Presented at POWER-GEN International, December 5-7, 2017

Elements and Enablers of the Digital Power Plant: Enhanced Delivery of Power Plant O&M Support Using Advanced Digital Technologies

Benjamin THOMAS
Mitsubishi Hitachi Power Systems (United States)

Prasanth THUPILI
Mitsubishi Hitachi Power Systems (United States)

Akihisa ENDO
Mitsubishi Hitachi Power Systems (Japan)

John KESSINGER
Mitsubishi Hitachi Turbine Generator Users' Groups

Abstract:

Rapid evolution of the power generation industry is driving many Owners and Operators of thermal power plants towards more flexible, and often more aggressive, operation modes - especially in areas where dispatch and load-following by existing plants are heavily influenced by newer, more efficient generation or increased penetration of renewable wind and solar resources. These operation modes can have significant implications for equipment reliability and life consumption, increasing the importance of rapid operator response based on broad situational awareness as well as effective predictive maintenance. At the same time, economic pressures and an aging skilled workforce are creating staffing, knowledge retention and training challenges for the traditional power plant industry. Mitsubishi Hitachi Power Systems (MHPS) has been working interactively with the Users of its major equipment to identify ways in which advanced digital technologies can best assist with meeting these challenges of a changing industry. Today's data management, analytics and communication technologies make possible real-time, interactive support to optimize alternative operation scenarios and operational trade-offs. Combined with advanced data analytics and expert systems that identify operational data trends to provide early warning, these technologies can enable immediate access to accumulated expert knowledge and specific recommendations based on fleet-wide experience.

I. Introduction

The power generation industry is increasingly challenged by market forces that are causing increased competition among power sources and increased penetration of renewable and other intermittent or distributed resources. The results of these market forces are causing many power plants to experience operating duty cycles that are far more challenging than the duty cycles anticipated when the power plants were originally designed and are creating challenging new duty cycle requirements for new plants that are in design or construction. These duty cycles often require extremes of flexibility and responsiveness that challenge both the operators and the designers of major power plant equipment and systems. These operation modes can have significant implications for equipment reliability and materials life consumption, increasing the importance of rapid operator response based on broad situational awareness. And, at the same time, these operation modes can adversely affect the economics of the power plant since many power markets have different compensation possible from the mix of providing energy, capacity and ancillary services. New and more efficient generation coming on-line can also adversely affect the economics of existing generation, which is likely to move down the dispatch curve. The result is extreme pressure to reduce O&M budgets at the same time that the more challenging duty cycles are resulting in greater needs for operator involvement and potentially more intensive equipment maintenance.

Responding to these O&M challenges requires more plant information and more subsequent knowledge derived from that information than in the past. This is compounded by headcount reductions and an aging power plant workforce that is seeing experienced operators and engineers retiring at a significant rate. Increasing the training, knowledge retention and productivity of the remaining workforce are challenges that must be addressed. Capturing and increasing the accessibility of the organization's "tribal knowledge" before it decays is a very important strategic imperative for power plant owners.

Fortunately, there are many new ways becoming available to manage that information as the result of advances related to what has been called the "Digital Power Plant". The Digital Power Plant is an all-encompassing "big picture" concept that became commonly discussed about 10 years ago. Strategic thinkers across the power industry have increasingly been talking about the Digital Power Plant -- promoting its promise, current status and prospects for full implementation. It has been a multi-year journey to today's Digital Power Plant, and that journey continues. Each step along the way has been enabled by what at the time were the latest advancements in digital and communications technologies, and always driven by evolving needs of power plant owners and operators.

MHPS began the journey towards the Digital Power Plant over 20 years ago, with major milestones including the heavily instrumented verification combined cycle power plant at the Takasago Machinery Works in Japan, commissioned in 1997 and dispatching into the Kansai Electric grid, and the implementation of Remote Monitoring and Diagnostics Centers (RMC) in 1999 and 2001. [References 1, 2] More recently, many data-driven digital solutions have been applied to improve the reliability, flexibility and performance of power plants around the World. [References 3, 4, 5, 6]

MHPS has been steadily leveraging advanced digital and communications technologies to develop its MHPS-TOMONI™ Digital Power Plant. Tomoni means “Together with” in Japanese and signifies heavy involvement with power plant owners and operators in a collaborative manner to most effectively unleash the potential of power plant digitalization. MHPS-TOMONI™ combines digital technology with extensive equipment and total plant designer knowledge and power plant operator O&M experience. It recognizes that power plant digitalization is not a “one-size-fits-all” solution and that there should be emphasis on solutions that meet the priorities of owners and operators and work synergistically with their existing strategies and investments. It has been useful to think of the Digital Power Plant as consisting of four layers as shown in Figure 1 below.

