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Power Plant Digital Analytics Platform and Application Cases for GTCC

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Abstract:

It has been a multi-year journey to today's digital power plant, each step along the way enabled by advancements in digital technologies and driven by needs of power plant owners and operators. It starts with the data, most of which has always been there but often underutilized, however, for years, companies have been offering "Big Data" analytics and diagnostics to provide added value based on software and data science expertise and experience. MHPS-TOMONI is the platform to realize digital power plant to provide solutions and improve plant operations by utilizing the "Big Data" and digital analytics that is based on the experience in Remote Monitoring and Diagnostics Centers at MHPS for nearly 20 years. Targeted integration of data-based capabilities with deep power plant system knowledge and fleet-wide experience has led to new proactive operating and maintenance strategies tailored to individual plants. This paper will describe the journey of Mitsubishi Hitachi Power Systems (MHPS) to define and implement the platform and cost-effective digitally-enhanced improvements. The platform, MHPS-TOMONI, contains applications which are designed to be adapted to the diverse markets of power generation and have been successfully applied. As a result, plant operators' KPI (Key Performance Indicator such as heat rate, availability, power output, flexible operation capability and reliability) was improved. Case studies of contribution of the software application are also introduced in the paper.

1. Introduction

Today's evolving technology in data analytics has a significant potential to deliver operational and economic benefits to GTCC plant owners. Those are competitive factors in the power market requiring improvements in environmental performance and life cycle economics of power sources. Advanced O&M (Operation and Maintenance) practice using the data analytics is one of effective areas addressed to realize such improvements. Power plant economics show that in a typical scenario 80% of COE (Cost of Electricity) of GTCC takes place through its service life after commercial operation starts. It is an area significantly affecting plant economics to address performance, reliability, maintainability and operability. In the area, companies have been offering "Big Data" analytics and diagnostics to provide added value based on software and data science expertise and experience. Mitsubishi Hitachi Power Systems (MHPS) define and implement the Information and Communication Technologies (ICT) platform called MHPS-TOMONI, which consists of various analytics engines, application services and solutions that lead to cost-effective digitally-enhanced improvements provided for plant operators.

2. ICT Platform, MHPS-TOMONI

MHPS-TOMONI is a revolutionary new digital solutions platform that finds ways to optimize power plant operations, based on a collaborative and customer first approach.

MHPS-TOMONI is a comprehensive family of digital solutions tailored to fit each customer's priorities at the power plants they operate. It maximizes the advantages of today's highly digitized power plants by emphasizing collaboration between OEM and plant operator, recognizing the need for expert human insights to boost efficiency and reliability, optimize O&M costs and enhance environmental performance.

