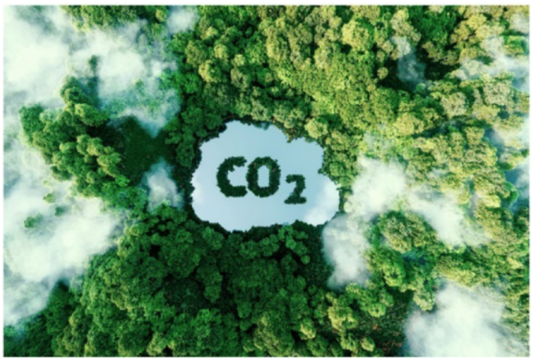
The Latest Initiative of Intelligent Solution TOMONI® to Achieve Carbon Neutrality



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At present, initiatives toward carbon neutrality are required of every business entity all over the world. Mitsubishi Heavy Industries, Ltd. (MHI) has formulated initiatives from both aspects of CO_2 emissions reduction and CO_2 capture. In order to contribute to achieving our carbon neutrality goal through the utilization of digital technologies, MHI is developing solution menus for the intelligent solution TOMONI®, mainly in power generation. This report introduces our solutions for reducing CO_2 emissions from gas turbine combined cycle (GTCC) and steam power (SP) plants and facilities to achieve carbon neutrality.

1. Introduction

Aiming to solve climate change problems which are global issues, the Paris Agreement was adopted in 2015 and over 120 countries and regions throughout the world have set a target of "2050 carbon neutrality" in order to realize the goals of the Paris Agreement. In October 2020, the Japanese government declared that by 2050 Japan would aim to reduce greenhouse gas emissions to net zero, that is, to achieve carbon neutrality. MHI has set two growth areas in its medium-term business plan "2021 Business Plan" announced in 2020: "Energy Transition" aiming for decarbonization on the energy supply side; and "Smart Infrastructure" achieving decarbonization, energy saving and manpower saving on the energy demand side. By promoting the businesses in these areas and also by promoting decarbonization, electrification and intelligence of existing businesses, we aim to achieve carbon neutrality by 2040 and contribute toward the achievement of a carbon-neutral society.

Our intelligent solution TOMONI is a collection of various digitally enabled products and services and contributes to the promotion of the above-mentioned "Smart Infrastructure". More specifically, some of those products and services lead to the reduction of CO_2 emissions directly by improving the efficiency and operation of power generation facilities through the optimization of control parameters required for the operation of a power plant or with add-on devices and reducing the consumption of fuel gas and coals. Others lead to the reduction of CO_2 emissions during manufacture by storing the operation data of a power plant in the cloud and analyzing the data to optimize parts replacement timing, or to the reduction of CO_2 emissions from the movement of people by remotely or automatically conducting maintenance work such as tuning.

This report describes examples of intelligent solutions that are under commercialization, development and demonstration testing, which contribute to the achievement of carbon neutrality from the aspect of digital technology utilization.

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2. What is TOMONI?

As of 2023, we have provided TOMONI services to 138 thermal power plant units worldwide (as of the end of May 2023), centered on GTCC plants and SP plants, with the connection to the cloud environment at a high cybersecurity level. TOMONI has provided to customers a foundation that supports comprehensive maintenance services for power generation facilities represented by Long Term Service Agreement (LTSA) and supports availability guarantees for power generation facilities. In recent years, however, TOMONI has played a role as a communication hub centered on our TOMONI HUB (remote monitoring center) through which the customer and our company can easily share information on daily problems in power plant operation to lead to actual measures to solve said problems, contributing to the establishment of good relationships with customers. The overview of TOMONI is shown in **Figure 1**. The introduction of TOMONI contributes to, for example, "the efficiency and certainty of daily patrol, inspection and management work in maintenance and the need for the judgment support of maintenance workers and manpower reduction" and the "increase of added values of our products in operation and achievement of specific customer's benefits such as economic values and carbon neutrality" . The representative examples of applications that are being put in practical use are summarized from the standpoint of "contribution to the reduction of CO_2 emissions" in **Table 1**. In Chapters 3 and 4, the individual applications are introduced.

