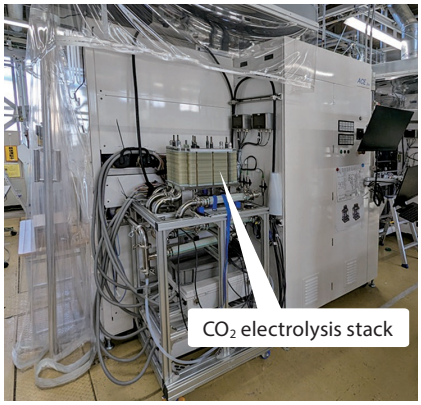
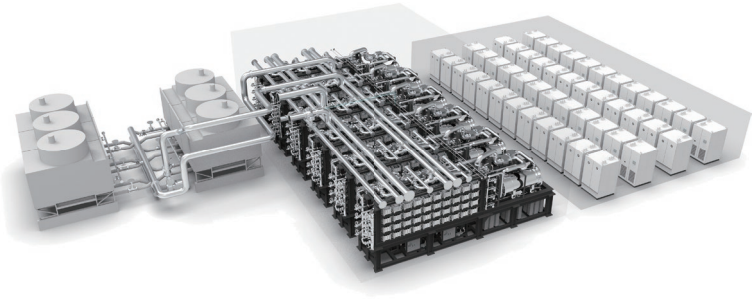
2. Energy Systems

2.1 Development of Prototype C2One™ CO_2 Electrolyzer and Performance Verification of Full-Scale Stack



Full-scale CO_2 electrolysis stack and electrochemical evaluation facility



Conceptual diagram of large-scale CO_2 electrolyzer plant (with annual CO production capacity of approximately 20 000 tons)

Toshiba Energy Systems & Solutions Corporation has developed the C2One™ carbon dioxide (CO_2) electrolysis system capable of converting CO_2 into carbon monoxide (CO) with a high level of efficiency with the aim of achieving practical application in 2026. C2One™ is designed to produce approximately 150 tons of CO per year.

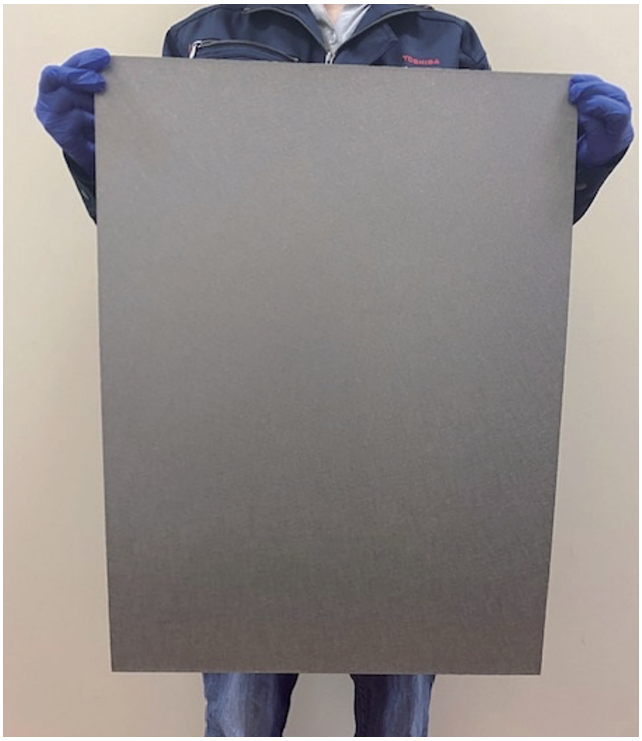
By 2022, we completed verification of a single cell and a 10-cell short stack. In 2023, we developed a full-scale prototype CO_2 electrolysis stack that consists of more than 100 single cells with an electrode area of 400 cm^2 and evaluated its basic electrochemical characteristics at a new test facility. Uniform gas flow and electrolyte distributions through individual cells are important for a full-scale stack. An evaluation confirmed that there is no cell-to-cell difference in distributions and that the full-scale stack produces CO with a high level of Faradaic efficiency equivalent to the 10-cell short stack. At present, we are verifying the robustness and durability of the full-scale stack for long-term operation.

Based on the basic design of the C2One™ and the performance verification results of a single cell and a short stack in 2022, we have completed the detailed design of the prototype C2One™ and are currently working on parts procurement and manufacturing cell stacks. The C2One™ evaluation facility will be completed in early 2024.

The CO produced by the C2One™ is intended to be used as feedstock for chemical products, sustainable aviation fuel (SAF), and synthetic fuel, but the amount of CO produced by a single C2One™ unit does not meet consumer requirements. Therefore, to further increase CO production capacity, we have created a basic design for a CO_2 electrolysis plant with multiple C2One™ units and conducted a conceptual study of a CO_2 electrolysis plant with a total CO production capacity of 20 000 tons per year.

Part of the results were obtained through the Project for the Establishment of a Circular Carbon Economy Model Through Carbon Dioxide Recycling commissioned by the Ministry of the Environment (MOE), Government of Japan.

2.2 Manufacturing Technology for Large-Scale MEAs with Ultralow Iridium Catalyst Loading for Hydrogen Production



Large MEA with area of 3 000 cm^2

As a component technology for producing hydrogen from renewable energy, Toshiba Corporation has established manufacturing technology for large-scale membrane electrode assemblies (MEAs) with ultralow iridium catalyst loading, providing samples starting in FY2023.

Power-to-gas (P2G) is a technology that produces green hydrogen by converting water into hydrogen and oxygen via electrolysis using electricity derived from renewable energy sources so that hydrogen can be stored and transported. Japan's Basic Strategy for Hydrogen revised in 2023 is attracting significant attention as it sets a target of introducing about 15 GW of water electrolyzers globally by 2030.

Proton-exchange membrane (PEM) water electrolysis is a water electrolysis method which is highly adaptable to renewable energy fluctuations and features excellent membrane durability. However, the catalyst in PEM electrodes uses iridium (Ir), one of the rarest precious metals with a global annual production of only about seven tons. Therefore, reducing the Ir requirement is a challenge that needs to be solved to facilitate the proliferation of PEM water electrolysis. We developed a unique Ir oxide (IrO_2) nanosheet laminated catalyst in 2017 using a sputtering method and we were the first in the world to manufacture a large PEM electrode in FY2022 that uses only 1/10th of the amount of Ir in conventional electrodes(*).

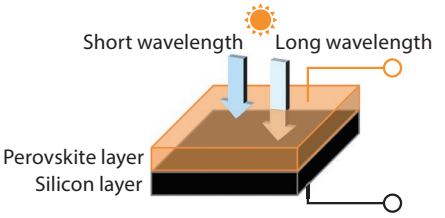
To use this electrode for PEM water electrolyzers, it is necessary to manufacture large MEAs composed of a stack of electrolyte membranes and electrodes using a hot press. However, we found it difficult to keep the thickness of large MEAs uniform, and it was necessary to align the MEA components with an accuracy of less than 1 mm.

To align the components of 3 000 cm^2-class MEAs with an accuracy of less than 1 mm, we improved the surface accuracy of the press platen, selected the optimal buffer material, and devised unique techniques for the alignment process. We succeeded in reducing variations in the pressure applied to the MEA to roughly 10%, making it possible to fabricate large MEAs without affecting hydrogen production performance.

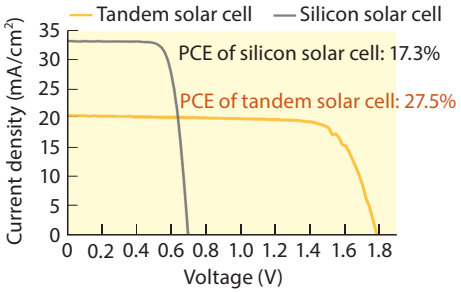
We will aim to commercialize large MEAs early to achieve widespread use of P2G in society.

(*) As of October 2022 (according to Toshiba Corporation research)

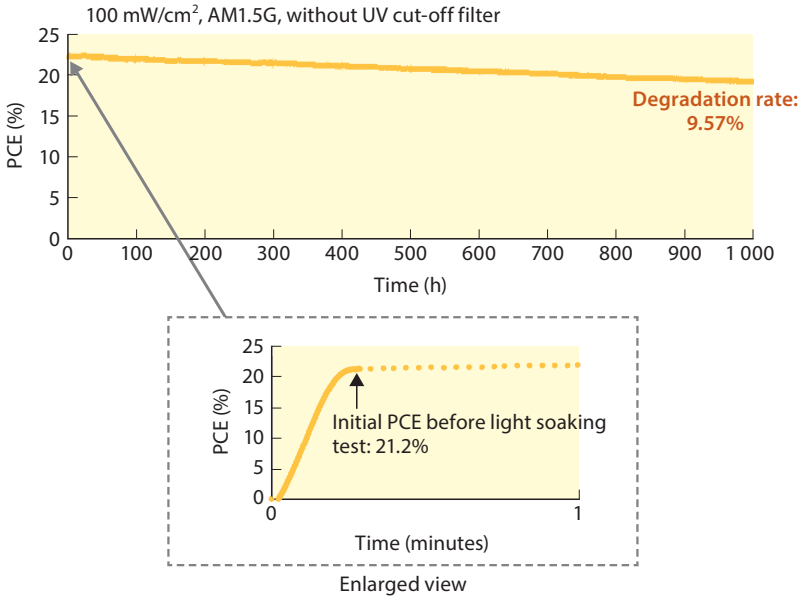
2.3 Perovskite/Silicon Tandem Solar Cell with Improved Power Conversion Efficiency and Light Stability



Basic principle of 2-terminal perovskite/silicon tandem solar cells



Power conversion efficiency of 2-terminal perovskite/silicon tandem solar cells



Light soaking test of 2-terminal perovskite/silicon tandem solar cells (100 mW/cm², AM1.5G, without UV cut-off filter)

Renewable energy plays an important role in achieving a carbon-neutral society, and innovative solar cells are required as one of the main power sources.

With this in mind, Toshiba Energy Systems & Solutions Corporation is developing a next-generation two-terminal perovskite/silicon solar cell. The tandem solar cell is composed of two active layers (perovskite and silicon layers) and generates more electricity than single-layer solar cells. While most tandem solar cells have two or four terminals, the new tandem solar cell is a two-terminal model, which is more suitable for deployment in solar parks because it can operate on a conventional electric system. As is the case with conventional solar cells with a product service life of more than 20 years, tandem solar cells require long-term outdoor stability for solar park applications.