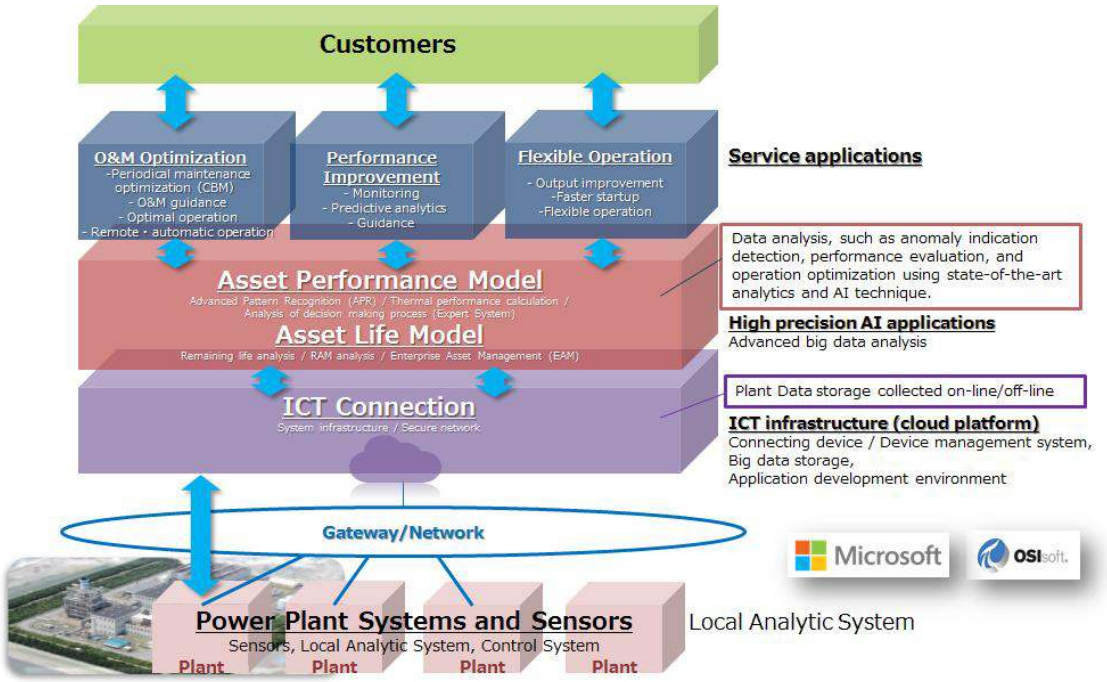

Figure MHPS-TOMONI Platform

MHPS-TOMONI is a consolidation of many MHPS digital solutions and is now being offered as a total solution package. MHPS-TOMONI is built on OSIsoft's PI System. MHPS-TOMONI enables us to:

+ predict and prevent operational issues at customers' total plant level;
+ turn data into actionable knowledge with automated expert systems and human experts;
+ and improve reliability and efficiency – saving O&M cost for our customers.

To answer a wide range of needs in a current dynamic power market, we provide a full line-up of applications, such as Condition based maintenance, Remote monitoring, and Soft repowering which allows our customers to generate higher output to meet market demand and to achieve a better economic performance.

These applications are continuing to expand and our solution scope helps make power plants more digital and more cognitive to meet the latest trends.

These applications are enabled by MHPS-TOMONI Analytics Engines, covering asset performance models and asset life models. Performance models include Advanced pattern recognition, Thermal efficiency models and Expert System. Life models consist of Remaining

life analysis, RAM analysis and maintenance/enterprise asset management. These models enable MHPS high precision cognitive AI applications and utilize state-of-the-art technologies in the industry.

The data used for analytics are collected and stored at the connection layer – MHPS-TOMONI analytics platform, which integrates Microsoft's Azure technology and OSIsoft's PI Systems. MHPS has established alliance relationship with Microsoft and OSIsoft.

Plant data collected from customer's plants through plant system and sensors are firstly processed in a local analytics system, where real time control and highly secure computation is taken place. This data is collected from thousands of sensors embedded in boilers, generators, turbines, emissions control and other systems.

3. Software Application

MHPS-TOMONI contains several application categories. The categories are defined as plant operators' values provided by the applications, which are consisted of O&M Optimization Suite, Performance Improvement Suite and Flexible Operation Suite.

