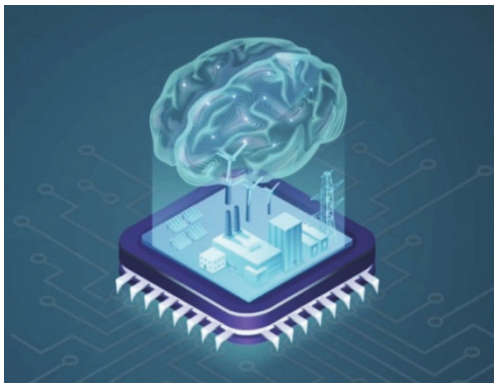
Smart Maintenance and Remote Monitoring by TOMONI® Utilizing Generative AI : Current Status and Future Prospects



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TOMONI®'s Smart Maintenance is a powerful supporter for customers doing maintenance. It accumulates data necessary for maintenance work and provides them out in a manner easy to understand from the user's perspective. Operating data from field plants/factories are stored in the cloud server, data security risks are managed, and cybersecurity requirements are handled and we support customers' equipment operation and management remotely by means of digital technologies and support tools. The in-house trial run of the generative AI (Artificial Intelligence)-enabled TOMONI application has been started, gradually making its usefulness and any possible problems clear to us, and these problems will be dealt with. By utilizing maintenance/operating data accumulated through TOMONI and combining generative AI with the existing applications, new services will be made available to customers as well.

1. Introduction

About a decade has passed since IoT (Internet of Things) and big data spread throughout industry including the power generation sector. Rapid development of AI has turned the situation regarding digital technology on its head and it is getting extremely difficult to master this technology. On the other hand, a wave of green transformation GX (Green Transformation) is sweeping through the power generation sector, which is further being hit by crisis situations such as infectious diseases and conflicts. The external factors including soaring fuel prices, depletion of human resources and floating exchange rates are also getting increasingly complicated, making predictions impossible. It is no longer appropriate for us to be content with just talking about the "application of digital technology". The situation has changed to the extent that, without a "business or service into which digital technology is incorporated as a default", we will be left behind by our rivals or other countries in the blink of an eye.

Having taken an active part over nearly a decade under such circumstances, Mitsubishi Heavy Industries, Ltd. (MHI) intelligent solution TOMONI has grown to be a pillar underpinning the energy business. Its application is expanding to other business sectors as well, which we believe is the very outcome of our initiatives being made in a "steady" and "continuous" manner.

The digital technology, which is popular with the public, mainly pertains to B2C (Business-to-Customer) involving a large number of users, while what we deal with is the B2B (Business-to-Business) world of mission-critical technologies. It should be noted that economies of scale are less likely to work effectively therein. Since there are many restrictions on security, etc., and the lifespan of equipment is extremely long, it can never be expected to have dramatic effects. The only option is to continue to make one small improvement after another.

Each chapter of this report deals with the items in the service menu and their underlying digital core technologies in the context of MHI's ideas of the "use of process data to operate power plants intelligently" and the "realization of smart maintenance through digitalization" for customers

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who are considering smartification of power plant operation/maintenance or those who are struggling with maintenance planning. This report also presents TOMONI's solutions enabling advanced maintenance and their underlying technologies. We hope that this report can give a vision for how MHI as a manufacturer will be able to go forward with customers and how the latest technologies such as generative AI can be incorporated into our services.

2. MHI's initiatives for smart maintenance

2.1 Background

The infrastructural equipment related to industrial energies such as electricity, gas and oil has long supported the Japanese industry and people's lives. Maintenance field for such equipment are faced with many management issues such as aging of equipment due to years of operation, securing of human resources and handing down of techniques. Under the banner of "smart security", the Ministry of Economy, Trade and Industry of Japan is strongly promoting the adoption of new digital technologies such as IoT and AI/drones to overcome these issues and maintain safety, enhance future security, maintain and improve productivity. On top of this, the waves of digital technology are coming as indicated by wide recognition of its remarkable advances in recent years.

MHI has proudly taken part in improving the reliability of power plant by closely involving itself in customers' equipment maintenance work for years even after making the delivery, including periodic inspections and troubleshooting. This is the very reason why MHI wants to make use of its expertise when customers are addressing their wide-ranging management issues from the viewpoint of digitalization. Thus, TOMONI Smart Maintenance has been launched. The system aims to help customers, from all directions, to reform the maintenance of their entire plants.

Figure 1 maps out the applications of digital technologies in plant maintenance. Plant maintenance involves a wide range of tasks from repair planning to routine maintenance and handling of incidents. In Smart Maintenance, it is considered important to have digital technologies ready to cover and handle as many tasks as possible and build optimal plant digitalization for each customer.

