Elements and Enablers of the Digital Power Plant:

What is a Digitally-Enabled Power Plant?

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Abstract:

The concept of the digital power plant has attracted a lot of visibility and hype in recent years, with a wide range of concepts and definitions fielded by consultants, research institutes, power generators, software companies, control system companies, EPC companies, equipment OEMs and others.

In keeping with its strengths, Mitsubishi Hitachi Power Systems (MHPS) has taken a very pragmatic, step-by-step approach to creating its digital power plant. At a basic level, a digital power plant applies sensor data and software to do more than human operators can do alone. This is especially relevant as competition continues to drive plant headcount and operating cost reduction while experienced experts retire and retention of even existing knowledge is a challenge. There are various options for building the software infrastructure that is at the heart of a digital power plant. The first decision a plant owner needs to make is whether to develop software internally, invest in a comprehensive software overhaul, or purchase application solutions that build on existing software investments. All of which come with their own set of costs and outcomes. The second decision is to prioritize the problems to be solved and avoid the danger of trying to do too much at once.

There are important lessons for power plant owners and operators from one company's practical journey that began with digital control systems and remote monitoring and proceeded through automated diagnostics, fleet-wide learning, targeted digital solutions, machine learning (ML) and AI to today's digitally-enabled power plant and which will ultimately lead to the smart power plants of the future, capable of autonomous or near-autonomous operation.

This paper will present the step by step strategy used by MHPS to work with power plant owners and operators to define the elements and enablers of the digital power plant and create their digital solution portfolio, where several factors came together to create a customizable approach that increases plant reliability, efficiency, flexibility, and profitability.

I. Introduction

How do you lower the cost of electricity and achieve environmental and business goals? The challenges facing the power industry are many and span from pairing with renewables, to competing with newer plants to changing fuel economics. Power plants must adapt and respond to these challenges to remain viable.

Power plants generate an overwhelming amount of data. What do you do with it? How can it help overcome your challenges? All of this drives the need for a digitally enhanced power plant. But, how do you build it? Can an existing plant become a digital power plant?

A digital power plant applies sensor data and software to do more than human operators can do alone. This is especially relevant as competition continues to drive plant headcount and operating cost reduction while experienced experts retire and retention of even existing knowledge is a challenge.

In keeping with its strengths, Mitsubishi Hitachi Power Systems (MHPS) has taken a very pragmatic, step-by-step approach to creating its digital power plant. The result is a digital power plant that is extremely flexible, able to adapt to changing operating requirements and ready to incorporate the steady advances in data visualization, AI and machine-learning technologies that are happening today and are certain to continue into the future. The elements of this digital power plant can be applied in whole or part to both new and existing power plants based on the business objectives of the owner/operator.

II. Sensors and Data Sources

Building a digital power plant starts with data monitoring. Most of the data is already available from existing sensors, but some industry analysts have estimated that less than 10% of available data is being actively monitored or acted upon. And recent advances in sensor and control system technology have made even more valuable data available.

In its infancy, monitoring of limited data points allowed for rules based analytics to be established based on understanding the equipment design and operational profiles. At MHPS, more extensive monitoring began at T-Point, MHPS' heavily instrumented, commercial power plant in Takasago, Japan. T-Point was built in 1997 to help validate new products in a real, grid-connected power plant that dispatches power to Kansai Electric Power Company. This type of proactive monitoring marked the start of a more comprehensive way to capture and analyse data, creating “the voice of the plant”. Each plant faces different challenges. Some are based on environmental factors or operating modes unique to that plant. Therefore, the individual experience of each plant adds valuable feedback to validate designs and improve O&M practices from fleet-wide learning. As a result, MHPS saw the potential of correlating real-time data from multiple plants to drive more efficient O&M processes and superior product development. In 1999, data communication technology evolved to the point that MHPS built a Remote Monitoring Center (RMC) in Takasago, Japan. The RMC allowed for the centralized collection and rigorous, structured analysis of fleet-wide data from power plants around the world and established the foundation of the digital power plant. The first RMC was so successful in data analysis and improving the reliability of existing and new plants that MHPS built regional centers in Orlando, Florida, USA, and Alabang, Philippines.

