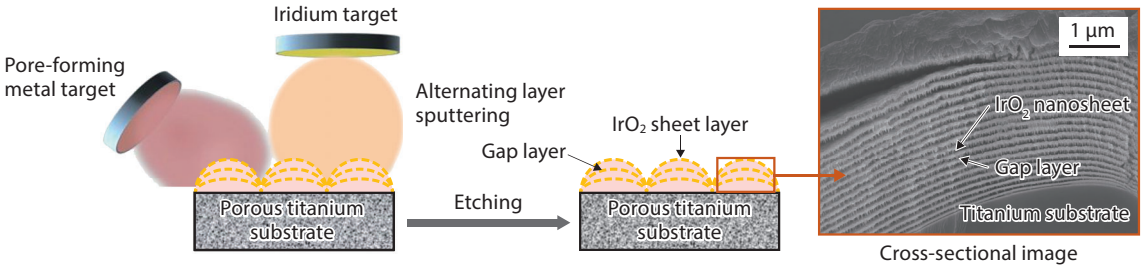
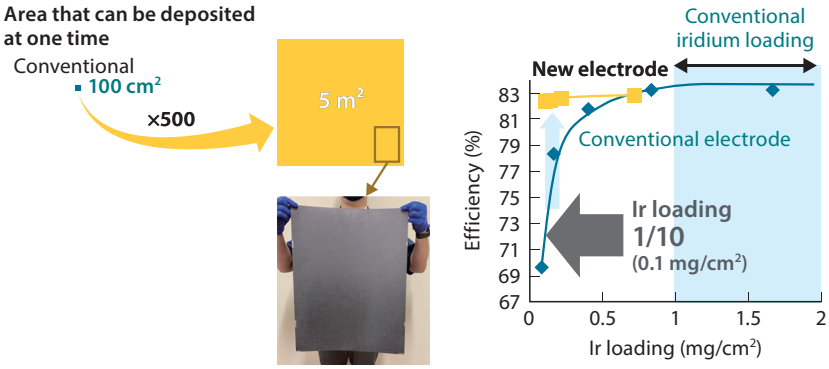
2. Energy Systems

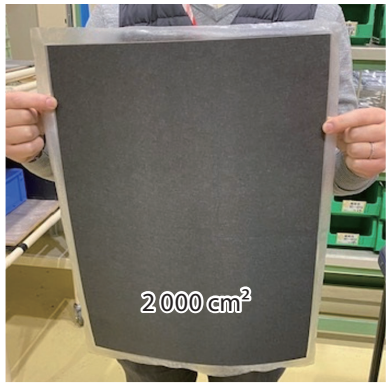
2.1 Large-Scale Membrane Electrode Assembly with Ultralow Iridium Catalyst for Hydrogen Production



Processes for manufacturing electrode for polymer electrolyte membrane (PEM) electrolysis developed by Toshiba Corporation



Performance of new electrode using a small amount of iridium and electrode with area of 5 m²



Membrane electrode assembly (MEA) with area of 2 000 cm²

Expectations continue to grow for power-to-gas (P2G), a technology that uses surplus energy from weather-dependent renewable power generation to produce hydrogen through water electrolysis. Although various types of water electrolysis exist, polymer electrolyte membrane (PEM) water electrolysis is attracting attention, as PEMs are highly durable and can handle power fluctuations.

However, the catalyst for PEM water electrolysis is made of iridium (Ir), one of the rarest precious metals, with a global annual production of only 7 to 10 tons. In 2017, the Toshiba Group developed a unique Ir oxide (IrO_2) nanosheet laminated catalyst using a sputtering method, being the first in the world to succeed in reducing the amount of Ir required to 1/10th of a conventional catalyst(*).

We have now developed new technology capable of depositing the IrO_2 nanosheet laminated catalyst over a maximum area of 5 m² at a time, making it possible to produce a large membrane electrode assembly (MEA) with an area of 0.2 m².

We will leverage the new technology to promote practical application of P2G and thereby contribute to achieving a carbon-neutral society.

(*) As of November 2017 (according to Toshiba Corporation research)

2.2 Demand Response Demonstration Tests of FH2R Hydrogen Production Facility Using Renewable Energy for Reserve Market

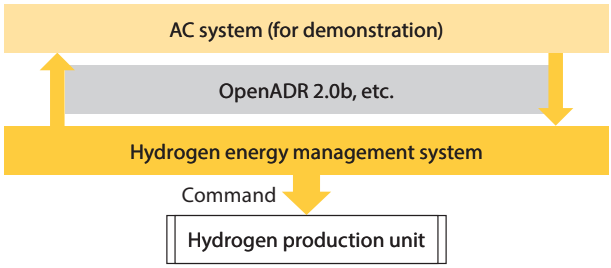
Toshiba Energy Systems & Solutions Corporation has developed and demonstrated a hydrogen production facility at the Fukushima Hydrogen Energy Research Field (FH2R) equipped with a 10 MW-class hydrogen production unit and a 20 MW solar photovoltaic (PV) power generation facility in Namie, Fukushima Prefecture. In this project, we aimed to establish two business models to achieve practical application of a large-scale P2G system: a business model for hydrogen utilization to contribute to grid balancing and a business model for hydrogen sales to produce hydrogen according to demand. To date, we have developed a hydrogen energy management system with two functions: (1) a planning function to minimize operating costs while meeting the requirements for both grid balancing and hydrogen demand and (2) a coordinated control function to control hydrogen production according to commands from the planning function based on constantly changing output from the PV power generation facility.

In 2022, we added a function related to reverse power flow to enable sales of PV electricity under optimal conditions. The specification for communication between an aggregation coordinator system and a hydrogen energy management system was upgraded to comply with version 2.0b of the Open Automated Demand Response (OpenADR) standard, a standard that stipulates the requirements for reserve market operations.

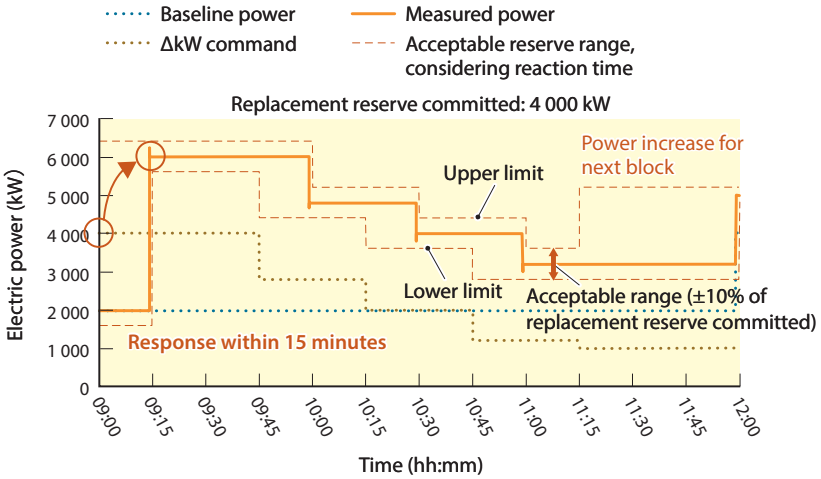
We applied the new functions to a hydrogen production unit and other systems and conducted a demonstration for the reserve market. We performed demand response (DR) tests for frequency restoration reserve (FRR), replacement reserve (RR), and replacement reserve for feed-in tariff (RR-FIT) and confirmed that the newly developed functions provide responsiveness equivalent to the requirements for products intended for reserve market applications.

We will continue to further improve and scale up the P2G system. This work was undertaken based on the results obtained from the Development of Technologies for Realizing a Hydrogen Society project (JPNP14026) commissioned by the New Energy and Industrial Technology Development Organization (NEDO) of Japan.

Fukushima Hydrogen Energy Research Field (FH2R)



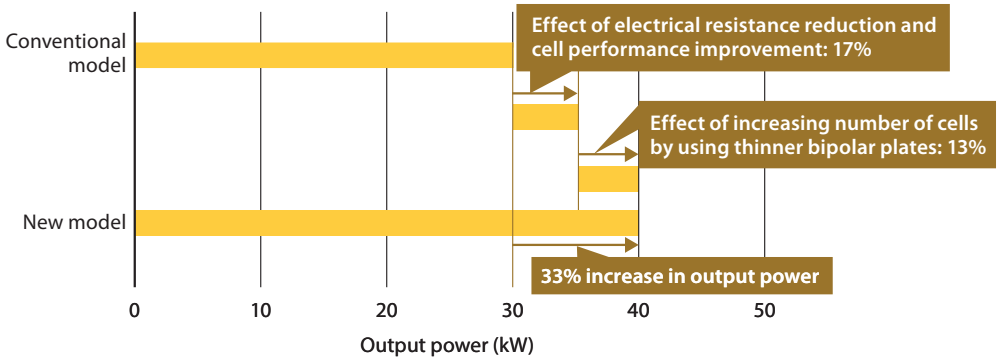
Hydrogen energy management system in conjunction with aggregation coordinator (AC) system



Results of demand response (DR) demonstration tests on replacement reserves

2.3 Development of Fuel Cell Stack with High Power Density

40 kW fuel cell stack for heavy-duty vehicles



Comparison of power density of conventional and new fuel cell stacks

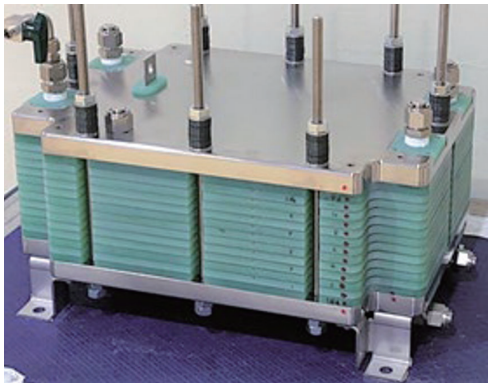
Due to their excellent durability, fuel cell stacks from Toshiba Energy Systems & Solutions Corporation are expected to be applied to buses, trucks, and other heavy-duty vehicles (HDVs) with long hours of operation. Fuel cell stacks for HDVs are required to be small in size to achieve high power density while maintaining high durability.

Under these circumstances, we have developed a new fuel cell stack by reducing the size of its components and improving the power generation performance of the fuel cells. Specifically, we have reduced the thickness of the bipolar plate adopting a porous material based on our proprietary technology, without compromising its humidification performance. The new bipolar plate is 12% thinner than the conventional component, making it possible to enhance the output density because of a 13% increase in the number of cells that can be stacked in the same volume, while reducing electrical resistance. We have also improved the cell performance by using a highly active catalyst and a thin electrolyte membrane. As a result, the new fuel cell stack provides 33% higher power density than the conventional model, achieving 40 kW power output.

The new 40 kW fuel cell stack has been shipped to Impact Clean Power Technology in Poland, a battery system manufacturer, which is currently testing and verifying the fuel cell stack for application to buses.

Our next step is to further expand the applications of the fuel cell stack, targeting hydrogen value chains in Europe and elsewhere.

2.4 Performance Verification of CO_2 Electrolysis Short Stack and Basic Design of C2One™ CO_2 Electrolyzer



10-cell CO_2 electrolysis short stack

C2One™ CO_2 electrolyzer

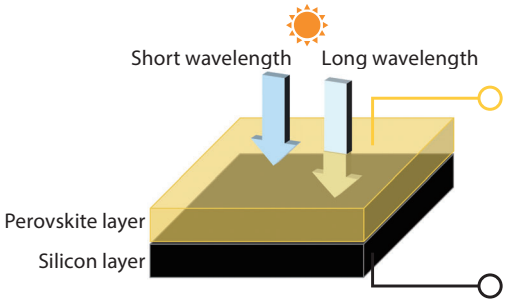
Leveraging its electrolysis technology to convert carbon dioxide (CO_2) to carbon monoxide (CO) with a high level of efficiency, Toshiba Energy Systems & Solutions Corporation has developed the C2One™ CO_2 electrolyzer with the goal of completing a prototype in 2023. Consisting of multiple electrolysis stacks containing 100 to 200 single cells with an electrode area of 400 cm^2, the C2One™ is designed to produce approximately 150 tons of CO per year.

We have fabricated a short stack of 10 single cells that are the same size as an actual unit and built an electrochemical evaluation facility to evaluate electrolysis performance. In electrolysis tests using this short stack, we verified that CO can be produced with a high level of Faraday efficiency equivalent to that of a small cell.

We have also created a basic design for the C2One™ based on the results of the electrolysis short stack performance verification. The basic design process is complete, including a study of heat and mass balance, process system design, equipment selection, electrical system design, control logic design, equipment layout, three-dimensional (3D) model design, and safety review.