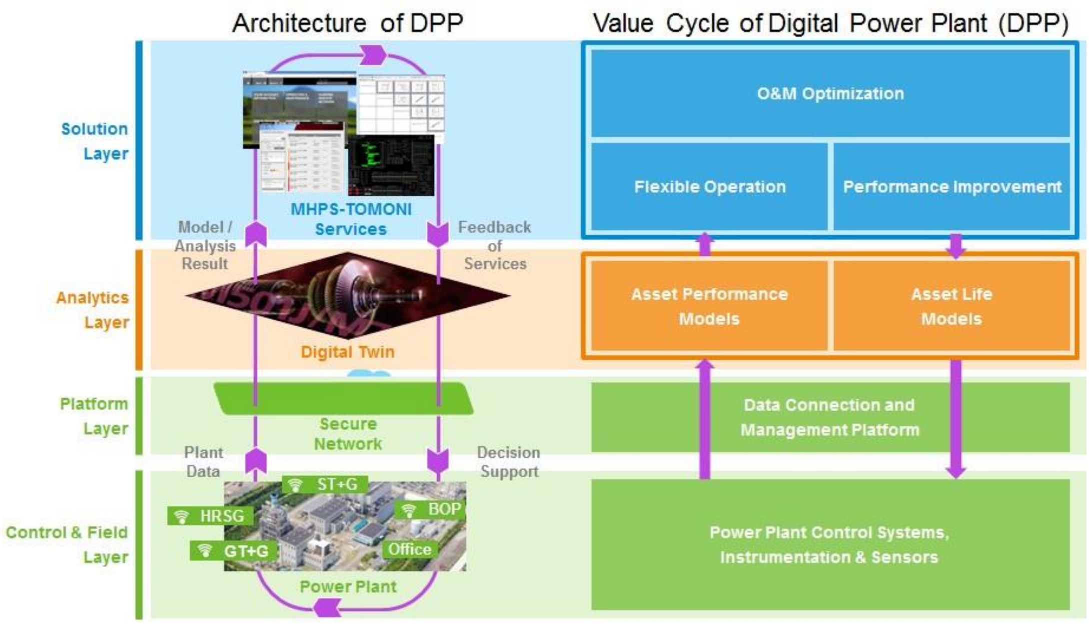

Figure 1: MHPS-TOMONI™ Digital Power Plant

This paper focuses on the O&M Optimization category in the “Solution Layer” in Figure 1. The long-range goal of MHPS is to deploy technologies capable of full remote operation and, ultimately, with the capability for autonomous or near-autonomous thermal power plant operation. But near-term implementation initiatives differ from plant to plant based on individual owner/operator strategies and priorities for implementation. A key enabler in most cases, however, is a plant connection that securely provides the operational data necessary to perform complex analytics that can create derived knowledge from that data based on the experience of multiple plants and inputs from multiple sources of expert knowledge. That connection enables knowledge and guidance for actions, which can be embedded in advanced software applications, utilize human experts or a desired combination of the two. The Platform Layer, as shown in Figure 1 and described further in Reference 5, is based on technologies from MHPS and alliance partners such as OSISoft® and Microsoft® and performs the critical function of securely connecting the data in the plant with the analytics, human experts and fleet-wide learning that have the potential to create additional actionable knowledge from that data.

The Users’ Groups that represent the owners and operators of MHPS designed equipment and systems are an important source of the collaboration that is at the heart of the MHPS-TOMONI concept. Over the past several years, input has been solicited from those Users’ Groups to make sure that the elements of the Digital Power Plant being conceived and delivered were aligned with the needs of the User communities. At the time of this paper, there are several pilot programs underway in collaboration with power generation companies in the Americas and elsewhere in the World. These pilot programs are directed at the digital priorities of each of the companies and in all cases, include significant focus on digital delivery of O&M support of the types shown in Figure 2.