Figure 1: Sensors and Data Sources

With thousands of sensors in a plant, there are already millions of data points to correlate, too much for human analysis, and the volume continues to grow. This increasing amount of data can be turned into knowledge and action. Such consolidation of knowledge would give the plant management team immediate and actionable information to make more informed decisions to improve reliability, reduce O&M costs and improve long-range revenue planning for the plant. To do that with data analytics and AI requires the transformation of total plant data from the multitude of sensors and control systems in the plant into a common data infrastructure that can be easily accessed, operated upon and communicated.

III. Robust Data Foundation

There are various options for building the data foundation that is at the heart of a digital power plant. Early on, MHPS recognized that power plant digitalization is not a "one-size-fits-all" solution. Feedback from active Users' Groups was used to gauge the best path to create a digital power plant. Surveys of the power plant Owners and Operators made it clear that User strategies differed significantly, emphasizing the importance of a flexible approach. One thing that was clear is that most Users had a strong preference for a data foundation that was compatible with the existing control systems, business processes and software systems they had in place and their employees were familiar with. This data foundation needed to be very robust and flexible, however, so data from all of the various sensors and controls in the plant could be correlated and analyzed as a whole, eliminating suboptimal "islands" of isolated data.

The OSIsoft PI System™ software is the data infrastructure most commonly used in the power industry for collecting and managing plant process and operational data. MHPS had been using the PI System in RMC applications for over a decade and, in 2016, entered into an alliance agreement with OSIsoft to make its software an integral part of many MHPS-TOMONI™ solutions. The PI System was also chosen because it already had a broad ecosystem of compatible software solutions, developed both by OSIsoft and their partners, that build on the PI System data foundation. As an example, MHPS makes heavy use of PI Process Book and PI Asset Framework for its data visibility solutions as well as partner applications such as APR (Advanced Pattern Recognition) software and data visualization software that was developed to leverage PI data.

IV. Cybersecure Connections

For a digital power plant to achieve anywhere near its full potential, it needs to be connected to multiple sources of information, knowledge and high-power computational engines that can perform advanced data analytics. Essential connections include analytics that are continually learning from fleet-wide experience, remote connections that allow the ability to perform maintenance of advanced logic solutions and the secure monitoring and installation of security patches. Additional connections that are becoming increasingly valuable will provide the plant's analytics with direct input on weather, grid conditions and wholesale power markets.

Safety and privacy protection for those data connections is of paramount importance as are the 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 systems from attack by an external source and securing the plant's data. MHPS has gone above and beyond national and international cybersecurity standards to ensure that both factors are strictly adhered to. An example of this is a recently developed solution called Netmation Protect Pack, which is a comprehensive and full-featured cybersecurity solution that supports the plant control system with state-of-art technologies that meet military-grade security requirements. The privacy of plant operating data is equally important to owners as it could become a competitive liability if it were to fall into the wrong hands. MHPS treats the protection of this data very seriously and as a result has developed the Netmation Secure Gateway to safeguard the transmission of plant operating data from the control systems to the MHPS databases where advanced analytics are applied. MHPS also recognizes that cybersecurity policies can vary from owner to owner so it is imperative to maintain flexibility to ensure the connection adheres to all situations.