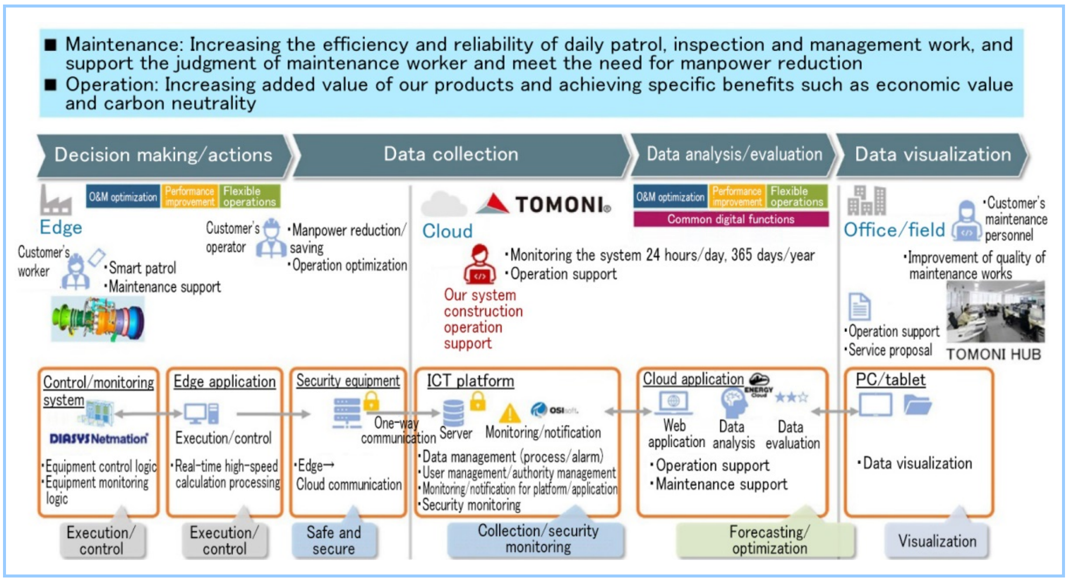

Figure 1 Overview of TOMONI

Table 1 Contribution to reduction of CO_2 emissions and examples of applications

	Category	Examples of applications(* introduced in the report.)
1	Contribution to the direct reduction of CO_2 emissions (Plant control optimization)	- Performance optimization package* ((1) IGV Optimization, (2) GT Cooling Air AI-Optimization, (3) TCA Optimization, (4) Full Load Performance Optimization) - Boiler optimization solutions* ((1) Boiler AI combustion tuning, (2) Netmation OscAR)
2	Contribution to the indirect reduction of CO_2 emissions (Proper maintenance, quick recovery from an unplanned outage, reduction of TA dispatch, etc.)	- Plant operation viewer - Inlet Air Filter Differential Pressure Monitoring* - GTCC Performance Diagnosis - Predictive anomaly detection (Pre-ACT) - Initial response support (Post-ACT) - Trip Prevention Package - GTCC remote combustion tuning/automatic combustion tuning

3. Solutions to achieve carbon neutrality

This chapter describes examples of solutions for individual facilities such as GTCC plants and SP plants and those for a group of facilities including these plants, respectively.

3.1 Solutions for GTCC plants

Even under the circumstances where renewable energy is positively introduced, thermal power generation still plays an important role in adjusting the balance between demand and supply, and especially, the presence of GTCC plants that are high-efficient power generation facilities is increasing. As case examples of solutions to further increase the added value of these GTCC plants, the "GTCC performance optimization package" that optimizes the efficiency through optimization of control parameters, the "remote combustion tuning and automatic combustion tuning" that reduces manpower and the "Inlet Air Filter Differential Pressure Monitoring" that leads to effective utilization of resources are described.

3.1.1 GTCC performance optimization package

At our GTCC power generation plants, we have strived to maximize the thermal efficiency at 100% load, automate the startup and shut down of units and improve the load following capability while observing the environmental regulation values. Recently, for plants where the operation rate is decreasing and partial load operations are increasing due to the introduction of renewable energy, we developed solution menus for optimizing the performance within limit values even in partial load region by optimizing the opening of the compressor inlet guide vane (IGV) and the operation of the cooling system. The developed solutions with TOMONI are (1) "IGV Optimization", (2) "GT Cooling Air AI-Optimization" and (3) "Turbine Cooling Air Optimization" [(1)], and have been delivered to GTCC power generation plants in Japan and overseas. On the other hand, even if the operating point is at nearly 100% load, it may deviate from the exhaust gas temperature controlled operating point due to aging of the gas turbine (GT) and changes in external conditions such as condenser vacuum. Therefore, we developed another solution: (4) "GTCC Full Load Performance Optimization" that allows us to additionally control the IGV while observing the actual equipment status and implemented it in commercial plants after the validation with actual equipment.