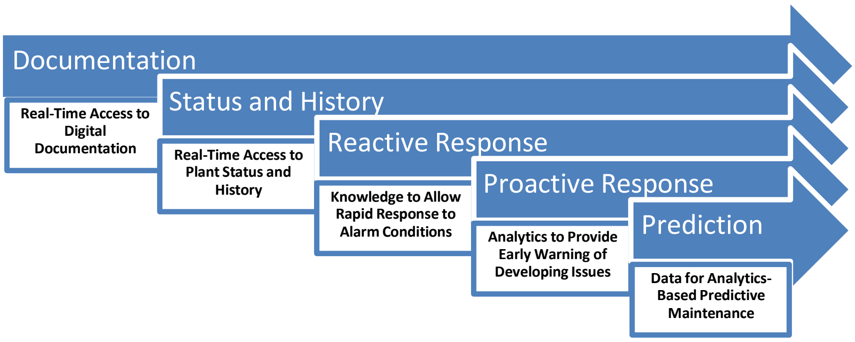

Figure 2: Opportunities for Digital Delivery of O&M Support

II. Real-Time Access to Digital Documentation

A fundamental challenge for Owners and Operators of power plants is to have at the fingertips of their operators and maintenance personnel up-to-date documentation on the plant design and current configuration, particularly on older assets that have been in service for some years, such documentation was originally generated as hard-copy and filed in a few locations for access as needed. Sometimes the custody and condition of this historical documentation shifts due to organization and personnel changes, and there is always the concern that up-to-date documentation may not be as accessible across the organization as would be desired. One of the most straightforward applications of the latest digital technologies is to digitize and make centrally available in real-time the mass of relevant documentation in a web-based format. When doing that, selection of a process that ensures that the documentation is controlled, searchable and updated in a single location is important to ensure that all functions and personnel are looking at the same information, whether they are at the plant site or elsewhere. This is especially the case when the documentation is used and/or updated by multiple organizations, which often include the owner's engineering department, the owner's maintenance department and the original designers/manufacturers of the major equipment in the plant.

The approach at MHPS has been to work closely with the owners and operators of its major power plant equipment and systems to prioritize User needs for information and knowledge, to digitize that information and make it available through centralized Customer Portals. The concept is a single electronically-accessible source of information during the life cycle of the power plant. Much of the information on the Customer Portals is kept updated by MHPS if it is traditional OEM-provided information, but there are also provisions for operator originated information and additional shared information that can be jointly updated or updated by the User personnel, depending on where the updates can most effectively originate. The types of information on the Customer Portals can vary depending on the priorities of each power plant, and confidential information is protected by site encryption and strict access control. The information always includes plant configuration information and applicable Technical Bulletins for the MHPS-supplied equipment. Often included are the latest version of the equipment or plant O&M Manual, Outage Reports for recent inspections and overhauls, as well as Repair and Refurbishment Reports for serialized parts. And if the plant is remotely monitored, the reports generated by the Remote Monitoring Center (RMC) - typically Issue Reports, Weekly Reports and Quarterly Reports are also automatically posted on the

Customer Portal. The interface varies by region, but typical Customer Portal Home Pages for the Americas and Asia-Pacific regions are shown below in Figure 3.

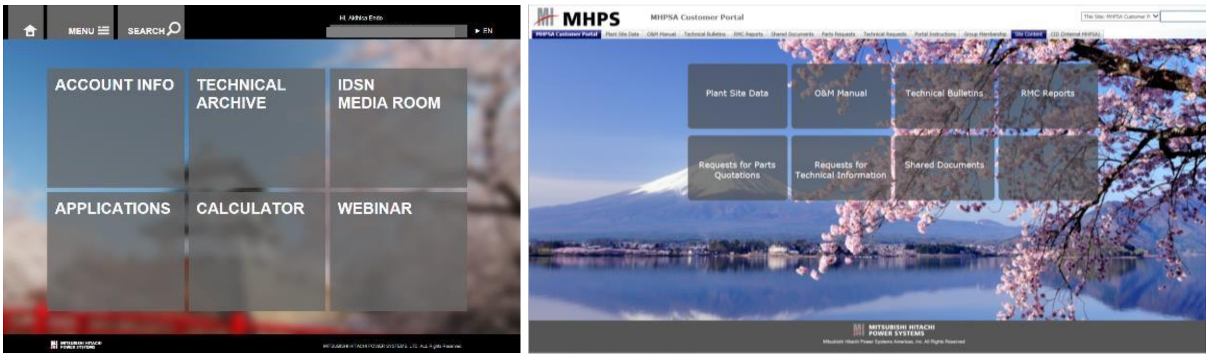

Figure 3: Asia-Pacific and Americas Customer Portal Home Pages

III. Real-Time Access to Plant Status and History

Operators in the power plant control room have real-time access to current plant operating status through the control room OPS, but timely and secure remote access can be a challenge. This is especially the case during events that may require transfer or access to large amounts of status and historical data for incident response or root cause analysis by the owner's corporate engineering departments or the engineering departments at the designers and manufacturers of the major equipment. Past history has also shown that access to needed historical operational information is often restricted by data historian limitations at the power plant. These issues can cause response delays and could in some cases increase risk to the plant operation.