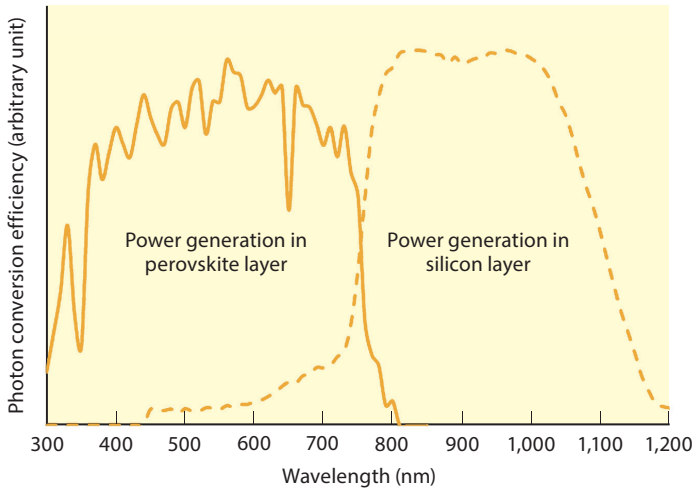
Part of the results were obtained through the Project for the Establishment of a Circular Carbon Economy Model Through Carbon Dioxide Recycling commissioned by the Ministry of the Environment (MOE) of Japan.

2.5 Development of Perovskite/Silicon Tandem Solar Cells



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

Perovskite solar cell waterproofing using a double glass encapsulation



Results of demonstration of power generation

Renewable energy will play an important role in achieving carbon neutrality by 2050. The development of innovative solar cells is needed more than ever before to establish renewable energy as the main source of electricity. To reduce the levelized cost of electricity (LCOE) of renewable energy and thereby expand its use, it is essential to increase the power conversion efficiency (PCE) and lifetime of solar cells.

With this in mind, Toshiba Energy Systems & Solutions Corporation is developing two-terminal type perovskite/silicon tandem solar cells as a green energy solution for the future. A tandem solar cell is composed of stacked multiple photovoltaic materials, each of which generates electricity from sunlight. The perovskite/silicon tandem solar cell that we have developed in collaboration with The University of Electro-Communications and the National Institute of Advanced Industrial Science and Technology (AIST) of Japan has achieved a PCE of 25.5%.

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We improved the properties of each material and optimized the overall cell design to balance the amounts of electricity generated by the perovskite and silicon layers. The perovskite/silicon tandem has achieved an 8.2% point increase in PCE, the world's highest-class increase(*), from the 17.3% PCE of the silicon layer.

The new two-terminal perovskite/silicon tandem solar cell can be deployed in existing solar parks because it can operate with the same electric system as for silicon solar cells. Encapsulated in a double glass structure, the tandem solar cell is also expected to have a long life. Estimations show that our target for power generation cost in Japan (7 yen/kWh) can be met if we achieve a PCE of 27 % and a product service life of 30 years.

We plan on accelerating the development of tandem solar cells to facilitate their commercialization and thereby contribute to carbon neutrality.

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

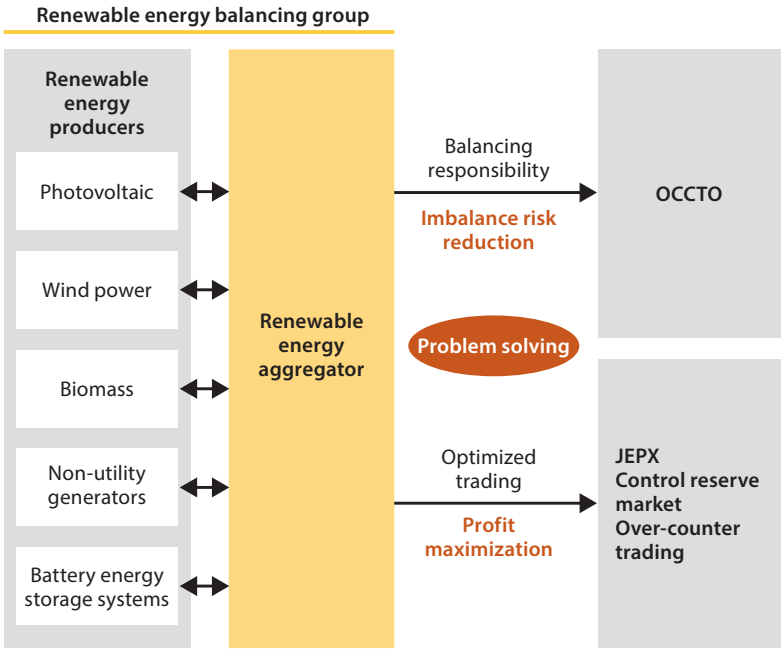
2.6 Development of a Renewable Energy Balancing Group System

In Japan, a feed-in premium (FIP) system started in April 2022 to establish renewable energy as the main source of electricity. Under the FIP system, renewable energy producers are required to sell their electricity on the trading market and maintain a planned electricity generation cycle. However, accurately forecasting renewable energy is difficult because generation fluctuates according to weather conditions. Therefore, aggregators are expected to provide renewable energy forecasting, sales, and balancing services for producers.

With these circumstances in mind, Toshiba Energy Systems & Solutions Corporation has developed REBSet™, a system that supports aggregators in performing tasks for operation of renewable energy balancing groups. It provides the following functions:

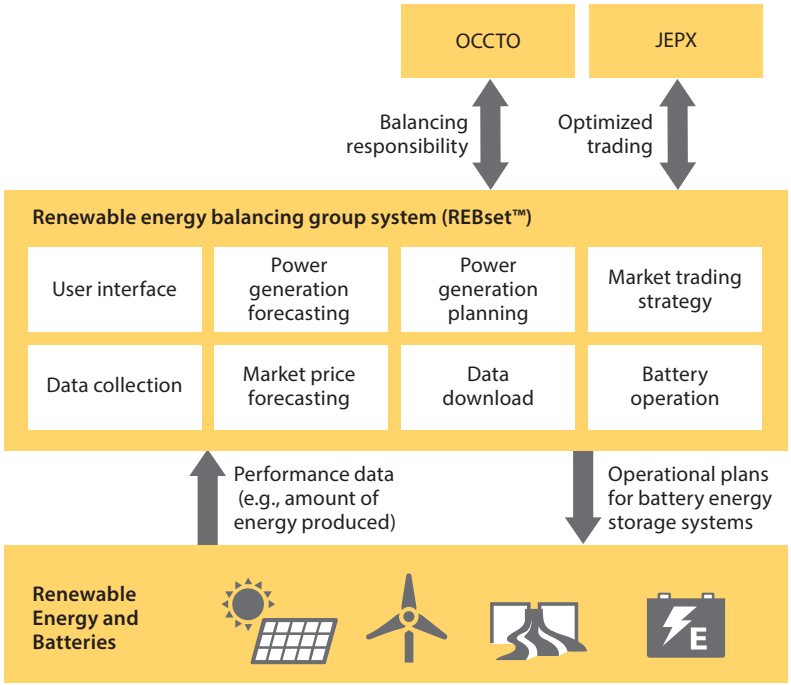
- Renewable energy forecasting: Accurate renewable energy output forecasting based on weather forecast data (e.g., solar radiation, temperature) derived from our unique numerical weather prediction model
- Artificial intelligence (AI) for creating market trading strategies: Optimization of trading plans considering the risk of energy imbalance based on past forecasts and actual outcomes
- Battery energy storage system control: Creation of operational plans for a battery energy storage system to minimize energy imbalances or maximize market trading revenues

We evaluated these functions through an FY2022 government-subsidized renewable energy aggregation project, confirming its benefits. In addition, we launched a renewable energy aggregation service using REBSet™ in May 2022. We will continually improve the usability of REBSet™ to further contribute to the spread of renewable energy.



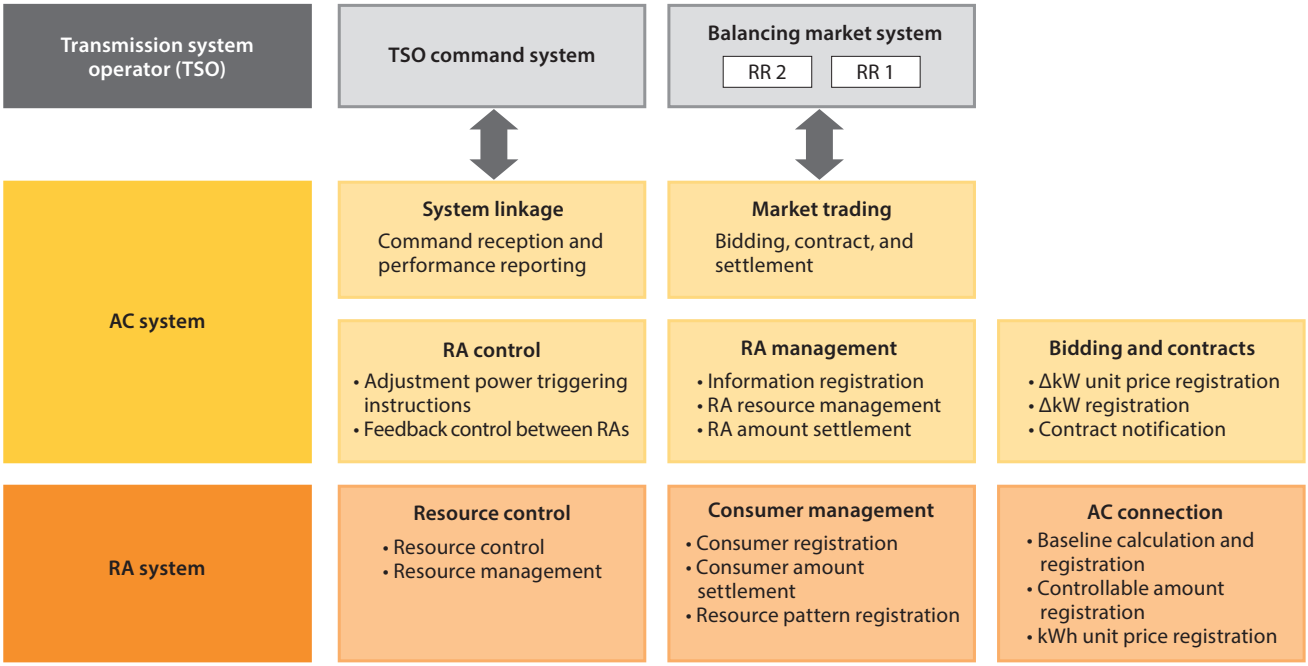
OCCTO: Organization for Cross-regional Coordination of Transmission Operators, Japan
JEPX: Japan Electric Power Exchange

Renewable energy aggregator positioning and functions



Overview of renewable energy balancing group system

2.7 Aggregation Coordinator and Resource Aggregator Systems for Balancing Market



RR: replacement reserve. Frequency Containment (FCR) and Synchronized Frequency Restoration Reserve (S-FRR) are to be addressed.

Structure of aggregation coordinator (AC) and resource aggregator (RA) systems for balancing markets

Beginning in FY2017, transmission system operators (TSOs) in Japan participated in public tender procedures held in each geographical area to buy electricity required for grid frequency control and supply-demand balancing. However, a balancing market was established in April 2021 to improve the efficiency of supply-demand balancing.

In the balancing market, TSOs in each geographical area invite bids for the purchase of electricity from providers that possess electricity generators and other resources to control their own electricity demand. Therefore, bidders need a system to access the balancing market and manage their demand control resources.

Since 2017, Toshiba Energy Systems & Solutions Corporation has been operating as a negawatt aggregator, providing a service that allows TSOs to communicate demand-shaving requirements to and purchase reserve electricity from consumers. We have now developed aggregation coordinator (AC) and resource aggregator (RA) systems, referred to collectively as ACRA systems, by adding bidding and other functions to this service.

The AC system provides functions for receiving commands from the TSO command system, transmitting performance data, offering and accepting bids for reserve electricity in the balancing market, instructing the RA system to activate demand-supply balancing, and settling payment. The RA system provides functions for the display of resource control results, baseline calculation, unit price registration, consumer payment, and resource management. Available in

the cloud as a software-as-a-service (SaaS), the ACRA systems allow flexible enhancement of their functions; for example, to improve usability and adapt to legal changes.

Our next step is to upgrade the ACRA systems to support the requirements for the primary and secondary reserve markets that will be launched in FY2024 as well as a function for forecasting prices in the balancing market.

