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

Elements and Enablers of the Digital Power Plant:
An Inclusive Approach to the Power Plant Digital Analytics Platform for Power Plants in the Americas

Daryl MASSEY
Mitsubishi Hitachi Power Systems (United States)

Hiroyasu ISHIGAKI
Mitsubishi Hitachi Power Systems (Japan)

Paul WHITLOCK
Mitsubishi Hitachi Power Systems (United States)

Beatriz BLANCO
Mitsubishi Hitachi Power Systems (United States)

Ronald THOMAS
Mitsubishi Hitachi Power Systems (United States)

Abstract:

Today's increasingly digitized power plants benefit from improved access to advanced analytics and fleet-wide data correlations. This paper describes the approach to this challenge taken by Mitsubishi Hitachi Power Systems (MHPS) that led to today's MHPS-TOMONI™ Analytics Platform. There are a number of data connection and management platforms available to power plant owners and operators, some direct-connected and some cloud-based, with varying degrees of integration and flexibility to interface with multiple technology control systems and existing power plant analytics, databases and historians. MHPS chose to develop their data connection and management platform by building on existing best-in-class software that is already in use in a large percentage of power plants in North America and world-wide, incorporating robust cybersecurity and adapting their internal analytics systems and processes to this platform. This paper describes the evaluation process that led to this approach and describes the advantages of this approach for power plant Owners and Operators in the Americas. This foundation is highly flexible and serves as data source for multiple analytics applications and O&M support systems that comprise today's MHPS-TOMONI™ Analytics Platform.

Several pilot applications at power plants in the Americas will be introduced where advanced data analytics and fleet-wide data correlations delivered by this platform are leading to substantial economic benefits for the power plant Owners.

I. Overview of MHPS Digital Power Plant Initiative

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 its full implementation. It has been a multi-year journey to today's Digital Power Plant, and 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 to 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 applications and digitally-delivered O&M support systems have been applied to improve the reliability, flexibility and performance of power plants around the World. [References 3, 4, 5, 6] These comprise the growing MHPS-TOMONI™ Suite of Digital Solutions.

At MHPS the approach to leverage steadily advancing digital and communications technologies is called MHPS-TOMONI. 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 digitization. MHPS-TOMONI combines digital technology with extensive equipment designer and equipment user collaboration and comprehensive total plant design, operation and maintenance experience. It recognizes that power plant digitization 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.

Today the challenge is how to best extend more than two decades of valuable monitoring and diagnostics experience to create a “conduit” for new and innovative two-way digital information exchange to assure that every plant can benefit from the latest advanced analytics, expert human knowledge and systems, design advancements and fleet experience -- whether it is fully remotely monitored or not. To do this requires a stable, secure and flexible data connection and management platform, to serve as the foundation for the advanced analytics and O&M support systems that are steadily advancing the Digital Power Plant. Such a platform should be able to communicate with a wide range of control systems, data sources and IoT Analytics packages. It should be able to effectively interface

with existing owner/operator data platforms, and it should be able to be flexibly implemented in either On-Premises or Cloud-based applications depending on individual owner/operator preferences and security requirements.

It has been useful to think of the Digital Power Plant as consisting of four layers as shown in Figure 1 below.