V. Needs-Driven Digitalization

Data and the knowledge derived from that data are important, but they're just a part of the story. There needs to be a clear strategy on what to do with the increased knowledge, to most effectively achieve the individual objectives of each power plant. To do that the "voice of the customer" is needed. This provides the perspective needed to create actionable knowledge from the data. Data analytics provide the "voice of the plant" and create a common language for closer relationships among designers, service engineers, plant operators and plant owners. Users' Groups and annual Users' Conferences with Owners and Operators around the world facilitated conversations that shared a broad range of best practices and insights related to the challenges in the power market and gave MHPS a better understanding and prioritization of Users' needs. This close collaboration, combining the power of the equipment design and total plant knowledge of MHPS and the User's engineering, operations and maintenance experts, is proving instrumental in targeting advancements in digital technology to solve challenges in the power industry. Armed with the fleet-wide data and User feedback, and leveraging technical advancements, MHPS partnered with their customers to develop pilot programs to create digital solutions based on real-world challenges, like the varying demands of the grid and evolution of competitive wholesale power markets, which ultimately led to the creation of MHPS-TOMONI™. Tomoni is a Japanese word meaning “together with” and embodies MHPS’ approach to the digitalization of power plants by working closely with the Owners and Operators of those plants.

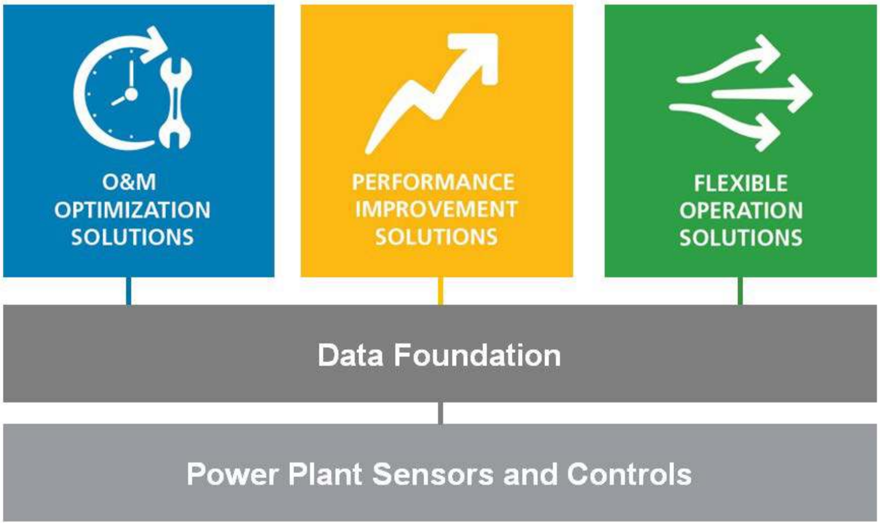

Figure 2: Key Elements of the Digitally-Enabled Power Plant

This diagram shows the relationship among the key elements of the digitally-enabled power plant. It starts with the data that is available from the power plant sensors and controls, which is then consolidated into the plant-wide data foundation for management, archiving and feeding to the three categories of solutions that can be empowered by that data. Some of the solutions are most effectively applied in the power plant at the “edge” and others are more effectively applied using secure connections to centralized analytics and knowledge bases.

The O&M Optimization Solutions include O&M Guidance, Monitoring & Predictive Analytics and Reliability Improvement. The Performance Improvement Solutions include Performance Diagnosis, Thermal Performance Improvement and Power Augmentation. The Flexible Operations Solutions include Operation Flexibility, Cyclic Operation Reliability and Fuel Flexibility.

There are a wide range of options available in each of the solution portfolios, so working with the Owner and Operator to prioritize their challenges – in keeping with the MHPS-TOMONI philosophy of "together with" – is important. Priority must be given to those solutions that can be most cost-effectively addressed and care must be taken to avoid the danger of trying to do too much at once. Solutions selected for application make use of the latest technologies in advanced control logic and advanced data analytics.

VI. Advanced Control Logic

Modern digital control systems allow a high level of flexibility for implementation of advanced control logic both at the time of plant commissioning and later as plant requirements and duty cycles evolve during the life of the plant.