2.8 Commencement of Commercial Operations at the Chubu Electric Power Co., Inc. Kuze Hydroelectric Power Station

Hydraulic turbine generators at the Chubu Electric Power Co., Inc. Kuze Hydroelectric Power Station

Hydraulic turbine

In July 2022, Chubu Electric Power Co., Inc. commenced commercial operations at the Kuze Hydroelectric Power Station following the replacement of all generating equipment. Located in Ibi District, Gifu Prefecture, the Kuze Hydroelectric Power Station consists of two units which generate 17,000 kW of electricity by drawing water from the Ibi River.

This power station was seriously damaged by flooding due to torrential rain in July 2018 causing the Ibi River to overflow, resulting in turbulent sediment-laden water flowing into the plant. After the flood, Toshiba Energy Systems & Solutions Corporation received an urgent request from Chubu Electric Power Co., Inc. to replace the damaged electric equipment thanks to our reputation for short delivery times.

We designed a hydraulic turbine with the T-Blade™ runner based on a similar model. Because the draft tubes of the new turbine have a different shape than those of the base model, we performed a computational fluid dynamics (CFD) analysis to achieve a maximum output of 100 kW per unit at the same flow rate as previously without compromising delivery time.

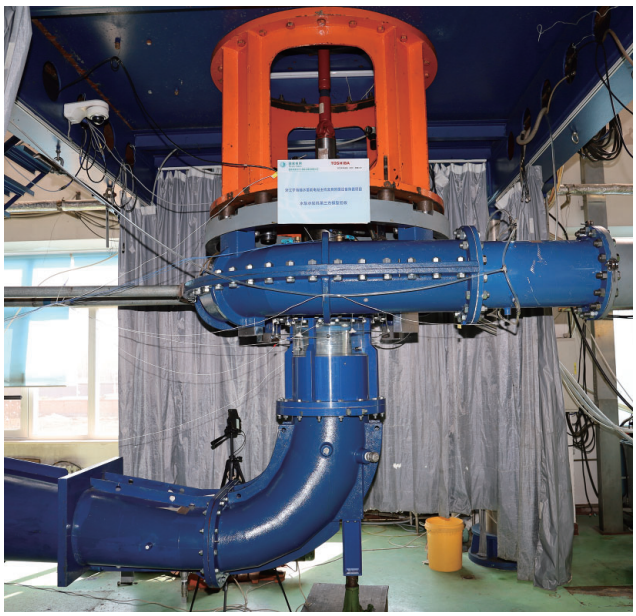
The new turbine is structured in such a manner that it can be disassembled and removed from the turbine pit walkway without disassembling the generator even in the event of turbine room flooding. In addition, the new turbine eliminates the need for hydraulic oil and related maintenance as it utilizes electric servo motors for the guide vane and the inlet valve, and air-cooled bearings for the turbine and the generator.

The monitoring system consists of a slave server at the power station and a master server at the management center. To facilitate maintenance, the slave server sends the monitored and measured data to the master server for data aggregation and analysis. Furthermore, we plan on connecting the slave servers of several power stations to the monitoring system for greater operating convenience at the management center.

The ratings of the turbines and the generators are as follows:

- Turbines: 9 100 kW, 34.62 m, 240 min^{-1}
- Generators: 10 000 kVA, 6.6 kV, 60 Hz, power factor = 0.9

2.9 Completion of Model Acceptance Test for Ninghai Pumped-Storage Power Station in China and Shipment of Draft Tube for Unit 1



Model acceptance test equipment for Ninghai Pumped-Storage Power Station, China

Shipment of draft tube for Unit 1

In March 2022, Toshiba Energy Systems & Solutions Corporation conducted an acceptance test of the pump-turbine model for the Ninghai Pumped-Storage Power Station with the customer observing. Conducted at the China Institute of Water Resources and Hydropower Research (IWHR), a third-party organization, the acceptance test confirmed that the pump-turbine model satisfies efficiency, cavitation, water pressure pulsation, and other requirements.

Toshiba Hydro Power (Hangzhou) Co., Ltd. (THPC) received an order for the project at the Ninghai Pumped-Storage Power Station in February 2021, which consisted of four 350 MW units providing a total output of 1 400 MW, the maximum capacity among any power station undertaken by THPC. In August 2022, THPC shipped the draft tube for the first unit, the first main part of the pump-turbine, to the Ninghai Pumped-Storage Power Station located 220 km southeast of Hangzhou, the capital of Zhejiang Province.

This is the second pumped-storage project in China for THPC, following the Qingyuan Pumped Storage Power Plant in Guangdong Province. We are only responsible for hydraulic design and performance model testing, with all pump-turbines and generator-motors for the power station designed and manufactured by THPC with our support.

We employed a splitter runner design with a mixture of long and short blades. Through CFD simulation and model development, we optimized the rate of change in the cross-sectional area of the casing, the shape and relative positions of the stay vanes and guide vanes, the clearance between the runner back and side pressure chambers, and the shape of the runner blades. As a

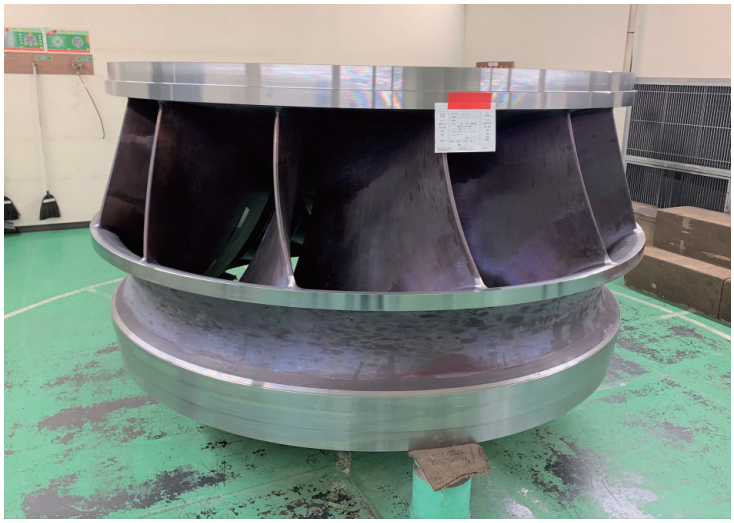
result, the model turbine has achieved a maximum efficiency approximately 0.5% greater than similar models and a reduced pulsation between the guide vane outlet and the runner blade inlet.

The installation of the draft tube for the first 1 unit was completed at the end of December 2022. The production and on-site installation of other units and equipment are underway. Commercial operation of the first unit is scheduled to begin in April 2024. The other units will commence commercial operation every four months thereafter, with the final unit scheduled for March 2025.

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

- Pump-turbine: 351.7 MW, 438 m/507 m, 428.6 min^{-1}
- Generator-motor: 388.9 MVA/384 MW, 18 kV, 428.6 min^{-1}, 50 Hz

2.10 Completion of Spare Hydraulic Runner for Kaligandaki A Hydropower Station, Nepal



Spare hydraulic runner before thermal spraying for Kaligandaki A HydroPower Station, Nepal

In December 2022, Toshiba Energy Systems & Solutions Corporation Keihin Product Operations applied thermal spray coating to a spare hydraulic runner at Kaligandaki A HydroPower Station, completing the unit.

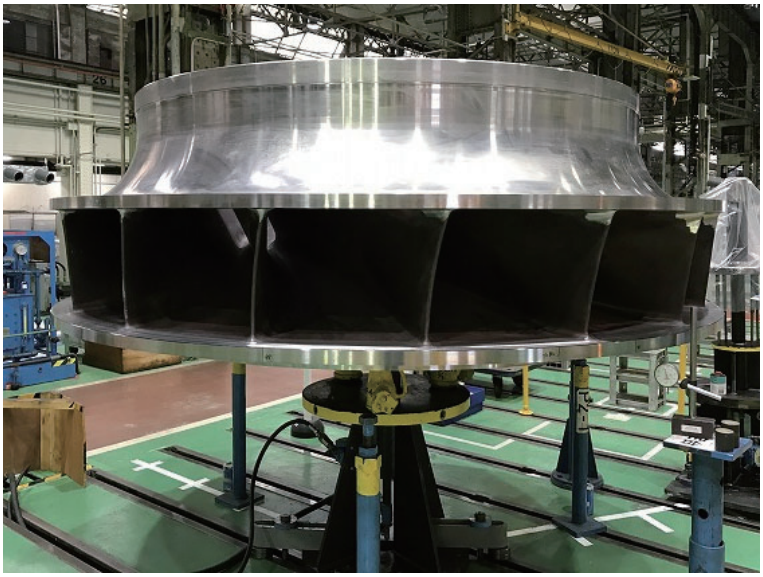
Three units at the Nepal Electricity Authority Kaligandaki A HydroPower Station commenced commercial operations in 2002. At that time, we delivered three hydraulic runners with thermal spray coating featuring excellent sediment wear resistance and three spares without a thermal spray coating. NEA applied thermal spray coating to spare runners on its own at a local vendor facility when it became necessary to replace the runner worn due to sediment abrasion with a spare. However, the coating on the runners peeled off easily, resulting in significant sediment abrasion.

On the other hand, the coating that we applied exhibited a high level of resistance to sediment abrasion. We then received an order from NEA for new spare runner with thermal spray coating. For this order, we increased the coating area on new runner and applied additional coating on the outlet side of the runner blade according to the results of our on-site survey. We also reduced the thickness of the coating on new runner to optimize the balance between abrasion resistance and impact resistance.

The rating of the hydraulic turbine is as follows:

- Hydraulic turbine: 48 000 kW, 115 m, 300 min^{-1}

2.11 Completion of Unit 4 Hydraulic Runner Updates at Siguragura Hydroelectric Power Station, Indonesia



Hydraulic runner updates at Siguragura Power Station, Indonesia

In June 2022, Toshiba Energy Systems & Solutions Corporation completed updates on the Unit 4 hydraulic runner at Siguragura Hydroelectric Power Station, which is the fourth updated unit. Siguragura Hydroelectric Power Station was constructed in 1982 along with an aluminum smelting facility by PT Indonesia Asahan Aluminum (Inalum), a joint venture that was first established by Nippon Asahan Aluminum Co., Ltd. and the Indonesian government before it was fully acquired by the Indonesian government in 2013.

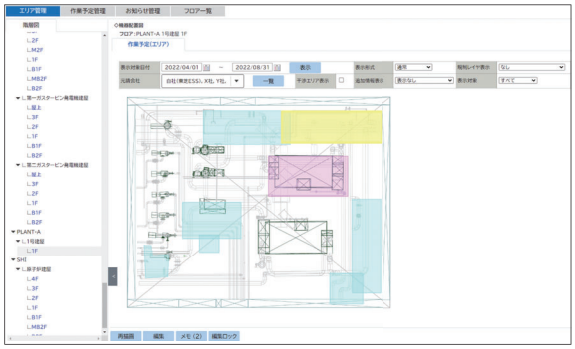
As the original manufacturer of the equipment at Siguragura Hydroelectric Power Station, we received an order to replace the hydraulic runners on Units 1 to 3 before Inalum was acquired by the government. In 2017, we received an order from the government to update the Unit 4 hydraulic runner thanks to updates of hydraulic runners on Units 1 to 3 being praised by the government.

We ran CFD simulations and model tests to upgrade the hydraulic turbine performance for all the units. Based on the results, we updated the guide vanes and installed extensions on the existing stay vanes in addition to updating the hydraulic runners. The new hydraulic turbines are 5% more efficient compared with the previous units.