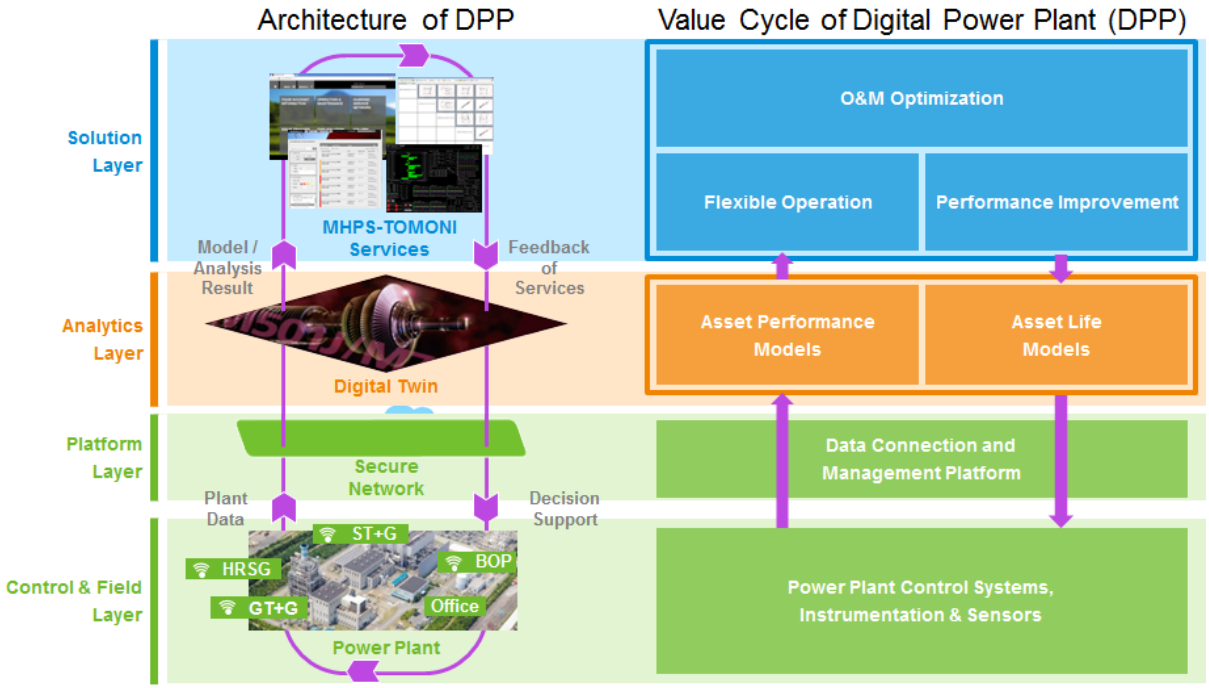

Figure 1: MHPS-TOMONI™ Digital Power Plant

The Control & Field Layer is located at the power plant, sometimes called the “Edge”, but different owner/operator preferences and priorities for implementation could result in the other layers being located partly in the power plant and partly at a centralized location such as an RMC or in a common Cloud-based implementation that communicates securely with multiple plants and multiple sources of owner, operator, equipment designer and plant designer expert knowledge. That expert knowledge could be embedded in advanced analytics software, utilize human experts or a desired combination of the two. In all cases, however, the Platform Layer performs a critical function of securely connecting the data in the plant with the analytics, human experts and fleet-wide learning that create 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 collaboration. Over the past several years input was 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.

A Users' Group survey of power plant owners and operators made it clear that User strategies differed significantly, emphasizing the importance of a flexible approach. Displayed below in Figure 2 is the distribution of responses to the question: "What do you think is the optimal mix of recommendations from direct involvement of people with expert knowledge versus rule-based computer analysis using algorithms, trends and historical data patterns."

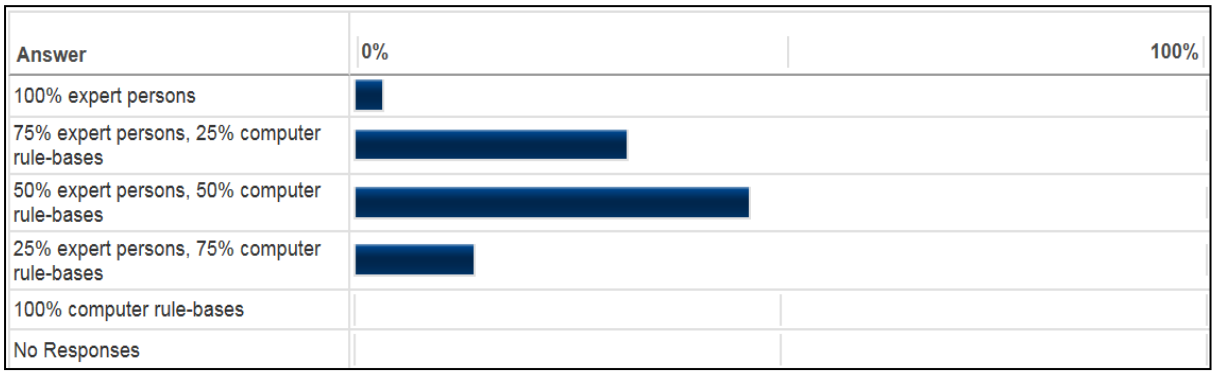

Figure 2: User Survey Responses

At this time, it appears that a 50/50 implementation would be consistent with the strategies of the majority of Users, but there are significant differences in preferences.

II. Digital Analytics Platform Definition

In defining the Platform Layer, MHPS applied the "TOMONI" concept. Power plant owners and operators today face complicated challenges in an energy market that will continue to evolve at a rapid rate. One thing that was clear is that many owner/operators had a strong preference for a platform solution that was compatible with the existing processes and systems they had in place and their people were familiar with. For that reason, an "inclusive' approach was taken whenever possible to create a digital data connection and management platform that coordinated with existing owner/operator data management platforms rather than making them obsolete. The graphic in Figure 3 displays the concept that was chosen to put together the "data puzzle" in an inclusive way.