In TOMONI Smart Maintenance, building a digital platform is considered the most important among numerous digital technologies. The next section introduces our undertakings mainly related to the aggregation, organization, management and utilization of basic maintenance data.

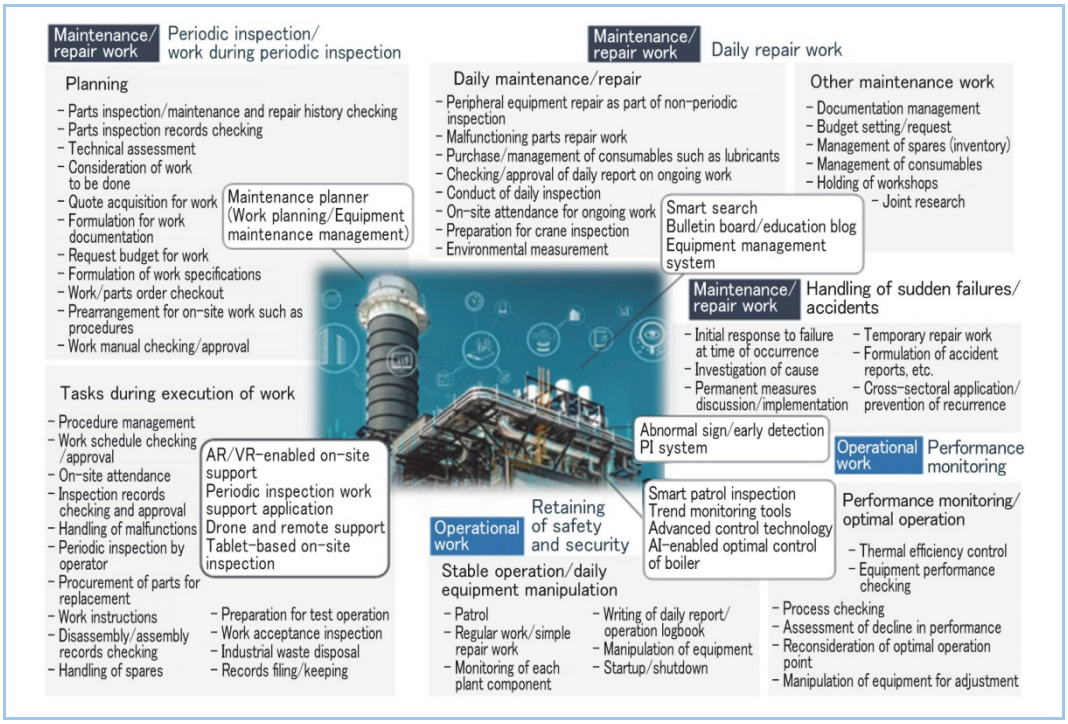

Figure 1 Digitalization of power plant maintenance

2.2 Our activities

2.2.1 Maintenance Planner

Whereas the equipment including gas turbines, boilers and steam turbines is inspected periodically (i.e., TBM : Time-Based Maintenance), how it is attended to on-site during inspection (e.g., repair or parts replacement) is often determined based on the conditions of the equipment (i.e., CBM : Condition-Based Maintenance). In thermal power plants, appropriate conduct of CBM is the key to "further enhancing the reliability of equipment and realizing more advanced maintenance".

"Maintenance Planner" is a maintenance work support system that helps make right decisions in conducting CBM by organizing TBM information into timelines for each piece of equipment for visualization (**Figure 2**). This system has the following three prime objectives:

The first is to get a full picture of the equipment. The overall conditions of the equipment have been made possible to grasp at a glance with the features such as hierarchical display of the whole equipment and colored inspection results for easy interpretation.

The second pertains to the qualitative and quantitative improvement of data required to determine how the equipment should be attended to. In this regard, it is important to consider not only the latest inspection results but also temporal elements such as the past work records and how the inspection results have changed with time. The availability of many pieces of information such as photographs, numerical data, drawings, technical documents of the time, and comments made by the inspectors on the site makes it easier for the equipment maintenance personnel to report the situation and make a proposal to the manager, which in turn makes it easier for the manager to make a right decision. With this system, such information can be entered or browsed on a basis of each piece of equipment for which maintenance work is discussed.

Lastly comes the prevention of failure to get all the work done when equipment needs to be attended to. The details of proposed procedures can be input into this system, which helps to carry out all the work or not to forget necessary arrangements.

Equipment maintenance work is a very complex process. If the whole process is tried to be systematized as it is, the system itself may become too complicated. In Maintenance Planner, therefore, MHI's after-sales service engineers analyze the process of work with the equipment maintenance personnel on the customer's side and provide leadership in planning and development. In this way, Maintenance Planner realizes a simple user interface with minimum functions that are required to run the PDCA (Plan-Do-Check-Action) cycle of maintenance. It thus becomes possible to take a first step towards digitalization without making major changes to the current maintenance work process.