It is necessary that these individual performance optimization solutions should be linked and work with one another and the performance and generator output at every load should be autonomously optimized in accordance with the operation needs of each power generation plant. However, the function of optimizing the performance at each load has not been linked so far. We are now developing a solution package including this function, aiming to provide it to customers so that they can not only conduct optimal control but also utilize the operating time and effects of the function displayed on the Web application as indicators for optimal operation of GTCC power generation plants.

Moving forward, we will provide it as a GTCC performance optimization package widely to customers and contribute to the reduction of CO_2 emissions by providing technologies that support GTCC plants more precisely and timely since the positioning and operation of GTCC plants are subject to change due to effects of the increase of renewable energy, etc.

3.1.2 GTCC remote combustion tuning/automatic combustion tuning

Stable combustion is very important in improving the availability of GT and GTCC power generation facilities, and therefore combustion tuning is conducted so that a proper input ratio of fuel and air (fuel-air ratio) can be obtained based on the fuel composition and atmospheric conditions. The parameters required for combustion tuning are determined by the combination with multiple systems in the power generation plant and combustion tuning is very complicated. Therefore, the expertise of our operation advisors and combustion tuning engineers is required. Conventionally, they had to go to the power plant to conduct combustion tuning in the site when a significant change in fuel properties and atmospheric conditions occurred and re-tuning was needed. Therefore, the operation could not be conducted or was restricted until our tuning engineer arrived at the site.

It is technically possible to configure the system that our combustion tuning engineer lets access the power generation plant over the network and to remotely change the parameters (remote combustion tuning system). However, the rotating equipment requires high-speed responsiveness every second and must be tuned within an operationally allowable delay time attributable to communication. As such, we also developed an “automatic combustion tuning system” that allows the simplification or automatization of the operation that has been conducted by our combustion tuning engineer using their expertise, and we are working toward the application to actual equipment (**Figure 2**). The automatic combustion tuning system allows the customer to check and judge on changing of parameters in the system, without waiting for our tuning engineer to arrive, while our combustion tuning engineers and related remotely can support as needed.

These systems will reduce the energy loss generated during the movement of the tuning engineer and become a means of solving the constraints of movement as experienced under the novel coronavirus pandemic. The validation of the systems for F-type GT units was conducted with certain commercial power plant and the technical development was completed. At present, the technical development for J/JAC/GAC-type GT units is being conducted.