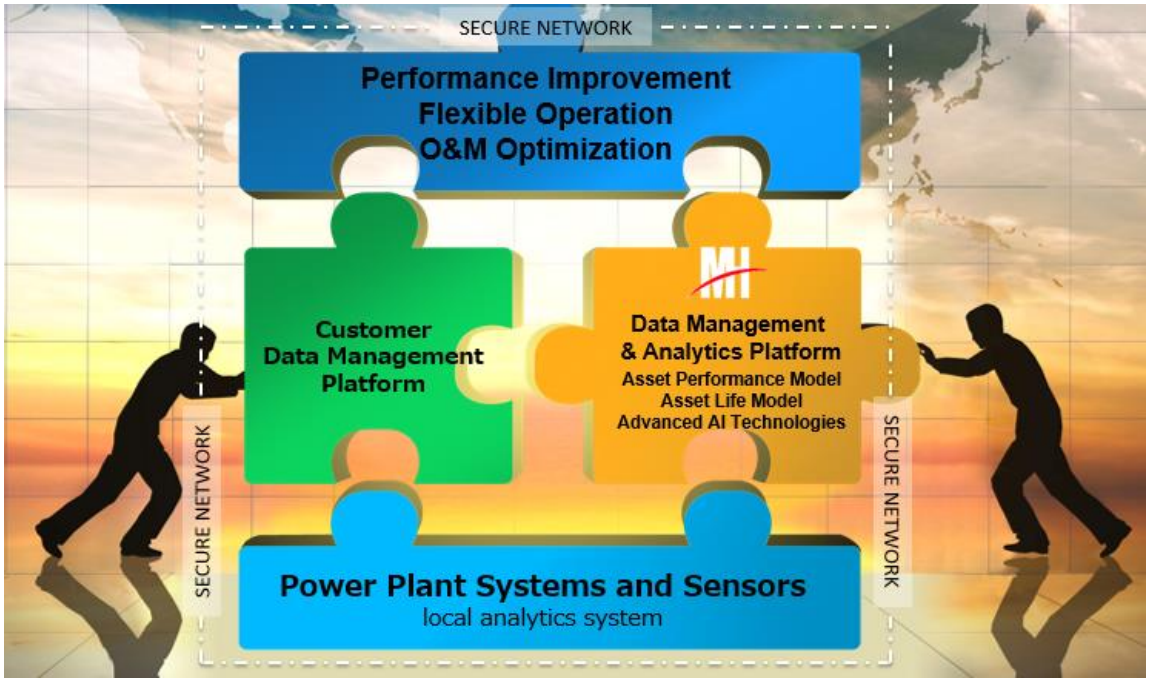

Figure 3: An Inclusive Platform Approach

Historically, most centralized power plant operational data management, analytics and fleet-wide correlation applications were implemented on platforms “On-Premises” with secure point-to-point connections via VPN or similar methods to consolidated platforms in Remote Monitoring Centers. As Cloud technologies have advanced, however, new opportunities are being created for cost and productivity improvements. As a result, the MHPS platform definition included compatible On-Premises and Cloud implementations.

The Digital Power Plant utilizes predictive analytics for monitoring the health of components within the power plant. Along with expert human knowledge and fleet experience, this information is used to improve the performance and reliability of the equipment. Models created using 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.

Predictive analytics with APR software, combined with close involvement of experienced experts, has proven very effective in improving the reliability and availability of connected power plants. Average reductions of up to 2.4% in plant reliability have been documented. 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 development and demonstration projects underway to add AI and ML algorithms to supplement traditional 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 operate independently.

III. Platform Partners

The “TOMONI” (Together with) concept was also applied to the selection of “Best-in-Class” software partners to power the MHPS-TOMONI Digital Power Plant.

Of particular relevance to the selection of platform partners was the feedback from Users that over 70% of the surveyed plants in the US and over 50% of the surveyed plants outside of the US used the OSIsoft® PI System™ for data management and operational intelligence. MHPS had extensive experience with the PI System in its Orlando, Florida, USA Remote Monitoring Center. In December 2016, MHPS and OSIsoft entered into an expanded global relationship to use the PI System as the core for new interactive analytics applications and to deliver total plant solutions to its customers. As part of this strategic alliance, MHPS and OSIsoft are collaborating to define and promote new integrated digital solutions that add increased intelligence to power plants around the world, using best-in-class software and leveraging their respective knowledge and expertise.

When it came to selecting a Cloud services provider, a similar User-driven approach was adopted. The overwhelming majority of power plant Users are heavily committed to Microsoft® application platforms, and the MHPS Netmation Control Systems also run on Microsoft platforms, so Microsoft was a logical choice. In addition, Microsoft cybersecurity is second to none, and the Microsoft Azure Stack seamlessly supports both On-Premises and Cloud-based implementations.

Another advantage to the approach taken is that OSIsoft and Microsoft both have a comprehensive suite of developed applications as well as extensive “Partner Ecospheres” that have already created hundreds, and perhaps thousands, of advanced applications that can provide value in power plant use cases. By building on those applications, the analytics and solutions layers of the Digital Power Plant can be steadily expanded by adapting and adding expert power plant knowledge to many of those existing software applications. In this way, implementation can be accelerated, and the MHPS and owner/operator expert

resources can work together to create actionable knowledge with reduced effort applied to writing new proprietary software.

The result of the platform partner selection process was the MHPS-TOMONI Analytics Platform concept shown in Figure 4.