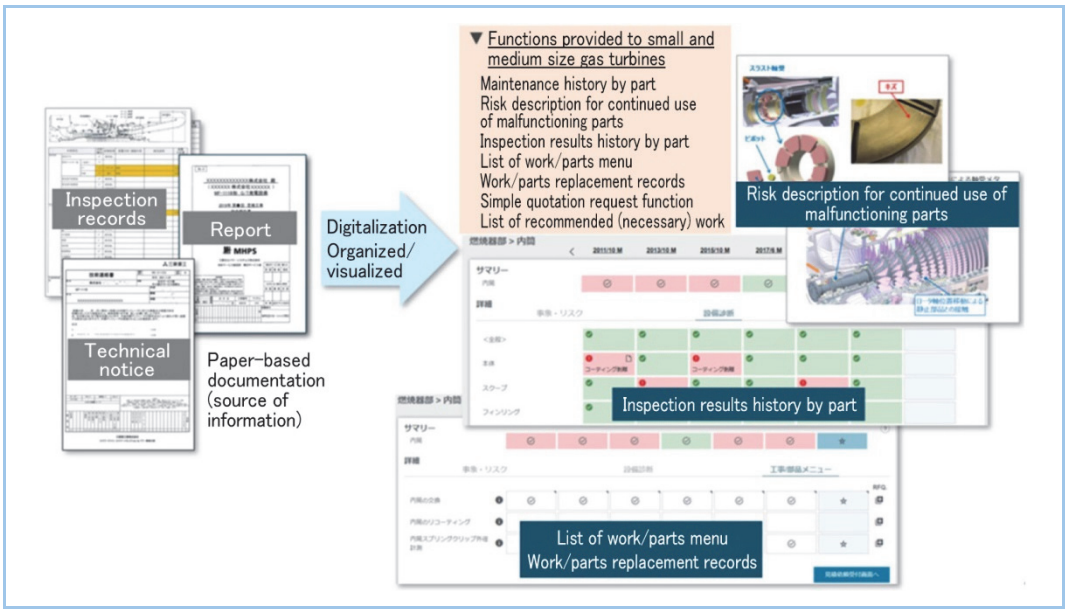

Figure 2 Maintenance Planner

2.2.2 Smart Search

The frustrations, which are often expressed during daily on-site maintenance work, include: “Maintenance history is not organized” and “Whenever I need a certain document, it is nowhere to be found”. Therefore, it is considered necessary to manage collectively all the data related to maintenance records and documents as digital information, and make them available (“ready”) anytime anywhere for the realization of smart maintenance.

In TOMONI, paper documents/records required for maintenance work are digitized and stored collectively in the cloud environment, for which full-text search and information reference can be performed by “Smart Search” (**Figure 3**). This system mainly has the functionality of search suggestion for retrieval candidates, recommendation of other documents related to the browsing one, and search tag filtering. Such efficient document search can help shorten the time of response to problems, etc.