The approach taken for the MHPS-TOMONI™ Digital Power Plant is to replicate the data stored on the on-site OSISoft® PI System™ servers through PI-to-PI interface to the long-term PI database at the MHPS RMC. This system is the backbone of the MHPS approach to the full remote site connection. Once the data is securely warehoused on MHPS servers, it can be used by a wide range of data analysis tools to provide owner/operators with condition assessments, predictive analysis of issues before they reach critical levels, or root cause analyses of conditions that reached critical limits. It can also be used to support predictive maintenance as discussed later in this paper.

For real-time remote access to the data, several digital solutions for data visualization are available, which in keeping with the MHPS-TOMONI concept were conceived and developed in coordination with pilot Users and which continue to be enhanced based on User feedback and experience.

One is the MHPS-TOMONI KPI Analyst, which takes data from plant-based control systems and formats it into easily understood graphical interfaces and delivers it to desktop or mobile devices as shown in Figures 4 and 5.

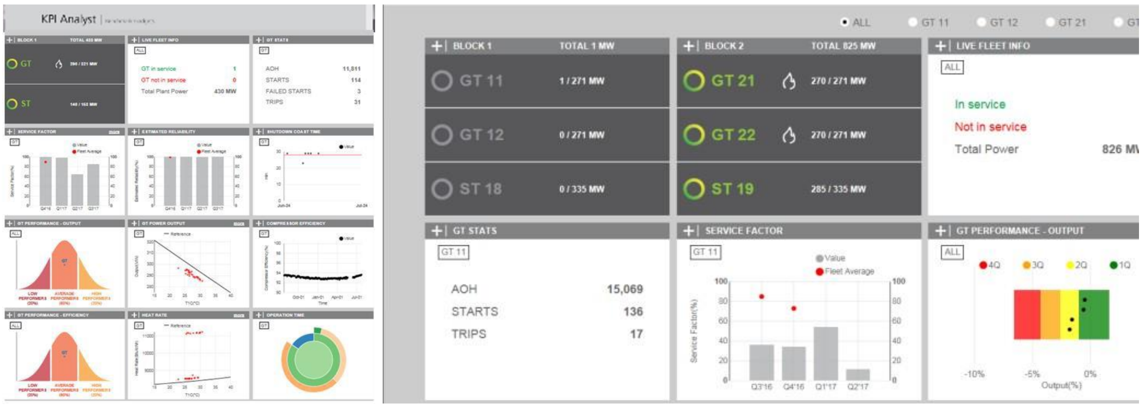

Figure 4: MHPS-TOMONI™ KPI Analyst Sample Screens from GTCC Power Plant

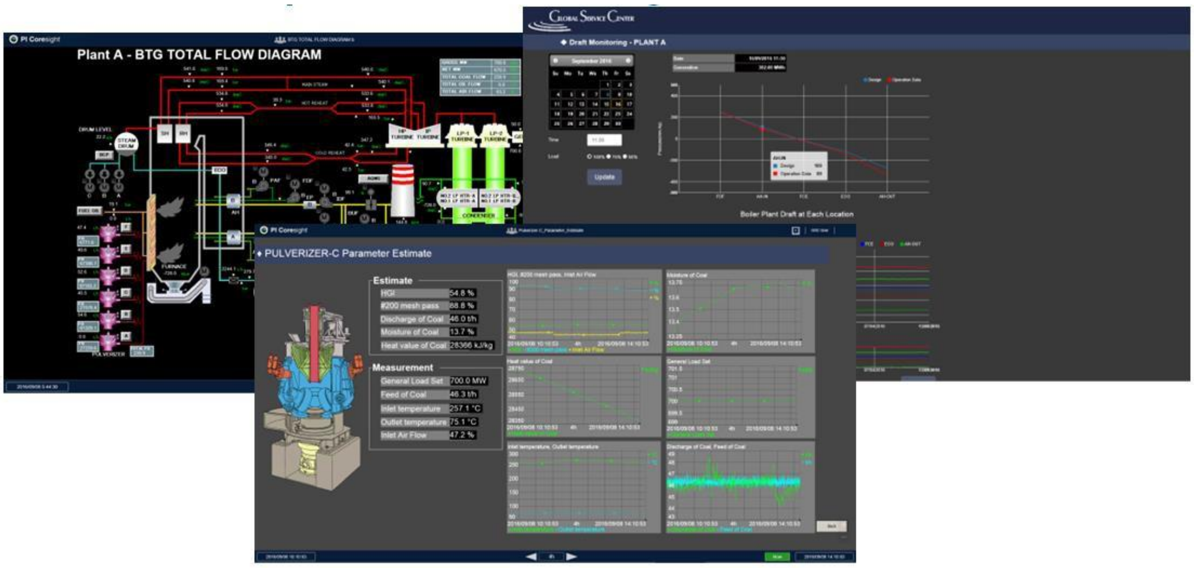

Figure 5: KPI Monitoring on a Solid Fuel Power Plant

The other utilizes a customized version of the ECG (Engineering Consultants Group) Glance Graphical Visualization Client to connect to the PI System data historian that is utilized in the MHPS-TOMONI Platform Layer to allow easy web-based access to plant data from modern browsers and devices such as iPads® , iPhones® , Android™ phones and tablets.

