The trunk transmission ISC system plays a role in preventing wide-area blackouts. In the event of a grid accident, the trunk transmission ISC system performs two functions: a transient stability control function that prevents electricity generators from going out of step by swiftly disconnecting some of the generators, and a system stabilizing control function that prevents sudden changes in the grid frequency.

Toshiba Energy Systems & Solutions Corporation developed a new technique for reducing the amount of computation and control required by the parent system to determine effective controls more rapidly than the previous technique. This helps to alleviate the impact of a grid accident on supply-demand balancing and other operations.

(*) The use of the trunk transmission ISC system in the eastern service area is scheduled to begin in 2020.

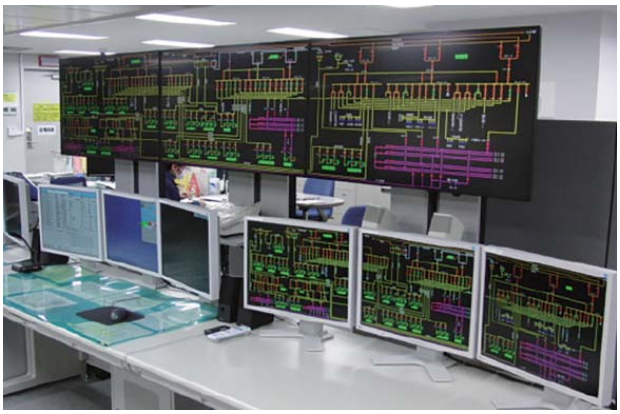
Processing equipment of trunk transmission ISC system of Chubu Electric Power Co., Inc.

## Commencement of Operation of Distribution Control System at Shinjuku Control Center of TEPCO Power Grid, Inc.

TEPCO Power Grid, Inc. has replaced a distribution control system with a two-level system that provides integrated monitoring and control of a local transmission system and a distribution system.

Toshiba Energy Systems & Solutions Corporation participated in this replacement project as a hardware manufacturer. The final part of the replacement system commenced operation at the Shinjuku Control Center of TEPCO Power Grid, Inc. in April 2017.

The previous distribution control system controlled the equipment in a distributing substation indirectly via a substation system, whereas the new two-level distribution control system can directly control the equipment in a distributing substation. Previously, the equipment in distributing substations and along distribution lines was supervised separately by operators in engineering and distribution departments. In contrast, the new distribution control system allows integrated supervision of their operations, improving the efficiency of supervisory control.



Distribution control system of TEPCO Power Grid, Inc.

## Commencement of Operation of Renewable Energy Management System at Central Load Dispatching Center of Kyushu Electric Power Co., Inc.

Due to the deployment of a large number of solar PV and other renewable energy installations, the electricity supply capacity in the Kyushu region is becoming excessive. This has given rise to the need for power output control.

Supported by Kyushu Electric Power Co., Inc., Toshiba Energy Systems & Solutions Corporation has developed a renewable energy management system for smooth and effective output control. This system, which commenced operation in October 2017, uses the latest area demand and weather forecast data to adjust the prediction for renewable energy output and accordingly optimize the level of output control. The new renewable energy management system can dynamically add and remove controls for remotely controllable power generation operators and keep output control logs, making it possible to control renewable energy output while ensuring equitability.

Renewable energy management system for central load dispatching center of Kyushu Electric Power Co., Inc.

***TOSHIBA REVIEW Science and Technology Highlights***
is published annually by Toshiba Corporation.



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