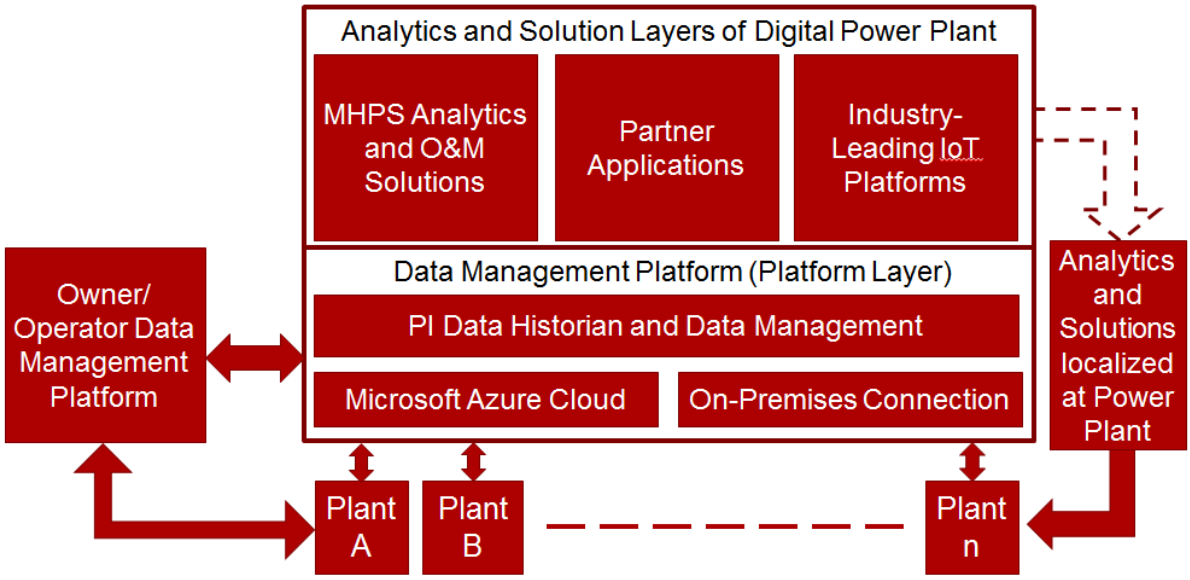

Figure 4: MHPS-TOMONI™ Analytics Platform Concept

There are already a significant number of analytics and O&M Support applications developed and running on this platform, some developed by MHPS and others configured by MHPS on proven best-in-class software developed by partners and embedding MHPS power plant subject-matter and technology expertise. Examples include:

- APR (Advanced Pattern Recognition) predictive analytics application with an advanced Diagnostics Advisor developed by OSISoft Partner ECG (Engineering Consultants Group) that is currently configured by MHPS and running on over 50 power plants.
- APR predictive analytics application developed by MHPS using Mahalanobis-Taguchi method (MT method) that is currently configured by MHPS and running on over 50 power plants.
- Real-time performance calculations configured by MHPS on total combined cycle power blocks using PI Analytics.
- Graphical visualization clients that allow easy web-based access to plant data from modern browsers and devices such as iPads®, iPhones®, Android™ phones and tablets.

- Utilization of PI Cloud Connect to securely share operational data between MHPS RMC and Strategic Power Systems, Inc. ORAP servers, to enable fleetwide RAM analytics and industry peer group benchmarking.

Other advanced analytics applications are in service or being developed and piloted using IBM Watson Analytics, Microsoft Azure Analytics and other leading analytics packages, again showing the inclusiveness and flexibility of the MHPS collaborative approach.

IV. Safety and Cybersecurity

Safety and privacy protection for power plant data is of paramount importance, as are cybersecurity measures needed for connections to the power plant control systems and data historians.

When planning a cybersecurity scheme for the Digital Power Plant, there are two main factors to take into account: securing the plant control system from attack by an external source and securing the plant's data.

NERC (North American Electric Reliability Council) creates standards to reduce exposure of critical cyber assets to attack and isolate them from the Internet. These policies can be found in NERC's CIP standards, which have become part of the regulatory process for generators connecting to the North American power grid. Owner/operator compliance is mandatory in North America, so the MHPS On-Site Monitoring System is designed to work within the owner/operator's methodology of compliance and MHPS' own internal security standards. This ensures intrusion security on the power plant site and security of the data being transmitted to and housed on the data management platform.

For traditional RMC direct connections, MHPS utilizes two standard methods of securing the connection to site: a dedicated T-1 line passing through MHPS controlled firewalls at each end or an encrypted B2B connection with the owner/operator.

Both methods consist of a secure OPC connection to the control system through a locked OPC relay (MHPS *Secure Gateway*) to an OSIsoft PI interface node. The interface node then transfers data to the on-site OSIsoft PI server. At this point, the owner/operator can choose to install a firewall that they control. This configuration option creates what is referred to as the DMZ. This configuration further ensures only traffic authorized by the owner/operator can pass to a midpoint in the network that is isolated from routable protocol. Below is an example of a recent On-Site Monitoring system implemented on a large combined cycle power plant at a major US investor-owned utility.