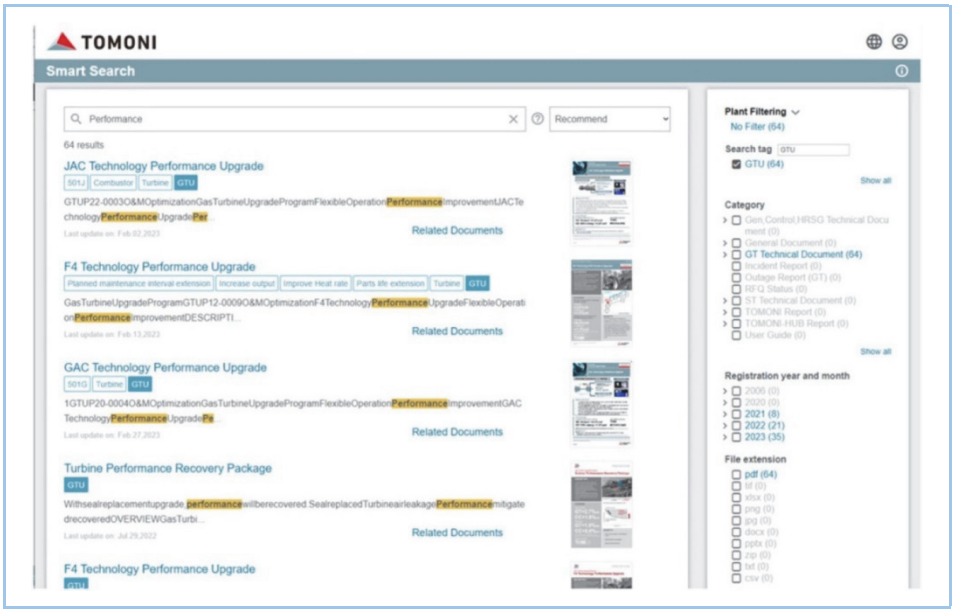

Figure 3 Smart Search

2.2.3 Communication function

Having been operated as one of the communication tools between the customer and MHI, “Customer Portal” will have a brand new design, which is being introduced gradually from September 2023 (**Figure 4**). The current version mainly served as “a point of access to the contents of TOMONI”. However, the renewed version functions as a “portal site to provide all the information to the customer from MHI” and shows the plant’s basic data, TOMONI application menu and document viewer (with which documentation such as technical documents can be browsed). The information that MHI especially recommends the customer to read (such as MHI Technical Review and news) will be posted/updated regularly. In the case of being under contract for remote monitoring services, the customer can check the real-time operating conditions on the Customer Portal.

Moreover, as a tool for interactive communication between the customer and MHI, a bulletin board app called “Connect Room” is also available. For example, when customers have a question, they can simply ask MHI’s maker engineers via this tool and receive an answer that is based on the OEM’s expertise. As both inbound and outbound communications are stored in TOMONI’s cloud environment, it becomes possible to accumulate and share the technical knowledge.

MHI also publishes a blog as another tool to disseminate information. Imaging the “user who has taken charge of maintenance for the first time”, we write commentaries in plain words on technical information about power plant equipment, industrial news and so on, which has been received favorably by customers.

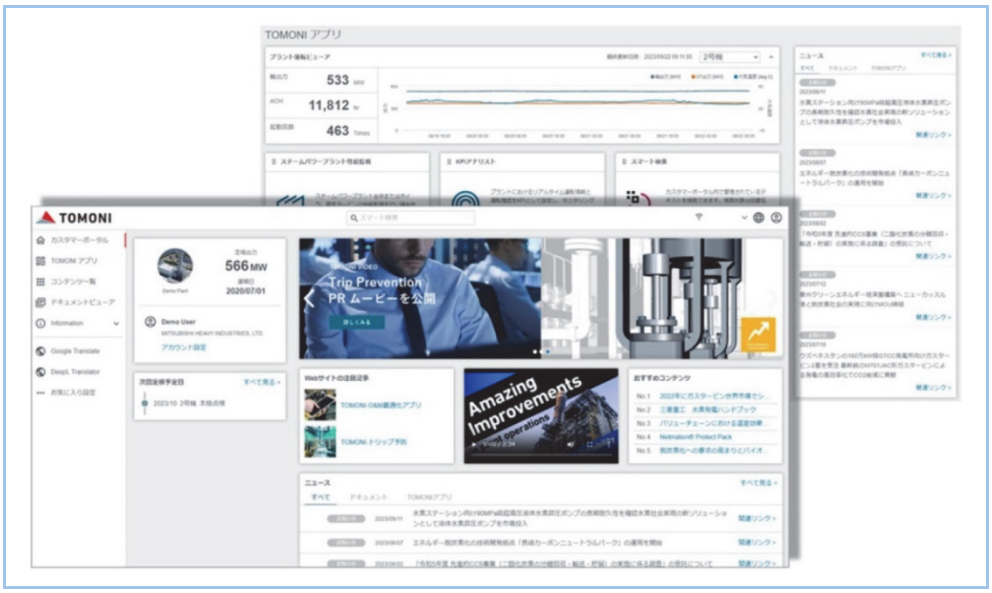

Figure 4 TOMONI customer portal

2.3 Summary

The contents of TOMONI, which are critical for realization of smart maintenance, is presented in this chapter. MHI has received the opinion that making the investment decisions is very difficult because it would take time to see the outcomes if conventional maintenance work is reformed while introducing digital tools at the same time, and besides, the outcomes are difficult to assess quantitatively. As a stepping stone to digitalization and to move forward together with customers, MHI has started offering the above-mentioned contents as a "Basic Package," which is low-cost and easy to introduce. In "TOMONI Smart Maintenance" including this basic package, we make a proposal for plant digitalization that is tailored and optimized through deep dialogues with each customer, thereby continuing to help customers improve their work efficiency and enable more advanced equipment maintenance.

3. Enhancement of cybersecurity

3.1 Background

Power plants are critical infrastructure and are a lifeline for us all. With regard to their control systems, it is also required to take cybersecurity measures and satisfy the control system security standards, in addition to stable operation of power plants.