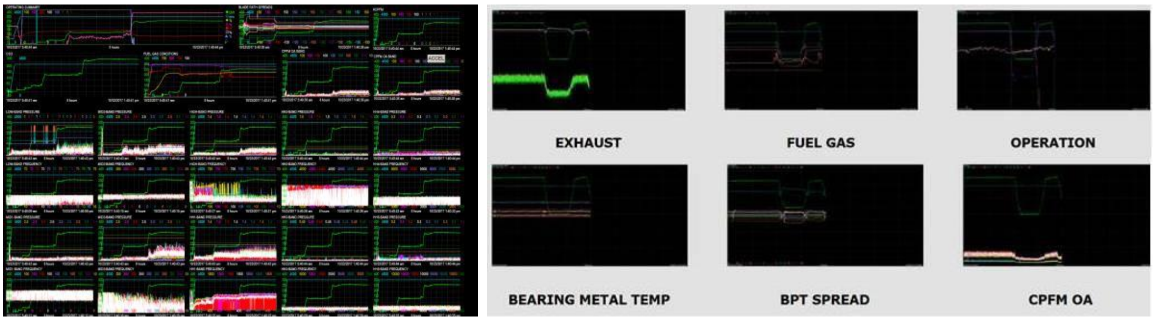

Figure 6: Glance Visualization Client Sample Screens

Both applications can be ported to the owner/operator personnel through the MHPS Customer Portals. The data visualization can also be customized based on User needs and priorities and can be accessed on a range of mobile devices to keep Users connected to their turbine control system, DCS data and PI System process data information whether they are in the plant, headquarters or in remote locations.

IV. Knowledge to Allow Rapid Response to Alarm Conditions

Once the latest plant documentation and plant status information is digitally available, the next opportunity for leveraging digital technologies to deliver real-time O&M support is assistance with rapid response when an alarm occurs. A digital solution called MHPS-TOMONI Alarm Wisdom has been developed and is being piloted to facilitate this rapid response.

Experienced and proficient operators are often able to take actions promptly and optimally based on their past experience and knowledge, resulting in effective countermeasures and minimum impact on operation and maintenance. But, a trend to more starts and more rapid load changes and other transient operations is likely to challenge even the most experienced operators. And, at the same time, attrition of experienced personnel is significantly reducing the average experience level at many plants.

MHPS-TOMONI Alarm Wisdom helps operators by giving guidance related to each alarm based on accumulated experience of MHPS design and commissioning engineers, incorporating recommended guidance and solutions based on real experience, engineering analysis and fleet experience on similar units. When the plant control system activates an interlock, MHPS-TOMONI Alarm Wisdom searches the incorporated alarm database and immediately identifies relevant documentation, potential solutions and the most important troubleshooting steps. That database is designed so it can be regularly updated based on both MHPS newly gained experience and local plant operator experience of similar issues and best-practice resolution. That ability to capture and make immediately available the lessons-learned of the plant operators and combine them with the accumulated MHPS and fleet experience can be very powerful.

Specific Alarm

Alarm Search

Alarm & Solution

Figure 7: MHPS-TOMONI™ Alarm Wisdom Sample Screens

In addition to the support from the MHPS-TOMONI Alarm Wisdom application, dedicated monitoring and support from an MHPS RMC is also available to provide additional support on a 24/7 basis for reacting to alarm conditions and troubleshooting to try to avoid trips and runbacks or troubleshooting to increase the probability of a successful restart.

V. Analytics to Provide Early Warning of Developing Issues

Quick and effective response to alarm conditions is one important element of O&M support, but preventing alarms is another primary goal of the Digital Power Plant.

With this goal of taking action to prevent alarms, MHPS has developed and utilized data analytics in its Remote Monitoring Centers for many years and has deep experience with several powerful data analytic software applications that perform predictive analytics for monitoring the health of components within the power plant. Supplemented by expert human knowledge and fleet experience available in the RMC, this predictive analytics has been proven to prevent alarms and improve the performance and reliability of the power plant. Models created using the predictive analytics software are divided among major systems and highly correlated functions. The parameters used to define model deviation, maximum limits and minimum limits are based on technical expertise and modelling experience. Predictive analytics give the ability to capture trends deviating from "normal" or "typical" operation well before standard control system alarm limits are reached.