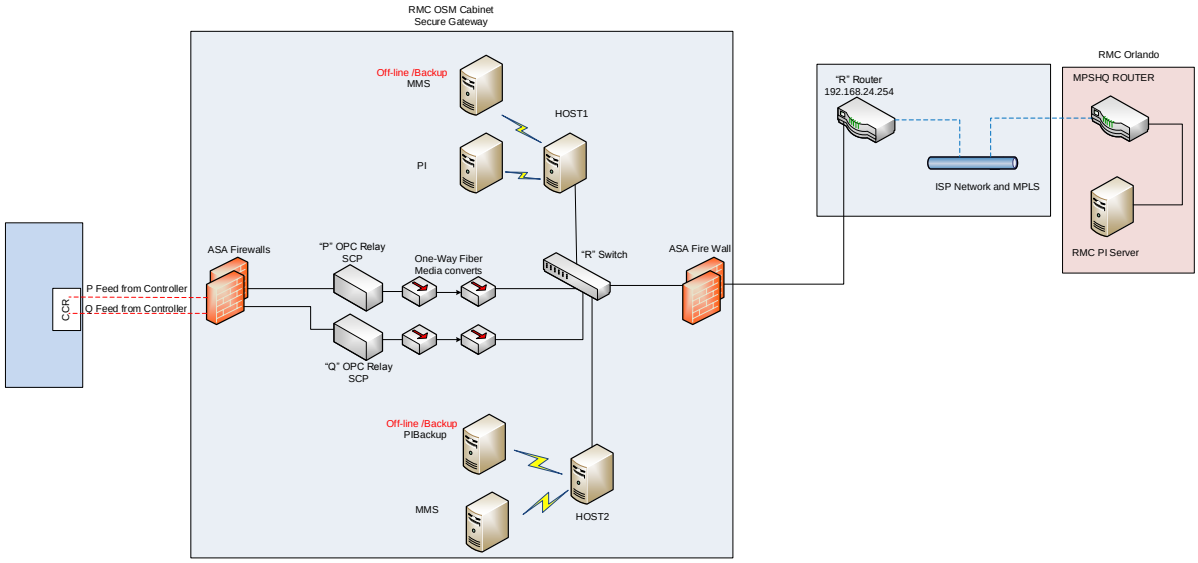

Figure 5: On-Site Monitoring System

The data stored on the on-site servers is then replicated through the OSIsoft PI-to-PI interface to the OSIsoft PI server at the MHPS RMC. The data passes through either the owner/operators B2B network to the RMC PI servers or an MHPS leased T-1 line with no connection to the Internet. Both connection types must pass the MHPS firewall at the RMC. The PI system communicates between servers on port 5450 and transmits encrypted data, which provides internal intrusion and data security. The direct T-1 line gives the RMC the ability to securely connect to site by a direct RDP session, while the B2B connection requires the use of a VPN to perform the RDP session. Both methods are acceptable and secure; however, this flexibility in the design allows the MHPS to comply with the owner/operator's policies and procedures.

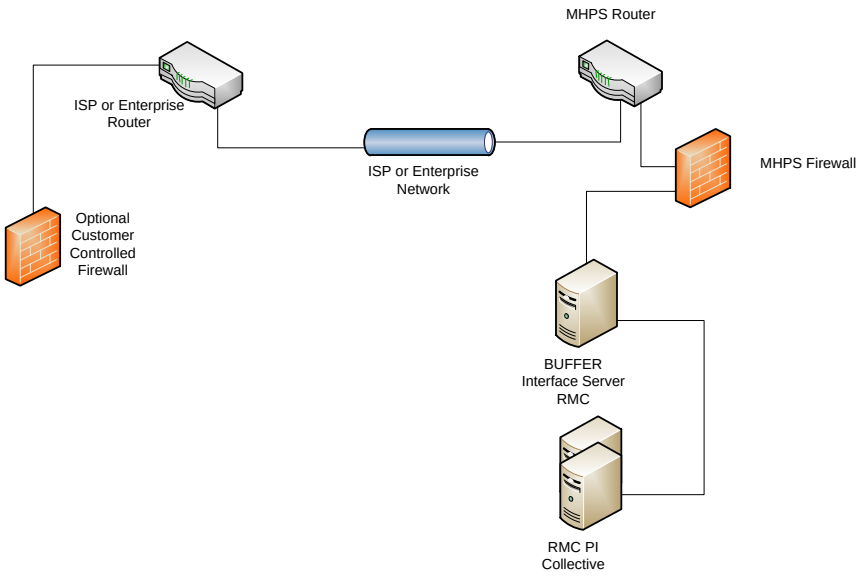

Figure 6: Networking Configuration

This system is the backbone of 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.

Recent advances in Cloud technologies are creating opportunities for cost and productivity improvements in analytics platform implementation. For the Cloud-based implementation of the MHPS-TOMONI platform, a powerful, flexible and secure monitoring/analysis infrastructure has been built on the Microsoft Azure Cloud.

The Microsoft Data Centers used for the Azure Cloud feature industry-leading security for customer data, developed and proven over the years. It includes compliance with the most stringent requirements such as ISO27001 or ISO27018.

Various aspects of Microsoft Azure provide a secure Cloud environment to protect owner/operator and MHPS data. Azure Active Directory and two factor authentication provide strict user identification and intrusion protection. Azure Security Center visualizes many aspects of security information of Cloud servers and networks and allows efficient maintenance of a secure condition. The Operation Management Suite allows analysis of various logs, including security appliance, applications and Windows servers.

