Intelligent Solution TOMONI® for Advanced Maintenance and Operation of Critical Infrastructure

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It has long been said that maintaining and improving security and maintenance activities is an urgent issue for important infrastructure equipment such as that in power plants. As one of the means to solve this issue, Mitsubishi Heavy Industries, Ltd. (MHI) has proposed the intelligent solution TOMONI. TOMONI aims to not only advance the control of power generation equipment using artificial intelligence (AI) or machine learning and to realize an automated autonomous plant, but also connects customers involved in operation monitoring and operation/maintenance with work processes of MHI, an original equipment manufacturer (OEM), using digital technology in order to support customers' digital transformation (DX) and at down-to-earth "Smart Industrial Safety", MHI develops and provides various solution menus, including TOMONI Maintenance Planner.

1. Introduction

It has been a long time since the digital transformation (DX) gained momentum. While the use of digital technology has significantly changed maintenance procedures in some fields, the reality is that digital technology has not penetrated many sites where paper-based information management still remains the mainstream. In such a situation, we began our efforts to support fundamental digital transformation at maintenance sites.

In addition, the Ministry of Economy, Trade and Industry established a public-private council two years ago, and is vigorously promoting "Smart Industrial Safety," which aims to overcome the challenges that electricity power security is facing, such as shortage of personnel, aging of facilities, and severe disasters, by introducing new technologies such as Internet of Things (IoT), AI, and drones, and to maintain and improve both security and productivity in the future. Such an initiative of the government including legislation is a tailwind for digital transformation.

Our intelligent solution TOMONI is a collection of various digitally enabled products and services, including functions that store and visualize data in the cloud, control equipment (Netmation) that operates power plants and its add-on devices (Boiler AI Combustion Tuning), tools that support the arrangement of periodic inspections and smartphone apps used in on-site work in periodic inspections. Some are provided to customers, others are intended for our own use, and the others connect the two.

TOMONI leads to activities that connect our various digital products. It aims to allow various departments to connect and cooperate with each other as much as possible, rather than each department to undertake development on their own without cooperation with other departments, in order to maximize the use of data and the customer's return on investment, and improve our own operational efficiency.

In this report, the chapter 2 summarizes the values created by TOMONI as our DX approach by classifying them into value for customers, value for our own business operations, and value for power generation plants, and the chapter 3 and subsequent chapters describe examples of intelligent solutions that are under commercialization, development, and testing.

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2. Value created by TOMONI

The value that TOMONI can create consists roughly of the following three parts (**Table 1**).

Table 1 Classification of values created by intelligent solution TOMONI

	Target	Content	Value
1	Digitization of customer work processes	O&M upgrading, knowledge management, data visualization, and cyber security enhancement	Cost saving, labor saving, efficiency enhancement, human resource development, technology transfer, safety, and business continuity
2	Digitization of MHI's own work processes	Strengthening remote operation support in response to the COVID-19 environment, and supporting customer asset management through the plant lifecycle by utilizing digital technology	Cost saving, labor saving, efficiency enhancement, infection disease response, safety, after-sales service quality improvement, and increase of product added value
3	Digitization of power plants	"Automatic autonomous" of power plant to realize optimal operation and maintenance, performance improvement, trip prevention, component life extension, demand forecasting, power generation optimization, and energy management	Performance improvement, Operation rate enhancement, power selling optimization, and flexibility improvement

2.1 Digitalization of customer work processes

In promoting the digitalization of MHI's own work process and delivered power plants, what is indispensable for digital innovation in asset management is to support "1. Digitalization of customer work processes". The customer's work processes are diverse, and digitalization of these processes is a drawn-out undertaking, but moving ahead with this will bring the following three benefits.

(i) Customers themselves can experience the transformation of maintenance through digitalization,

(ii) Information necessary for optimal asset operation and maintenance enhancement can be organized, accumulated, and visualized, and

(iii) Contribution to uniform management of maintenance information can be made.

This support also improves communication between MHI, the manufacturer, and customers, the users, which enables more seamless information sharing and data coordination, and is expected to increase customer earnings and create new solutions through synergies between the two parties.

TOMONI aims to contribute to our customers' continuous digital innovation by adopting secure communication connections to the field and the latest and most reliable digital technology and system architecture with plant safety operation as the first priority, and by providing solutions that have been proven in critical infrastructure facilities.

2.2 Digitalization of MHI's own work process

Currently, we are actively working on "2. Digitalization of MHI's own work process", such as strengthening remote overseas commissioning support under circumstances where overseas travel is restricted due to the COVID-19 outbreak. For the Nakoso and Hirono Power Plants, for example, in addition to real-time operation data monitoring during the commissioning period, we also produced more advanced commissioning support tools in a very short period of time, contributing to the execution of the project. In other words, among the input information to TOMONI necessary for major test verification, identify data that hinders analysis such as missing or duplication, and perform analysis processing after data cleansing that processes data according to the purpose of verification, AI prediction of events occurring in equipment components, driving support dashboards, etc.