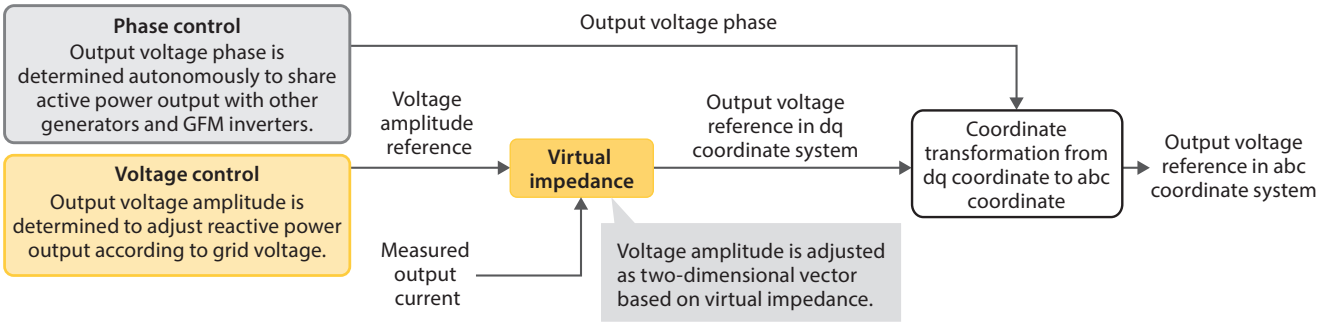
Therefore, we have improved perovskite layer uniformity and the electrode structure of the tandem solar cell, achieving a power conversion efficiency (PCE) of 27.5%. In addition, the tandem solar cell that we developed in 2023 in collaboration with The University of Electro-Communications, the National Institute of Advanced Industrial Science and Technology (AIST) of Japan, and Fujico Co., Ltd. achieved the world's highest light stability(*). A 1 000-hour light soaking test showed a PCE degradation rate of less than 10% after 1 000-hour illumination of 100 mW/cm^2 under AM1.5G (air-mass 1.5 global) without a UV cut-off filter. The new tandem solar cell also exhibited approximately double the durability of the tandem solar cells previously reported. We presented this achievement at the Japan Society of Applied Physics (JSAP) and published it in the Nature Photonics journal.

2. Energy Systems

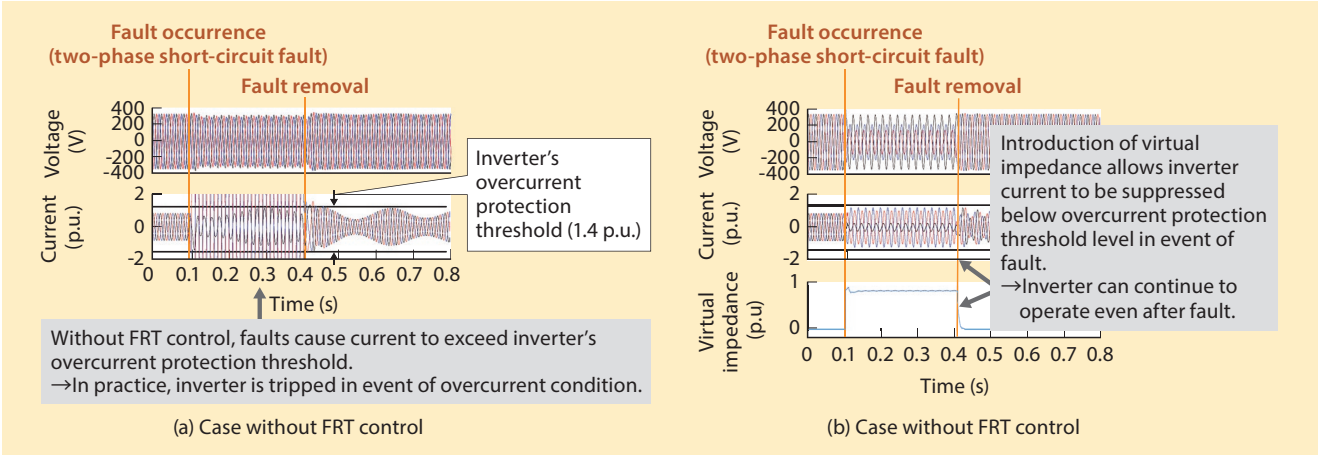
Our progress demonstrates the potential of the next-generation solar cell. We will accelerate our development efforts to contribute to achieving a carbon-neutral society.

(*) As of December 2023, for two-terminal perovskite/silicon tandem solar cells (according to Toshiba Energy Systems & Solutions Corporation research)

2.4 Fault Ride-Through Control for Grid-Forming Inverters



Overview of proposed FRT control for GFM inverters



Verification of FRT overcurrent suppression via electromagnetic transient simulation

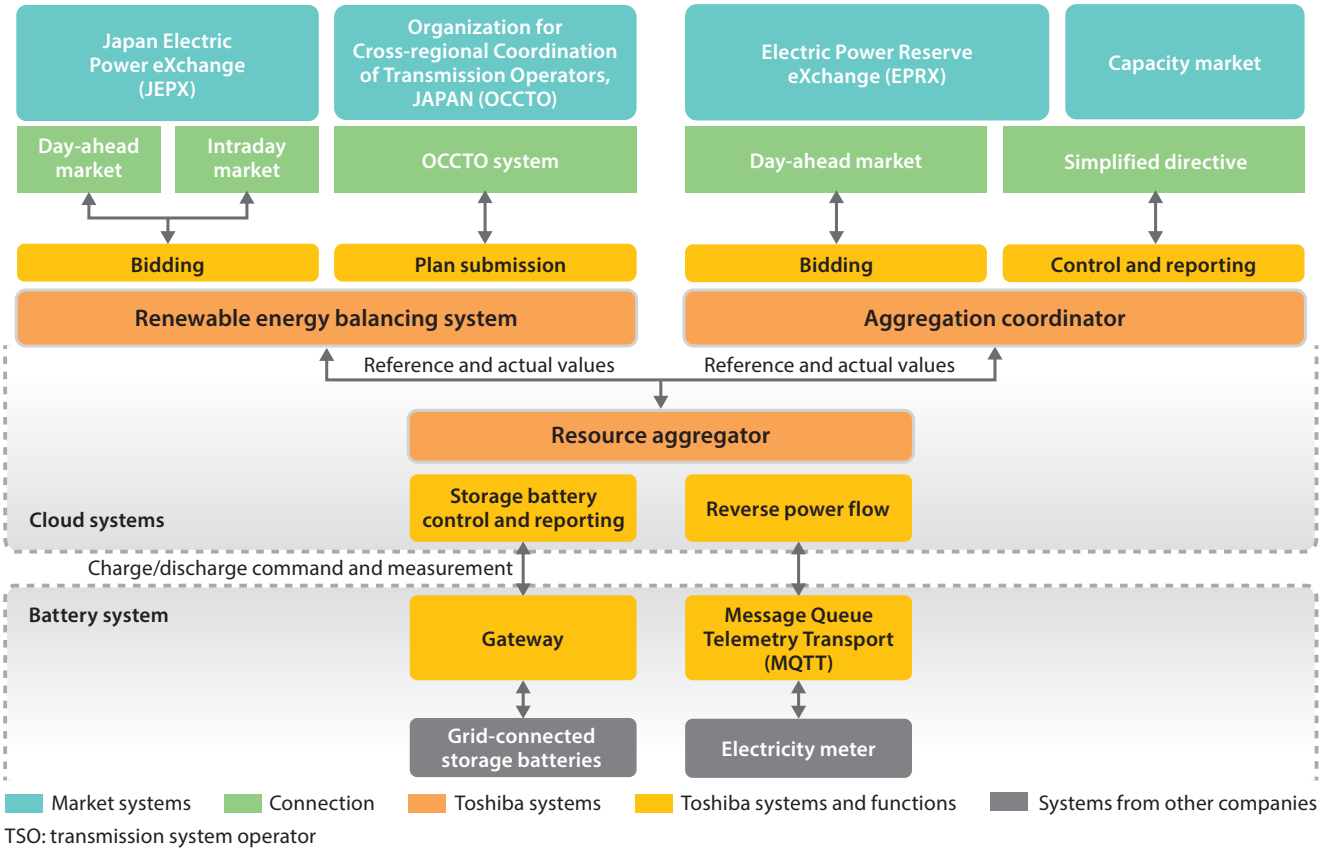
The increasing uptake of inverter-based resources (IBRs) such as photovoltaic power generation and battery energy storage can cause a reduction in power system inertia and an increase in frequency fluctuation. A grid-forming (GFM) inverter, or an inverter that acts as a voltage source, is a promising solution to these problems. However, in the event of a ground fault condition, a GFM inverter tends to shut down due to excessive current. This can cause a cascading disconnection of IBRs from the electrical grid, which is the reason for its instability. The development of fault ride-through (FRT) control is urgently needed to use GFM inverters for improving grid operations and thereby preventing excessive current.

With this in mind, Toshiba Energy Systems & Solutions Corporation has proposed FRT control for GFM inverters based on virtual impedance. The proposed method can reliably prevent overcurrent conditions by adjusting virtual impedance according to an inverter's output current. This method can contribute to grid stability because it is capable of handling unbalanced fault conditions.

An electromagnetic transient simulation confirmed that the proposed method can reduce an inverter's output current within 1.4 p.u. (per unit) even in the event of a two-phase short-circuit fault. We also confirmed that GFM inverters smoothly return to normal operation after grid voltage recovery.

At present, we are engaged in field verification, aiming to achieve practical application of GFM inverters.

2.5 Operational Support System for Grid-Connected Storage Batteries



Overview of operational support system for grid-connected storage batteries

In recent years, the proliferation of renewable energy resources in the power grid has progressed rapidly toward the goal of carbon neutrality. This has resulted in curtailment of solar power generation during the daytime becoming a problem. To counter this, grid-connected storage batteries are being used more frequently, and there is a growing need for multi-use storage batteries to ensure supply-demand balancing capabilities and maintain stable grid operation.

Toshiba Energy Systems & Solutions Corporation is developing an operational support system that assists with battery capacity bidding and operation in the wholesale, capacity, and balancing markets. This operational support system consists of the REBSet™, aggregation coordinator (AC), and resource aggregator (RA) systems.

This renewable energy balancing system incorporates functions for the managing energy balancing groups. The AC system communicates with a balancing market system to control resources, and the RA system supports multiple markets.

We have developed and incorporated the following functions into an existing operational support system to enable storage battery energy usage: (1) arbitrage operation planning function of REBSet™ for grid-connected storage batteries and (2) a function to communicate reference and actual values between the RA system and the REBSet™ and between the RA and AC systems using a Web application programming interface (API).

Because the REBSet™, AC, and RA systems are all implemented in a cloud environment as software as a service (SaaS), it is possible to enhance functionality according to statutory changes and flexibly improve user convenience. We will improve the operational support system in a timely manner to deal with various changes anticipated in the future, improve ease of operation of grid-connected storage batteries, and contribute to the prevalence of renewable energy resources.