MHI offers various solution services in this regard. Specifically, these include "Power Plant Security Assessment" for power plant security diagnosis, "Netmation Care Program" for control system maintenance, "Netmation Protection Pack (NPP)" for advanced security measures, and training in handling power plant control system incidents. The following sections describe these services.

3.2 Cybersecurity solution services in detail

3.2.1 Power Plant Security Assessment

Taking advantage of our certified CSMS (Cyber Security Management System CSMS) and the knowledge obtained through having security measures in place for our own company, we offer assessment and consultation to customers regarding their power generation equipment as Power Plant Security Assessment. Specifically, it includes extracting the problems by analyzing the current state of security, considering measures and creating action plans. Therefore, even customers with less experience in security can implement effective security measures according to the order of priority (**Figure 5**).

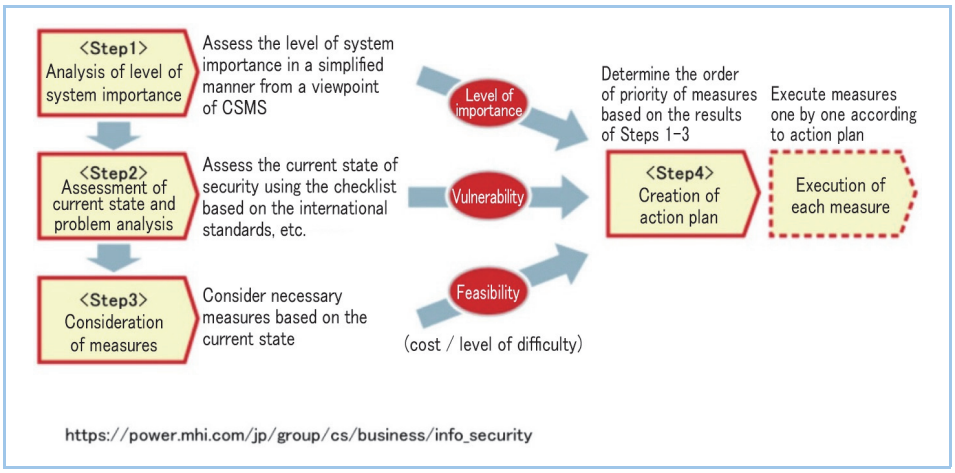

Figure 5 Power Plant Security Assessment

3.2.2 Netmation Care Program

Netmation Care Program includes: 24-hour helpline service to provide, for example, flexible support for daily operation/maintenance, immediate response to emergencies and early replacement of parts; express delivery of parts in the event of failure; and dispatch of engineers and training.

3.2.3 Netmation Protection Pack (NPP)

NPP is a comprehensive control systems security solution that provides threat management, risk management, application management and systems management capabilities, in compliance with the control systems security standards (i.e., IEC 62443-3-3: 2013, NERC-CIP and JESC Z004-2016). It is being introduced mainly in the countries with stringent security requirements and newly built power plants.

Having the functionality based on the framework of NIST (the National Institute of Standards and Technology NIST), NPP keeps security patches for control systems and anti-malware definition files updated to the latest ones available. It also provides the multi-layered cyber defense that is necessary to always meet the latest cybersecurity requirements, including security monitoring of network equipment and user interface. The mechanism to protect control systems from threats has thus been established.

3.3 Collaboration with TOMONI

By connecting to TOMONI cloud and linking the control system information to it, NPP will become able to provide even more advanced services in which our know-how as a maker is utilized. Specifically, these include the management of appropriate provision and application of security patches, monitoring and analysis of security logs of control systems, and diagnosis of control systems by MHI's experts. The next development that we are making is linking to InteRSePT®, which enables monitoring and prevention of unauthorized access to the control network.