When a direct connection to the power plant control system is made, there must be reliable protection from intrusion implemented. This type of connection enables secure communication with better cost performance for remote monitoring of a relatively small amount of data. The edge security device (Netmation Secure Gateway) utilizes asymmetric data communication mediums (optical and serial) to provide the same functionality as a data diode security device. It also utilizes HTTPS communication to transmit process data to the MHPS-TOMONI platform with proper digital certification on the server and client sides.

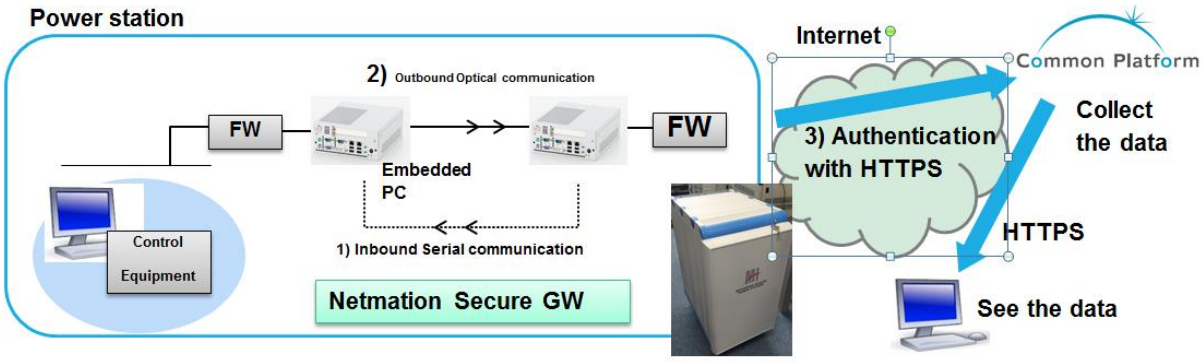

Figure 7: Netmation Secure Gateway

In addition to these hardware and networking security configuration approaches, the MHPS-TOMONI Protect Pack (TPP) is being implemented to integrate with MHPS Netmation control systems to simplify and strengthen cybersecurity and compliance efforts. Among the security implementation challenges faced by power plants with past approaches are:

- Compliance is labor intensive
- Requires physical system isolation
- Auditable records are the plant's responsibility
- The required 35-day business rhythm makes compliance difficult

The MHPS-TOMONI Protect Pack (TPP) can make it easy to keep Netmation control systems compliant with NERC 6 and beyond by providing:

- Threat Management and Application Control
- Backup and Recovery services
- Patch Management (automatic and manually initiated)
- Compatibility with the future of Netmation HMIs
- Automated Auditing and Alerts
- Assured Supply Chain
- Blue Team System Scanning/Assessment services

TPP is an integrated MHPS-TOMONI solution that delivers patch management and Blue Team services remotely to the power plant controls system through the MHPS-TOMONI data connection and management platform.

V. Owner/Operator Access and Integration

Owner/operators have access to the real-time data and applications running on the MHPS-TOMONI Analytics Platform via bidirectional communications between owner/operator and MHPS data servers allowing the owner/operator to continue utilizing their existing data platform, system and processes.

For the Cloud-based implementation, MHPS uses thin clients of Microsoft Azure to access and process data. Thus, data basically remains in the Cloud. This virtual working environment on the Cloud enables MHPS to develop various applications and services for owner/operators with short lead time and experienced engineers' knowledge. Tools on the environment include PI System tools (Process book, Datalink), Microsoft Visual studio to develop applications and Issue Tracker to manage various activities.