2.6 Commencement of Commercial Operation at Alvin W. Vogtle Electric Generating Plant, U.S.A

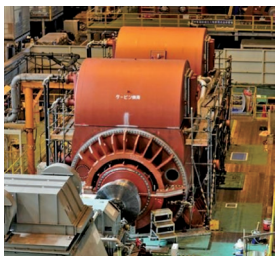
Alvin W. Vogtle Electric Generating Plant Units 3 and 4, U.S.A

Equipment	Specification
Steam turbine	Tandem compound, six-flow exhaust (TC6F) 52-inch last-stage blade: 1 800 rpm
Turbine generator	1 389 MVA three-phase synchronous generator, 0.9 power factor, 1 800 rpm, water-cooled stator, hydrogen-cooled rotor, thyristor-controlled excitation device
Condenser	Three-shell multi-pressure condenser, titanium cooling tube
Feedwater heaters	Seven regenerative stages (including one deaerator)
Moisture separator reheater	Two reheating stages

Major equipment specifications

(a) High-pressure turbine rotor

(b) Low-pressure turbine rotor



(c) Turbine generator

Major equipment

Alvin W. Vogtle Electric Generating Plant (also known as Plant Vogtle) Unit 3 (1 200 MW-class AP1000) in Georgia, U.S.A. operated by Southern Nuclear Operating Company, Inc. commenced commercial operation on July 31, 2023. Toshiba Energy Systems & Solutions Corporation supplied the main equipment for Units 3 and 4, including steam turbines, turbine generators (including excitation devices), condensers, and moisture separator reheaters, and provided installation and commissioning support.

2. Energy Systems

Nuclear power generation is anticipated worldwide as a means of achieving energy security and carbon neutrality. Plant Vogtle Unit 3 is the first new nuclear power unit built in the United States in 30 years, and we contributed to increasing the value of the construction project by providing equipment.

To increase the unit's electrical output, we equipped the steam turbine with a 52-inch last-stage blade, one of the largest in the world for 60 Hz applications(*) and leveraged state-of-the-art three-dimensional (3D) blade design and loss reduction technologies to improve turbine performance. We also optimized the condenser tube arrangement to improve cooling performance.

To reduce construction costs, we applied a spring-supported foundation to the integrated turbine-condenser structure and the installation deck. This made it possible to reduce the amount of structures thanks to a considerably reduced load.

To support equipment installation and commissioning, we dispatched experienced technical advisors well-versed in nuclear power equipment and operation to the construction site. Our engineers also stayed in the United States to facilitate cooperation between Southern Nuclear and our personnel and to quickly resolve various testing and operational issues. Southern Nuclear praised the high reliability, stability, and low vibration of our turbine and generator achieved through effective guidance and troubleshooting during commissioning.

In addition to continuing to support the commissioning of Unit 4(*), we will provide superior inspection and maintenance methods, promptly respond to repair needs, and supply parts in a timely manner to ensure stable operations of Units 3 and 4.

We will contribute to the goal of global carbon neutrality and energy security through consistent provision of high-quality, highly reliable, and high-performance equipment for nuclear power plants.

(*) As of December 2023 (according to Toshiba Energy Systems & Solutions Corporation research)

2.7 Completion of Construction Work at Rokkasho Reprocessing Plant to Conform to New Safety Regulations

Active vessel off-gas treatment units under construction

Completed active vessel off-gas treatment units

Following the accident at the Fukushima Daiichi Nuclear Power Station, Japan revised the Nuclear Reactor Regulation Act. With this in mind, Toshiba Energy Systems & Solutions Corporation was contracted by Japan Nuclear Fuel Limited (JNFL) to implement additional safety measures at the Rokkasho Reprocessing Plant to meet the new regulatory standards. Construction work began in 2019 and was completed in May 2023.

To conform to the new regulatory standards, we mainly implemented the following measures:

(1) To prevent fire from spreading, we installed additional fire sealing materials, dampers, detectors, and extinguishing equipment.

(2) To protect against water overflow, we installed shutoff valves in systems that were a possible source of overflow and sealed wall penetrations according to the expected submersion depth in each area.

(3) To enhance earthquake resistance, we performed a seismic evaluation against the seismic motion specified in the new regulatory standards and added reinforcements according to the evaluation results.

(4) To prepare for the loss of safety functions due to design extension conditions, we installed criticality accident detectors, an automatic chemical injection facility to avoid criticality conditions, and a waste gas storage facility to contain radioactive gases.

During the project, we worked on design and construction concurrently. In addition, several contractors worked simultaneously in a confined space. This resulted in frequent interference with mutual tasks and equipment. It was also difficult to secure and add skilled workers. Many workers were inexperienced in nuclear facilities and construction work, resulting in construction delays.

To maintain the construction schedule, the design and project personnel resided on-site, and efforts were made to promptly resolve any pending issues, including site interferences. In addition, because of the extensive scope of electrical instrumentation work, we expanded the tasks that mechanical and plumbing subcontractors could handle to make effective use of human resources. Depending on subcontractor delays, we shifted work to other subcontractors while the parties involved in design, project management, and on-site construction coordinated drawings, equipment, and interactions.

Additional construction work required to conform to the new regulatory standards and post-approval work is planned for the future. The Toshiba Group will work as one to share the lessons learned and measures implemented in this project to ensure that additional construction and post-approval work will proceed smoothly, contributing to the completion of the Rokkasho Reprocessing Plant.

2.8 Installation of Automatic Open-Phase Condition Detection Device at Shimane Nuclear Power Plant

Automatic OPC detection device

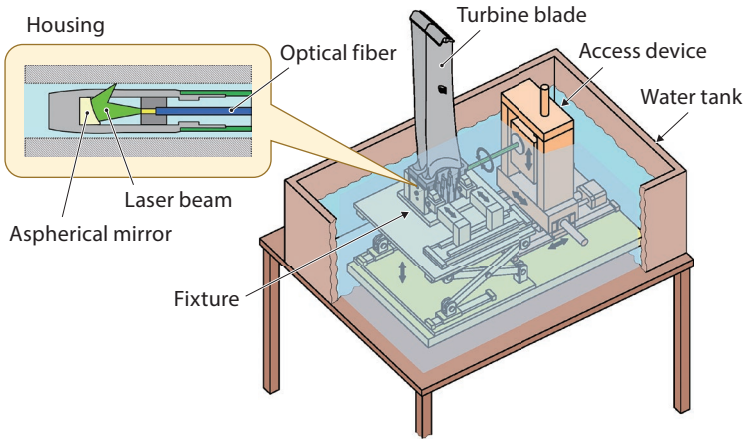
Toshiba Energy Systems & Solutions Corporation has developed a device to automatically detect open-phase conditions (OPCs) along overhead lines that connect to external power sources in nuclear power plants. In February 2023, we installed this device at the Shimane Nuclear Power Plant operated by The Chugoku Electric Power Co., Inc.

OPC is a fault that has occurred at U.S. nuclear power plants, and Japan's new nuclear regulations(*) require OPC detection. Our new OPC detection device provides enhanced OPC detectability.

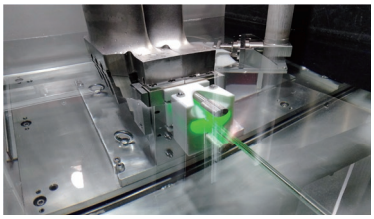
Conventional OPC detection devices require dedicated current transformers to detect minimal electric current. The new OPC detection device, however, incorporates a new analog-to-digital converter, which eliminates the need for a dedicated current transformer, allowing the use of an existing one. The new OPC detection device therefore helps reduce construction work and costs and contributes to improved nuclear power plant safety.

(*) Interpretation of the regulations concerning the Standards for the Location, Structure, and Equipment of Commercial Power Reactors and Auxiliary Facilities

2.9 Verification of Laser Peening Technology to Increase Strength of Pinholes at Forks of Low-Pressure Turbine Blades at Tokyo Electric Power Company Holdings, Inc. Kashiwazaki-Kariwa Nuclear Power Station Units 6 and 7



Laser peening device for low-pressure steam turbine blade

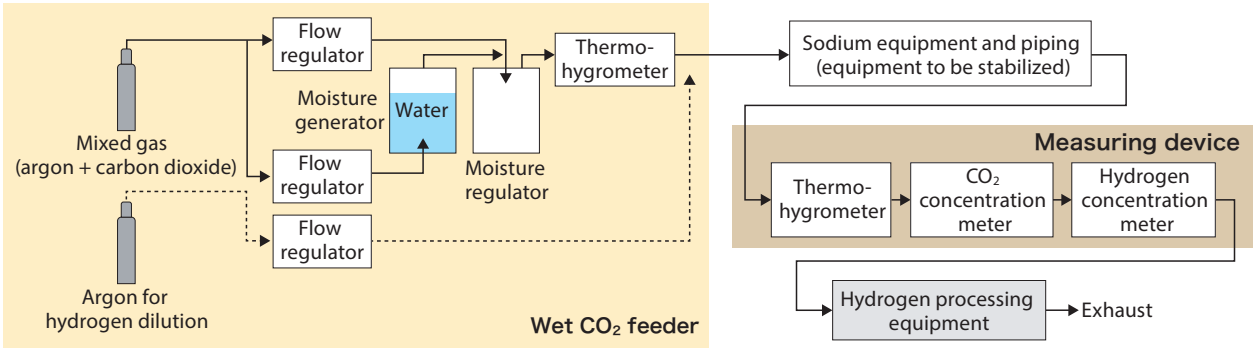


Laser peening

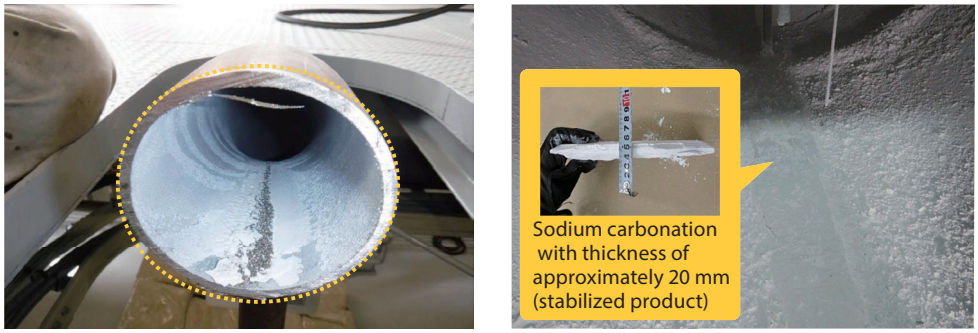
In 2008, an inspection of the third-party steam turbines at Kashiwazaki-Kariwa Nuclear Power Station Units 6 and 7 operated by Tokyo Electric Power Company Holdings, Inc. discovered damage to the pinholes at the forks of low-pressure turbine blades. The blades were presumably damaged by high-cycle fatigue due to the turbine blades' vibration induced by the turbulence of the blade steam flow experienced during low-load operation and load shutdown. A plan is underway to replace the turbine with a new design. In the past, shot peening was employed to increase the strength of turbine blade materials, however it is difficult to apply this technique to narrow pinholes at the forks of low-pressure turbine blades.