TOMONI is also expanding its scope of application to digital solutions beyond the so-called IoT, such as the provision of a support system for estimating necessary items for the next periodic inspection based on the utilization of past periodic inspection data, and the use of digital applications (such as AI-based foreign object management and work flow management) in on-site work during periodic inspections.

In this way, the solutions of TOMONI are brushed up by in-house use and improvement, and they are provided to customers as well if they are determined to be valuable to offer as services or products.

2.3 Digitalization of power plants

To realize "3. Digitalization of power generation plants," we build systems that require real-time operation monitoring and decision making in the power plant premises, and allow them to be linked to a cloud environment suitable for big data collection and analysis to form optimal systems as a whole. Examples include AI-based boiler combustion adjustment, gas turbine (GT) performance improvement solutions, and automatic opening/closing test functions for key valves for prevention of trips during startup.

Going forward, we will not only digitalize these individual facilities, but also link them to an energy management system (EMS) that combines forecasts of plant power consumption, renewable energy generation, and electricity sales prices, in order to create a so-called "automatic autonomous plant" where the plant is operated automatically and autonomously to maximize overall facility profitability and achieve reduction of carbon/CO_2 emissions.

3. Smart maintenance

Smart maintenance aims to improve the efficiency and quality of maintenance through smartification as described in 3.1, and is supported by the security services described in 3.2.

3.1 TOMONI Smart Maintenance: maintenance reform with digitalization

While many maintenance sites are seeking to promote DX and smartification, spectacular measures such as AI and predictive abnormality detection tend to attract attention. However, based on our experience of diverse discussions and practices over the past seven years since the launch of TOMONI's predecessor, we believe that DX is also a drawn-out undertaking, and that what is needed for innovation is to continue to incorporate digital technology, even including simple matters, into maintenance work processes, and to spread that wave to every corner of the world. Through this steady activity, the accumulation of a sufficient amount of information and its systematization and coordination are made possible. We believe that this will enable the effective handling of information, which will ultimately lead to the realization of more sophisticated and higher quality maintenance. Furthermore, we are aiming for a future vision of maintenance in which individual maintenance activities are connected by digital technology and all of them are managed centrally. As a plant manufacturer that supports maintenance, we have started using TOMONI to bring this vision to the commercialization process. As a stepping stone, we are currently offering the TOMONI Basic Package (**Figure 1**) to support our customers' day-to-day maintenance operations. This package is designed to be as "ready-to-use" as possible for customers by incorporating technical information on the hardware equipment we supply to strongly support digitalization of customer work processes, and includes the following contents.

- Improvement of maintenance work in efficiency and quality: maintenance planner to widely support maintenance processes such as maintenance history management and work planning support, and boiler smart inspection to visualize inspection history, etc.
- Smart search for easy search of technical materials and documents,
- A bulletin board that serves as a communication tool with manufacturer engineers, and
- TOMONI blog that provides brief explanations of technical information, industry information, etc.

In addition to the basic package, we have prepared a large number of individual solutions that contribute to smartification. In the future, we will organize, integrate, and expand them to build a new "TOMONI smart maintenance" process as described above.