As an example, predictive analytics monitoring a gas turbine alerted early trends on the blade path temperature model shown in Figure 8. One blade path temperature spread was slightly deviating from expected values, past the tight model limits set. Upon further investigation, other adjacent blade path temperature spread models were also slightly deviating, along with correlating changes in the disc cavity temperature models. The predictive analytics tool alerted RMC operators when the deviation was far from any of the control system alarm limits, and they were able to alert the plant operator and MHPS Engineering to the condition. Engineering recommended a controlled shutdown. Upon inspection of the unit, extreme component wear was found. The same component wear had previously caused a failure event with significant damage and repair time in another unit. In this instance the ability of the analytics to apply fleet lessons-learned detected the subtle deviations and averted the failure mode.

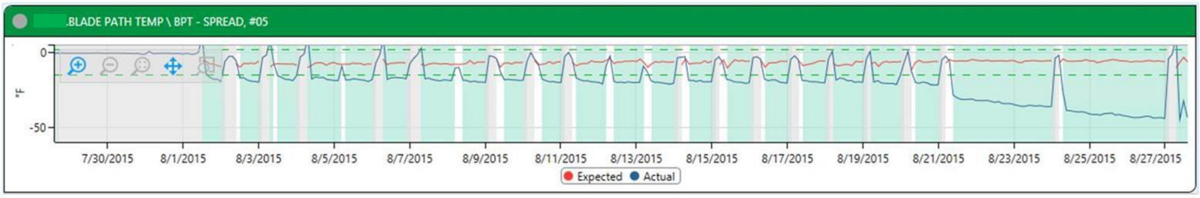

Figure 8: Predictive Modelling Trend

Based on this depth of experience in the Remote Monitoring Centers performing predictive analytics on MHPS-provided equipment, MHPS is now working with several power generation companies to extend the predictive analytics applications to the total power plant, both for remote monitoring from the MHPS RMC and also for local installation of the predictive analytics software at the power plants and/or the power generating company's engineering headquarters.

Predictive analytics with APR (Advanced Pattern Recognition) software, combined with close involvement of experienced experts, has proven very effective. The next step being taken in the journey of the Digital Power Plant is to supplement APR software with expert systems that can both capture and automate application of the knowledge of the experts and do so with expert systems that can subsequently refine their knowledge by "learning" autonomously based on analysing additional operational data and events. These systems are often called artificial intelligence (AI) or machine learning (ML), and MHPS has several pilot projects underway to add AI and ML algorithms to supplement the APR predictive analytics. These pilot projects involve cooperative development agreements with several of the leading global AI software companies and show promise to have enhanced effectiveness with less intensive use of human experts as the AI models are deployed to learn on their own.

One such system that is already being piloted at several power plants is called the MHPS-TOMONI AI Guardian application. In addition to analyzing identified parameters, MHPS-TOMONI AI Guardian includes a pattern matching system that seeks similar patterns of parameters and any developing abnormal deviation from previously experienced issues. AI Guardian then suggests possible causes of the issue with a ranked probable cause distribution and associated recommended actions for operators to address developing issues in early stages. MHPS-TOMONI AI Guardian works in real-time and immediately provides information to help identify and address issues which conventional monitoring methods do not detect and helps even less experienced operators take actions by the expert system without direct human expert involvement.