To solve this issue, Toshiba Energy Systems & Solutions Corporation has developed a laser peening technology for the narrow pinholes. The new technology transmits a laser beam through an optical fiber and uses a compact irradiation head to perform laser peening. Before applying this technique to the pinholes, we conducted residual stress and fatigue tests to evaluate its effect on fatigue strength improvement. We verified that the laser-peened pinholes provide 30% higher fatigue strength than unpeened ones due to laser peening imparting compressive residual stress to the material surface. At present, we are applying laser peening to the pinholes at the forks of rebuilt low-pressure turbine blades.

2.10 Sodium Stabilization Technology Contributing to Decommissioning of Fast Reactors



Overview of carbonation equipment



Piping diameter (inner diameter: 80 mm) Inside tank (inner diameter: 1.6 m)

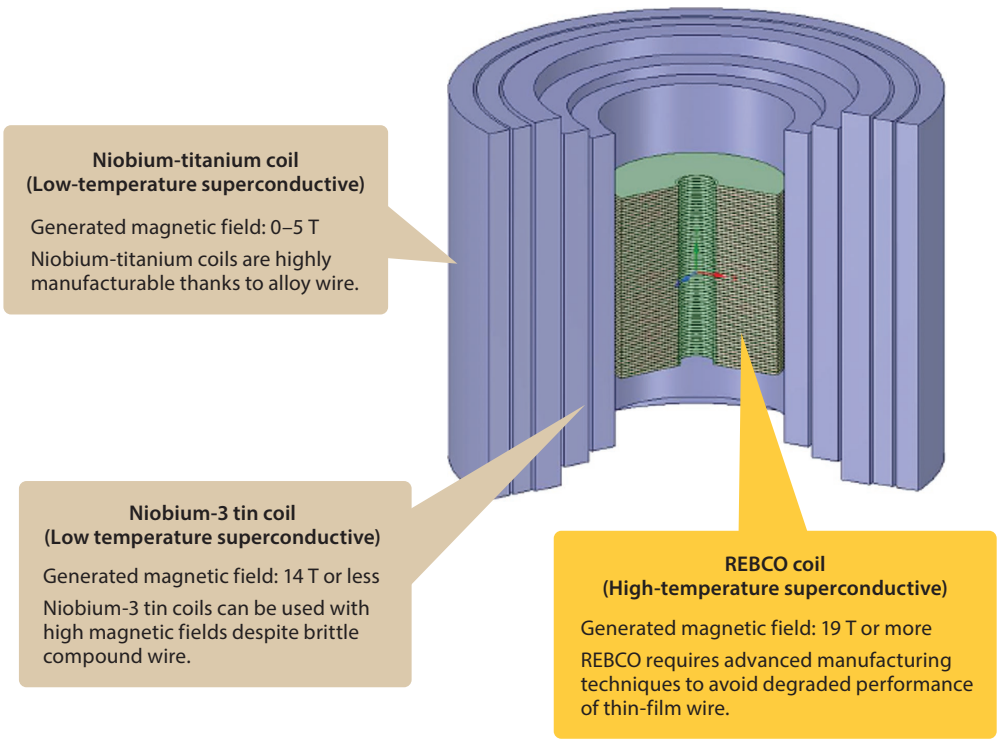
Internal states of piping and tank after carbonation treatment

Sodium used as a coolant for fast reactors adheres to and remains on the inner surface of the constituent equipment and piping. Because sodium burns in the air, a traditional method used to dismantle a fast reactor would be to cut the equipment and piping in plastic bags filled with an inert gas. However, this results in increased decommissioning times. To dismantle a fast reactor safely in a short period of time, it is important to inhibit the chemical reaction between sodium and air.

To facilitate the dismantling of sodium loop test equipment, Toshiba Energy Systems & Solutions Corporation has developed carbonation technology for sodium stabilization. Carbonation is a method of sodium stabilization that brings sodium into contact with moist CO_2 to form chemically stable sodium carbonate. The carbonation equipment consists of a wet CO_2 feeder, a unit to process the hydrogen produced by the carbonation reaction, and other units. We employed the carbonation equipment to stabilize the surface or all the layers of residual sodium on the equipment and piping of the sodium loop test equipment and completed the subsequent dismantling work safely in a short period of time.

In the future, we will leverage the knowledge from this experience for the planned dismantling of sodium equipment and piping at Monju, a prototype fast-breeder reactor of the Japan Atomic Energy Agency.

2.11 33 T Cryogen-Free Superconducting Magnet



33 T cryogen-free superconducting magnet coil configuration

Toshiba Energy Systems & Solutions Corporation is collaborating with Tohoku University to develop a cryogen-free high-field magnet that does not require liquid helium. At present, we are developing a 33 T cryogen-free superconducting magnet (33T-CSM) with the world's highest magnetic field(*).

The 33T-CSM consists of three types of superconducting coils to efficiently generate a high magnetic field. Whereas the 25 T cryogen-free superconducting magnet we developed in 2015 uses a bismuth-based superconducting wire with excellent workability for the innermost high-temperature superconducting coils, we will now use an $REBa_2CuO_y$ (REBCO) wire (rare-earth-based superconducting wire) which provides excellent strength and current-carrying properties in high magnetic fields.

The REBCO wire consists of a thin film of a superconducting material on a metallic tape, making it prone to degradation due to forces in the direction of thin-film peeling. We have solved this problem by adopting a method that eliminates winding turn-to-turn bonds so that no peeling force is applied to the wound REBCO wire.

We will combine the technologies that we have developed so far, including measures to prevent REBCO wire peeling, to develop the 33T-CSM.

(*) As of March 2022 (according to Toshiba Energy Systems & Solutions Corporation research)

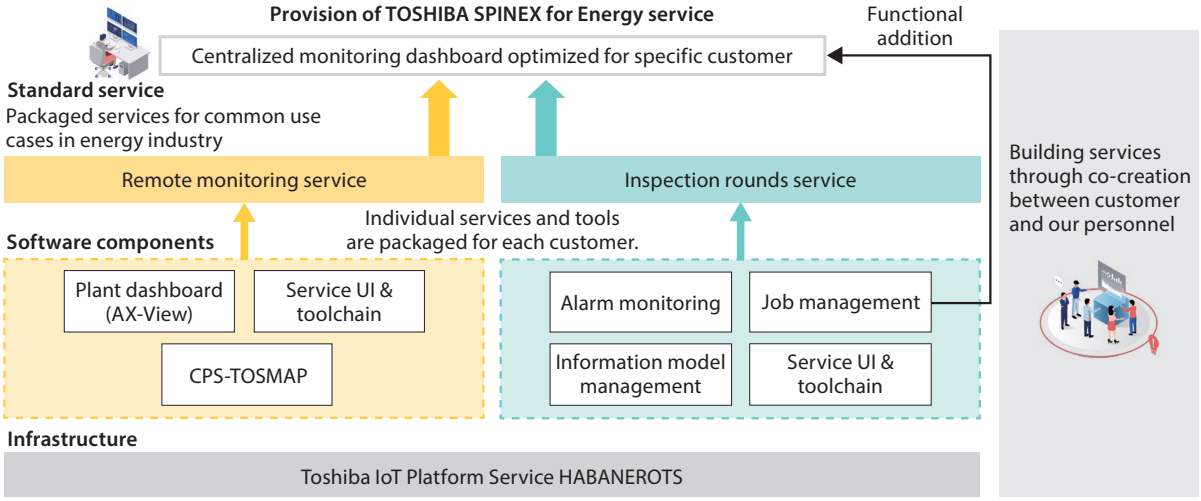
2.12 CPS Solutions for Thermal Power Plants Contributing to Carbon Neutrality

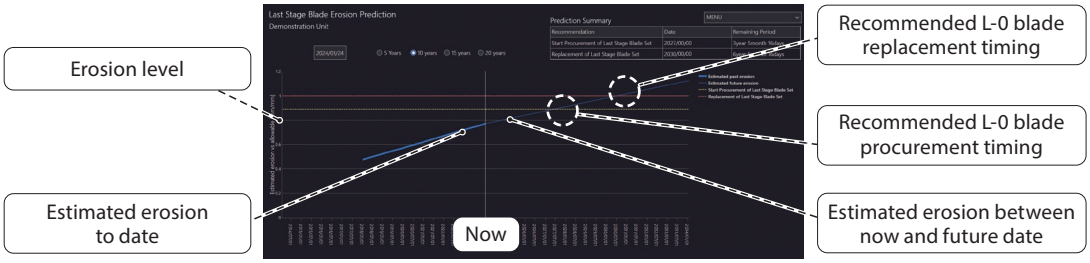
In many countries, the movement toward decarbonization is gaining momentum with the goal of achieving a carbon-neutral society, spurring the proliferation of renewable energy. Because increasing renewable energy generation makes it difficult for the power grid to absorb frequency fluctuations and load changes, existing thermal power plants are expected to serve as power resources to maintain grid and electric power system stability. However, thermal power generators are designed for baseload operation and are not suitable for variable load operation. Therefore, keeping them in good condition according to original maintenance plans could be insufficient.

To address this, Toshiba Energy Systems & Solutions Corporation offers various solutions related to thermal power plant operation and maintenance using cyber-physical systems (CPS) technologies. These solutions are available as applications of TOSHIBA SPINEX for Energy, an Internet-of-Things (IoT) platform for energy businesses.

For example, the erosion of the last-stage (L-0) blade of a low-pressure (LP) steam turbine progresses gradually near the rated output and quickly under low-load conditions. It is difficult, however, to accurately determine the erosion rate of an actual steam turbine with different load profiles (especially at low loads). To resolve this issue, we have developed an erosion model based on actual equipment data and the results of computational fluid dynamics (CFD) simulation of water droplet behavior. TOSHIBA SPINEX for Energy provides an IoT application incorporating this erosion model, which indicates current and future erosion amounts and recommends L-0 blade replacement timing, eliminating the need to disassemble the turbine.

We will continue to develop IoT solutions using CPS technologies unique to a power generation equipment manufacturer with the goal of contributing to carbon neutrality.