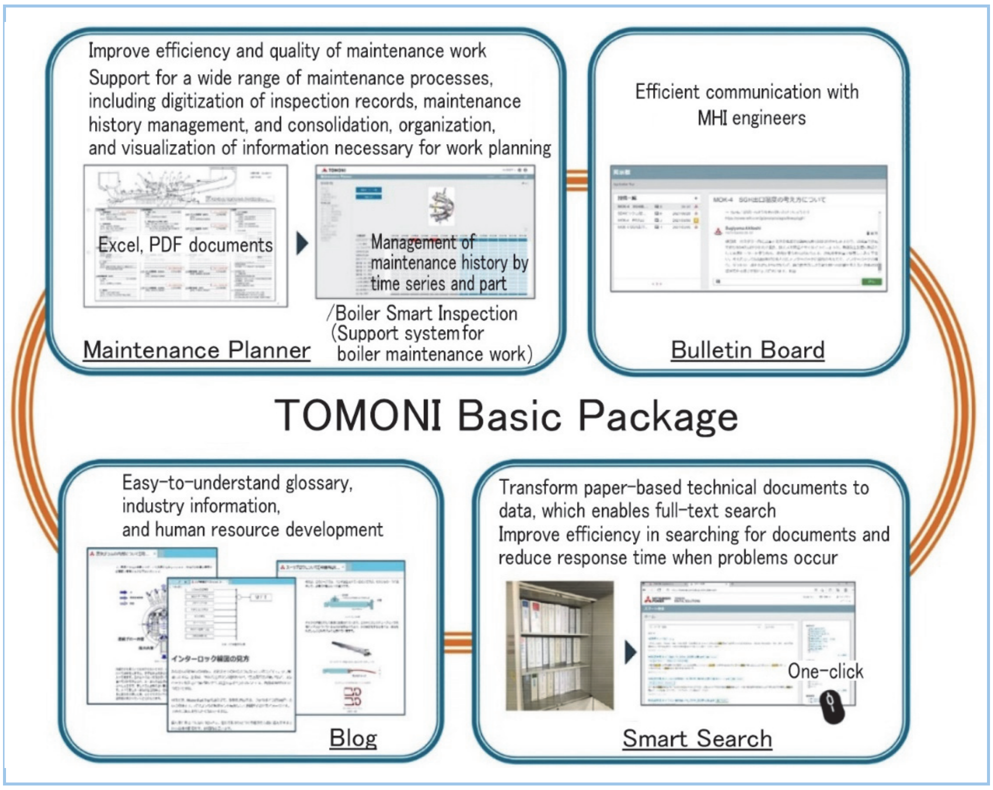

Figure 1　Maintenance reform with digitization: Smart Maintenance

3.2　Control system security services (NPP: Netmation Protect Pack)

Standards for control system security for critical infrastructure facilities have been developed, and compliance with various standards such as IEC62443-3-3:2013, NERC-CIP (Middle Impact BES Cyber System), and JESC Z0004-2016 is required. To achieve advanced maintenance operations, it is necessary to build not only a cloud system but also a secure system architecture that includes the entire control system on the power plant premises. We have developed NPP for our control system, DIASYS Netmation, to allow it to comply with this standard, and have delivered it to overseas gas turbine combined cycle (GTCC) plants with strict security requirements. We have conducted a gap analysis between DIASYS Netmation and the above-mentioned standards, especially the SL-2 target requirements of IEC62443 3-3, and developed security requirements and solution specifications that NPP should address based on the National Institute of Standards and Technology (NIST) framework as the NPP's required specifications (**Figure 2**). In the future, we will start full-scale services such as appropriate provision of Windows security patches, patch application and management, and monitoring and analysis of collected security logs, in order to improve the reliability of control systems for our customers and integrate them with TOMONI's digital solutions.