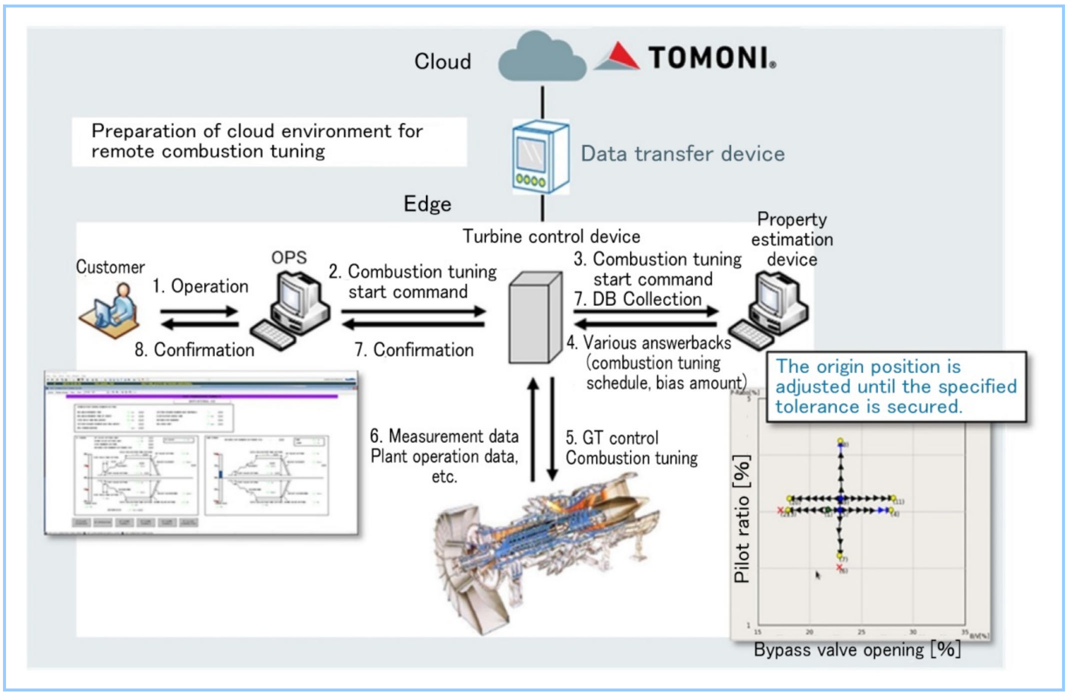

Figure 2 Automatic combustion tuning

3.1.3 Inlet air Filter Differential Pressure Monitoring

One of the factors of the reduction of GT performance is an increase in pressure drop due to contamination or clogging with time of the inlet air filter installed at the compressor inlet. At conventional GTCC plants, generally, the inlet air filter was replaced with a new one according to the Time Based Maintenance (TBM) to reduce pressure drop and maintain high-efficiency operation.

Now it has been confirmed that by storing the data on the inlet air filter differential pressure as a big data in the cloud environment and preprocessing or adding some user interface adjustment, users can be provided with materials for making judgment on the economic performance and as a result, more appropriate timing for replacement of inlet air filters can be estimated compared to the TBM. In other words, when the system has a function of displaying the comparison data between the past differential pressure trend data and the present data, and the influence quantity data of output and efficiency reduction as a manufacturer knowing the characteristics of GT, it will allow us to judge the optimal timing for replacement of intake air filters (Condition Based Maintenance (CBM)) based on cost-effectiveness.

Furthermore, it makes it possible to detect signs of anomaly in a short time and support the operator's judgment on maintenance. For example, when a cold wave comes, the inlet air filter differential pressure may suddenly increase due to freezing or adhesion of snow. In the Inlet Air Filter Differential Pressure Monitoring, when a sign of such a differential pressure rise is detected, an alert is issued. Then, the operator conducts a site investigation and promptly operates the anti-icing system. The anti-icing operation contributes to the safe operation, but after the anti-icing operation is started, some of the compressed air that had been supplied to the combustor is supplied to the anti-icing system and the plant performance will be lowered. Hereafter, the anti-icing operation will be operated only when needed according to the alert of this application so that the fuel consumption can be reduced (**Figure 3**).