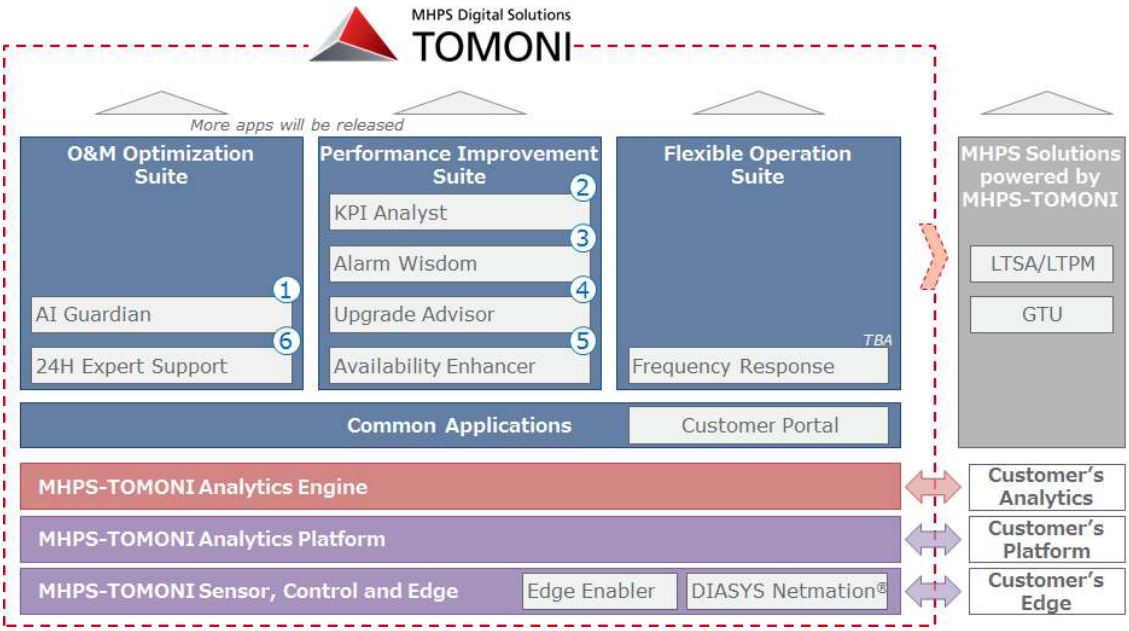

Figure MHPS-TOMONI Applications

3.1 O&M Optimization Suite

O&M Optimization Suite provides solutions to improve plant operation and maintenance and the affected KPIs are Reliability, Availability and Maintainability. MHPS-TOMONI covers this area by MHPS-TOMONI AI Guardian (hereinafter AI Guardian) and MHPS-TOMONI 24H Expert Support (hereinafter 24H Expert Support) so that plant operators are able to minimize forced and planned outage and to rectify issues if forced outage happens, resulting in longer MTBF (Mean Time Before Failure) and less MTTR (Mean Time To Repair).

In order to achieve this, MHPS now operates three Remote Monitoring Centers (RMCs) and is continually upgrading their capabilities as new technology and best-in-class software becomes available. The RMCs are monitoring 30GW GTCC facilities over the world on 24-7 basis.

The RMC in Takasago Japan is monitoring the MHPS fleet and remotely operating the T-point power plant. T-point is MHPS' in-house GTCC power plant where the latest 501J gas turbine are installed and operated since 2011. Its purpose is to provide long term validation of newly-developed technology and equipment systems and to dispatch to a local electricity grid. T-point has temporary instruments and sensors installed for validation purposes, and data-driven solutions are created based on the full-scaled power plant applications. This is a great advantage to realize the digital power plant providing beneficial solutions for actual plant operators in MHPS-TOMONI.

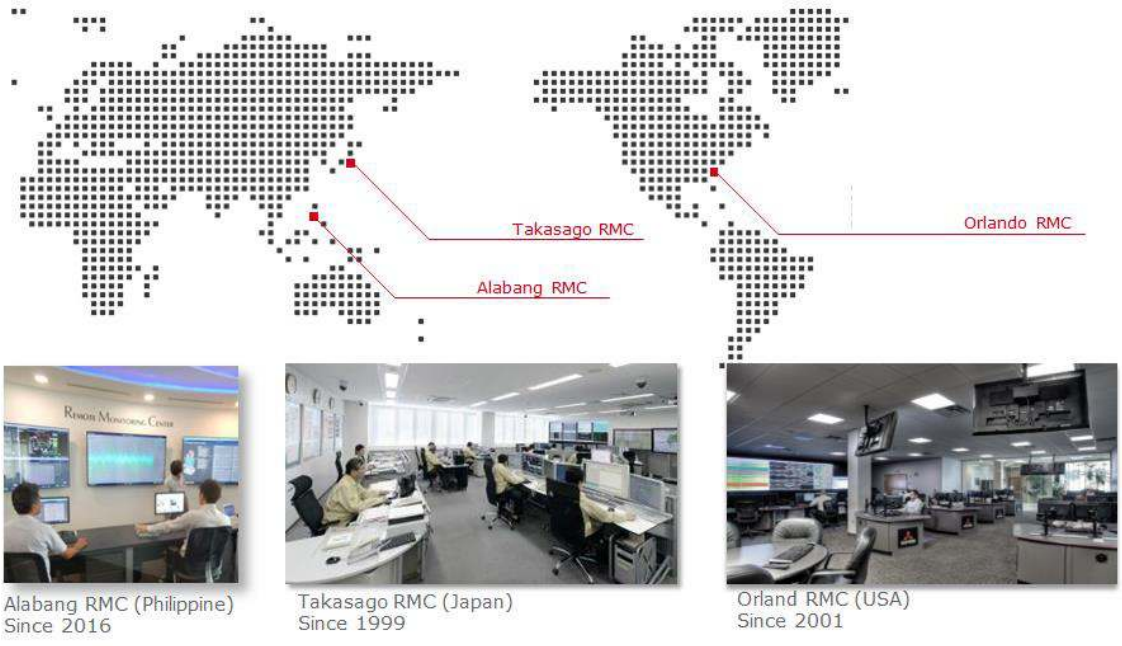

Figure MHPS-TOMONI RMC

Analysis and response to “Voice of the Plant” data to improve the KPIs are easier and more effective when there is a direct data feed from the plant to an RMC or other centralized place where analysis by expert systems and human experts can take place on a fleet-wide basis. For that reason, MHPS promotes the benefits of connection to the plant, whether through full RMC implementation when that makes economic sense or less intensive connection to the power plant.