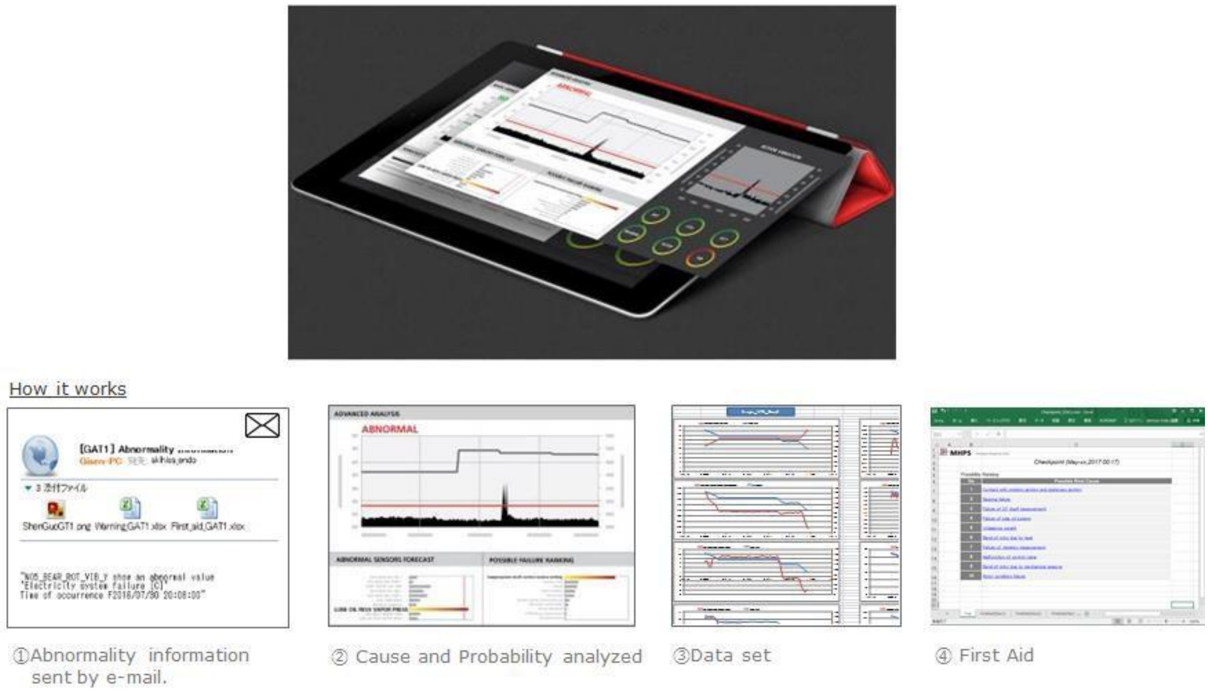

Figure 9: MHPS-TOMONI™ AI Guardian Sample Screens

The MHPS-TOMONI AI Guardian application and several other similar AI-based applications are currently being piloted and are adding new digital solutions as elements of the comprehensive Asset Performance Model of the MHPS-TOMONI Digital Power Plant.

VI. Data for Analytics-Based Predictive Maintenance

Getting to true predictive maintenance has been a goal of the power generation industry for a long time, but having enough data and the derived knowledge from that data has always been a challenge.

Equipment designers and power generation operating companies have debated this topic for years. In theory, life consumption of individual components and systems can be accurately calculated to extend calendar-based maintenance intervals into true predictive maintenance.

The main problem has always been the availability of sufficient reliable and consistent historical data to make the life consumption calculations. A lot of data is needed to define the conditions that the key components have been exposed to over their life or since their last inspection. Large volumes of historical data need to be retained and accessible for those calculations. Typical data historians in power plants are not set up to retain that amount of data. And, in some cases, additional sensors are needed to provide supplementary data for asset life and predictive maintenance modelling. More aggressive duty cycles compound the issue by making the potential accelerated life consumption more uncertain, thus making the historical data even more important.

Another problem has been the availability of the analytics and computing power at the power plant to prioritize and analyse the mass of historical data and reduce it to allow actionable conclusions and risk analyses.

The elements of the MHPS-TOMONI Digital Power Plant will help address this challenge. [Reference 2] Once a connection to the plant is established, the data can be streamed and accumulated centrally in PI historians and backup data storage to enable analytical calculations and correlations of life consumption.

In addition to AI-based real-time asset performance modelling of the total plant, AI-based asset life and predictive maintenance models are also being deployed, and those promise to not only predict the optimum timing and scope of planned outages but also to allow real-time operational trade-offs of life consumption and forecast maintenance costs compared to the potential economic gain of allowing an aggressive operation event.

VII. Knowledge for Maintenance Implementation

Predictive maintenance is intended to do “at-the-best-time” maintenance, driven by knowledge that allows optimum timing -- maintenance that is balanced in a cost-effective manner to take place before system equipment damage is significant but no sooner than is cost-effective given the life consumption strategy of the owner.

MHPS is transitioning to heavy use of electronic outage information, work packages and documentation, using tablet computers to access data as well as to input inspection data. This increases as-needed data availability, enables real-time flagging of out of tolerance input data and ensures real-time data visibility to subject matter experts as needed, regardless of their current location. In addition, outage planning now makes heavy use of the Issue Reports generated by the RMC predictive analytics to assure that this derived knowledge is managed for maintenance attention before it can affect plant operation. Typical open issues going into a planned outage might include the types of things listed in Figure 10. These are often of a level of detail below what is considered in conventional outage planning, and if left unaddressed, many of these could result in subsequent issues.