TOSHIBA SPINEX for Energy concept and application user interface (UI) screen for prediction of steam turbine L-0 blade erosion

Components	Application	
Steam turbine	L-0 blade erosion prediction	
	Nozzle diaphragm creep deformation prediction	
	First-stage blade erosion prediction	
	LP turbine rotor wheel SCC and CF progress prediction	
	High-temperature turbine component remaining life assessment	
Generator	Generator stator online insulation diagnosis (online PD diagnosis)	
	Reverse root cause analysis (RRCA)	Layer short
		Rotor imbalance
		H_2 cooler degradation
	Generator collector ring spark monitoring	
Condenser	Condenser tube wall erosion prediction	
	Condenser performance recovery evaluation	
Boiler	Boiler combustion optimization (BCO)	
	Soot blowing optimization (SBO)	
Common	RCA for turbine, generator, and condenser	

SCC: stress corrosion cracking
CF: corrosion fatigue
PD: partial discharge

Examples of IoT solutions for thermal power stations

2.13 Completion of Turbine Refurbishment Work at Aioi Biomass Power Plant for Fuel Conversion

Refurbished turbine-generator equipment at Aioi Biomass Power Plant

Aioi BioEnergy Co., Ltd. took over operations of Aioi Power Station Unit 2 from the Kansai Electric Power Co., Inc. and refurbished its boiler for fuel conversion from heavy oil to woody biomass. Renamed the Aioi Biomass Power Plant, it is now the largest biomass power plant in Japan with a rated output of 200 MW.

Because it uses fuel derived from plants, absorbing CO_2 from the atmosphere, and releases no more CO_2 than the plants absorb during growth, biomass power generation is carbon neutral.

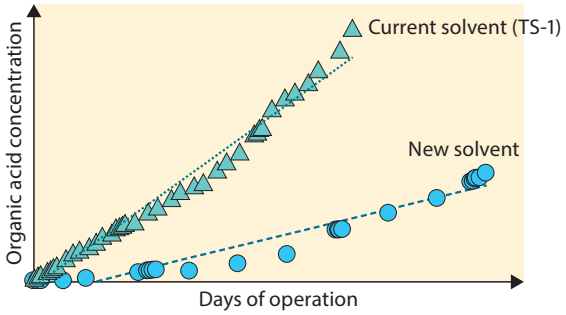
Toshiba Energy Systems & Solutions Corporation began the fuel conversion work in February 2020 and conducted the design, manufacturing, replacement, and test runs of the steam turbine, generator, and control equipment, commencing commercial operation in March 2023.

As a result of fuel conversion to woody biomass, the rated output of the power plant decreased from 375 MW to 200 MW. Therefore, to improve its thermal efficiency, we performed a degradation recovery process for the steam turbine and set the optimum operating point according to the new rated output. This upgrade contributed to a reduction in fuel consumption. Furthermore, as the rated output decreased to 200 MW, we performed a test to verify that the new power plant operates safely and stably with a single condensate pump. We reduced the number of condensate pumps in operation from two to one, thereby cutting power consumption within the power plant. In the course of this project, we also reduced the size of other existing equipment and improved power generation efficiency through turbine cycle engineering that we are responsible for.

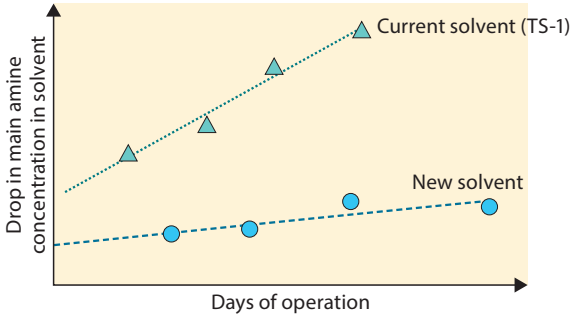
We will leverage this experience to help decarbonize other existing thermal power plants and thereby contribute to society.

2.14 Completion of On-Site Verification Test of New Absorbent for CO_2 Capture Plant

CO_2 capture facility at Saga City waste incineration plant



Comparison of organic acid accumulation speed in new and current CO_2 solvents



Comparison of decrease in main amine concentration in new and existing CO_2 solvents

To increase the uptake of CO_2 capture plants with the goal of achieving a carbon-neutral society, it is important to reduce operating costs. To capture CO_2 from exhaust gas, the CO_2 capture plant uses an amine-based aqueous solution as a CO_2 solvent to absorb CO_2 at low temperatures and release it at high temperatures. However, from the operator's point of view, the performance of the CO_2 solvent must be improved to reduce the operating and maintenance costs of the CO_2 capture plant.

With this in mind, Toshiba Energy Systems & Solutions Corporation has developed a new CO_2 solvent with a reduced degradation rate while maintaining the energy required per unit of captured CO_2 at the same level as the current CO_2 solvent. We introduced this highly durable solvent for a CO_2 capture plant (with a capacity of 10 tons per day) that we delivered to a waste incineration plant in Saga City in 2016.

We ran the CO_2 capture plant continuously to compare the durability of the new and current CO_2 solvents. In the degradation process, the main amine component of the new solvent decomposes, producing formic acid and other organic acids. By comparing organic acid accumulation over time, we confirmed that the new solvent exhibits approximately one-third the organic acid accumulation rate of the current CO_2 solvent. We also confirmed that the new CO_2 solvent exhibits higher durability with a two-fifths rate of decrease in main amine concentration. In October 2023, the operating time of the CO_2 capture plant exceeded 5 000 hours, demonstrating the durability of the new CO_2 solvent.

When the waste incineration plant was shut down for a routine inspection in November 2023, the CO_2 capture plant was also shut down for approximately one month for a routine inspection. The durability test of the new CO_2 solvent then continued until the end of 2023 to verify commercial viability.

2.15 Commencement of Commercial Operation of Cirebon2 Coal-Fired Power Plant

1 000 MW Cirebon2 Coal-Fired Power Plant, Indonesia

Following the completion of construction in May 2023, the Cirebon2 Coal-Fired Power Plant commenced commercial operation.

Toshiba Energy Systems & Solutions Corporation supplied the equipment for the turbine islands. We achieved excellent turbine cycle efficiency and carbon emission reduction by employing cutting-edge technologies such as a turbine steam sealing system with a narrow gap clearance to reduce steam leakage, and a desuperheater to raise the final feedwater temperature.

The COVID-19 pandemic temporarily necessitated minimizing on-site staff, so we implemented thorough COVID-19 infection control measures on-site while providing online support, completing construction and plant commissioning with minimal impact on the schedule.

This project is the culmination of our standard model for 1 000 MW power plants, which has resulted in excellent quality and reliability thanks to thorough implementation of countermeasures for the issues that we faced during the engineering and commissioning phases of the previous project. Since the commencement of commercial operation, the Cirebon2 Coal-Fired Power Plant has continued to operate smoothly.

We will continue to contribute to the goal a carbon-neutral society by delivering high-quality, highly efficient, reliable power plants.

2.16 Completion of Replacement of Futtsu Thermal Power Station Unit 4-3 Gas Turbine

Source: GE Vernova, pic of 9HA Gas Turbine

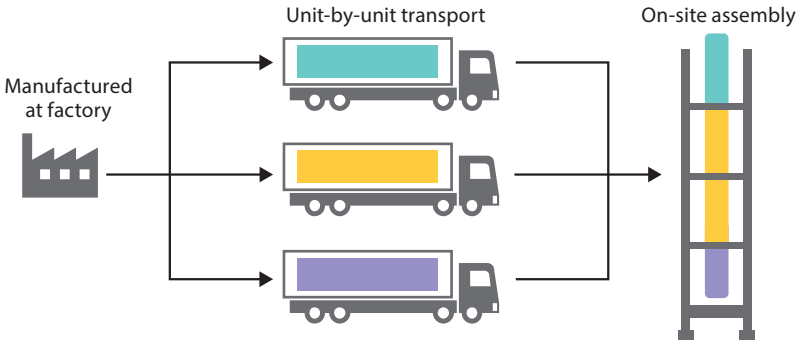
Installation of Unit 4-3 gas turbine at JERA Co., Inc. Futtsu Thermal Power Station Group 4

The JERA Co., Inc. Futtsu Thermal Power Station Group 4 consists of three combined-cycle units. Toshiba Energy Systems & Solutions Corporation has been involved in the Group 4 replacement project since 2016 and upgraded the gas turbines and auxiliary equipment of Units 4-1 and 4-2. We completed upgrading Unit 4-3, the last unit, in July 2023.

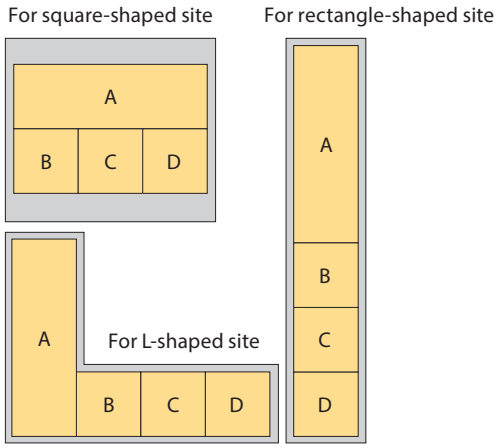
Because we lacked sufficient technical information about Unit 4-3, identifying unit conditions efficiently was the key to ensuring engineering reliability and maintaining the construction schedule. To compensate for the lack of information, we employed a 3D scanner to collect 3D data and simulated the entire engineering process to ensure that it would proceed smoothly. The data were helpful in identifying issues, improving construction methods, and optimizing engineering work. This process allowed us to complete the replacement of Unit 4-3 earlier than scheduled, contributing to a stable electricity supply in summer.

We will utilize the knowledge and expertise gained through this experience to upgrade and improve efficiency at major facilities of other power plants.