RMC provides 24H Expert Support by OEM dedicated experts by using expert systems and advanced software. MHPS-TOMONI is also able to provide the advanced software as applications for plant operators, examples include the application of AI Guardian. AI Guardian is able to detect slight changes of operating parameters even before an interlock, such as trip, alarm and run-back, which may affect power generation, is activated. It contains an advanced pattern recognition system and pattern matching to identify abnormal parameter and possible cause of the issue. The advance pattern recognition is Mahalanobis-Taguchi method (MT method), which is a diagnostics system originally developed by MHPS. It is a general point of view that operating parameters have correlations among multiple parameters and even if a value of one parameter is within the threshold of interlock the value may be deviated from normal patterns of multiple parameters. Such deviation is detected by pattern recognition of multiple parameters and is represented by a single index called as Mahalanobis Distance(MD). The MD notifies the machine integrity whether it is in a normal or may be in an abnormal condition. If it detects abnormality, Taguchi method outputs SN ratio, Signal to Noise Ratio, to identify possible parameter causing abnormality, which is simultaneously calculated along with MD. In addition to the identified parameters, the pattern matching system seeks for a similar pattern of parameters including abnormality from experienced issues. AI Guardian then suggests possible causes of the issue with probability and associated first aids for operators to address issues so that plant reliability and availability are improved. AI Guardian works on-line and provides the information helping identify issues which the conventional monitoring method does not detect and helps even unexperienced people take actions by the expert system without expert involvement. The information is also provided by e-mail for notification if something is detected by the AI Guardian application.