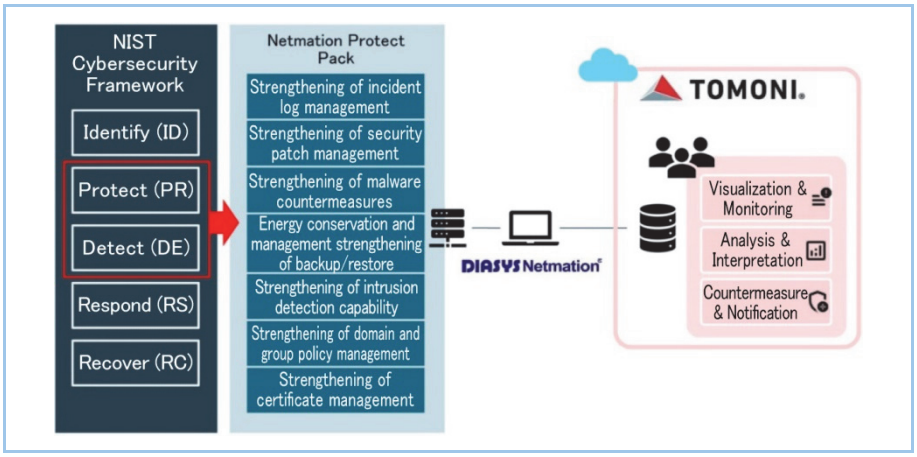

Figure 6 Netmation Protection Pack

3.4 Summary

It is expected that protection of power plants and their control systems from cybersecurity threats will become more and more critical, as digital technology progresses in the years to come. MHI's security solutions services in which its own know-how is utilized are considered capable of protecting customers' power plants and control systems from threats and helping achieve safe/secure power plant operation.

4. Development of technologies and tools underlying remote monitoring

4.1 Background

As of the end of August 2023, mainly among GTCC (Gas Turbine Combined Cycle) plants and SP (Steam Power) plants across the world, 144 units are connected to TOMONI. The remote monitoring services are thus provided to thermal power plants under the cloud environment with ensured security. TOMONI's remote monitoring system is utilized for power plant maintenance services such as the gas turbine's LTSA (Long-Term Service Agreement) and guarantee of a power plant's operation rate as a base to support our comprehensive maintenance services. Moreover, TOMONI HUB (remote monitoring center) serves as a communication hub to strengthen the connection with customers, through which their problems with daily power plant operation can be shared easily. This, in turn, can lead to taking action against any problems. Our good relationship with customers is established in this way.

With TOMONI, the data obtained every second to every minute are accumulated in the cloud environment for years. The engineers at TOMONI HUB or other MHI offices can use their own computers to check the operating conditions in real time. To enable not only short-term process monitoring but also medium to long-term monitoring of trends and conditions such as deviation from the normal operating conditions, decline in performance and remaining lifetime, various tools have been made available as web apps. Aggregating the operating data from the units delivered worldwide makes it possible to immediately retrieve/analyze the data at the time of failure occurrence, the past plant data, maintenance information, and so on.

When a failure occurs, these features allow the initial response (i.e., grasping the situation and analyzing the root causes) to be carried out quickly, shortening the time required for recovery. For our customers of power producer, this means shorter unscheduled downtime and retaining/improvement of the availability rate. Making use of its own know-how, MHI has developed and introduced various remote-monitoring tools to help customers with operation and management, which are described in the following sections.

4.2 Remote-monitoring support tools

4.2.1 Anomaly detection system (Pre-ACT)

The development and application of digitally enabled tools for remote monitoring services have been promoted.

An original anomaly detection system was first developed by employing the MT (Mahalanobis-Taguchi) method and is now in operation. The objective was to improve the real-time monitoring of gas turbines and prevent the occurrence of a failure or detect a sign at an early stage.

For detection of an abnormal sign at a power plant, it is effective to monitor not only the trends but also the correlations among the parameters. However, the monitoring items for a power plant are too many to easily keep monitoring them in a timely manner for monitoring staff. In MHI's anomaly detection system, the correlations among so many parameters have been replaced by an assessment indicator called the MD (Mahalanobis distance) value, thereby making it possible to monitor abnormal signs in real time.

4.2.2 Operating Support Tool

A specialist's judgement is indispensable for checking in detail the deviation from the normal conditions detected by the anomaly detection system or assessing daily operating conditions. To facilitate the judgement, Operational Support Tool has been introduced as shown in **Figure 7**. With this support tool, multiple data at different times are extracted from the time series data and can be superimposed on each other. For example, the tool can be used to superimpose the

data at the time of a specific event such as the startup onto the corresponding ones in the past. Thus, the data processing time needed by the specialist is shortened, allowing instead such specialist to immediately take on high-value-added work such as analysis and judgement.