2.17 Modularized Carbon Capture System Designed for Easy Installation, Hook-up, and Integration



Modularized CO_2 capture system concept



Equipment layout according to shape of land

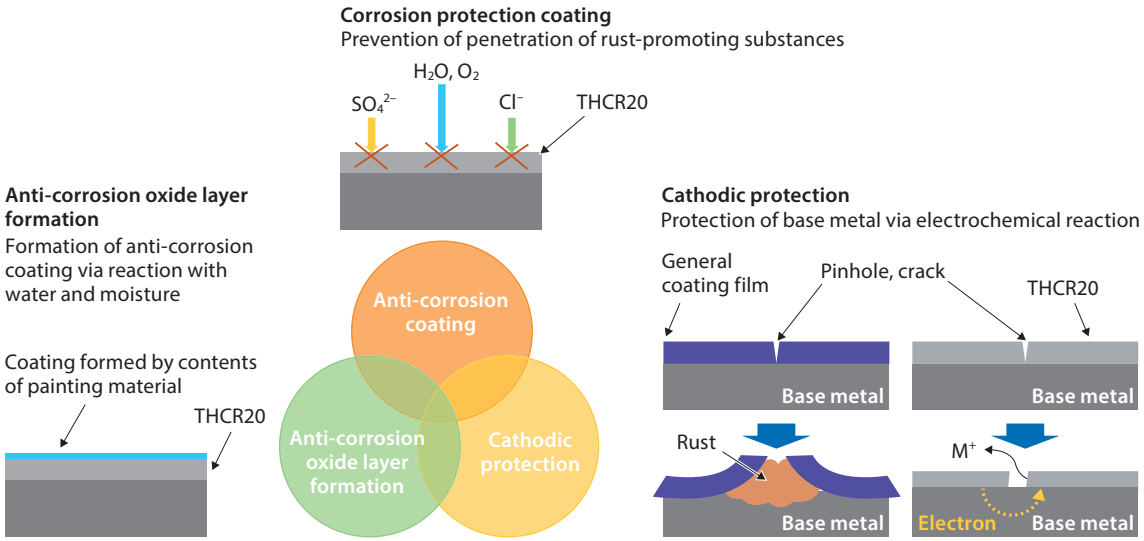
Carbon capture systems separate CO_2 from exhaust gas generated at power and industrial plants. Toshiba Energy Systems & Solutions Corporation has a track record of delivering carbon capture systems capable of capturing several kilograms to 600 tons of CO_2 per day to power generation and industrial sectors.

To further increase popularization of carbon capture, customer requirements for easy installation, hook-up, and integration must be met. With this in mind, we have developed a modularized carbon capture system that is preassembled as modular skids and units at the factory and optimized for road transportation.

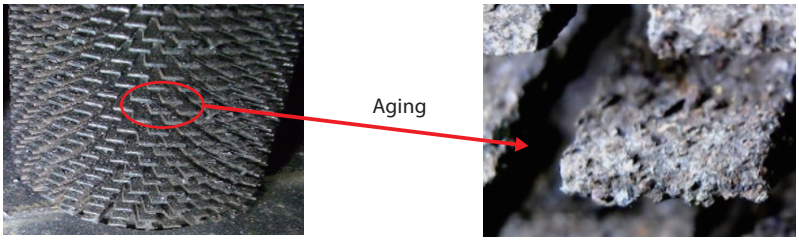
This system offers flexible installation to match the layout of the installation site. Design specifications are also standardized while providing various integration options according to customer requirements. The new carbon capture system therefore requires approximately 20% less capital cost than the previous model. The standardized design also helps optimize the construction process and improve quality control during installation.

We will continue to develop high-quality, low-cost products to contribute to the goal of carbon neutrality.

2.18 Anti-Rust Painting Technology for Heat Exchanger Tubes to Stabilize Operation and Prolong Life of Thermal Power Plants

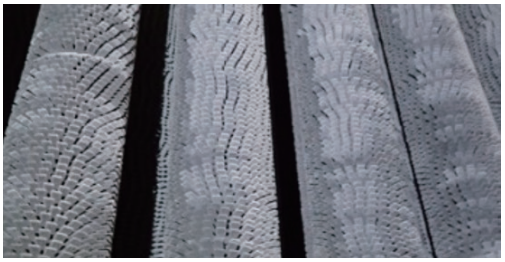


Anti-rust painting (THCR20) mechanism



Heat exchanger tubes (at time of manufacture)

Heat exchanger tubes (aged)



Heat exchanger tubes (1.5 years after anti-rust painting)

H_2O: water O_2: oxygen SO_4^{2-}: sulfate ion Cl^-: chlorine ion M^+: metal ion

Mechanism of anti-rust painting system and application to HRSG

Rust forms on the outer surfaces of fin-and-tube heat exchangers on heat recovery steam generators (HRSG) at gas turbine combined-cycle (GTCC) power plants due to corrosive substances in exhaust gas and condensation generated during plant operation.

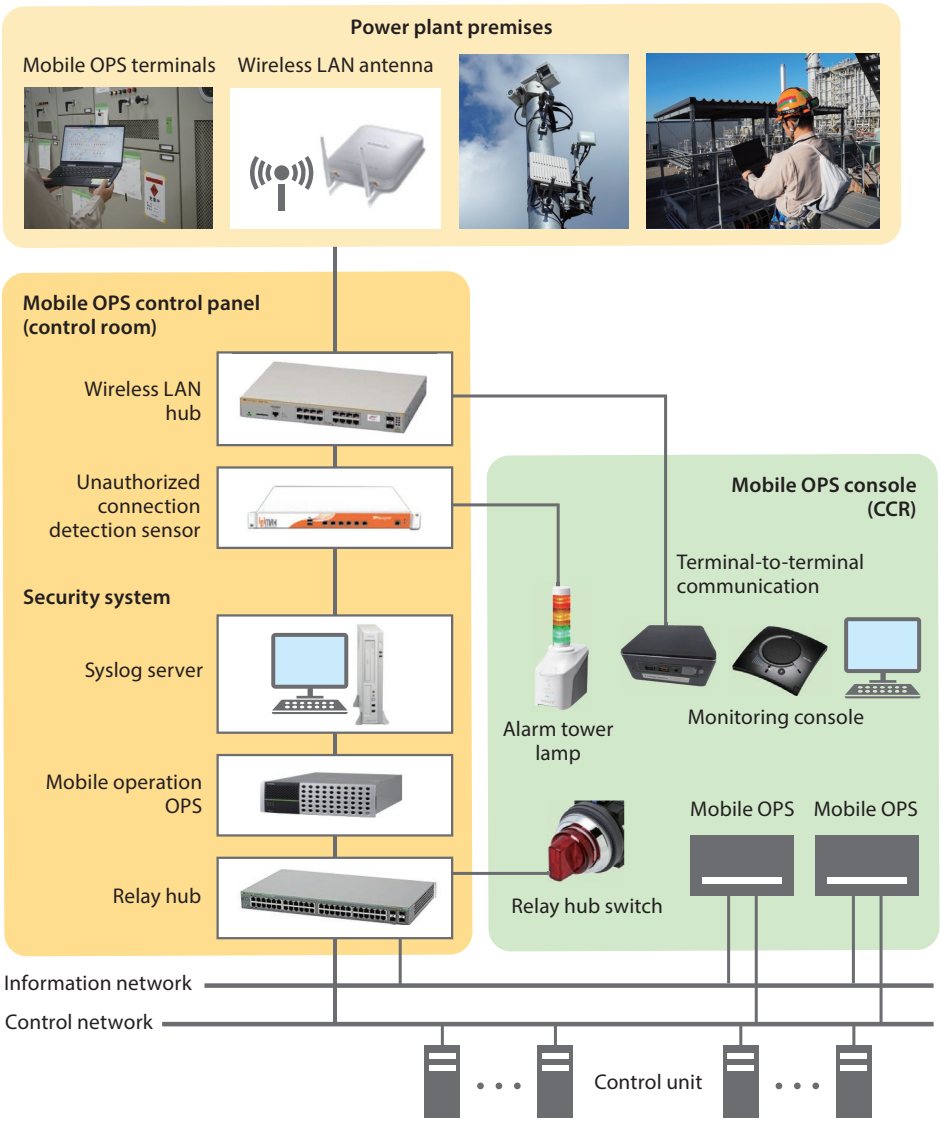
Operation of modern GTCC power plants involves frequent startup and shutdown cycles and is required to adapt to varying electricity demand. This greatly increases the risk of rust forming on the outer surfaces of fin-and-tube heat exchangers.

To prevent rust formation, Toshiba Energy Systems & Solutions Corporation has developed THCR20 rust-proof paint, which provides protection via (1) anti-corrosion oxide layer formation, (2) anti-corrosion coating, and (3) cathodic protection.

We coated the fin-and-tube heat exchanger of the HRSG at an actual GTCC power plant and confirmed after 1.5 years that THCR20 kept the painted surfaces clean and rust-free.

THCR20 can be used for both new and aging heat exchangers under extremely rust-prone conditions.

2.19 Distributed Control System for Thermal Power Plants Applying Mobile Operator Station



Overview of mobile operator station (OPS)

Thermal power plants are conventionally monitored and controlled from a central control room (CCR). Toshiba Energy Systems & Solutions Corporation has developed a mobile operator station (OPS), which constitutes part of a distributed control system (DCS) and allows real-time thermal power plant monitoring and operation not only from a CCR but also from a customer's office or anywhere on the plant premises.

The mobile OPS provides the following benefits:

(1) Decentralized, remote monitoring and operations make it possible to avoid closed, crowded, and confined spaces with poor ventilation and implement work style reforms.

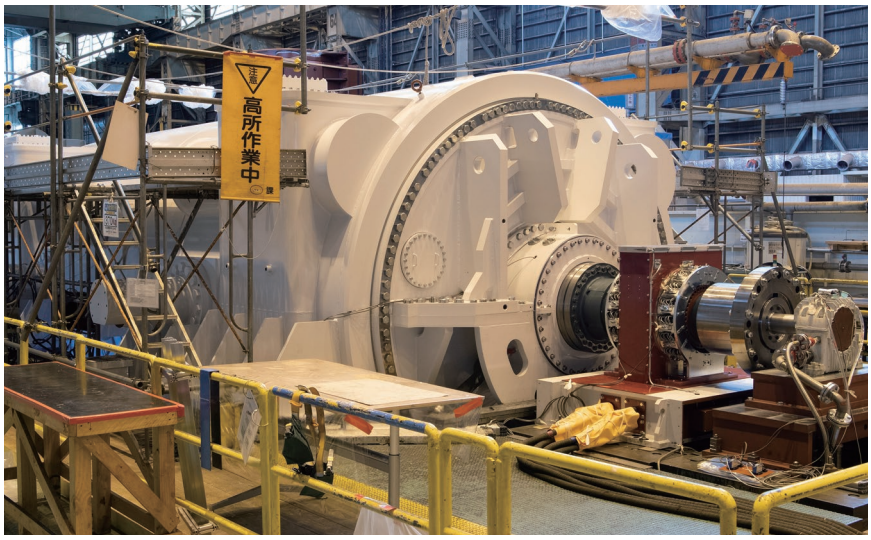
(2) The mobile OPS makes it possible to expand the scope of daily inspections that can be performed by small groups and thereby save on-site labor.
(3) The mobile OPS helps improve worker safety as it allows them to check a plant's operating conditions and detect hazards during an on-site inspection.
(4) In the event of a problem, experts can provide support remotely to reduce the time required to rectify it.

To make the DCS compliant with the Guidelines for Power Control System Security from the Japan Electric Association, we have also prepared an authentication server to prevent unauthorized operations from external terminals, a sensor to detect unauthorized connections, and a syslog server.

Furthermore, the mobile OPS notifies of abnormal network access via an alarm tower lamp installed in the CCR and provides a switch to shut off the network physically.

We plan to offer this system for new thermal power plants.