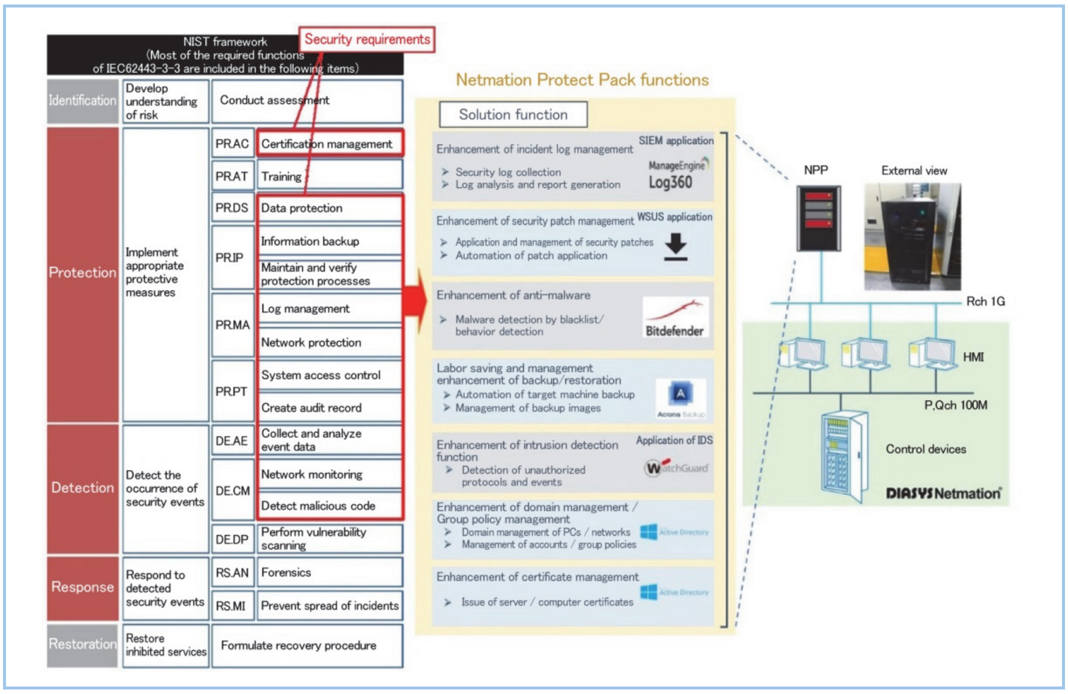

Figure 2 Control system security services

4. AI-based control improvement and trip prevention applications

4.1 Trip prevention application for GTCC

MHI has been provided remote monitoring services to support power generation plant operation and maintenance mainly for customers who have long-term service agreement (LTSA). This service has been provided by the TOMONI HUB, which not only provides remote monitoring functions, but also combines our various solution capabilities to help improve the value of facilities and realize a decarbonized society together with our customers. As a result of analyzing big data collected by the TOMONI HUB, 76% of trips in GTCC plants occurred during GT load operation, and 24% during GT startup in the overall factors. With the rise of renewable energy sources in recent years, GTCC plants play a role of adjuster of power grid than ever before, and the number of startups and the opportunities for startups from a standby state are increasing. Against such a background, we have focused on reducing the trip factor during GT startup. In addition, it has been found that the top six items account for about 80% of the trip factors during startup (**Figure 3**).

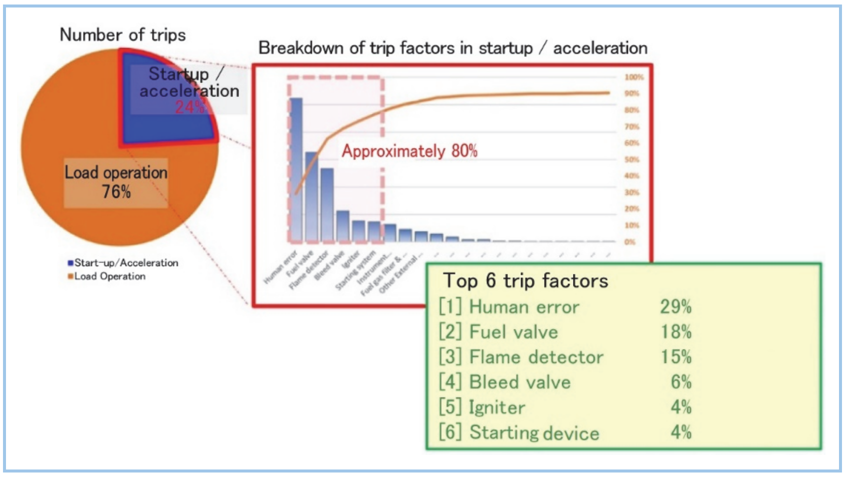

Figure 3 Factor analysis of trip in GTCC plant

Therefore, we developed an application to improve workability with the aim of reducing human error, which is the top item of the six mentioned above. Of the human errors, 35% were caused by poor system isolation or restoration work after maintenances. For example, there was a case where a manual valve that should be open during normal operation was closed for a periodical inspection, and the operator forgot to open it again after the inspection, resulting in a trip during the plant restart process. To prevent such an error, we developed an application that provides instructions for manual valve operation and status management (**Figure 4**). This application makes it possible to identify the manual valve to be worked on by reading the RFID tag attached to the manual valve in advance using a smartphone on-site, and links the isolation and restoration work procedures and the system diagram data to each other to enable centralized data management and confirmation with a smartphone.

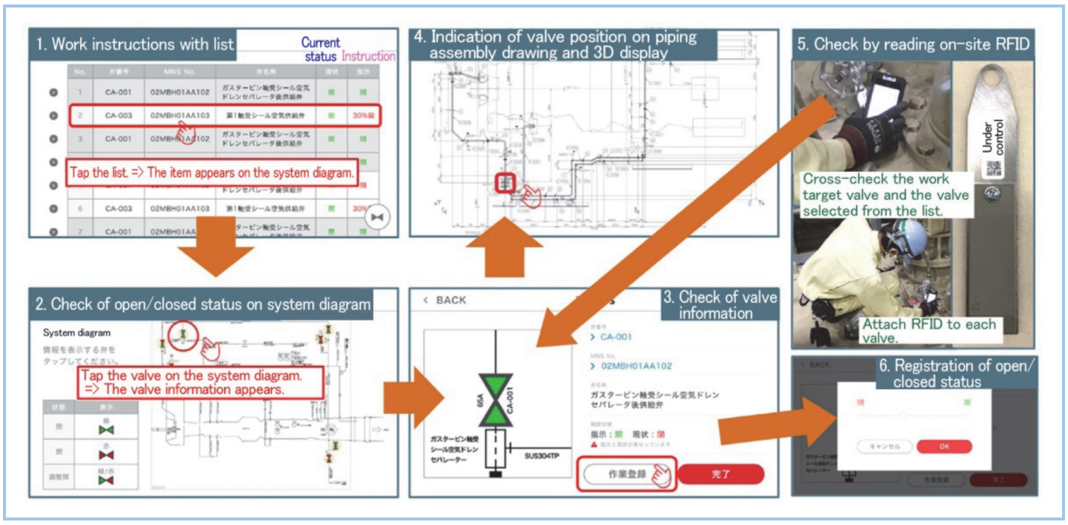

Figure 4　Example of workability improvement application

For fuel valves, bleed valves, and igniters (**Figure 5**), which are next in the list of trip factors during GT startup, we have developed an application that activates these devices while the plant is shutdown (before startup) to acquire data and diagnose the device status (**Figure 6**). By grasping the before-startup and over-time device status with this application and displaying recommended inspection items if an abnormality is suspected, performing appropriate maintenance in advance has been made possible so as not to affect the startup of the plant, which contributes to the maintenance planning and improvement of starting reliability.