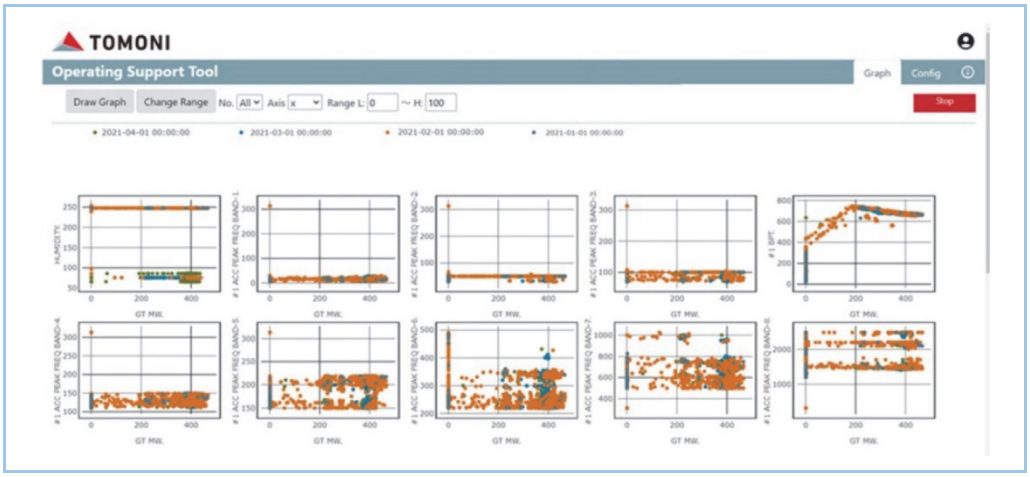

Figure 7 Operational support tool

4.2.3 OperationKarte

As a high-quality and prompt response is needed in monitoring work, past events and responses should be accumulated as know-how and made to be retrievable quickly. OperationKarte has therefore been introduced as a tool to keep records of problems that occurred in daily monitoring work and operating conditions (**Figure 8**).

OperationKarte can keep the records of data on past problems and their measures in the system; the information therein can be shared by monitoring staff. Furthermore, the information such as events, which is recorded at many monitored plants on a daily basis, is valuable know-how. The capability to perform full-text search of the recorded information with high accuracy extraction is equipped so that, when an emergency occurs, similar events in the past can be immediately available for discussing measures. It is expected that the use of this system by monitoring staff enables prompt action of primary support by means of easy search with past records and decision of the cause of the event.

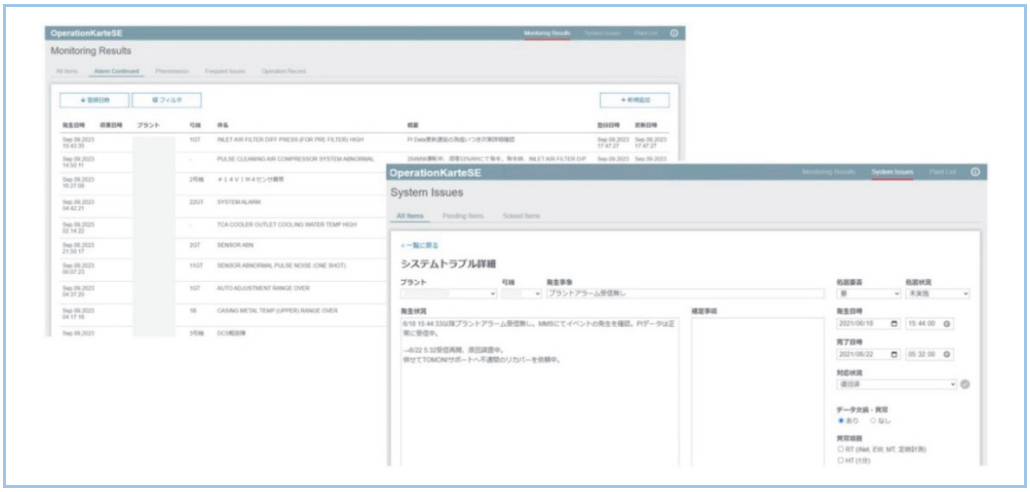

Figure 8 OperationKarte

4.3 Summary

MHI has provided customers with remote monitoring services mainly for thermal power plants for more than 20 years. Our recent focus is placed on not only simple remote monitoring of operating conditions, but also the establishment of a data-driven service business process based on various data shared with customers through remote monitoring systems (**Figure 9**).

By developing and employing all kinds of digital technologies including the support tools described in this report, MHI continues to assist customers with operation and management through remote monitoring services.