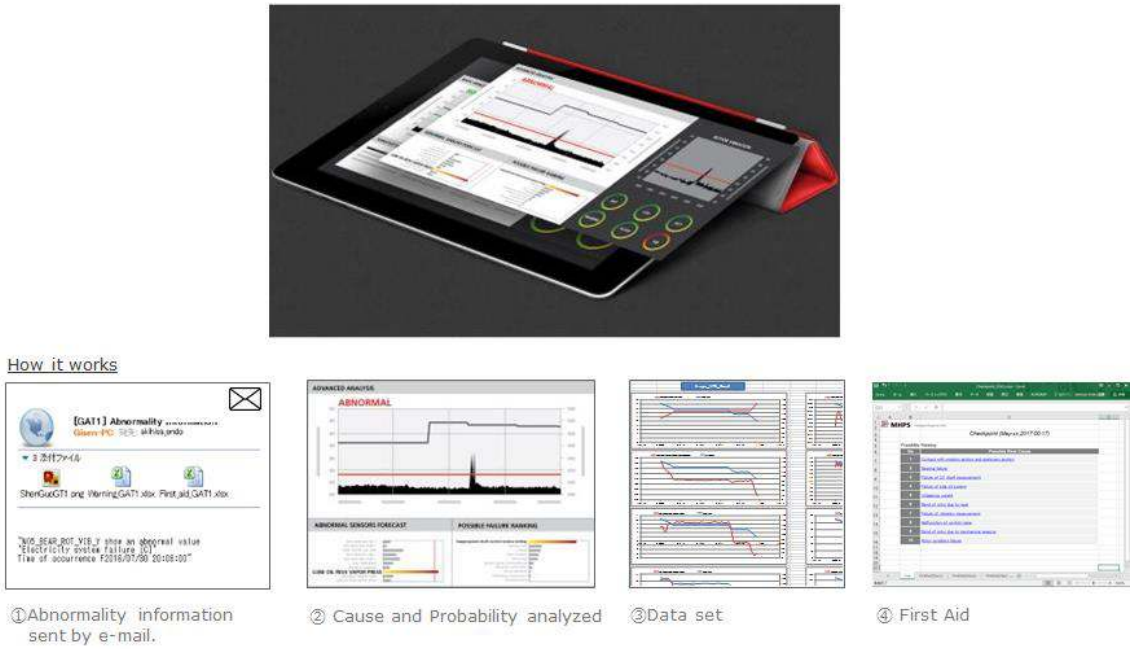

Figure MHPS-TOMONI AI Guardian

AI Guardian helps detect possible abnormality by a slight change, which appears in operational parameters before an interlock is activated. It is a case that an interlock activates without any parameter change before, where predictive system is not able to. Such cases may take place and plant operators encounter alarm, run-back or trip of a plant system. Experienced and proficient operators may take actions promptly and properly based on their past experience and knowledge, resulting in effective countermeasure and minimum impact on operation and maintenance. MHPS-TOMONI Alarm Wisdom (hereinafter Alarm Wisdom) helps unexperienced operators do so by giving guidance based on OEM experience. When the plant control system activates interlock, Alarm Wisdom seeks suitable guidance for the activated signal, where OEM recommended guidance and solutions are incorporated into the system and operators are also able to accumulate their experience so that the experience is shared and utilized in a next opportunity, if it recurs. Alarm Wisdom is hence designed to improve MTTR primarily.

Figure MHPS-TOMONI Alarm Wisdom

3.2 Performance Improvement Suite

This suite provides application and solutions to improve KPIs, some of which are thermal efficiency, power output, reliability and availability. The current competitive market of power generation forces plant operators to improve competitiveness so as to maintain a better position to keep in service. MHPS-TOMONI KPI Analyst (hereinafter KPI Analyst) provides visibility of KPI in plant operation and maintenance and insights to improve market competitiveness including performance, RAM analysis and operation status. This application helps the plant operator understand where they are in terms of performance, reliability, availability and figures, which may affect the plant economics and recognize insight to improve the position.

KPI Analyst along with MHPS-TOMONI Upgrade Advisor (hereinafter Upgrade Advisor) and MHPS-TOMONI Availability Enhancer (hereinafter Availability Enhancer) suggests possible improvements and a program to be implemented in order to make the KPIs better, examples include performance deterioration recovery and improvement, where analysis of operational data may provide insights of causes of performance deterioration and measures to recover it by adjusting parameters. Such data-driven upgrades are realized through the Upgrade Advisor so that performance deterioration is minimized. It contains optional recommendation of hardware replacement and upgrades of components based on operational data analysis and economical assessment. Another example in Upgrade Advisor is optimization of performance. The latest software and control to improve performance are incorporated to optimized performance as a position in fleet. The existing unit is able to catch up with a newer unit by implementing the latest control techniques.