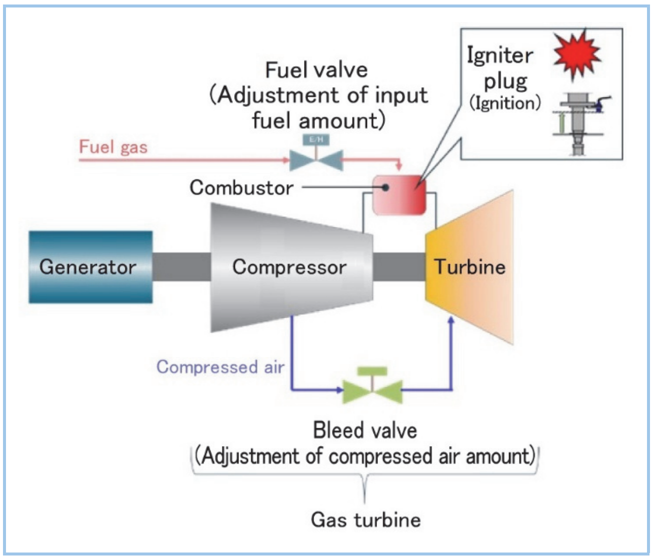

Figure 5　Schematic diagram of fuel valve, bleed valve, and igniter

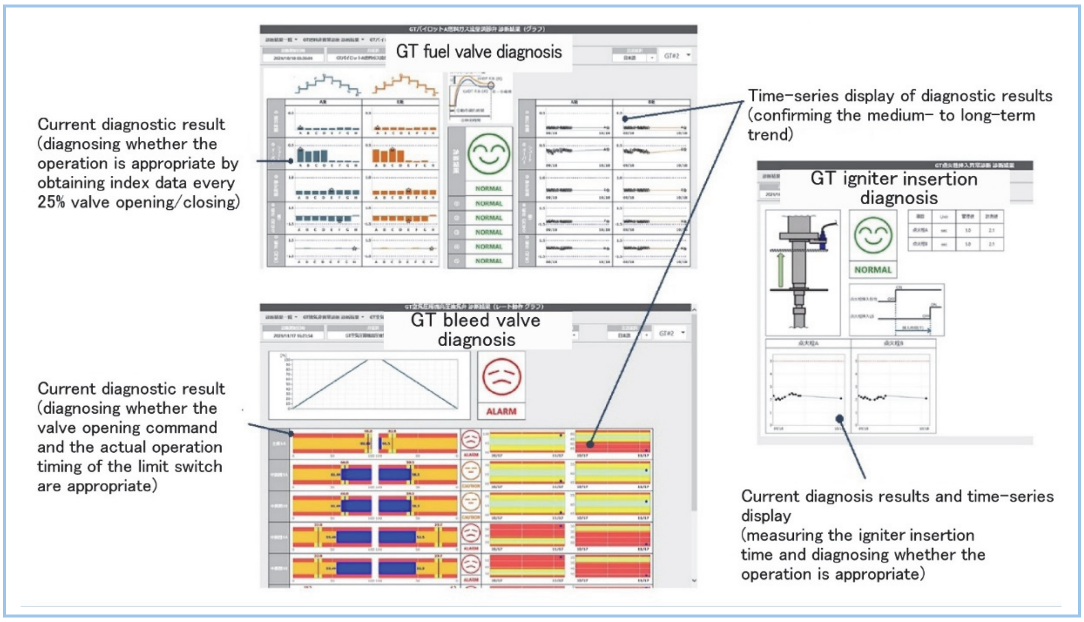

Figure 6 Example of trip prevention application for GTCC

4.2 Application for improving workability

This section describes the efficiency improvement of heat insulation work of GT as a case example. In the past, the heat insulation work of GT includes time-consuming undertakings, such as restoration work while checking the mounting position for each piece of heat insulation material with the drawing and repair work, in case of damage, including size readjustment of the heat insulation material. To solve this problem, we have developed modular heat insulation blocks and a guide system application for disassembly and restoration work. The modular heat insulation blocks have a shape suitable for each mounting position and a size that can be carried by one person, and their mounting method is also revised to be simpler, requiring only hooking of metal fittings, fastening with velcro fasteners, or the like. As a result, the labor and time required for repair work can be reduced by approximately 80%, compared with conventional cases.