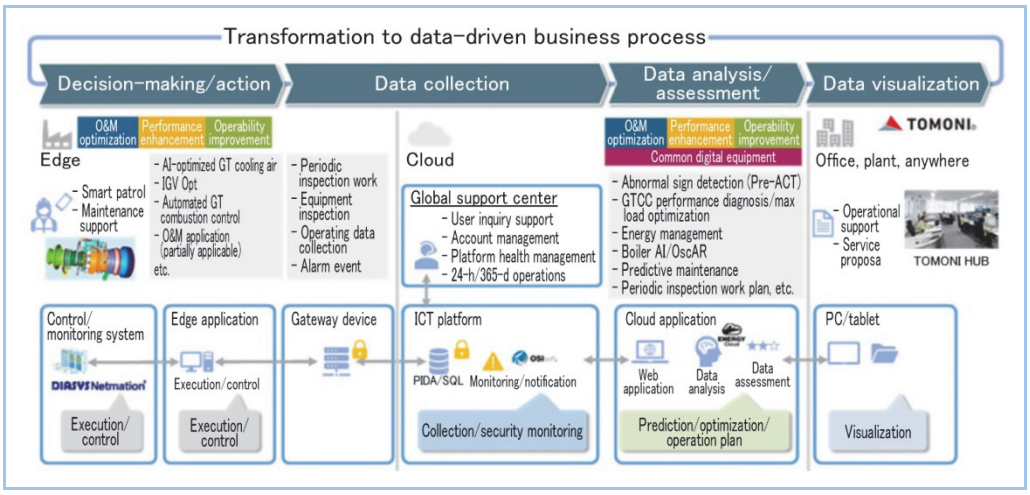

Figure 9 Data-driven service business process with use of remote-monitoring systems

5. Application of generative AI to digital services

As described so far, while smartification of operation and maintenance has been aimed at, the problems faced by the whole industry are the same as before: fewer personnel for task execution and the falling level of experience with retirement of skilled staff. With the aim of reducing the workload of those in charge of carrying out the task by offering customers solutions into which generative AI is incorporated, MHI has first started testing in-house the application of generative AI.

In January 2023, Microsoft launched “Azure OpenAI Service”, which has made it possible to use the service without worrying about the information input to the generative AI to be leaked outside the company. Thus, the web application “TOMONI TALK with ChatGPT”, in which the above-mentioned technology is utilized, was made available for in-house trial use in June 2023 (**Figure 10**). This application enables the user to request the generation of texts by defining the role of AI through a dialogue interface.

While favorable responses including a comment about its usefulness for polishing the writing have returned from the users who participated in the trial, the analysis of their usage has revealed the following problems that are particular to generative AI.

1. Unable to handle the information specific to our company.
2. Unable to verify the accuracy because of the lack of the source of information.
3. Unable to input a long sentence.

Regarding problem 1 in particular, many of the inexperienced staff voiced requests to make it possible to generate texts based on the in-house technical documents, which indicates a high need for use as a knowledge database.

In TOMONI, as described in Section 2.2.2, “Smart Search” has already been made available inside and outside of our company as a means of accumulating and managing unstructured data. Through the technical verification, it has been indicated that the three problems listed above can be dealt with by combining the search engine running in this application with generative AI. Looking forward, early provision of necessary capabilities through the web application and the assessment of their effects will be carried out.

As described so far, although the prospect of utilizing generative AI to reduce the workload by combining with existing technologies has been obtained, the priority is placed on establishing a system to appropriately accumulate and manage accurate unstructured data for practical use. Generative AI can “generate” only from the information given to it, but cannot correct wrong information. Therefore, the key to maximum utilization of generative AI is enabling “accurate data” to be accumulated in a “data format that is suitable for use in the system” and how "easily" it can be accumulated if practicability is taken into consideration. By incorporating the tools presented in the previous sections into daily work for not only our company but also customers, the problems will be overcome. Customers themselves will become able to start aggregating, organizing, managing and utilizing the accumulated maintenance data for their repair/operational

work, as shown in Figure 1. The ultimate goal of this initiative is thus the provision of generative AI as part of the total solution for digitalization.

Figure 10 TOMONI TALK with ChatGPT

6. Conclusion

This report presents the current status of TOMONI's Smart Maintenance and remote monitoring, and the future prospects obtainable when combined with generative AI. In Smart Maintenance, the condition of all the equipment is comprehensively checked by Maintenance Planner. When it comes to the complicated maintenance work processes for each piece of equipment, the information is provided through a simple user interface in suitable quality and quantity according to the maintenance work to be done, with the aim of helping maintenance personnel to get all the work done without fail. NPP enables us, together with customers, to establish a mechanism of managing the security risk of daily-updated data and conducting appropriate management, as well as meet the latest cybersecurity requirements. Easy extraction of necessary information from a huge amount of time series data about power plants and their comparison/analysis contribute to reducing the workload of those engaged in handling non-conforming events or performing analysis assessment, and improving the level of services provided to customers.

With regard to these technological platforms and components of TOMONI, applications into which generative AI is incorporated are being constructed. A trial app has been made available to the users in our company. Through this trial, the effectiveness and problems particular to generative AI have been revealed. Developments for the next step are underway. For realization of the full-fledged application, we will solve these problems and further improve the usability with verification to realize a service that can be provided to customers.

These initiatives are undertaken in line with the solution concept of making MHI Group's entire product portfolio autonomous and intelligent (ΣSynX® or Sigma Syncs). As our responsibility for promoting energy transition, we support customers who are the users of our products in such a way that they can operate and maintain their equipment without worries by intelligently interconnecting and controlling a group of equipment.

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