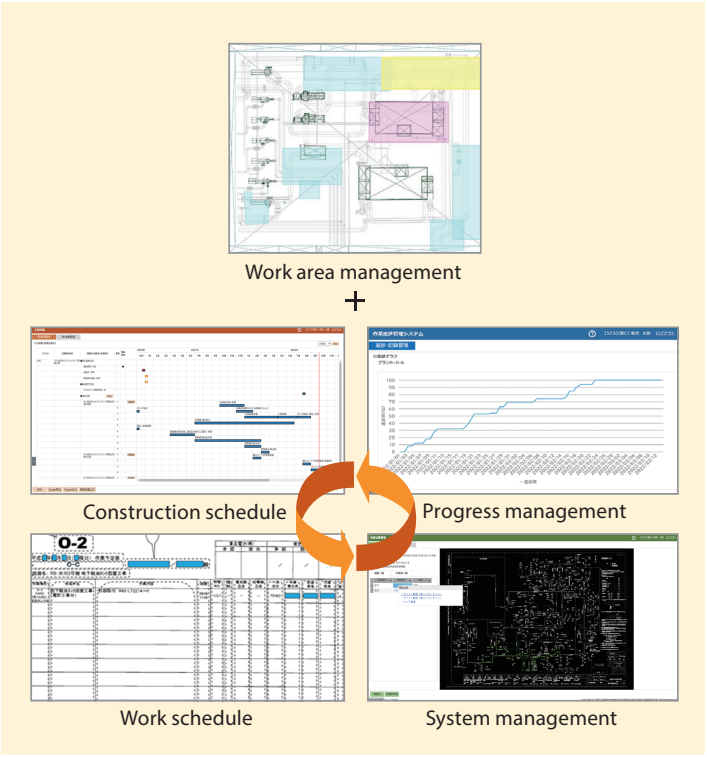
The hydraulic turbine ratings are as follows:

- 73 200 kW, 218 m, 333 min^{-1}, 4 units

2.12 Unified Management of Information on Work Areas in Nuclear Power Plant



Example of database application display for unified management of construction area information



Further expansion of database application functions

In a second meeting held in August 2022, the Green Transformation (GX) Implementation Council at the Prime Minister's Office of Japan recommended operating 27 nuclear power plants by 2030. To achieve this, power companies are working to comply with new nuclear regulations to restart nuclear power plants. Most power companies place an order with several prime contractors to proceed with a large number of construction projects simultaneously.

In order to facilitate the construction work, each prime contractor needs not only to coordinate the tasks of their own subcontractors on a daily basis, but also to orchestrate operations with subcontractors from other prime contractors. It is particularly important to ensure that multiple subcontractors working in the same area do not interfere with one another. This is a considerable burden on prime contractors as it is a non-routine task involving many subcontractors.

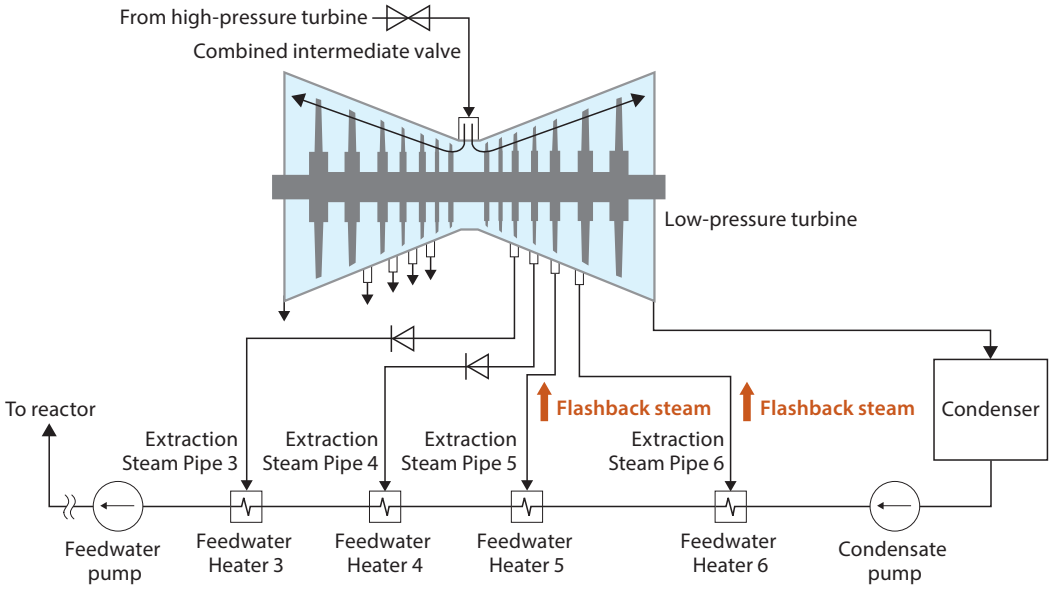
To solve the problem, construction managers dispensed with conventional handwritten whiteboard notes and relied on general-purpose software to check information on a given work area while coordinating with others by telephone and email. However, the situation at work sites changes constantly, even on an hourly basis, making it difficult to update the information in a timely manner.

With this in mind, Toshiba Energy Systems & Solutions Corporation has developed a database application for unified management of construction area information. It uses an externally available service accessible via an Internet browser so that work area information can be shared in real time among all prime contractors. To provide a user-friendly interface, we have continuously improved data entry methods.

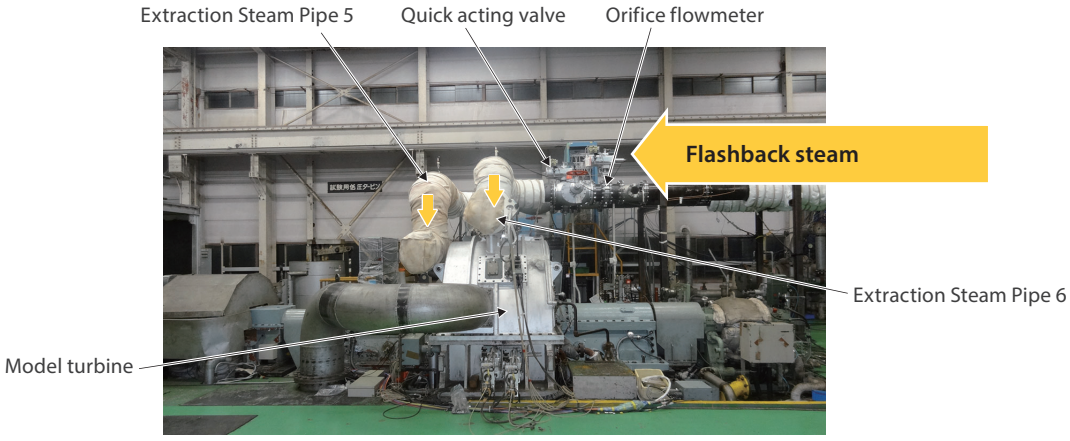
In April 2022, Tohoku Electric Power Co., Inc. introduced the new database application for construction work at Onagawa Nuclear Power Station Unit 2, to allow about 400 construction managers to manage information on more than 7 000 work areas in real time and thereby reduce their workload. We have also received inquiries about this database application from other power companies.

Our next step is to add process, system, and progress management functions to this database application in order to transform it into a work coordination platform that facilitates integrated fieldwork management. Furthermore, we will run simulations using the accumulated data to help to reduce the time required for periodic power plant inspections and thereby increase availability.

2.13 Structural Reliability Verification of Low-Pressure Steam Turbine at Tokyo Electric Power Company Holdings, Inc. Kashiwazaki-Kariwa Nuclear Power Station Units 6 and 7



Fatigue failure of existing turbine blades caused by flashback phenomenon



Subscale model turbine test facility

In 2008, damage to the long blades of the third-party low-pressure steam turbines was discovered at Kashiwazaki-Kariwa Nuclear Power Station Units 6 and 7 operated by Tokyo Electric Power Company Holdings, Inc.

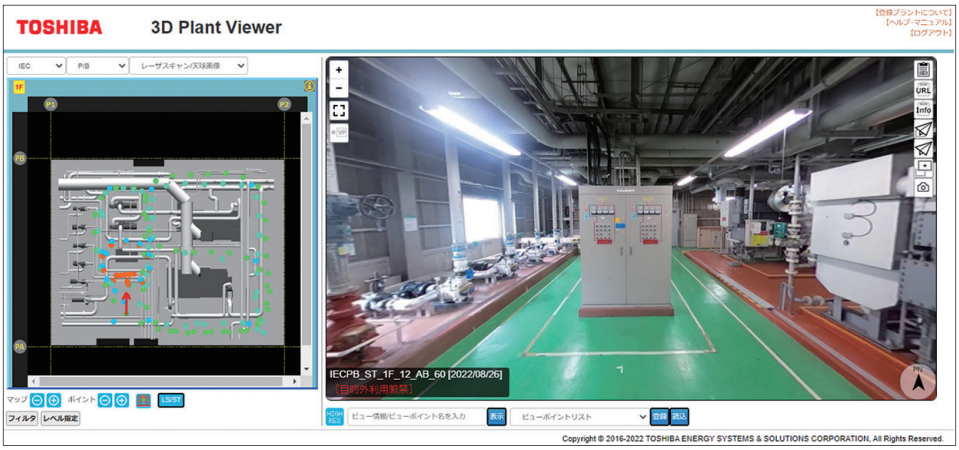
The blades were presumably damaged due to high-cycle fatigue caused by a phenomenon called flashback.

In the event of a turbine shutdown, pressure in the turbine steam path suddenly drops to a vacuum, causing the saturated water pooled in the heaters to boil immediately. The resulting steam returns to the turbine, potentially causing serious damage to the long blades.

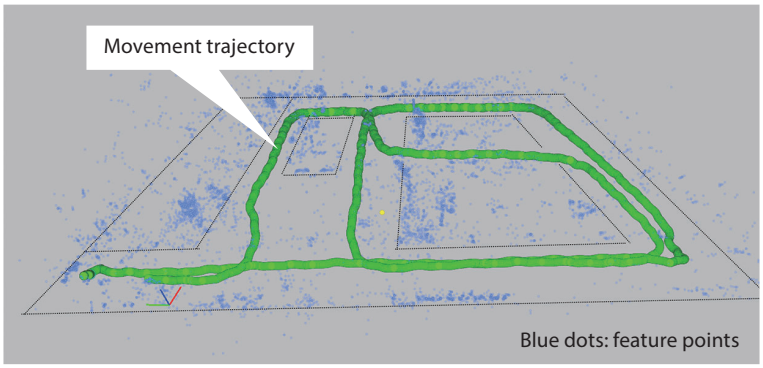
Toshiba Energy Systems & Solutions Corporation is planning to replace the steam turbine as a safety improvement countermeasure. To verify the structural reliability of the blades, we conducted tests using a model at 1/4.2 the size of the full-scale steam turbine at the Keihin Product Operations test facility, which is equipped with hot-water tanks and connecting lines to the turbine.

Tests were performed under the severest possible conditions, i.e., assuming generator load rejection at 100% load generating the maximum amount of flashback steam. Tests confirmed that the vibration stress to which the long blades of the replacement steam turbine would be exposed in the event of flashback is sufficiently lower than the strength of the blade material.

2.14 Technology to Identify Conditions at Power Station Using 360° Panoramic Images



Example of 3D Plant Viewer display with arranged and registered 360° images estimated from shooting positions



Estimation of movement trajectory results based on shooting positions

Toshiba Energy Systems & Solutions Corporation has been working to comply with Japan's new nuclear safety regulations. When installing new equipment and facilities at nuclear power plants, we must consider space constraints and coordinate schedules with other vendors. Sharing design information with all the parties concerned is effective in facilitating on-site work.

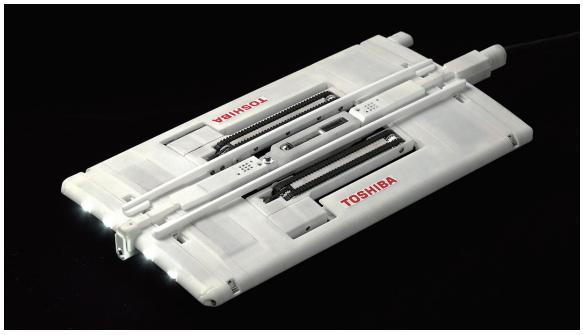
To achieve this objective, we have updated 3D Plant Viewer to provide 360° panoramic views of construction sites, allowing users to view on-site conditions easily. 3D Plant Viewer now provides a function for viewing 360° panoramic images in a Web browser in addition to a function for viewing a 3D computer-aided design (CAD) models and point cloud data (released in 2019).

In the past, on-site information was updated only once every few years as considerable time was required to acquire point cloud data. To resolve this issue, 3D Plant Viewer now estimates

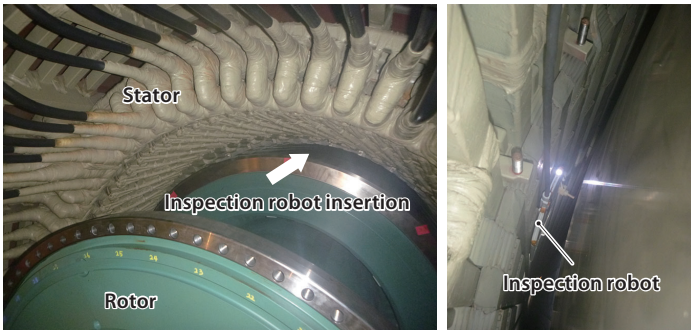
movement trajectory based on the shooting positions of a 360° panoramic camera. 3D Plant Viewer can now update site information every few weeks, making it possible to share the latest information about conditions with concerned parties.