2.20 Development of 870 MVA Indirectly Hydrogen-Cooled Double-End-Drive Turbine Generator for Combined-Cycle Thermal Power Plant



870 MVA turbine generator for Goi Thermal Power Station Replacement (shop test)

Toshiba Energy Systems & Solutions Corporation has delivered an 870 MVA turbine generator to the Goi Thermal Power Station Replacement. It provides the world's largest capacity(*), when considering double-end drive or indirect hydrogen cooling. While the double-end drive system delivers superior operation, it was necessary to increase the collector shaft strength to transmit torque from steam turbine.

Designed based on the 650 MVA double-end-driven turbine generator delivered in 2017, the turbine generator incorporates a new collector shaft to increase torque transmission capacity. The turbine generator also provides insulation with high thermal conductivity and an optimized cooling system. These enhancements enable use of an indirect hydrogen cooling system to cool the stator windings for turbine generators in a capacity range that were previously water-cooled.

An electrical performance test confirmed that the turbine generator meets specifications and standards and provides a generator efficiency of 99.2%. We will now proceed with on-site installation and commissioning tests, followed by commencement of commercial operation.

(*) As of November 2023 (according to Toshiba Energy Systems & Solutions Corporation research)

2.21 Replacement of Secondary Excitation Device for Generator-Motor Completed at Electric Power Development Co., Ltd. Okukiyotsu No. 2 Power Station Unit 2

New power converter for secondary excitation device at Electric Power Development Co., Ltd. Okukiyotsu No. 2 Power Station

IEGT module of power converter for secondary excitation device

Unit 2 of the Okukiyotsu No. 2 Power Station, an adjustable-speed pumped storage unit, resumed commercial operation in October 2023 after replacing the secondary excitation device. This device uses AC current to excite the secondary winding of a generator-motor, making it possible to operate an adjustable-speed pumped storage system at an arbitrary speed within a predetermined range.

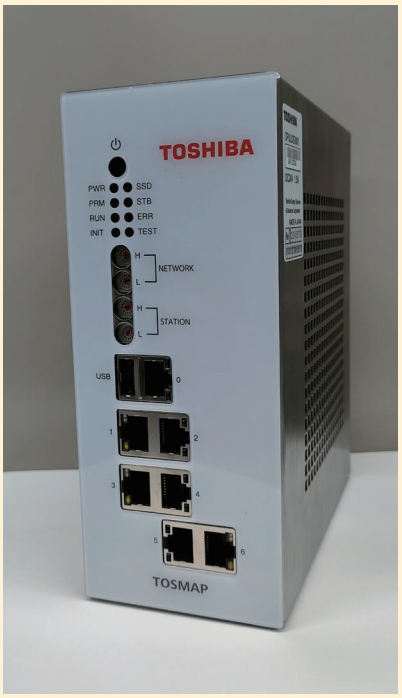
The previous secondary excitation device on Unit 2 had been running for more than 25 years since commercial operation began in 1996, requiring frequent inspections and parts replacement due to aging equipment. To improve the reliability and maintainability of the secondary excitation device, Toshiba Energy Systems & Solutions Corporation replaced the power converter, the adjustable-speed control device, and the unit operation control device.

The power converter incorporates power semiconductor devices to convert grid power (50 Hz) to DC power and then back to AC power at an arbitrary frequency. The previous power converter employed gate turn-off thyristor (GTO) as power semiconductor devices, whereas the new power converter uses injection-enhanced gate transistor (IEGT) and a modified main circuit to reduce the required number of parts. As a result, the new power converter experiences less power loss and is physically smaller than the previous device.

Our latest TOSMAP-LX series was selected for its adjustable-speed and unit operation control device. It consists of multiple module controllers and is smaller than conventional controllers, only requiring replacement of module controllers when a system upgrade is required or when controller failure occurs. Additionally, the enclosure and other parts except for module controllers are reusable. These features help improve manufacturability and maintainability of adjustable-speed and unit operation controllers.

Although semiconductor shortages occurred in the wake of the COVID-19 pandemic, we adjusted our factory and site schedules while working on procuring the necessary semiconductor devices. For preliminary verification, we utilized a real-time simulator specifically prepared for this project to minimize the need for on-site control parameter adjustment, which allowed us to complete the project on schedule.

2.22 Replacement of Monitoring and Control Systems at Kansai Electric Power Co., Inc. Okuyoshino Power Station



TOSMAP-LX controller and control room at The Kansai Electric Power Co., Inc. Okuyoshino Power Station

Kansai Electric Power Co., Inc. Okuyoshino Power Station resumed commercial operation in July 2023 following the replacement of monitoring and control systems. Located in Totsukawa Village, Yoshino, Nara Prefecture, Okuyoshino Power Station is a closed-loop pumped-storage hydroelectric power plant consisting of six pump-turbines and generator-motors with a total output of 1 206 MW.

Toshiba Energy Systems & Solutions supplied a common control system for all units and some unit control systems to prevent a stable power supply from being affected by the aging components that were previously replaced nearly 20 years ago, in 2004. The new control systems incorporate the latest fanless controllers in our TOSMAP-LX series.

The new control systems support the communication protocol specified by the International Electrotechnical Commission (IEC) 61850-7-410 standard, an open network standard in which information exchanges between different devices are modeled as logical nodes for protection, control, measurement, and other functions. While the IEC 61850 standards have been widely used for substation applications, they are also becoming popular for hydroelectric power plants.

In this project, only some unit controllers were replaced, so old and new networks coexist. The new control system is designed to minimize modifications required for future replacement. We also installed operator terminals in the control system network so that operating status can be checked simultaneously to facilitate on-site testing and enhance maintenance efficiency.

2.23 Commencement of Commercial Operation of Final Unit at Hubei Xinji Hydropower Plant, China

Hubei Xinji Hydropower Plant, China

The final unit (Unit 4) of the Hubei Xinji Hydropower Plant (30 MW×4) commenced commercial operation on April 13, 2024. Toshiba Hydro Power Corporation (Hangzhou) Co., Ltd. (THPC) received a contract for this project in December 2020. THPC designed and manufactured the turbine generator for Unit 4 while Toshiba Energy Systems & Solutions Corporation was responsible for hydraulic turbine performance development and model testing. Because we have extensive experience in bulb turbine development and possess model data for similar turbines, we were able to meet the guaranteed performance levels in a short period of time, contributing to shorter delivery lead time.

This plant has one of the largest bulb turbine generators in China and has a water turbine runner with an outer diameter of 6.9 m and a generator rotor with an outer diameter of approximately 7.1 m. The model turbine also ranks among the largest bulb turbine generators in the world. Furthermore, the hydraulic turbine hatch is electrically operated to improve maintainability while an electric elevator is used to access the inside of the turbine generator pit.

The turbine and generator ratings are as follows:

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

Generator: 33.333 MVA, 10.5 kV, 50 Hz, 0.95 pf, 78.95 min^{-1}

2.24 Completion of Phase 1 of SCADA and Control Systems Renovation for Nam Ngum 2 Hydroelectric Power Station Unit 3 in Laos

Control panel for Nam Ngum 2 Hydroelectric Power Station Unit 3, Laos

Toshiba Energy Systems & Solutions Corporation completed Phase 1 of renovations on the supervisory control and data acquisition (SCADA) and control systems for Nam Ngum 2 Hydroelectric Power Station Unit 3, which resumed commercial operation in December 2023.

In 2010, we supplied the original hydraulic turbine, hydraulic turbine generator, and SCADA and control systems for all three units at Nam Ngum 2 Hydroelectric Power Station. It became necessary, however, to replace the control systems with the latest version due to the discontinuation of the original control system.

Because the customer required that the shutdown period be limited to about 50 days per year, we planned to renovate one unit per year. The renovation of Unit 3 was completed in 43 days, and renovations of Units 1 and 2 are scheduled for 2024 and 2025, respectively.

For this project, we developed an integrated system to control all the units, which incorporates our latest TOSMAP-LX controller to connect the SCADA, a programmable logic controller (PLC), and governor functions via LAN. With our engineering support, Toshiba JSW Power Systems Private Limited engaged in designing, procurement, manufacturing, fieldwork, and commissioning testing, and dispatched the site manager and engineers to Nam Ngum 2 Hydroelectric Power Station.

We will continue working together on renovating the remaining units.

2.25 Commencement of Operation of Ehime Grid Control Center at Shikoku Electric Power Transmission & Distribution Co., Inc.

Control room at Shikoku Electric Power Transmission & Distribution Co., Inc. Ehime Grid Control Center

Shikoku Electric Power Transmission and Distribution Co., Ltd. is replacing the aging control systems at its grid control centers. For the first step of the project, Toshiba Energy Systems & Solutions Corporation renovated the Ehime Grid Control Center, which is now operating, consolidating functionality of the Toyo Grid Control Center.

We have also built a wide area network connecting the Ehime Grid Control Center and the Kochi Grid Control Center which will start operation in March 2024. These grid control centers will serve as mutual backups in the event of a large-scale disaster, enhancing utility resilience in the Shikoku region.

The new control system also provides enhanced support for increasingly complicated grid operation. For example, it incorporates a function to quickly assess the adequacy of a grid-switching procedure based on the current grid status. This allows the grid-switching procedure to be handled by a single person, whereas it previously required two.

2.26 Certification of 765 kV Transformer Protection Relay for Korea Electric Power Corporation

GR-200 Series 765 kV transformer protection relay

Toshiba Energy Systems & Solutions Corporation previously delivered GR-200 Series relays for the protection of transmission lines, busbars, transformers, etc. to Korea Electric Power Corporation (KEPCO), except for the protection of 765 kV-class ultrahigh-voltage (UHV) transformers to which the preceding GR-100 Series was applied. Because we are discontinuing the GR-100 Series, we acquired KEPCO certification for UHV application of the GR-200 Series in 2023.

Certification testing was conducted at two sites. The Korea Electrotechnology Research Institute (KERI) tested the mechanical and electrical characteristics of the relay as well as electromagnetic susceptibility (EMS) and other environmental performance metrics. The protection function of the relay was tested at our Fuchu Complex in the presence of KEPCO personnel using a real-time digital simulator to simulate the UHV transformer under actual operating conditions. The GR-200 Series showed satisfactory test results and received KEPCO certification in October 2023.

2.27 TOSHIBA SPINEX for Energy Standard Services

Toshiba Energy Systems & Solutions Corporation offers TOSHIBA SPINEX for Energy, a collection of digital services to solve energy-related issues through co-creation, providing a lineup of software components incorporating the Toshiba Group's expertise. We aim to swiftly create solutions tailored to the needs of each customer. To that end, we have launched several standard services, including the following four, which package together several software components, considering common use cases in the energy sector:

(1) Remote monitoring service

This service enables remote monitoring simply by placing edge devices at remote sites. It enables collection of temperature, humidity, image, and other data and facilitates data utilization.