The guide system uses a smartphone to read a barcode attached to each modular heat insulation block and provides guidance on the installation and storage locations of the heat insulation block on a 3D drawing. As a result, the system eliminates the need for conventional checking on drawings and improves the work efficiency (**Figure 7**). In addition, when a worker inputs his/her work progress into his/her smartphone, it is reflected on the management screen in real time, and the progress is shared with other smartphones. This not only improves the efficiency of disassembling and restoring heat insulation as well as enhances the quality due to prevention of omissions, but also enables heat insulation work to be performed with uniform quality even when workers' experience varies, because conventional wiring and size readjustment is no longer needed and the possibility of installation position error is eliminated.

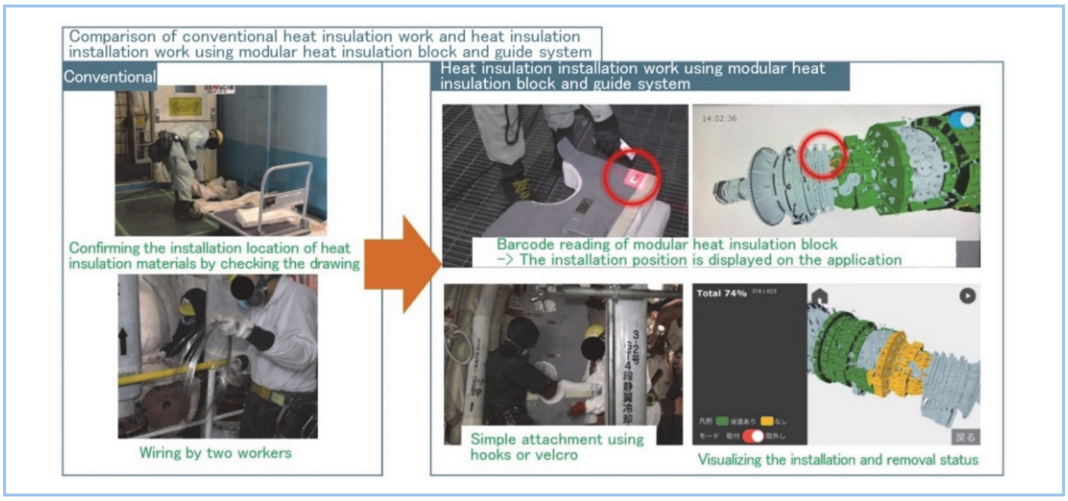

Figure 7 Modular heat insulation block application

4.3 Boiler AI Combustion Tuning and control optimization of steam power generation (Netmation OscAR®)

MHI offers the boiler control optimization system (Netmation OscAR) which MHI Power Control Systems Co., Ltd. develops for steam power generation and the boiler AI combustion tuning which MHI develops for coal-fired boilers as widely applicable digital solutions for improving the economic performance and stabilizing the operation of steam power generation regardless of domestic power generation, private power generation, or IPP.

Specifically, Netmation OscAR improves the controllability of boilers, the operation of which is restricted such as being operated with lowered main/reheat steam temperature settings due to controllability problems to enable operation with the temperature settings unrestricted, thereby improving the efficiency. In addition, the system can stabilize operation by suppressing alarms and reducing manual intervention by operators due to reduced control fluctuations. Furthermore, the Boiler AI Combustion Tuning can comprehensively improve environmental performance, boiler efficiency, auxiliary power, etc., and achieve improvement of the economic efficiency. These systems are, by being offered through TOMONI, enabled to cooperate with smart maintenance and other digital solution menus, which improves services. In addition, future applications to biomass co-firing and ammonia co-firing are also expected.

4.4 Optimization of desulfurization using AI for update of desulfurization computer

We are working on digital solutions for the purpose of optimizing the operation and maintenance and reducing operating costs of desulfurization equipment, using AI technology. Demonstration testing is underway.

- Reduction of continuous operation cost (power consumption in the plant) of desulfurization equipment
- Improvement of gypsum board (by-product) quality by improving the concentration of calcium carbonate in the absorber.
- Development of a calcium carbonate concentration soft sensor to enhance performance and equipment diagnostic functions

For customers who need to measure the calcium carbonate concentration, we have conventionally provided analyzers, but there are many issues with their maintainability, such as clogging of sampling pipes. Therefore, by formulating and verifying the physical formula for predictive calculation, the calcium carbonate concentration soft sensor achieved a prediction accuracy of 2.57% (FS) with a physical formula plus neural network model using NODE (Neural Ordinary Differential Equations). Furthermore, the transfer learning achieved a 7.88% (FS) error (**Figure 8**). Looking ahead to future alternatives to requesting the removal of calcium carbonate concentration meters for thermal power plants in commercial operation, we are carrying out in-house verification.