A combination of tagging, time-series archiving, and information-sharing functions on 3D Plant Viewer has been requested by electric power companies for use in various situations, including in-house training. We will continue to improve functions to meet such needs.

2.15 First Application of Inspection Robot on Turbine Generator at Barakah Nuclear Energy Plant Unit 1



Inspection robot for turbine generators



Detailed inspection of turbine generator applying inspection robot at Barakah Nuclear Energy Plant Unit 1, United Arab Emirates

In April 2022, Toshiba Energy Systems & Solutions Corporation completed a robotic inspection of the turbine generator at Barakah Nuclear Energy Plant (Barakah NEP) Unit 1 in the United Arab Emirates (UAE) during the first refueling outage. We received this contract through Doosan Enerbility Co., Ltd., the prime contractor of Nawah Energy responsible for operation and maintenance at Barakah NEP.

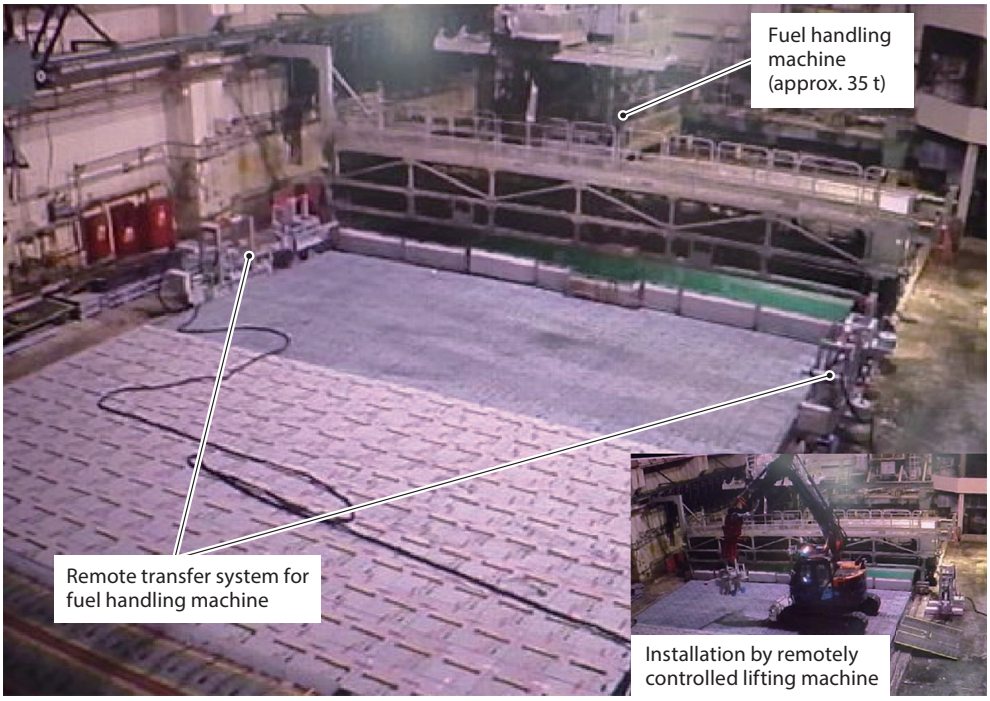
Because the inspection robot travels through narrow gaps between the rotor and the stator, it eliminates the need for removing the rotor in detailed inspections, nearly halving the time required.

For the inspection at Barakah NEP Unit 1, we employed an ultrathin robot with a frame thickness of 10 mm, one of the thinnest in industry(*). The robot performed a visual inspection of the rotor to check for scratches, overheating marks, and clogged ventilation holes, a visual inspection of the stator to check for scratches and overheating marks, and an acoustic analysis of the stator to check for loose wedges. The inspection confirmed the soundness of the turbine generator.

We will further improve the functions of the inspection robot to enhance client satisfaction. We will also expand the applications of our robotic inspection and maintenance service while contributing to the improvement of power plant availability and the reduction of maintenance costs through optimized turbine generator inspection.

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

2.16 Completion of Remotely Operated Transfer of Fuel Handling Machine in High-Dose Environments



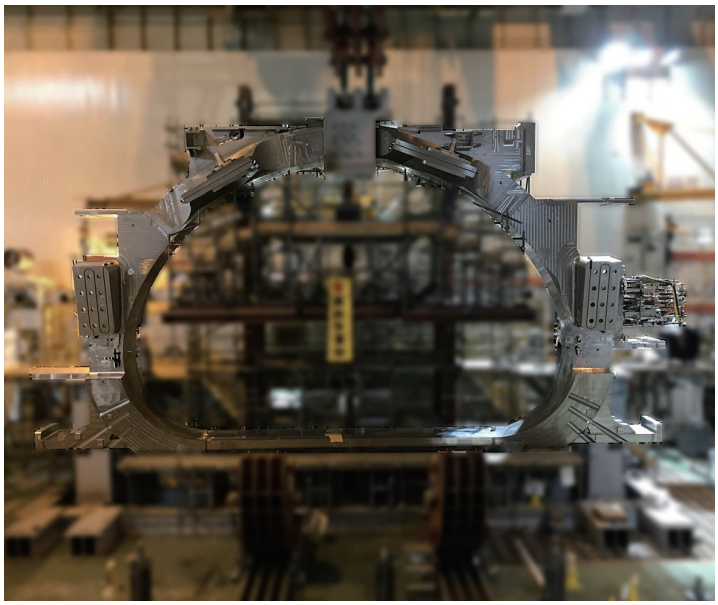
Moving fuel handling machine installed at Fukushima Daiichi Nuclear Power Station Unit 2

For the safe removal of spent fuel from the reactor building of Fukushima Daiichi Nuclear Power Station Unit 2, Toshiba Energy Systems & Solutions Corporation has developed a system to remotely transfer the fuel handling machine left over the spent fuel pool. Features of this transfer system include: (1) sufficient pulling force in case of sticky gears or wheels, or brake failure in the fuel handling machine, (2) a positioning guide for remote-controlled installation using only camera images, and (3) a lightweight, small size for ease of transportation. In addition, the transfer system includes a control device to monitor the travel distance, drive current, and pulling force, ensuring that both sides of the fuel handling machine is pulled evenly as it runs on two rails.

After verifying functionality at the factory, we installed the transfer system using a remotely controlled machine, relying only on camera images. Later, the transfer system was used to move the fuel handling machine 15 meters away from the spent fuel pool on the rails.

We will continue with efforts to develop remote control technologies based on this achievement in order to contribute to the decommissioning of the Fukushima Daiichi Nuclear Power Station.

2.17 Completion of Four TF Coils for ITER



Fourth toroidal field (TF) coil for ITER in standing position before machining

ITER is the thermonuclear experimental reactor under construction in France, and this project is currently underway with the participation of seven member parties including Japan and the European Union (EU). Toroidal field (TF) coils are key devices for generating a strong magnetic field to confine high-temperature, high-density plasma in order to produce a fusion reaction.

The ITER TF coil is the world's largest superconducting coil(*) with a length of 17 m, a width of 9 m, and a weight of 320 tons. ITER consists of 18 TF coils.

Toshiba Energy Systems & Solutions Corporation received an order from the National Institutes for Quantum Science and Technology (QST) of Japan for four TF coils. We manufactured and shipped the last TF coil in March 2023.

To manufacture a TF coil, a wound superconducting conductor is assembled and housed in a coil case, followed by a machined finish. Despite a large structure, the TF coil requires a dimensional error on the order of several millimeters, necessitating outstanding assembling, welding, and machining technologies.

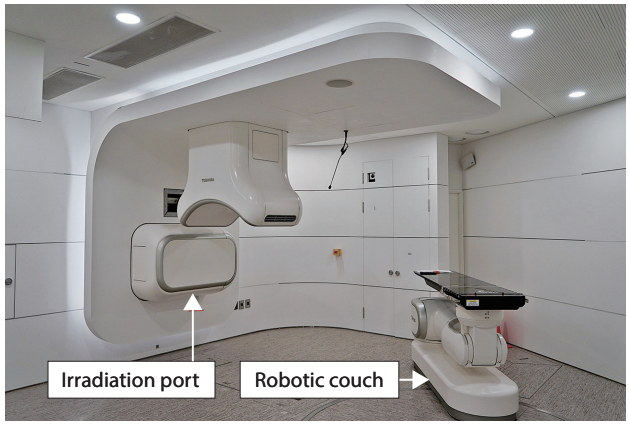
For the machining process, we developed a system to measure the product temperature in real time and automatically correct the machining program. This system allowed us to improve the machining precision and work efficiency while controlling thermal expansion and deformation within the required tolerance.

We will continue to contribute to future energy supply and the realization of carbon neutrality through our nuclear fusion technology.

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

2.18 Completion of Construction of Fixed-Beam Irradiation Room at Yonsei University

Heavy-ion radiotherapy facility installed at Yonsei University, South Korea



Fixed-beam irradiation room

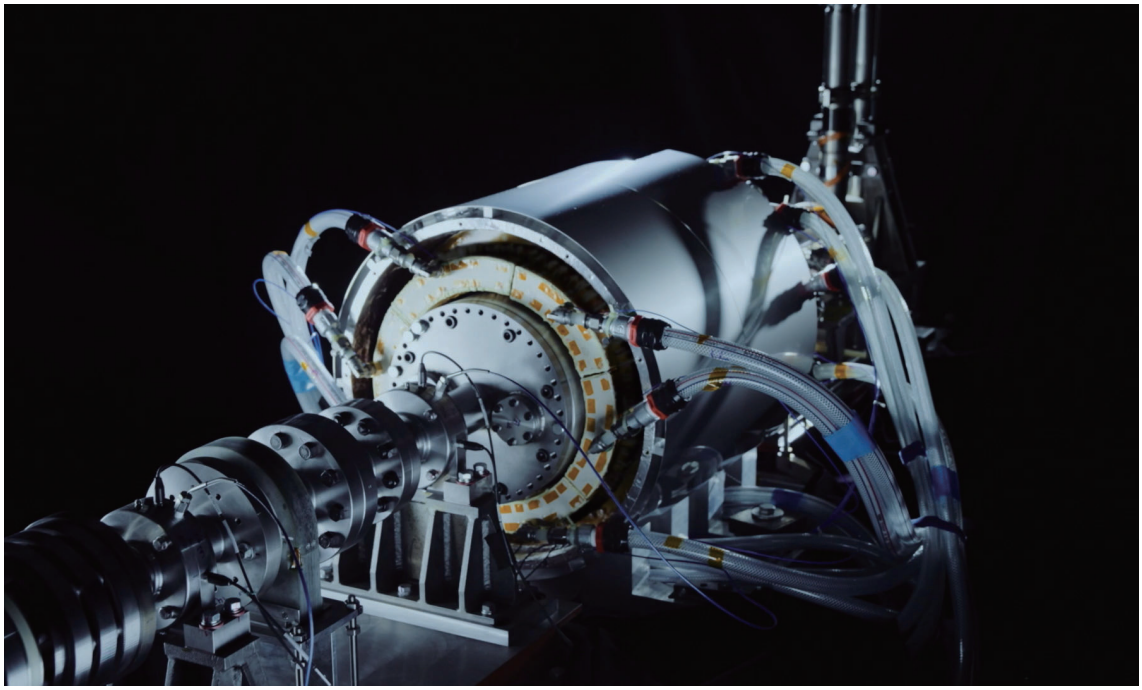
Toshiba Energy Systems & Solutions Corporation is endeavoring to increase its international presence in the field of heavy-ion radiotherapy systems. As part of such efforts, we completed the construction of a fixed-beam irradiation room at the Yonsei Cancer Center (YCC) of the Yonsei University Health System (YUHS) in October 2022.

Heavy-ion radiotherapy helps not only to reduce the treatment burden and side effects, but also to minimize damage to normal cells around the tumor exposed to high-dose radiation. We are the sole supplier of heavy-ion radiotherapy systems with a superconducting rotating gantry capable of focusing heavy-ion beams on the tumor from any angle around a patient's body axis(*). The rotating gantry makes it possible to concentrate high-dose radiation more precisely on the target area.

In March 2018, we received a contract for one fixed-beam treatment room and two treatment rooms equipped with a rotating gantry irradiation system from YUHS. Since then, we have proceeded with the project, forming a consortium with DK Medical Solution Co. Ltd. in South Korea. Installation of the large equipment at YCC began in March 2021. Later, a particle accelerator and a beam transport system were tested to ensure that the entire system performs satisfactorily as medical equipment. Finally, in February 2023, the fixed-beam treatment room was delivered to YCC, which is scheduled to start providing radiotherapy in April 2023. The next phase of the project is to deliver rotating gantry treatment rooms.