(2) Inspection rounds service

This service streamlines daily inspection rounds using mobile devices and allows inspection data to be utilized for analysis.

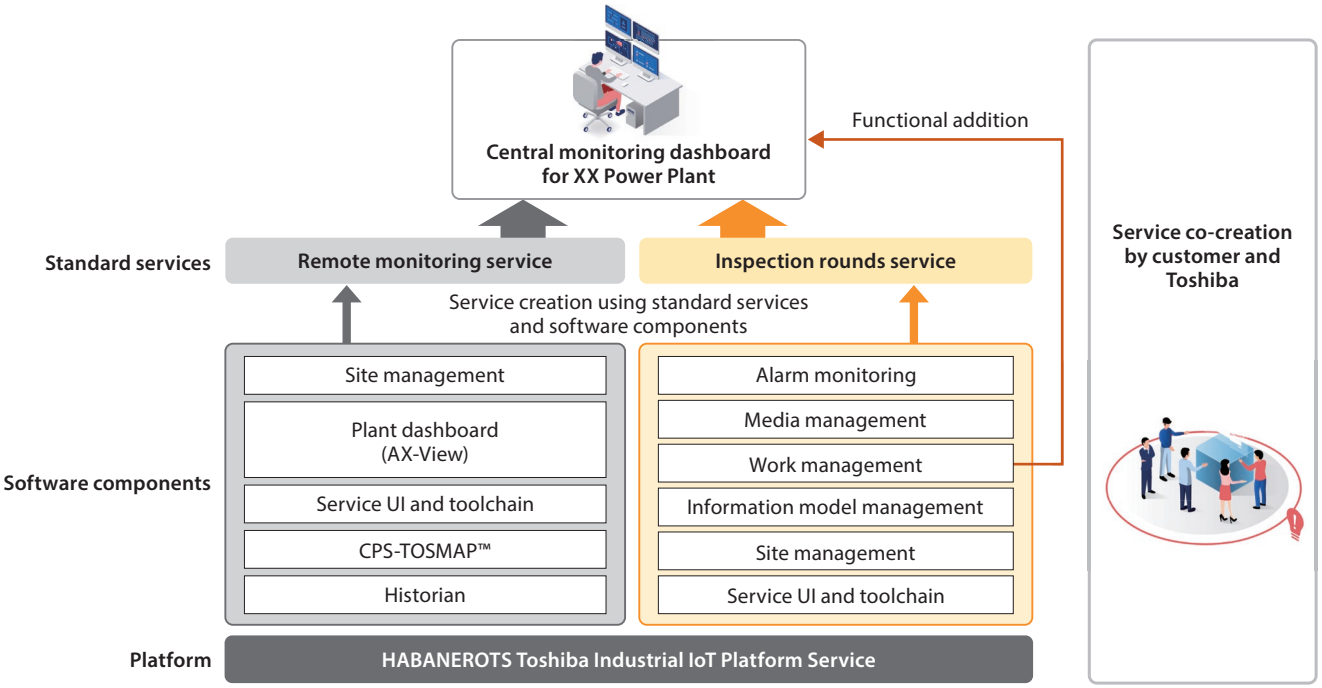
(3) AI-based inspection image analysis service

This service detects anomalies automatically, facilitating inspections by analyzing captured images using AI. It helps identify anomalies that may be missed in visual inspections. This makes it possible to avoid dependence on individual expertise, enabling less experienced personnel to perform inspections with confidence.

(4) Incident management service

This service defines the steps necessary to respond to an incident as tasks and supports the entire plan-do-check-act cycle. Digital management of this process streamlines administrative tasks, information sharing, and other activities.

These standard services can be applied to a wide range of use cases such as centralized remote monitoring and operation and maintenance (O&M) support. We aim to co-create solutions with customers using TOSHIBA SPINEX for Energy that contribute to resolving issues.



UI: user interface

Services provision process using TOSHIBA SPINEX for Energy

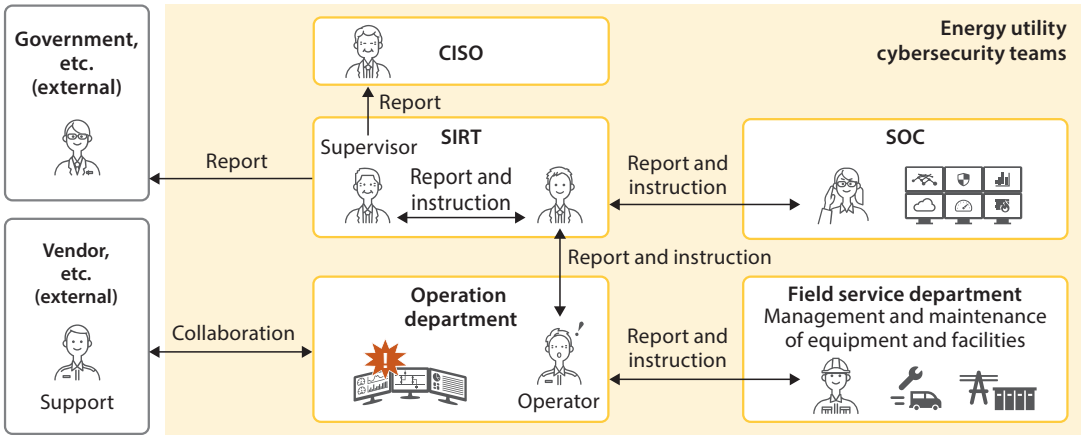
Standard services described herein

Standard services	**Remote monitoring service**	**Inspection rounds service**	**AI-based inspection image analysis service**	**Incident response service**
	EtaPRO® VirtualPlant Real-time monitoring and diagnosis of plant efficiency	**EtaPRO® APR Early failure detection via operation data**	**Topology optimization tool**	**Simulation tool for CO_2 visualization**
Software components	Inspection rounds support: Work management; Media management; Inspection support using drones or robots; Meter reading recognition; 360-degree-view inspection recording; Event management	Job management: People counting; Personal authentication; Motion recognition; Document management; Web chat; Task management; Alarm monitoring	Prediction and diagnosis: Weather forecasting; Anomaly detection (two-stage AE); Specific anomaly detection (cracks, rust); General anomaly detection; Abnormal waveform detection (OCLTS); Depth sensing; Battery degradation diagnosis	Asset management: Information model management; Site management; Asset management; Historian	UI framework: Plant dashboard (AX-View); Service UI and toolchain Edge: CPS-TOSMAP™; LPIS™; Multi-GW agent; Odor sensor; Millimeter-wave radar (vibration visualization)

CO_2: carbon dioxide AE: autoencorder OCLTS: one-class learning time-series shapelets GW: Gateway

Lineup of services provided by TOSHIBA SPINEX for Energy

2.28 Cybersecurity Training Service for Energy Utilities



CISO: Chief Information Security Officer
SIRT: Security Incident Response Team
SOC: Security Operation Center

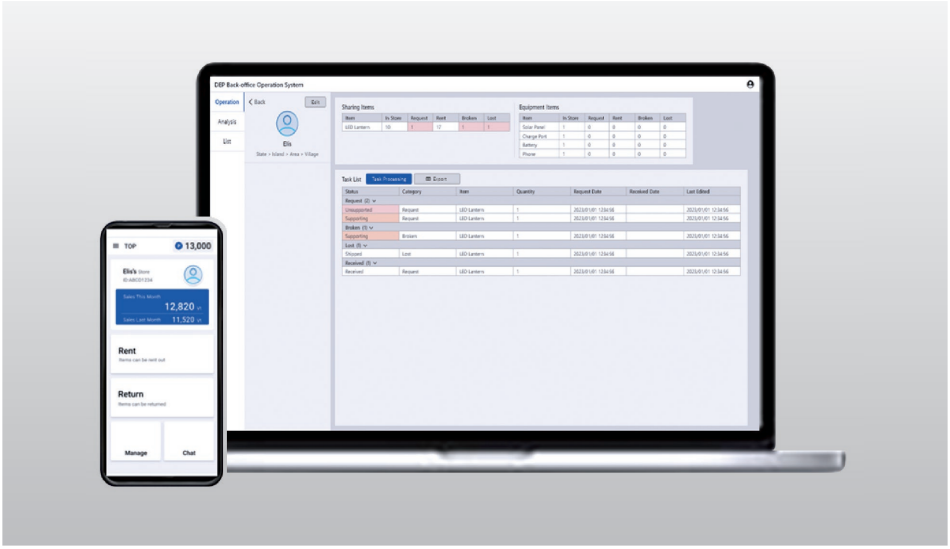
Cybersecurity training system for simulating organizational responses in event of cyberattack

As cyber threats to critical infrastructure escalate, the world recognizes the urgency to prepare for cybersecurity incidents. With this in mind, Toshiba Energy Systems & Solutions Corporation has developed a cybersecurity training service for power transmission and distribution operators by leveraging its extensive expertise and experience with energy control systems.

To provide a realistic environment, the new service employs a power grid operation training simulator capable of simulating electrical events and grid control equipment responses. The simulator therefore allows trainees to experience and respond to simulated cyberattacks. In addition, the new service provides hands-on role-playing exercises spanning different organizations—for example, a grid operator, a security operation center (SOC), and a security incident response team (SIRT). Such a setup facilitates training to acquire practical skills in responding to cybersecurity incidents promptly and systematically.

We are currently expanding training services to include thermal, nuclear, and other energy utilities. The next step is to support a wide range of training scenarios tailored to the issues and needs of specific infrastructure operators while contributing to human resource development. Furthermore, we aspire to contribute to sustainable personnel development in non-energy critical infrastructure sectors to help enhance their security expertise and incident response capabilities.

2.29 Shared Service Payment System to Enable Use of Electrical Products in Areas Without Power



Payment system for sharing services in DEP

An estimated 750 million people around the world have no access to electricity. In the Republic of Vanuatu and other Pacific island nations, dispersed populations and low income levels make power line electrification economically unviable, therefore inhibiting progress.

To help resolve the situation, Toshiba Energy Systems & Solutions Corporation has launched a sharing service project (DEP: Delighting Everyone Project), involving local retailers, which is designed to enable the use of electrical products such as solar panels, batteries, and other power generation and charging equipment, as well as rechargeable light-emitting diode (LED) lanterns.

The products offered through this service are generally equipped with locks, which are unlocked using a payment system that we have developed along with loyalty points. Loyalty points are sent to the payment system via a back-office system based on remittance information from retailers, authenticating the use of products. The products can then be unlocked via Bluetooth® Low Energy communication by pressing the Unlock button on the payment system.

This project will help build infrastructure that can be used by everyone in areas without electricity.