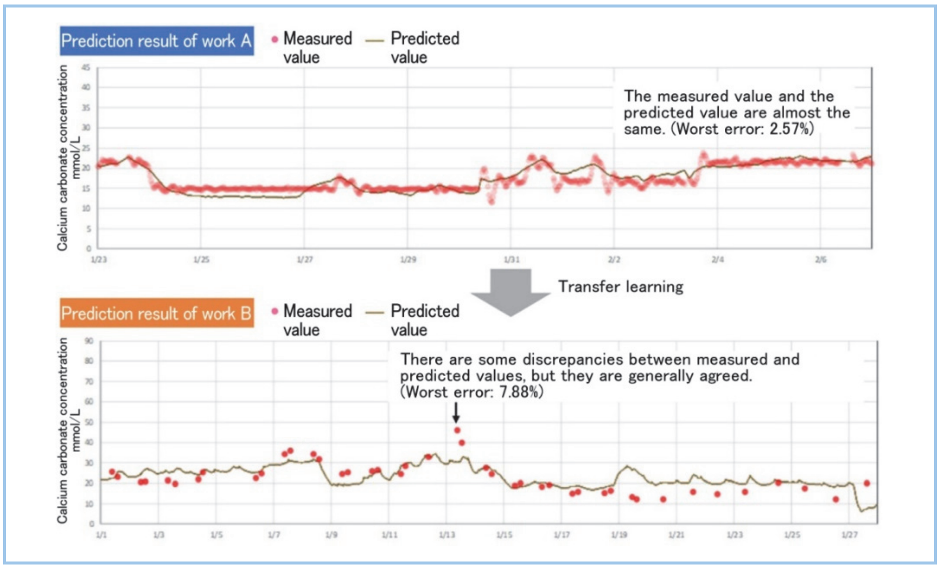

Figure 8 Improvement of prediction accuracy using calcium carbonate concentration soft sensor

In addition, for plants where the settings of the number of absorber pumps and pH with respect to load increase are fixed, we propose the optimum operation function, which optimizes these settings according to changes in operating conditions, such as coal type. This function outputs an optimum operation index diagram (optimum index of the number of operating slurry circulation pumps and pH setting value with respect to the generator output) (**Figure 9**). By reducing the number of slurry circulation pumps in operation while properly maintaining the pH, it becomes possible to reduce the power consumption in the plant. In the demonstration test for comparison with a conventional computer, it has been confirmed that the same prediction performance has been achieved. Especially under the operating conditions where the load change is large, an advantage is found in that the adjustment coefficient is recalculated as needed. We have started business negotiations along with the development for commercialization.

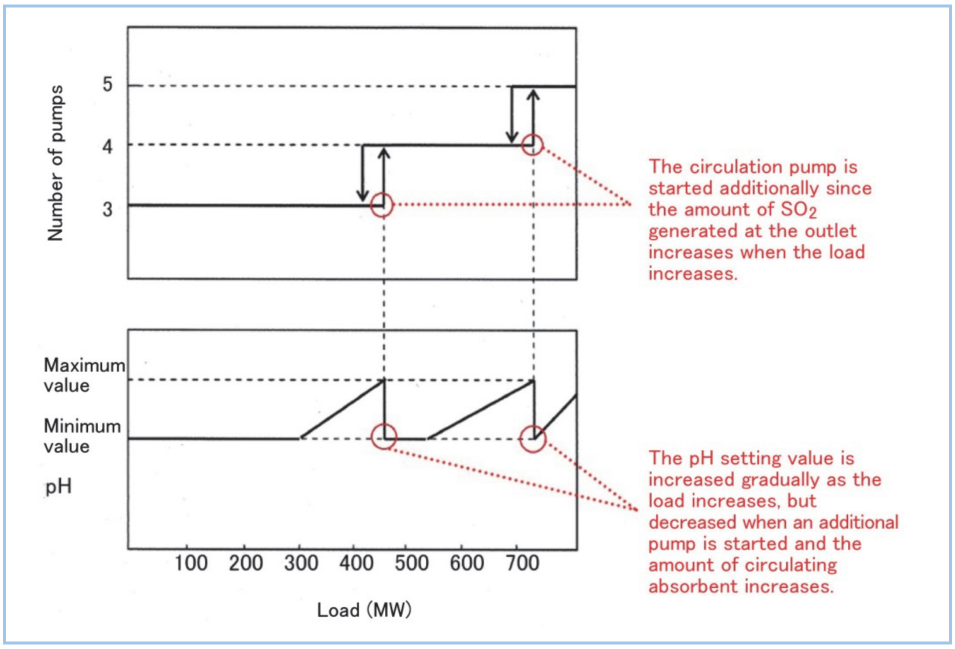

Figure 9 Optimum operation index diagram of slurry circulation pumps (example)

5. Energy management using TOMONI

MHI Group has declared the achievement of carbon neutrality (CN) by 2040 and is strongly promoting energy transition aimed at decarbonization. In Japan and overseas, the introduction of renewable energy sources such as photovoltaic (PV) and wind power generation and battery energy storage systems (BESS) for CN is progressing. On the other hand, energy management through optimal operation of thermal power generation facilities and BESS is indispensable to improve factory profits and reduce CO_2 emissions under the circumstances where the electricity market and fuel prices fluctuate while making maximum use of unstable renewable energy sources.