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

2.19 Prototype Lightweight, Compact, High-Power Superconducting Motor for Mobility Applications



Prototype superconducting motor

Toshiba Energy Systems & Solutions Corporation has developed and completed verification testing for the world's first 2 MW-class lightweight, high-power superconducting motor(*) for next-generation mobility applications. This superconducting motor is suitable for large mobility applications, including aircraft, ships, and trucks. We aim to commercialize it in the second half of the 2020s in collaboration with the mobility industry.

As global environmental awareness grows, the mobility industry is accelerating its efforts to reduce CO_2 and other greenhouse gases. For example, the aviation industry has set a goal of achieving net-zero CO_2 emissions (i.e., carbon neutrality) by 2050. Therefore, a transition from conventional fossil fuels to alternative fuels derived from non-petroleum sources (known as sustainable aviation fuel or SAF for short) is under way.

However, to achieve total carbon neutrality, it is necessary to explore not only carbon-free SAF but also aviation systems as a whole, including the electrification of propulsion systems and the development of light high-power motors. Motors with the power required for aircraft propulsion would be too heavy to be mounted on aircraft if manufactured using conventional methods. Therefore, we have employed superconducting coils to produce strong magnetic fields and increased the motor's rotation speed, thereby reducing the weight and increasing the power of the motor. We have embedded the superconducting coils into a rotating machine, combining manufacturing technology for superconducting coils, adiabatic cooling technology to maintain low temperatures, and design and manufacturing technologies for high-speed rotat-

ing machines represented by turbine generators. The new superconducting motor has an outer diameter of about 500 mm and a total length of about 700 mm. It is less than 1/10th the weight and size of a conventional motor with the same level of power output.

We have already embarked on the next project to develop more lightweight motors to continue offering industry-leading products.

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

2.20 Completion of Gas Turbine Replacement at Futtsu Thermal Power Plant Unit 4-2

Updated gas turbine enclosure and fuel gas skid at JERA Co., Inc. Futtsu Thermal Power Station Unit 4-2

Replacement gas turbine

JERA Co., Inc. Futtsu Thermal Power Plant Unit 4 is a combined-cycle thermal power plant that consists of three 1 500°C-class single-shaft gas turbines, each with a rated output 507 MW. Unit 4 has been in operation for more than 13 years.

Toshiba Energy Systems & Solutions Corporation completed replacement of the General Electric Company (GE) 9H gas turbine at Unit 4-1 with the 9HA.01 in the span of one year from September 2016 to September 2017. Because GE announced the end of production of hot gas path components for the 9H gas turbine such as turbine buckets, JERA planned to update the gas turbines and control units for Units 4-2 and 4-3, resulting in this order. The replacement gas turbine model provides the rated output in a wider ambient temperature range and thus contributes to the improvement of JERA's power supply capability in the hot summer season.

The project period for updating Unit 4-2 was only seven months, approximately three months shorter than that for the Unit 4-1 update, as JERA needed to resume commercial operations of Unit 4-2 before summer when electricity demand rises.

We implemented various measures to complete the project in the shortest possible time and to minimize costs, including new installation methods for the gas turbine and other large equipment, transporting the gas turbine casing in a disassembled state, re-routing transportation, and pre-fabricating and adjusting piping around the gas turbine. As a result, Unit 4-2 resumed commercial operations on schedule in late June 2022.

Furthermore, the new gas turbine consumes less fuel per unit output and thus contributes to reduced CO_2 emissions and environmental load.

Next, we will replace the gas turbine at Unit 4-3, drawing on our experience from Unit 4-2.

2.21 Completion of Construction on Tanjung Jati B Coal-Fired Power Plant Units 5 and 6 in Indonesia

Tanjung Jati B power plant, Indonesia

Construction of Unit 5 at the Tanjung Jati B ultra-supercritical coal-fired power plant was completed in March 2022, followed by Unit 6 in July 2022.

Toshiba Energy Systems & Solutions Corporation supplied the equipment for the turbine islands. We have achieved a high level of 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, a main steam valve with low pressure loss, and a desuperheater to raise the final feedwater temperature.

We have already supplied turbine islands for Units 1 to 4 at the Tanjung Jati B Power Plant and have now constructed Units 5 and 6. With a total output of 4 640 MW, the Tanjung Jati B Power Plant is one of the largest in Indonesia, making it one of the backbone power plants in the country.

Many of our personnel were infected with COVID-19 during the construction and commissioning of Units 5 and 6, and Indonesia implemented immigration restrictions for technical advisors from Japan. This necessitated minimizing on-site organization temporarily.

In response, we thoroughly implemented COVID-19 testing and infection control measures on-site while working proactively to minimize the impact on the schedule, such as proposing a modification of the scheduled commissioning processes. These activities were highly praised by the customer.

We will continue to contribute to the realization of a carbon-neutral society by supplying highly efficient power plants that satisfy customer requirements.

2.22 Amine Emission Control Technology for CO_2 Capture Demonstration Facility

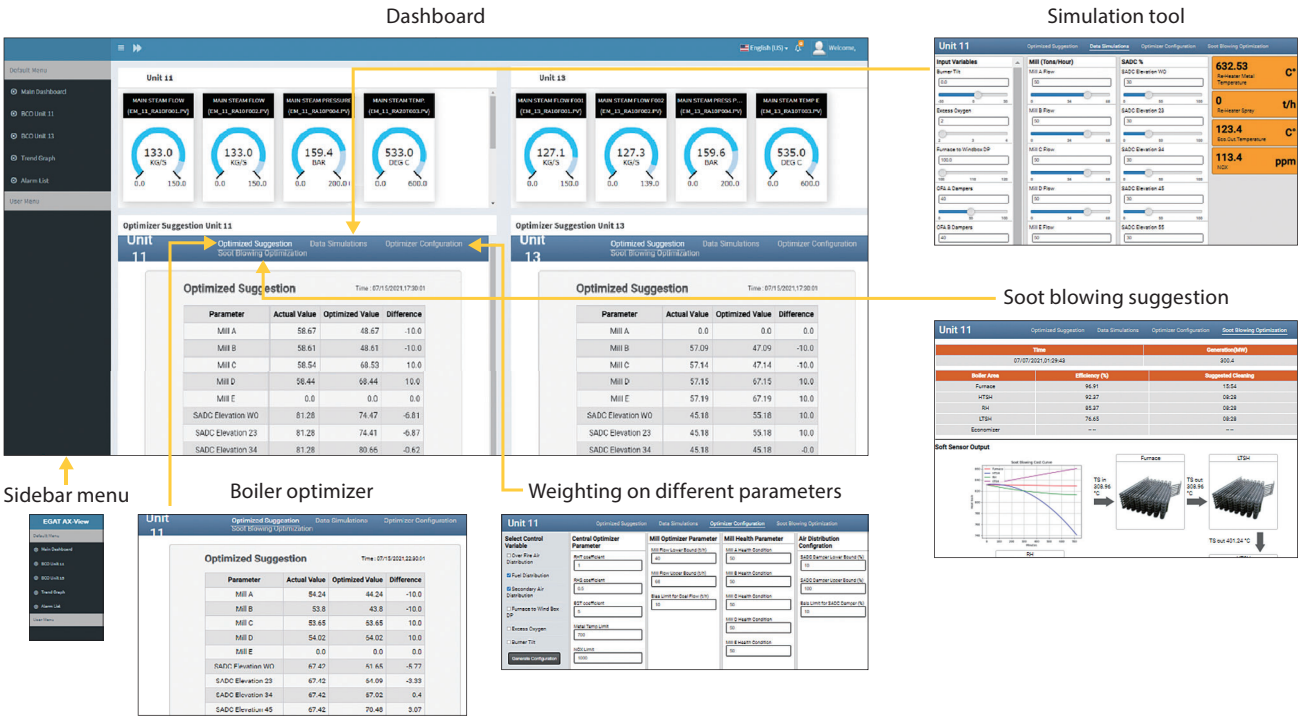
Large-scale CO_2 capture demonstration facility at Mikawa Power Plant, SIGMA POWER Ariake Corporation

Japan has set a target to reduce greenhouse gas emissions by 46% from 2013 levels by 2030. CO_2 capture and storage (CCS) technology is one of the most important measures for reducing CO_2 emissions.

As part of the Sustainable CCS Project commissioned by MOE of Japan, Toshiba Energy Systems & Solutions Corporation installed a CO_2 capture demonstration facility using an amine-based absorbent at the SIGMA POWER Ariake Corporation Mikawa Power Plant. Capable of recovering 600 tons of CO_2 per day, the facility commenced operation in 2020.

This CO_2 demonstration facility employs a spray washing system that exhibits dramatic effects on the reduction of total amine emissions into the atmosphere. A conventional packed-bed washing system reduces total amine concentration to about one-fourth the volume compared to the concentration at the absorber outlet. On the other hand, the new spray washing system achieved a washing efficiency of more than 99%. We also confirmed that the new washing technology works well even if the flue gas flow rate changes.

2.23 Boiler Operation Optimization Solution for Thermal Power Plants



Soot blower: a device for removing soot deposited on the internal furnace tubes of a boiler during combustion to prevent gas pass plugging and maintain boiler efficiency (Source: Wikipedia)

Dashboard and other images in the Boiler Operation Optimization Solution

Toshiba Energy Systems & Solutions Corporation and Toshiba Software India Pvt. Ltd. have developed the Boiler Operation Optimization Solution for thermal power plants, which monitors the thermal efficiency and operating conditions of boilers. It provides plant operators with optimal combustion conditions and operating timing calculated by a machine-learning model based on data from plant sensors. This solution employs a neural network model, which is an AI technique, to learn a boiler's operating conditions and obtain the bias value (correction value) which optimizes the boiler's internal combustion and decreases the heat distribution imbalance, thereby improving the efficiency.

We have also developed a soot blowing optimization technique for plant efficiency optimization, which can suggest the optimum soot blowing timing based on the combination of a dynamic plant simulation model and Extended Kalman Filter prediction.

The Boiler Operation Optimization Solution is deployed on a cloud system so that it can be accessed by plant operators with a web browser.

We are promoting the global rollout of cyber-physical systems (CPS) combined with energy IoT services to contribute to achieving a carbon-neutral society, help solve the problems of power producers, and drive digital transformation (DX).

2.24 Completion and Energization of New Babil 400 kV Substation Installation, Iraq

400 kV GIS at New Babil 400 kV Substation, Iraq

400 kV transformers

132 kV GIS

Toshiba Energy Systems & Solutions Corporation delivered 400 kV and 132 kV gas-insulated switchgear (GIS) and 400 kV oil-filled transformers to the Ministry of Electricity of Iraq New Babil 400 kV substation and completed energization in October 2022. This is in addition to the four substations in Iraq (Maysan, Al Mothana, Shatra, and Shat Al Arab) that we energized in July 2021.

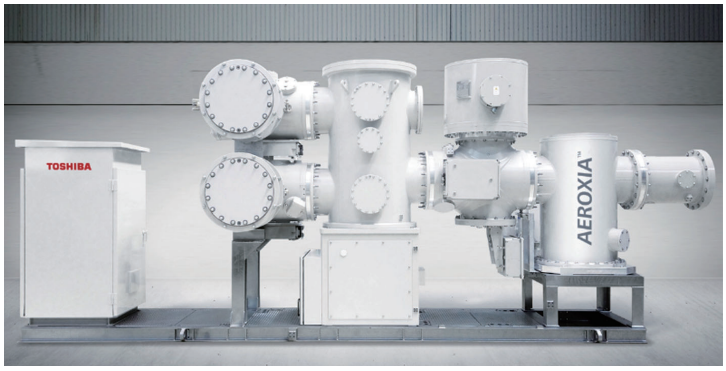
As part of Iraq's plan to improve its power grid after the end of the Iraq War, we received an order in 2020 from Toyota Tsusho Corporation, the primary contractor for the project, for equipment and support services in on-site installation and testing. However, the Ministry of Foreign Affairs of Japan had in place a Level-3 "Reconsider Travel" advisory for Iraq, making it difficult to send engineers. In addition, the COVID-19 pandemic made it extremely difficult to coordinate with various project stakeholders.