IR No.	Item Title	System
6805	BRG VIB 1X Abnormal / Bad Quality	Bearing/Vibration
6798	CPFM PS #03 Pre-Alarm	CPFM
6723	CPFM PS #16 Low Sensitivity (All Bands)	CPFM
6389	(CPFM) Elevated Activity HH4 Band	CPFM
6329	Warming Sequence Operations Exceed Time	Combustor Warming
5986	Accel #15 erratic behavior	CPFM
5985	Accel Sensor #11 erratic behavior	CPFM
5493	RAC Temperature High RS T/C	Rotor Cooling Air
5413	Increased Fluctuation On The Main FCV DP	Fuel Gas
5064	IGV Deviation (Position vs IGVREF) Pre-Alarm > 2.5%	Inlet Guide Vane
6724	CPFM PS #03 Faulty- Flat lined	CPFM
6708	BPT Spreads #10 & #11 Step Changes	Blade Path Temperature
6680	RAC LS Bad Value During Turning Gear	Rotor Cooling Air
6648	BPT Spread #15 Sudden Step Change	Blade Path Temperature
6329	Warming Sequence Operations Exceed Time	Combustor Warming
6023	Main A PCV increased deviations	Fuel Gas
5249	BRG 1Y High Vibration Spike During Shutdown	Bearing/Vibration
4897	Faulty Thrust BRG Metal Temp Sensors	Bearing/Vibration

Figure 10: Examples of Open Issues Identified by RMC Analytics

Maintenance implementation is the final step in the continual cycle of O&M Support shown in Figure 11 below.

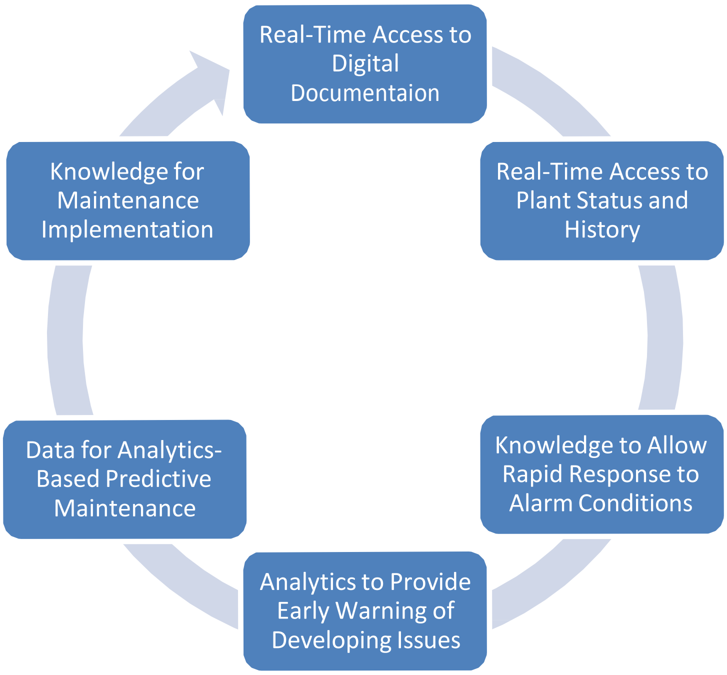

Figure 11: Continuous Cycle of O&M Support

Once the maintenance is accomplished, the cycle begins again. Since all of the data and actions taken are digitally documented, updates of the plant status is easy and in many cases automatic. Updated data is critical to provide ongoing support to the plant O&M personnel and enable continuous improvement based on individual plant and fleet-wide learning.

VIII. Conclusion and Future Vision

Operating a reliable and cost-effective thermal power plant has always been challenging and recent power market dynamics have made it even more challenging. Rapid evolution of the power generation industry is driving many owners and operators of thermal power plants towards more flexible, and often more aggressive, operation modes. These operation modes can have significant implications for equipment reliability and life consumption, increasing the importance of rapid operator response based on broad situational awareness as well as effective predictive maintenance. At the same time, economic pressures and an aging skilled workforce are creating staffing, knowledge retention and training challenges for the power generation industry.

The evolving Digital Power Plant will help power generators respond to those challenges. Mitsubishi Hitachi Power Systems (MHPS) will continue to work interactively with the Users of its major equipment to identify ways in which advanced digital technologies can best assist with meeting these challenges of a changing industry. Communications and knowledge sharing through MHPS-TOMONI™, signifying heavy involvement with power plant owners and operators in a collaborative manner to most effectively unleash the potential of power plant digitalization, will be a big part of the future of the Digital Power Plant. The Digital Power Plant enables a wide range of services and solutions with valuable and convenient data access for the power plant owner/operator, all with industry-leading security features. Many of these provide real-time digital delivery of O&M support to help power plant operators as the power generation industry continues to evolve.

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