Based on the wealth of expertise in energy equipment that we have accumulated as a comprehensive plant manufacturer, we have been developing demand forecasting technology using AI, technology for optimizing the performance in operational load zones, and an energy management system (EMS) that combines these devices[(4)]. Currently, we are studying to realize a carbon-neutral factory through demonstration tests at our own factory, conducted by our Research & Innovation Center. The cloud-side EMS utilizes our original AI-based demand forecasting engine (ENERGY CLOUD®) to forecast factory electricity demand and photovoltaic power generation in TOMONI platform in order to visualize forecasts and actual results and optimize energy control. The edge-side EMS provides power sharing commands to subordinate PV and BESS equipment based on demand forecasts and planned values from the TOMONI, and is also equipped with an adjustment function to suppress the imbalance between supply and demand based on the assumption of self-wheeling (**Figure 10**). In this demonstration test, we are verifying 100% utilization of PV for self-consumption and minimization of life-cycle costs by optimizing the equipment operation using the EMS.

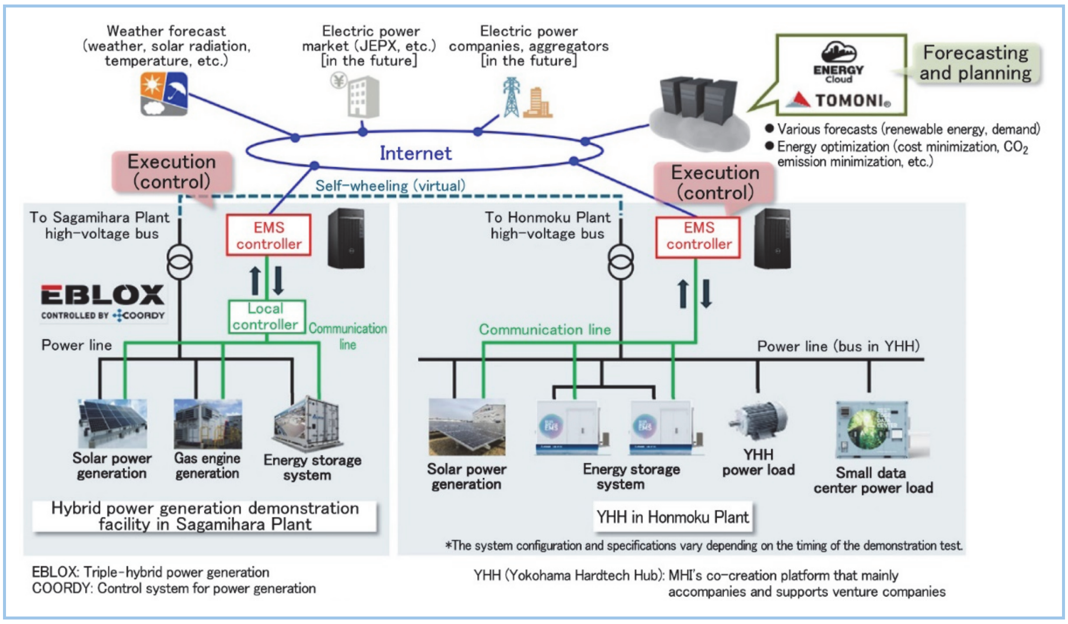

Figure 10 Configuration of energy management system

Moving forward, we plan to provide EMS digital solutions tailored to customer facility configurations, scale, and operational needs by coordinating domains within the MHI Group, building an EMS that controls electric energy and thermal energy equipment, and promoting standardization of user interfaces.

6. Conclusion

We support the realization of a high level of security and maintenance throughout the lifecycle of critical infrastructure by working on digitization of our customers' and our own work processes and power plants and providing the intelligent solution TOMONI. In addition, to ensure safe handling of data between facilities and between the edge and the cloud, we take security measures in accordance with standards to enhance the reliability of the entire system. We conduct our activities in a down-to-earth manner, in close contact with our customers and the operation sites, and are gradually expanding the systems starting with ones that will be effective in their implementation in order to allow them to be used continuously. We are planning to establish a hydrogen power generation demonstration facility at our T-Point in Takasago machinery works in Japan to build a system that will enable us to verify our own hydrogen production and power generation technologies in an integrated manner. We will also work diligently to build an energy management system that will require the comprehensive capabilities of the MHI Group to establish more advanced operation and maintenance technologies.

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Netmation OscAR® is a registered trademark of MHI Power Control Systems Co., Ltd. in Japan.

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