This was the fifth substation project that our Overseas Transmission & Distribution Systems Division undertook in Iraq. Part of preparations included making a training video for the engineers at the Egyptian engineering, procurement, and construction (EPC) company selected as the Toyota Tsusho joint venture partner. We were able to complete the project by utilizing technical instructors from our subsidiary in the United Arab Emirates and online tools to communicate with engineers from the joint venture partner in Iraq.

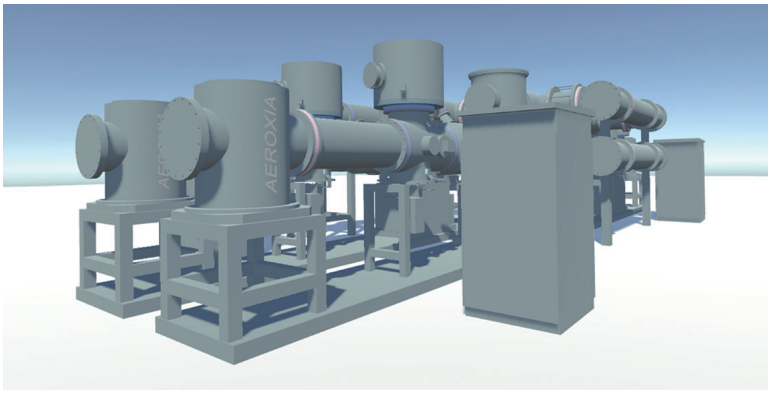
This was the first time we delivered 400 kV transformers manufactured by Toshiba Transmission & Distribution Systems (India) Pvt. Ltd. to Iraq in addition to 132 kV GIS.

Through this project, we were able to demonstrate our comprehensive technical capabilities, achieving results that will help further improve resource management practices and expand opportunities for future projects.

2.25 Delivery of 72 kV GIS Using Natural-Origin Gas to Fuchu Substation, TEPCO Power Grid, Inc.



72 kV GIS using natural-origin gases



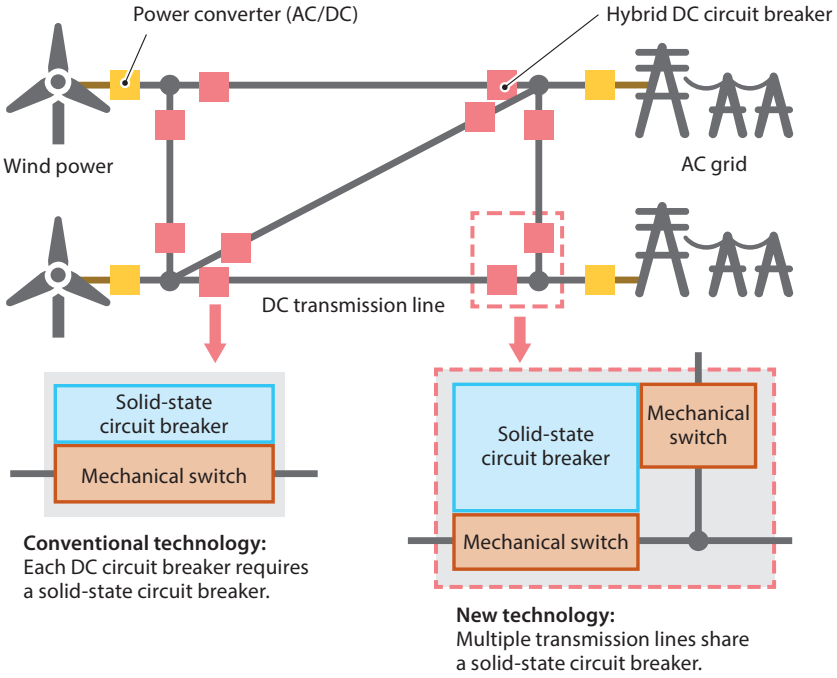
Rendering of 72 kV GIS using natural-origin gases for TEPCO Power Grid, Inc. Fuchu Substation

Toshiba Energy Systems & Solutions Corporation has delivered the first environmentally-friendly GIS using natural-origin gas to TEPCO Power Grid, Inc. to replace the existing 72 kV GIS at the Fuchu Substation. This GIS uses a mixture of nitrogen and oxygen (called synthetic air) as insulating gas instead of sulfur hexafluoride (SF_6), which exhibits a high global warming potential, because synthetic air is safe and has no impact on global warming even in the event of leakage.

We developed the new GIS jointly with Meidensha Corporation and released it following the prescribed type testing. We have been collaborating with Meidensha since 2020. The GIS for the TEPCO Power Grid, Inc. Fuchu Substation uses natural-origin gas for full insulation, including the main bus bar, switchgear, and cable head. The GIS also supports substation digitalization and is equipped with a monitoring and diagnostic system compliant with the International Electrotechnical Commission (IEC) 61850 standard.

We will continue to contribute to achieving carbon neutrality through the development of products with superior environmental compatibility and accelerate the development of high-voltage, high-capacity GIS using natural-origin gas.

2.26 DC Interruption Technology for Protection of Offshore High-Voltage DC Transmission Grids



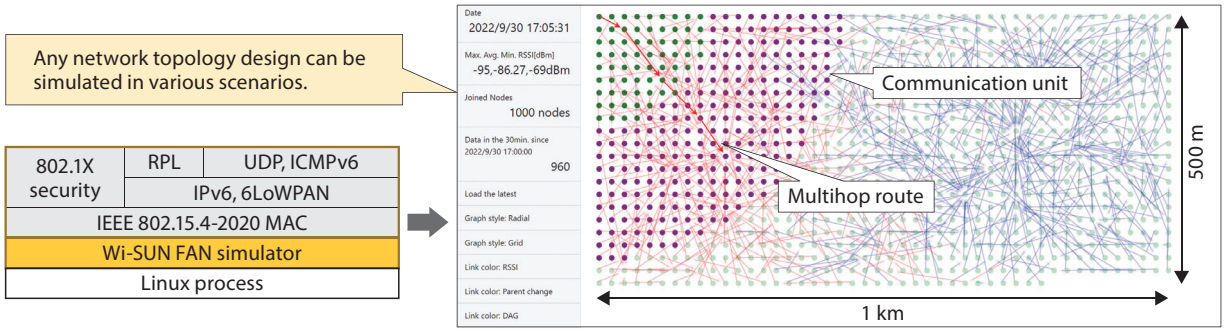
Configuration of offshore high-voltage DC transmission grid and differences between conventional and newly developed hybrid DC circuit breakers

Offshore wind power generation is a promising solution for expanding renewable energy usage to achieve carbon neutrality. Although high-voltage DC transmission grids are suitable for stable long-distance transmission of electricity from offshore wind farms to onshore consumers, they require DC circuit breakers (DCCBs) in some cases so that DC current can be interrupted instantaneously to protect the grid. Although several hybrid DCCBs that combine a mechanical switch and a solid-state circuit breaker with such requirements are available, their drawback is a large number of constituent components.

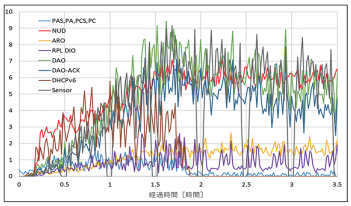
With this in mind, the Toshiba Group has developed a new circuit topology in which multiple branches of transmission lines share a single solid-state circuit breaker at the common connection point. The operating principle of DC interruption is identical to that of the conventional hybrid DCCB; that is, the current flowing through a mechanical switch is commutated to a solid-state circuit breaker and is interrupted. Because the solid-state circuit breaker is shared by all branches, the new topology minimizes the number of components required.

We will continue development work for further expansion of offshore wind power generation.

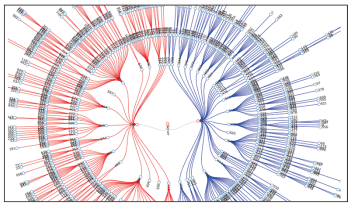
2.27 Wireless Multihop Network Simulator Compliant with Wi-SUN FAN Specification



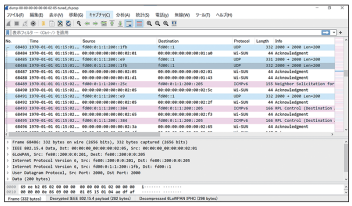
1 000 communication units arranged in square



Traffic statistics



RPL tree-based route information



Packet monitoring

RPL: Routing Protocol for Low-Power and Lossy Networks
UDP: User Datagram Protocol
IPv6: Internet Protocol Version 6
ICMPv6: Internet Control Message Protocol Version 6
6LoWPAN: IPv6 over Low-Power Wireless Personal Area Networks
IEEE: Institute of Electrical and Electronics Engineers
MAC: Media Access Control

Wi-SUN field area network (FAN) specification compliant wireless multihop network simulator features

The Wireless Smart Utility Network for Field Area Network (Wi-SUN FAN) technology supports a tree-based multihop network infrastructure with enhanced security based on public key infrastructure (PKI). The Wi-SUN FAN specification standardized from Wi-SUN Appliance is attracting attention in Internet of Things (IoT) data communication services such as next-generation smart metering.

To achieve a high-availability network, performance must be evaluated and improved under various operational scenarios. However, a testbed for a large-scale wide-area multihop network requires considerable maintenance such as firmware updates and log collection in addition to installing many communication units. It is also difficult to capture the wireless congestion and packet logs of many communication units simultaneously for debugging purposes.

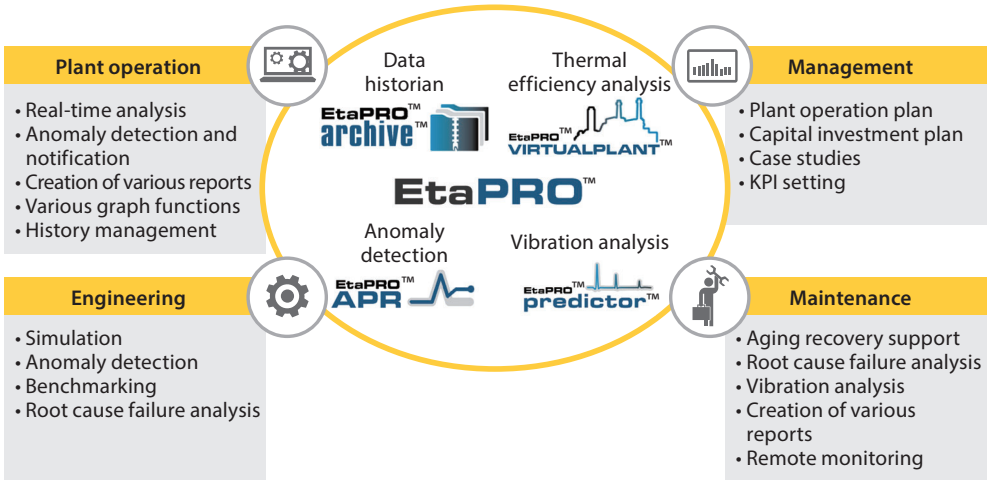
To resolve these issues, Toshiba Energy Systems & Solutions Corporation has developed a wireless multihop network simulator compliant with the Wi-SUN FAN specification. Our Wi-SUN FAN firmware for the communication unit is emulated in Linux. The new simulator allows communication units that work in parallel to be arranged arbitrarily in two-dimensional space while supporting the 920 MHz band for 100 kbps 2-frequency shift keying (2-FSK) modulation and 600 kbps orthogonal frequency division multiplexing (OFDM).

This simulator supports real-time simulation of 1 000 communication units, intercommunication with Linux application servers, ping and traceroute tests on Linux, arbitrary communication unit packet capturing, and visualization of the entire network topology.

The new simulator allows us to rearrange communication units quickly and evaluate wireless propagation conditions and Wi-SUN FAN parameters. It is therefore possible to simulate any network topology in various operational scenarios. Furthermore, the new simulator supports the evaluation of network topology changes, communication logs, traffic patterns for each type of packet, and packet reachability, enabling analyzation of overall network behavior in detail.

We will utilize this simulator for network integration and performance improvement.