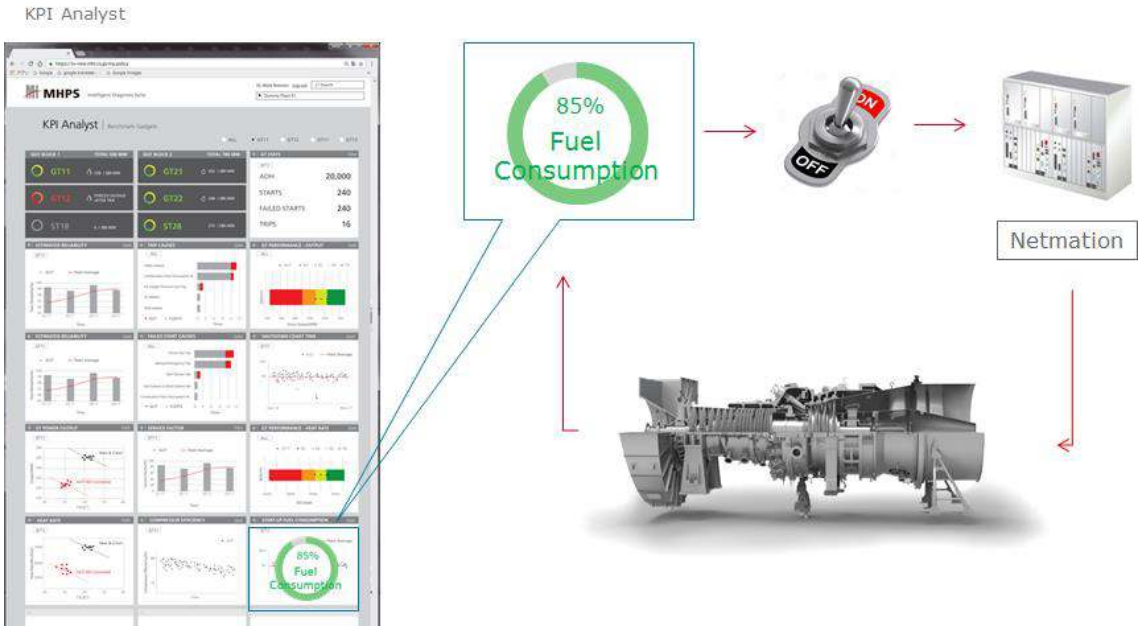

Figure MHPS-TOMONI KPI Analyst and Upgrade Advisor

The Upgrade Advisor also allows plant operators to improve competitiveness in the dynamic market. Plant maintenance practice affects KPIs such as availability, reliability and cost of electricity so that reduced scope and shortened outage in maintenance practice are interesting areas to be improved for plant operators. Time-based maintenance is a conventional and widely-used practice introduced in GTCC. From a technical point of view, component and system aging and deterioration are affected not only by elapsed time of service but actual conditions where each component and system is exposed in the service. Physical parameters are different time by time, which are affected by ambient conditions and operating loads. As another perspective, the components and system have a variety of deterioration modes and attributed factors, which are not always affected by the magnitude of time period. Individual deterioration is hence evaluated by the affecting factors, which is achieved by data analytics. This is a condition-based maintenance (CBM) concept allowing to optimize maintenance activity from economical and operational points of view while maintaining the reliability of system.

A specific example in Availability Enhancer is to monitor the working condition of a shaft, which is rotating with interference so as to control a magnitude of wear on the shaft. The working time is not necessarily corresponding to the service time period of the system, and condition monitoring is an effective approach to estimate aging more precisely, resulting in economical and reliable maintenance.

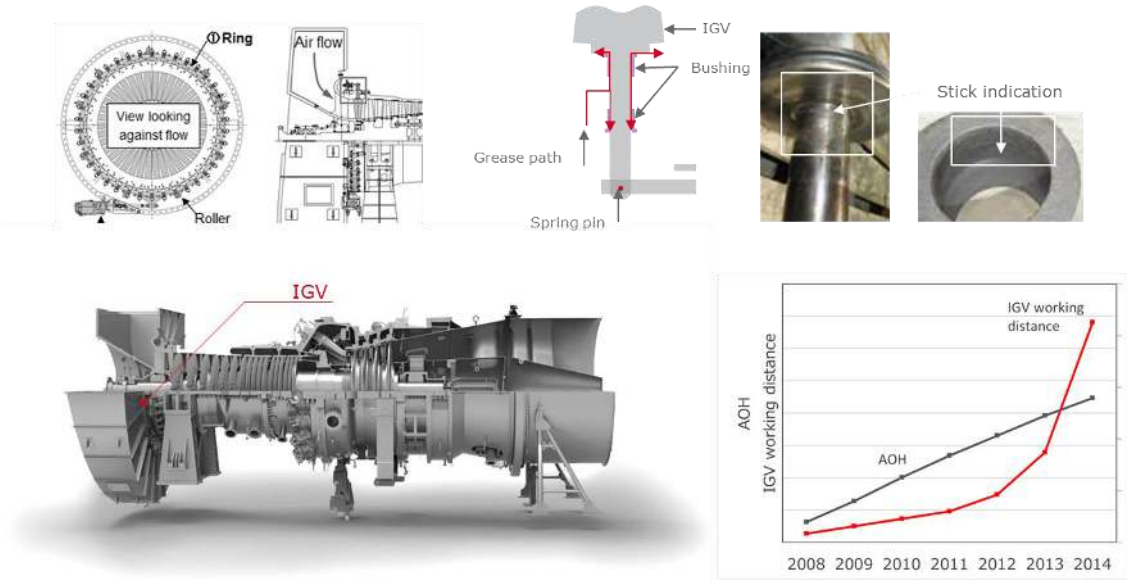

Figure MHPS-TOMONI KPI Analyst and Availability Enhancer

3.3 Flexible Operation Suite

In the past several years, many GTCC power plants have moved from continuous base load operation to frequent start/stop operation and reduced operating hours per year, which are a consequence of emerging renewable energy sources (RES) in some countries. MHPS has been developing and applying a range of data-driven digital flexibility solutions that can help plant operators achieve a more responsive, reliable and economically viable operation in the dynamic market while maintaining the reliability and availability compared to base-load operated units. Since 2011, more than 125 cumulative flexibility elements have been implemented in GTCC plants, primarily in Europe, where more RES has been deployed than a place else, to achieve faster start-up, lower combined cycle loads and better part load efficiency. These solutions have placed plants in a better position in the market, resulting in higher utilization than the past years. Further development of digital solutions is ongoing to make the power plants more flexible and sustainable to adapt to a dynamic market.