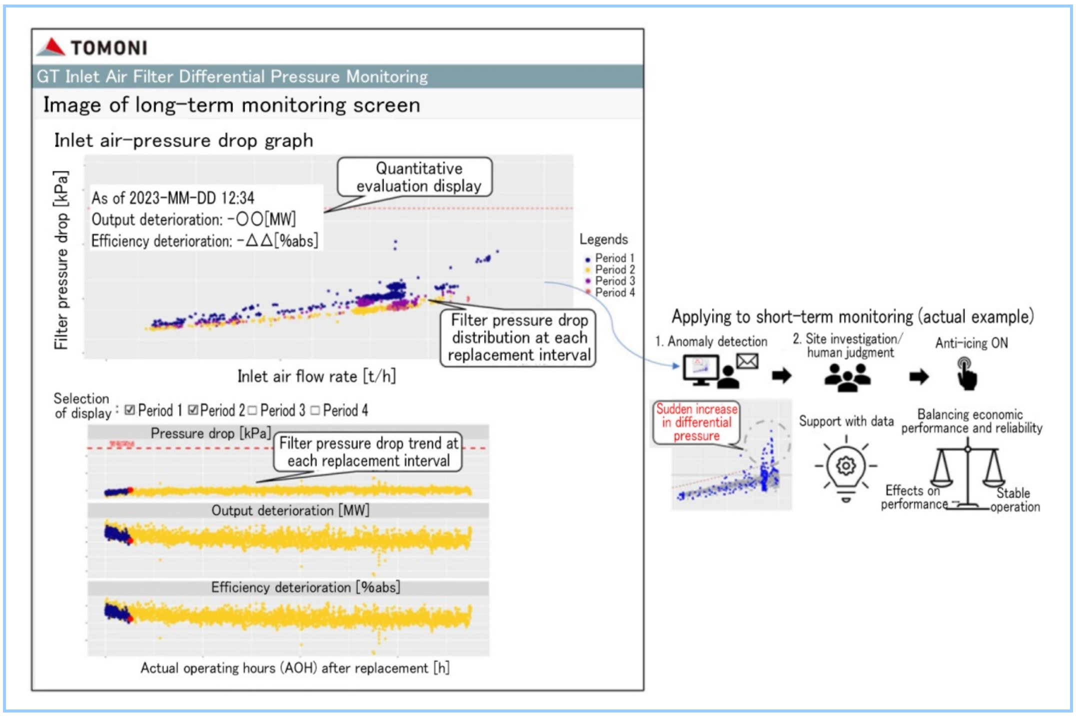

Figure 3 Monitoring screen of Inlet Air Filter Differential Pressure Monitoring and use case

3.2 Solutions for SP plants - Boiler optimization solutions -

One of the efforts toward carbon neutrality is the decarbonization of coal-fired boilers through fuel conversion into ammonia. Until the technology is implemented, there is a need for technologies that contribute to the stabilization of the entire power system while reducing CO_2 emissions through efficiency and controllability improvement. MHI is developing solutions for SP plants, aiming to provide widely applicable intelligent solutions for improving the efficiency and economic performance and stabilizing the operation of SP regardless of domestic power plant, private power plant or IPP.

Static heat balance, combustion properties and dynamic load responsiveness of boiler change due to fuel properties, aging deterioration, etc. Therefore, it is desirable to conduct combustion tuning in order to maintain an optimal operation state. In this section, Boiler AI Combustion Tuning for improving the static characteristics and the boiler control optimization system (Netmation OscAR®) for improving the dynamic characteristics are introduced.

3.2.1 Boiler AI combustion tuning system

There are diverse processes and combinations of control parameters that affect the combustion state of boilers, and combustion tuning has long relied on the experiences and expertise of manufacturers' skilled engineers. By replacing them with AI and using a digital twin (a model in digital space representing the same behavior as that of a real machine), we developed a system to support the combustion tuning for boilers (**Figure 4**). We confirmed that the system could comprehensively improve boiler efficiency, environmental performance, auxiliary power, etc., and achieve improvement of the economic efficiency and reduction of CO_2 emissions.

We construct a digital twin that simulates the relationship between changes in boiler operating conditions and changes in control parameters by using the boiler measurement data and conduct simulations depending on the operating conditions at the time. Thus, it becomes possible to provide optimal control parameters. Furthermore, we set the constraint conditions of the target real equipment based on expertise in design and control that we have accumulated as a boiler manufacturer, thereby proposing a practical operation-end setting, and by reflecting it in real equipment at a proper rate, we can improve the economic efficiency while maintaining stable operation. In May 2023, we delivered this system for a domestic commercial boiler which is in commercial operation. In addition, we have had inquiries about several other projects and are in negotiations.