2.28 Promotion and Introduction of EtaPRO™ Plant Monitoring Software for Power Producers



Type	EtaPRO™ archive™	EtaPRO™ APR	EtaPRO™ VIRTUALPLANT™	EtaPRO™ predictor™
Gas	●	●	●	●
Coal	●	●	●	●
Nuclear	•	•	•	•
Geothermal	•	•	•	•
Hydro	•	•		•
Wind	•	•		•
Solar	•	•		
Battery	•	•		

KPI: key performance indicator

Overview of EtaPRO™ plant monitoring software for power producers

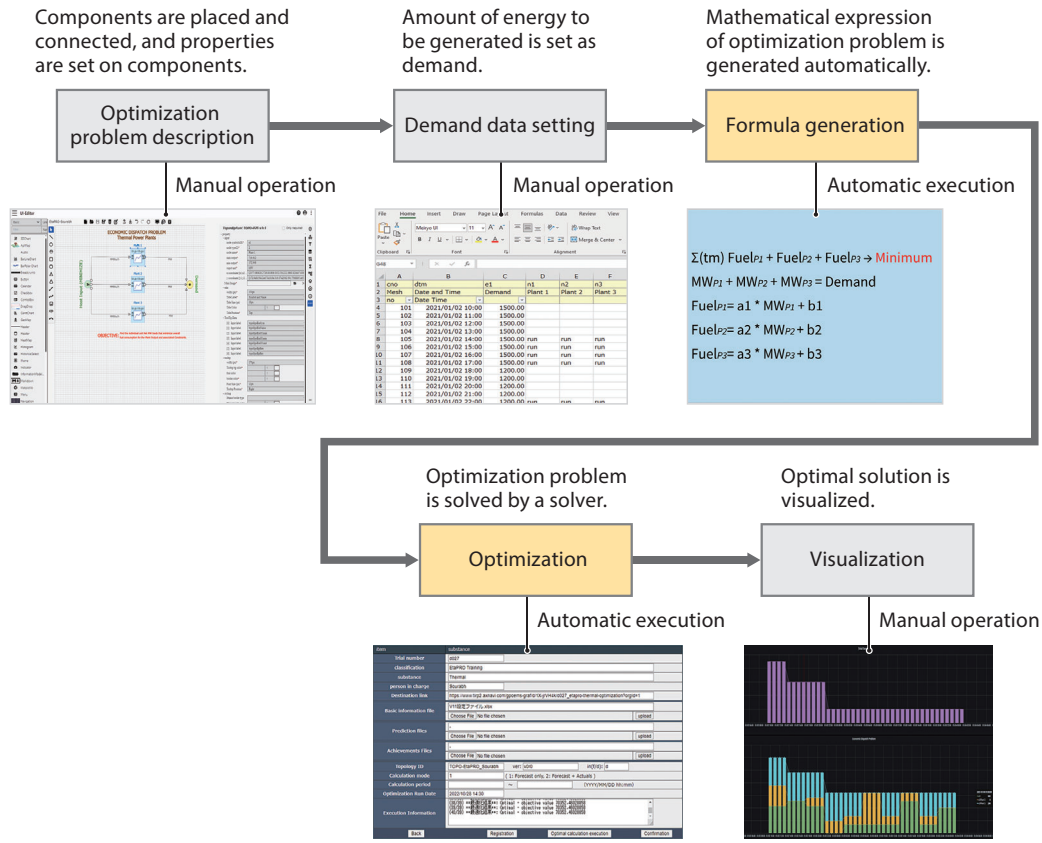
In October 2021, Toshiba America Energy Systems Corporation, an affiliate of Toshiba Energy Systems & Solutions Corporation acquired the EtaPRO™ business from GP Strategies Corporation, a global provider of workforce transformation solutions in the United States. EtaPRO™, plant monitoring software for power producers, helps to improve power plant operation by monitoring thermal efficiency and operating conditions to detect deterioration and abnormalities related to plant equipment. EtaPRO™ has been installed at more than 3 000 power plants in 60 countries around the world, including all Tohoku Electric Power Co., Inc. thermal power plants and two Hokuriku Electric Power Company power plants in Japan.

We are globally promoting our CPS that combines EtaPRO™ and TOSHIBA SPINEX for Energy, modularly designed and componentized services for the maintenance of turbine, generator, and other equipment to achieve a synergistic effect.

In 2022, the CPS was installed at Patuha Geothermal Power Station in Indonesia, Mae Moh Thermal Power Station Units 11 and 13 in Thailand, and two Hokkaido Electric Power Co., Inc. thermal power stations in Japan.

We will continue to introduce our CPS to contribute to the realization of a carbon-neutral society, help to solve the problems of power producers, and achieve DX.

2.29 Release of Tool to Find and Visualize Optimal Solutions for Intuitively Described Optimization Problems



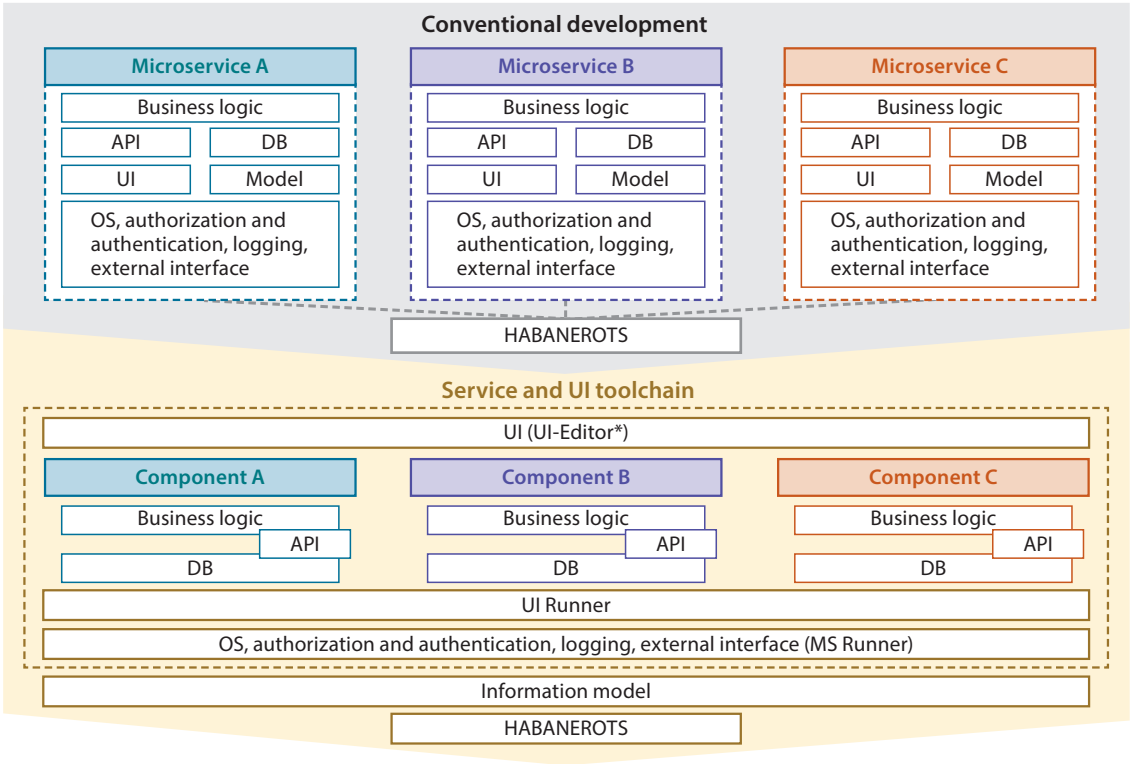
Optimization tool featuring intuitive user interface (UI) to provide optimal solutions to issues faced at power plants and factories

Toshiba Energy Systems & Solutions Corporation has developed a tool that makes it easy to intuitively describe optimization problems and find optimal solutions to optimization problems, such as power plant operation and factory energy management plans. For example, the tool allows users to select icons that represent a power plant and plant equipment (such as boilers, turbines, and batteries) and place them on the canvas. The flow of energy (e.g., electric power and steam), exhaust (e.g., CO_2), and cost (e.g., electric power and fuel purchasing cost) can be modeled intuitively simply by connecting the icons.

The user can set an energy demand value in the model and instruct the tool to find a solution for minimizing cost while satisfying energy demands. The tool then automatically generates and solves a mathematical expression that represents the optimization problem and visualizes the optimal solution.

Once a model is created, it is easy to change the equipment properties and add new equipment. Even engineers who lack expertise in optimization software can customize the model. The new tool is expected to help improve staff ability to propose energy management services.

2.30 Integrated Software Development Environment with Model-Driven Data Handling Capability



API: application programming interface DB: database MS: Microservice
* UI editing tool

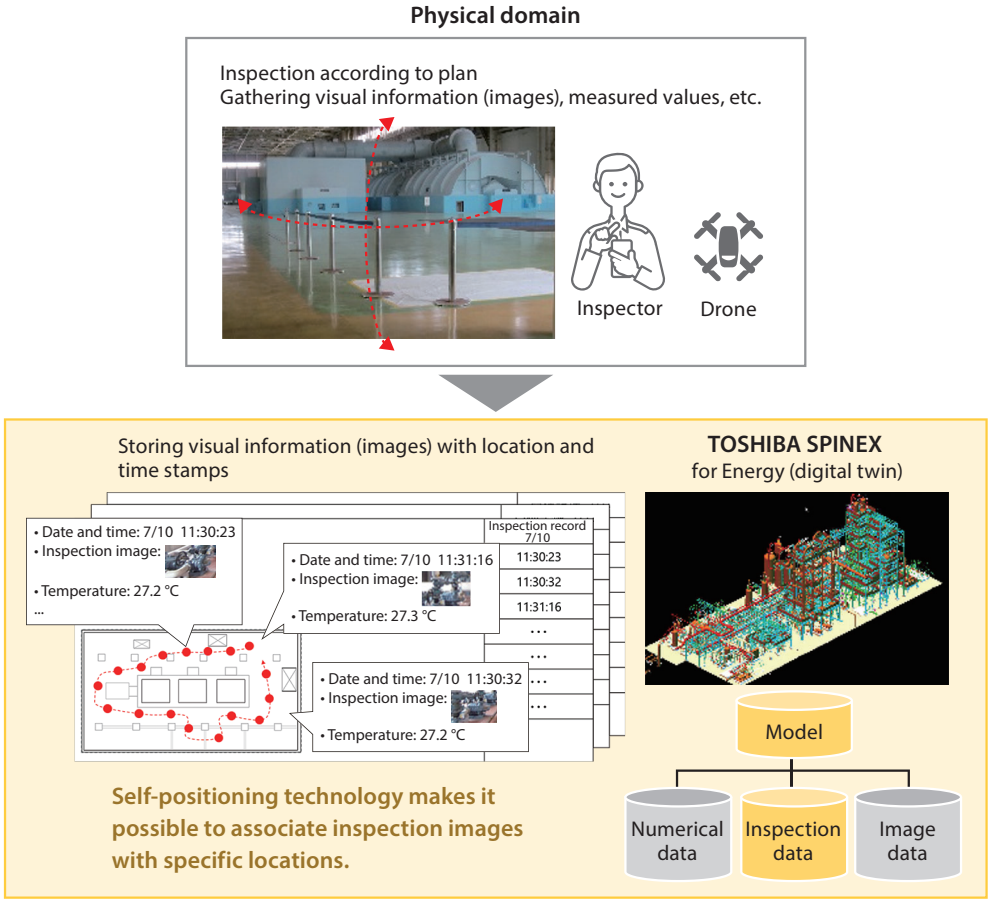
Overview of integrated software development environment including service and UI toolchain and conventional environment improvements

In order to access UI in infrastructure systems, an ID specific to each plant, such as a name, is required. However, sharing the same recognition on operating status and other conditions of a plant at the conceptual level proved difficult.

Toshiba Energy Systems & Solutions Corporation has therefore developed and released a service and UI toolchain, an integrated software development environment capable of modeling not only things but also human thoughts and interests, including UIs. The new integrated software development environment helps reduce communication errors and allows the use of models at the interface between services for solution development. In addition, when creating new services, the integrated software development environment helps prevent individual developers from using their own processes and codes.

The shared development base simplifies software development and allows developers to focus on business logic creation, making it possible to launch a series of new services at low cost and in a short period of time.

2.31 On-Site Operation Support Service for Associating Video Images of Facilities with Location and Time Stamps



On-site operation support service using video images captured by 360° camera

Toshiba Energy Systems & Solutions Corporation has launched an on-site operation support service for monitoring the status of power station and substation equipment at arbitrary points in time by associating video images with location and time stamps. The self-positioning function creates a site layout model from video captured with a 360° camera based on differences of given positions from a predefined origin. The service uses a web browser to display links to images and timestamps on a site layout diagram, allowing the user to check the status of any piece of equipment at arbitrary points in time.

This technology can be used to inspect and record equipment and site status in any industrial sector, including electric power infrastructure, consumer infrastructure, and factories. In addition, it is expected to contribute to further improvements in operation and maintenance (O&M) efficiency as robots or drones equipped with a 360° camera can be used as an alternative means of inspection in place of human workers.