4. Application Cases

MHPS-TOMONI is a digital platform that offers packaged software solutions developed by MHPS and its software partners. Those advanced applications have been proven in the individual experience. Many solutions have helped improve the KPI of plant operators by a sophisticated software system and unique solutions developed by the OEM (Original Equipment Manufacturer).

4.1 O&M Optimization Suite

AI Guardian is a software to detect a sign of abnormality which may appear in operational data, identify possible causes and give actionable recommendations. It applies the MT method as an advance pattern recognition system utilized in RMC for almost 10 years, helping the experts effectively detect issues.

One of the actual cases where the system protected the machine from failure and unexpected outage is a good example to understand how it works. Blade path temperature (BPT) is an important parameter in a gas turbine to represent the integrity of combustor and turbine. BPT has an interlock system of alarm activation so that plant operators are able to notice critical issues which may happen in the combustor and turbine. Even before the critical issue takes place, initial failure may appear as a slight change in BPT. AI Guardian gave a caution by increasing Mahalanobis Distance (MD) over the threshold before the BPT interlock activation and the BPT value exceeded its threshold. The increased MD is caused by a certain parameter and the Taguchi method can identify the parameter by SN ratio. In this case, #16 BPT is raised as the parameter causing increased MD. Based on this outcome, the plant operator inspected combustion and observed distress at the conditions which was able to be rectified with a limited scope of work. Critical failure was avoided, and an impact on plant operation wase minimized by the guardian.

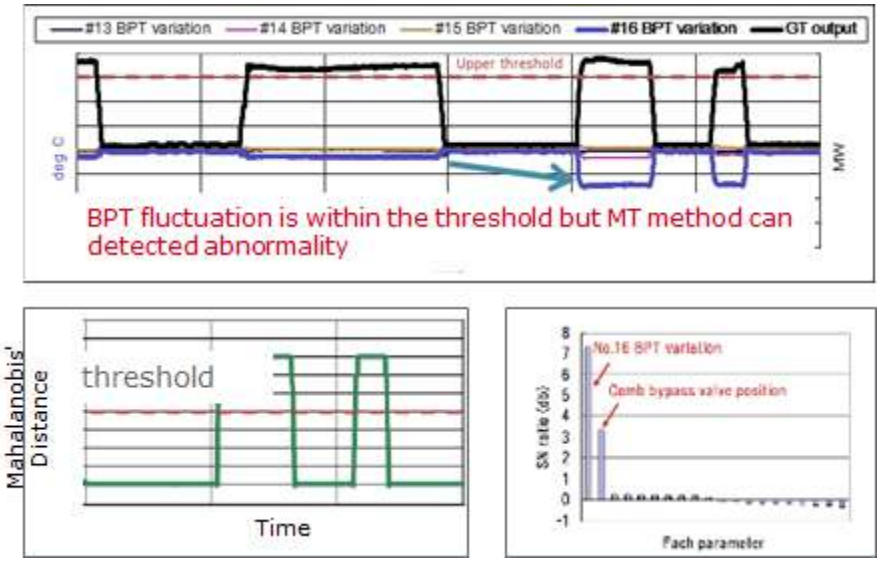

Figure Case of O&M Optimization Suite

The positive effects of this type of application service utilizing analytics and plant data are evident in both internal MHPS RAM (Reliability, Availability and Maintainability) statistics and the third-party ORAP database of RAM statistics maintained by Strategic Power Systems (SPS), based on data that the owners/operators report to ORAP and SPS validates. Examples include a 40% or more reduction in trip events per unit on large 50 Hz. gas turbines with the application service installed, since 2007. SPS ORAP data shows very favorable comparisons for MHPS designed gas turbines over the past 5 years.

SPS DATA FIRST

Period	Apr 2012 - Mar 2017		Apr 2012 - Mar 2017	
Category	"F" Class	M501F	Advanced Technology	M501G
Number of Units	663	18	31	24
Reliability*	97.71%	98.51%	98.37%	99.26%
Availability*	91.01%	92.23%	91.23%	92.32%
Forced Outage Factor**	0.91%	0.67%	1.03%	0.37%
Unscheduled Maintenance Outage Factor**	0.60%	0.29%	0.40%	0.32%
MTBF** (hours)	2,311	4,927	3,955	5,368
MTTR** (hours)	19.29	11.92	28.33	18.64
Frame	GT24/26, 6F/FA, 7F/FA, 9F/FA, 7FB/9FB W501F, V84.3, V64.3A, V84.3A, V94.3A M501F/M701F		7H/9H W501G M501G/M701G	