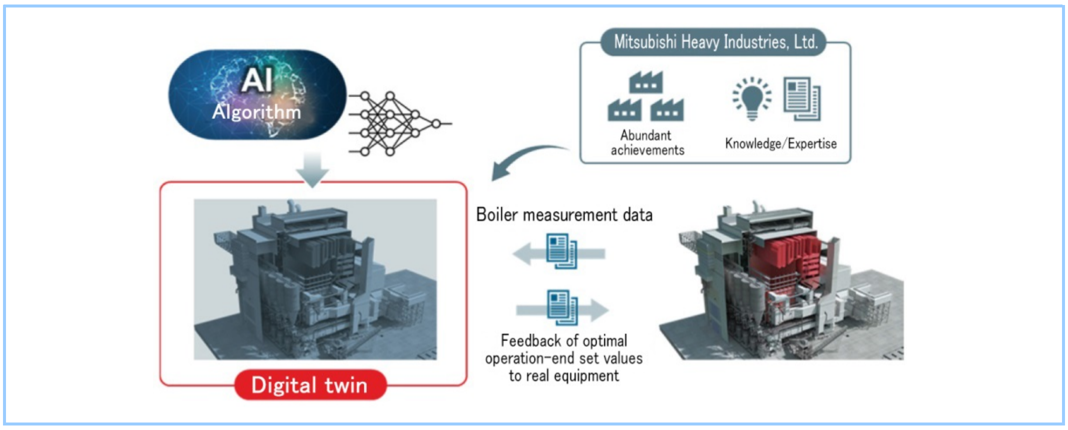

Figure 4　Overview of boiler AI combustion tuning system

3.2.2 Netmation OscAR (Optimized Suitable Control with AI Robust technology)

With our plant control technologies cultivated over many years, we have achieved stable operation of boilers for SP at partial load and 100% load with dynamic main process values such as fuel, air and temperature according to various customer needs. On the other hand, there is plenty room for improvement of fluctuations of main steam temperature, pressure, etc., caused by changes in fuel properties due to conversion from coal single-fuel firing to biomass co-firing, etc., to reduce CO_2 emissions, aging, disturbances due to blowing of a Soot Blower (SB), etc. We have studied approaches other than the conventional control algorithm and conducted system development. Netmation OscAR is a system that can greatly contribute to fuel cost reduction and stable operation through “advanced control using AI” and “improvement of control combined with improvement of an existing control loop” that embodied the expertise that MHI has cultivated as a plant manufacturer, which no other ICT manufacturers could realize. Specifically, we delivered the system for domestic industry and cooperative thermal power boilers, and confirmed the effects shown in **Figure 5**.

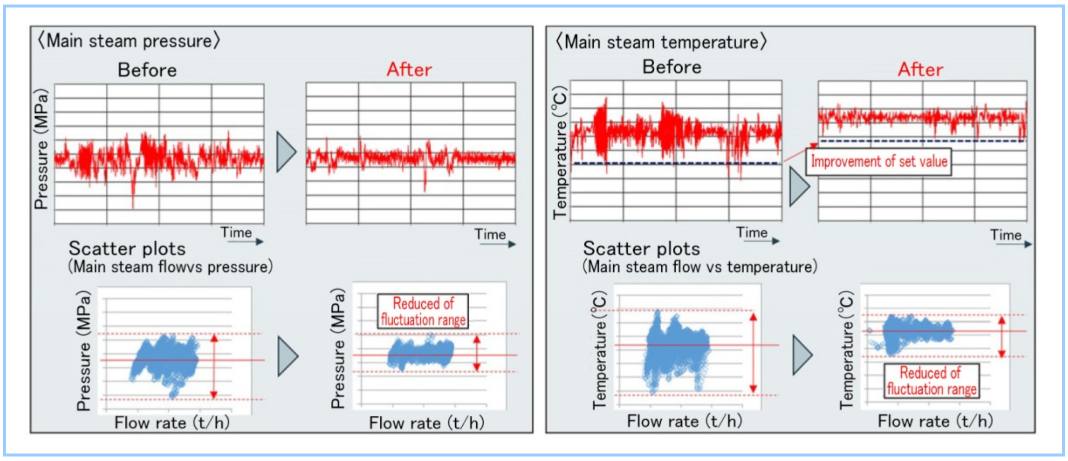

Figure 5　Example of introduction of Netmation OscAR system

The system has the control improvement functions, “PID Online Optimization Function” and “Disturbance Suppression Advance Control” and provides improvement of control for optimal operation. In addition, it can be easily introduced because it has a simple system configuration with only an external PC to be added and connects with customer's DCS for communication of signals. (**Figure 6**)

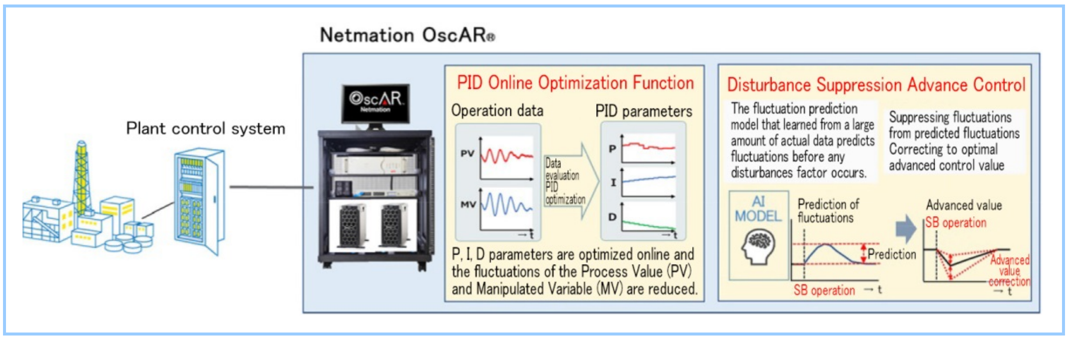

Figure 6 Overview of Netmation OscAR system

3.3 Energy management solutions

To develop power generation technologies using hydrogen as fuel for fuel conversion which is important for the decarbonization in thermal power generation, we are constructing the “Takasago Hydrogen Park” at our Takasago Machinery Works where technologies from hydrogen production, hydrogen storage to power generation can be verified in an integrated manner.