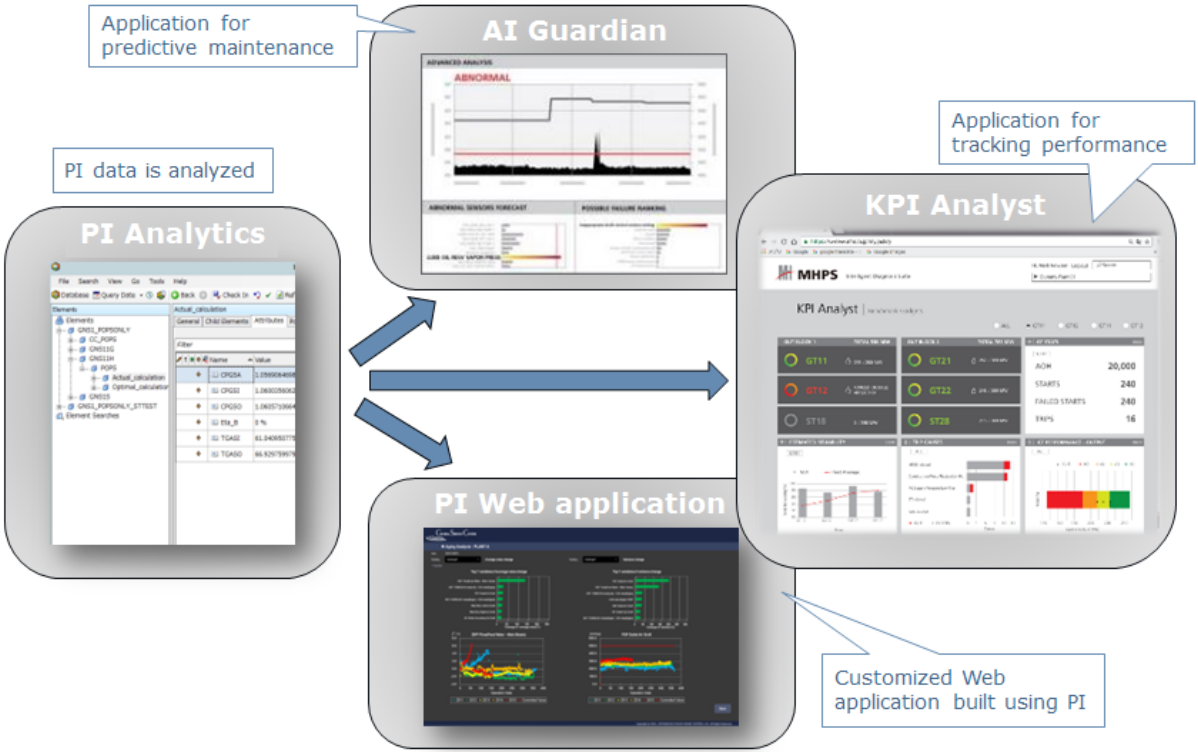

Figure 8: Example Applications

Figure 8 shows screenshots from several applications that digitally deliver analytics results and O&M Support. MHPS-TOMONI Alarm Wisdom, with screenshots shown in Figure 9, is another efficient tool to help plant operators make decisions when some important alarms occur in their power plant.

Figure 9: MHPS_TOMONI™ Alarm Wisdom

VI. Case Studies

MHPS has been monitoring and providing analytics-based recommendations for many power plants for many years and is steadily expanding the scope of this activity with new Cloud-based services available for various power plant configurations including GTCC and coal fired conventional plants.

A recent example was developed together with a large Japanese utility company, where a real-time data exchange infrastructure was established between different Cloud platforms, enabling collaboration to develop new and valuable data analysis applications.