ORAP

* - Values based on "Simple Cycle Plant" = GT + Gen. + Controls + Direct Ancillaries + Station Equip.
** - Values based on "Gas Turbine only"

Source: ORAP®; All rights reserved: SPS® May 2017

Figure SPS ORAP data

On a self-reporting sample of large gas turbines conducted by the M701F Users' Group, those plants connected to a Remote Monitoring Center (RMC), which provides 24H Expert Support with analytics, had 2.4% higher reliability than those plants that were not connected.

Hence, the O&M optimization suite shows significant effect in improving KPI of availability, reliability and maintainability.

4.2 Performance Improvement Suite

Performance Improvement Suite also gives a good example where a plant operator obtained a benefit and successfully improved the plant operability. A certain power plant had frequently been in service at partial load due to lower dispatch factors, and they wanted to improve plant heat rate at partial loads to significantly improve economics. MHPS discussed with the plant operator and determined the best option to achieve dynamic heat rate optimization was to apply advanced digital controls to modulate the gas turbine's IGV angle. Using the advanced control, the IGV closes more and inlet air flow is reduced, thereby higher exhaust gas temperature is delivered to the heat recovery steam generator and bottoming cycle resulting in higher power generation there. The advanced control of IGV was proven and validated through verification testing at the T-Point full-scale demonstration plant and operational monitoring from the RMC.

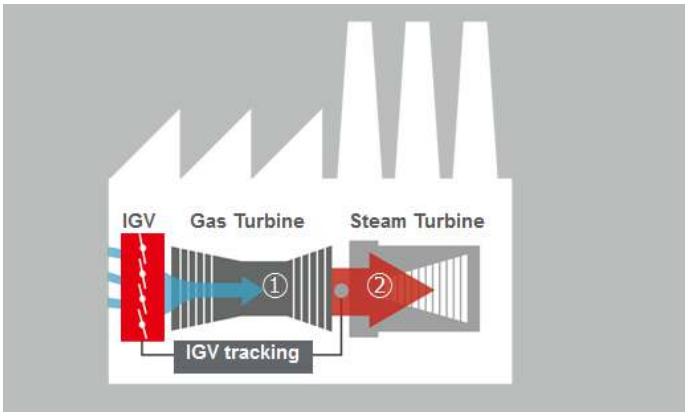

Figure Case of Performance Improvement Suite

The plant successfully implemented the upgrade during a planned outage and achieved the plant part load heat rate improvement without compromising operability. The advanced digital control logic optimized plant heat rate at partial load while maintaining operational flexibility and engine reliability, yielding significant fuel savings, approximately $850,000 US annually.

4.3 Flexible Operation Suite

Since 2011, more than 125 data-driven digital flexibility elements have been implemented in GTCC plants globally to achieve faster start-up, lower combined cycle loads and better part load efficiency, one of which is discussed below.

A plant wanted to reduce starting time for their GTCC units. In addition to various digital solutions to reduce starting time of the GT (gas turbine), MHPS implemented a digital solution aimed to reduce the starting time of the ST (steam turbine), thus enabling the plant to get the best of both the GT and ST in terms of starting time. This helps in minimizing fuel cost in starting the units. Usually, for GTCC plants, GT load hold and CC load-up rate increase are fixed based on discrete functions of the ST HP inlet metal temperature. Variable start-up modes enable implementation of a linear function of the HP inlet metal temperature for GT load hold and CC load-up rate in warm start mode as well as cold start mode.

After implementation, the plant has gained fuel savings of ~7000 Nm3 during hot start by reducing APS (Automatic Plant Start) completion time up to 15 min in warm start.

Solutions in Flexible Operation Suite are available in various applications and able to meet a variety of flexibility needs as the requirements are different from the context and market situations.

5. Conclusion

MHPS now continues with the expansion of our innovations from remote monitoring to solutions using state-of-the-art digital technology, such as big-data analysis, artificial intelligence, machine learning, Internet of things and so on. The MHPS-TOMONI platform provides a combination of human insight, digital technology and analytics to make this a successful endeavor. MHPS works closely with customers to customize a solution that addresses their specific priorities and needs.

MHPS will continue to develop innovative thermal power and environmental technologies that open the door to a brighter future for our planet.

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