The Takasago Hydrogen Park is equipped with power generation facilities using hydrogen (large-size GTCC and medium-size GT) and hydrogen production facilities (water electrolyzer, methane pyrolysis facility, Solid Oxide Electrolysis Cell (SOEC)), which need to be operated while keeping a balance with the electric power demand of Takasago Machinery Works. Based on the wealth of expertise in operation of energy equipment that we have accumulated as a comprehensive plant manufacturer, we have been developing an Energy Management System (EMS) by combining these facilities (**Figure 7**). For power generation facilities, the EMS utilizes our original AI-based demand forecasting engine (ENERGY CLOUD®) to forecast factory electricity demand and devise a power generation plan that enables transmission of electric power. For hydrogen production facilities, the EMS enables operation planning for optimal hydrogen production with power generation status and power demand status taken into account by the system linkage. Furthermore, when the Battery Energy Storage System (BESS) is combined with the EMS, the EMS controls the discharge and charge of the storage battery, and thus a stable and efficient energy supply is realized (Figure 7). We will continue the development of the EMS function of “smartly connecting and controlling” these facilities and conduct a long-term validation while using it in our facilities and then aim to provide the EMS to other commercial power generation facilities as an energy management solution. The development of such solutions has been conducted based on the concept of ΣSynX[6].

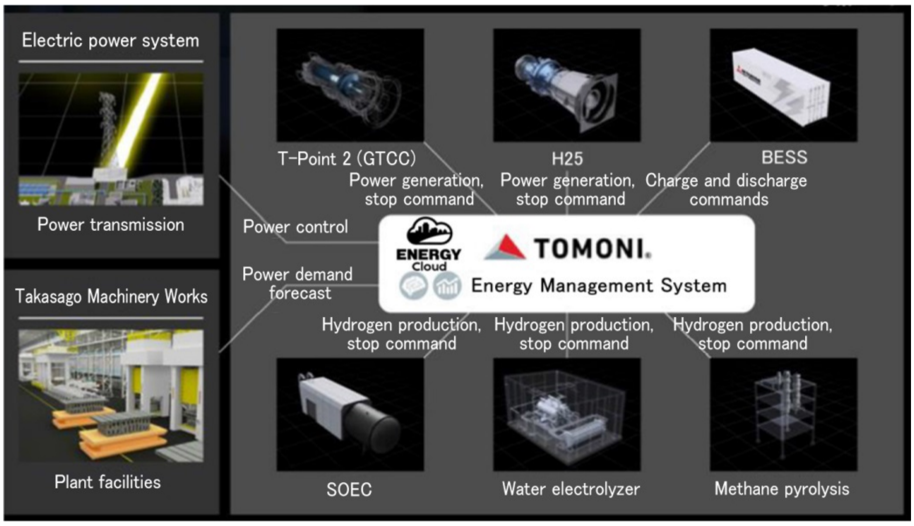

Figure 7 Energy Management System

4. Conclusion

In this report, we presented some case examples of our intelligent solution TOMONI that contribute to the achievement of a carbon-neutral society. They contribute to the reduction of fuel consumption, improvement of the efficiency of physical and human resources and reduction of CO_2 emissions for GTCC plants and SP plants. The MHI Group is also working to improve the efficiency of power generation facilities and promote the use of hydrogen and ammonia toward the decarbonization of thermal power generation. As described above, the use of the intelligent solution TOMONI allows us as a facility manufacturer to provide the processing and analysis of operation data, improve the efficiency of facilities and effectively utilize human and material resources in an integrated manner. In addition, we aim to not only optimize individual facilities but also construct an energy management system that "smartly connects" a group of facilities based on the concept of ΣSynX as described above. TOMONI allows the sharing of digital technologies throughout the whole MHI Group and the creation of synergy through combination with other various solution menus and contributes to the achievement of carbon neutrality.

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