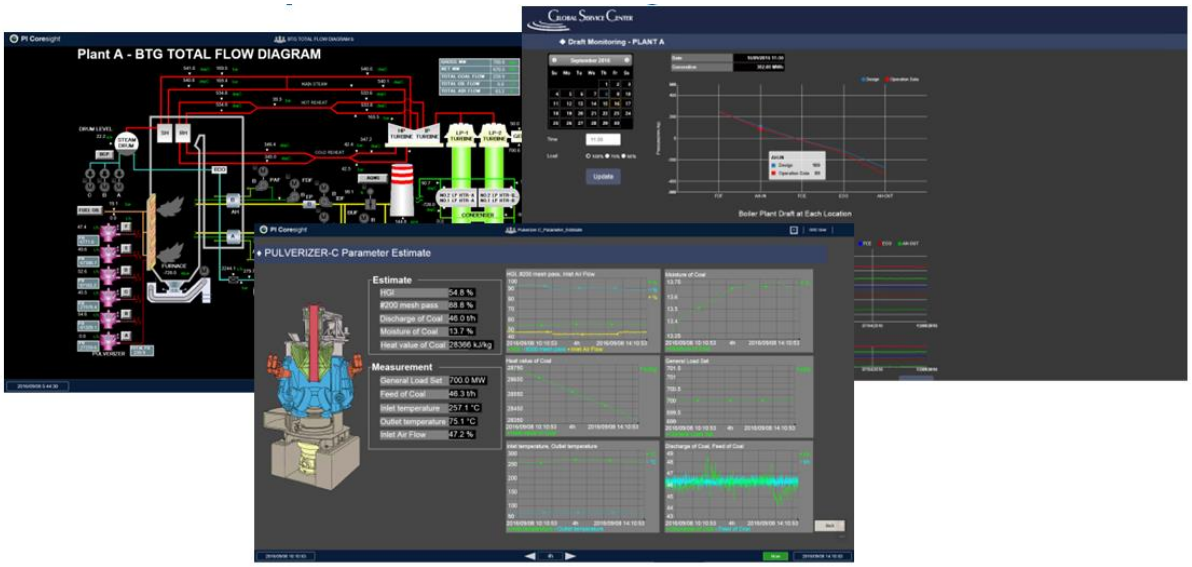

Figure 10: KPI Monitoring

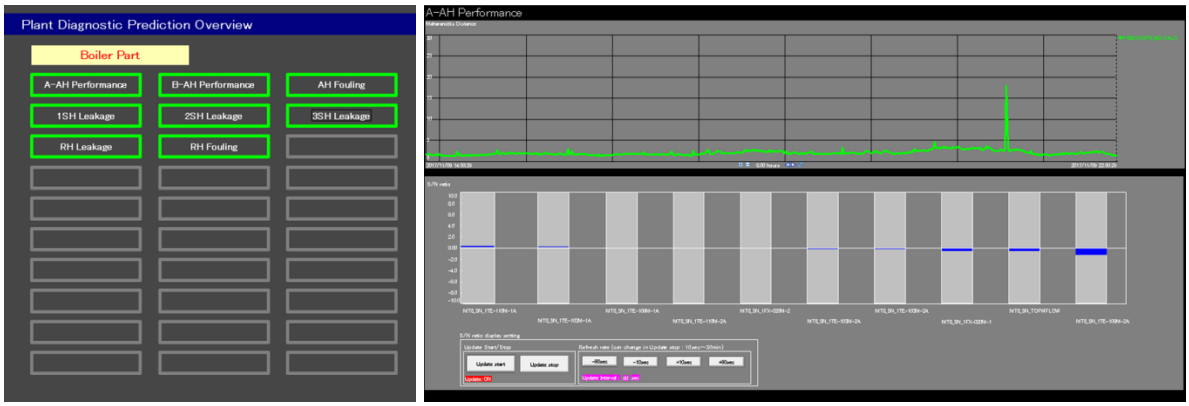

Figure 11: Degradation Monitoring, Performance Monitoring, Life Assessment

That successful pilot program is now being extended and supplemented by several additional pilot programs addressed at digitization objectives in collaboration with several owners and operators of GTCC plants in the Americas.

One such group of pilot programs is with a large US investor-owned utility and is being implemented at one of the newest and largest GTCC power plants in the US. This collaborative effort includes specific digital applications directed at improving the flexibility of the plant to maximize revenue from ancillary services markets, eliminate potential sources of unavailability based on systematic RAM analysis, more accurately measure air and fuel flow

to enable more precise combustion control and development of applications which increase real-time digital delivery of information to the plant operators.

Another such group of pilot programs is with a US IPP that owns and operates GTCC power plants. This collaborative effort is also directed at applying digital solutions to increase the dispatch profile of the plant as well as to extend the predictive analytics from the turbine generators to the total plant and extend thermal performance modelling to allow for real-time performance calculations and reporting.

A third such group of pilot programs is with a global power plant owner that operates several GTCC IPP plants in Latin America. This collaborative effort will establish a Cloud-based platform that will be jointly managed by the MHPS and Owner RMCs and extend total plant predictive analysis software to support traditional early warning of impending issues as well as maintenance optimization and outage planning.

All of these collaborative pilot programs have been defined based on substantial and quantifiable benefits for the power plant owners.

VI. Implementation Scenarios

MHPS has developed a growing family of analytics and other value-adding digital applications that run on the combined owner/operator and MHPS-TOMONI platforms. These elements of the MHPS-TOMONI Suite of Digital Solutions incorporate technology from MHPS, application partners and other best-in-class software providers

For owner/operators who plan to establish or upgrade their internal data and analytics platform, MHPS can provide support and advice based on many years of experience to create infrastructure and applications comparable to and compatible with the MHPS-TOMONI Analytics Platform, tailored based on owner/operator objectives.

MHPS can also provide support and advice on security enhancement for Cloud-based or On-Premises platforms.

VIII. Conclusion and Future Vision

New and existing power plants are becoming increasingly digitized to improve their reliability and responsiveness, but the Digital Power Plant is not a “one size fits all” solution. The benefits to be obtained from leveraging the combined knowledge of designers, manufacturers, operators and maintainers are significant. Communications and knowledge sharing through MHPS-TOMONI, will be a big part of the future of the Digital Power Plant.

The optimum application of MHPS-TOMONI Digital Solutions results from engagement with power plant owners and operators in a collaborative manner to most effectively unleash the potential of power plant digitization. The MHPS-TOMONI Analytics Platform enables a wide range of services and solutions to improve the reliability, availability and convenient data access for the power plant owner/operator, all with industry-leading security features. In this way, MHPS, its software alliance partners and the Users of MHPS equipment and systems are actively collaborating and providing leadership to advance the Digital Power Plant.

References

1. Endo et al. 2015, "Advancement of Remote Monitoring & Diagnostic Service", Power-Gen Asia 2015, Bangkok, Thailand
2. T. Tanaka et al. 2016, "Modern Predictive Maintenance Technologies and Methodologies for Power Plants' Profitability", Power-Gen Europe 2016, Milan, Italy
3. D. Massey et al. 2016, “Elements and Enablers of the Digital Power Plant: Digitally-Enhanced Productivity and Performance Improvements”, Power-Gen International 2016, Orlando, Florida
4. Narayanaswamy K.V. et al. 2017, “Elements and Enablers of the Digital Power Plant: Digital Solutions for 50 Hz. GTCC Responsiveness”, Power-Gen Europe 2017, Cologne, Germany
5. Massey et al. 2017, “Elements and Enablers of the Digital Power Plant: An Inclusive Approach to the Power Plant Digital Analytics Platform”, Power-Gen Europe 2017, Cologne, Germany
6. Imakita et al. 2017, “Power Plant Digital Analytics Platform and Application Cases for GTCC”. Power-Gen Asia 2017, Bangkok, Thailand