In the past several years, an increasing number of power plants have moved from continuous base load operation to frequent start/stop operation and reduced operating hours per year, as a consequence of emerging renewable energy sources (RES), shifting fuel economics and competition from newer, more efficient generation. MHPS has been developing and applying a range of data-driven digital flexibility solutions that can help plant operators achieve more responsive, reliable and economically viable operation in dynamic markets while maintaining reliability and availability comparable to base-load operated units. As an example, more than 125 cumulative flexibility solutions have been implemented in GTCC plants, beginning in Europe where more RES has been deployed to date than any place else, to achieve faster start-up, lower combined cycle loads and better part load efficiency. These solutions have improved those plants' position in the market, resulting in higher utilization. Further development of digital solutions is ongoing to make power plants more flexible and sustainable to adapt to changing market dynamics.

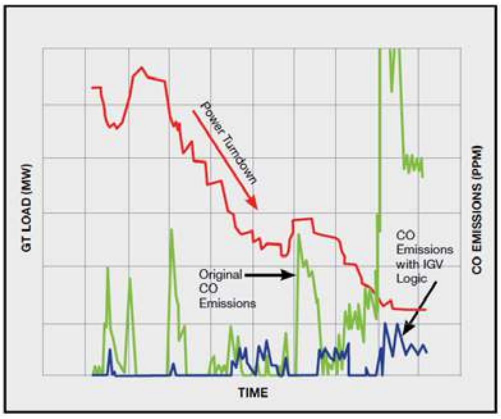

Figure 3: Reduced Emissions and Greater Turndown

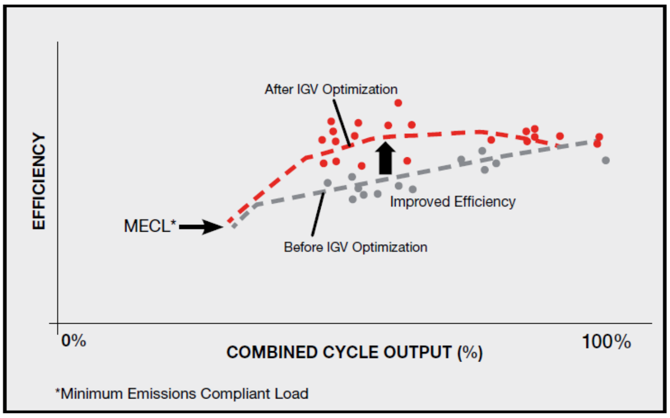

Figure 4: Improved Part-Load Efficiency

Another advantage of advanced control logic is the ability to apply different logic implementations at different times, providing the optimal response to grid requirements and additional profit opportunities in energy, capacity and ancillary services markets. Different logic implementations have different benefits, and there will often be trade-off decisions to be made. For example, one control strategy might increase peak power output but potentially reduce cycle efficiency and increase parts life consumption, while another would increase plant efficiency at the expense of peak power output but have a positive impact on parts life and maintenance costs. Switching back and forth between these two operating modes can be enabled by advanced controls based on total plant economics, taking into account spot market prices, fuel cost and O&M cost. Such business context should affect which control strategy is applied and it should vary at different times.

MHPS-TOMONI™ provides options where plant operators can selectively apply different advanced control logic at their discretion. One option is called Flex Pack, which has two available modules. The Performance Module allows selection between maximum efficiency, maximum output and peak firing. The Turndown Module improves gas turbine turndown capability for more flexible operation, reduced emissions and more efficient part-load operation.

Another option is called the Edge Enabler, which supplements the control system with additional capacity for a wider range of operation modes and control logic upgrades and allows prediction of the effect of each operating mode prior to enabling that mode.

The decision process to optimize the use of available operating modes can also be driven by advanced data analytics that guide the operators to optimal business decisions or, in the future, by varying levels of control system autonomy.

VII. Advanced Data Analytics

As digital technologies evolved, MHPS began using statistical reasoning analytics to investigate the relationships between variables and expanded the ability to use data from the plant to make informed recommendations that proactively provided customers with expanded O&M support. This led to more frequent interaction between MHPS and customer experts. Results included improved reliability and the knowledge to support predictive maintenance, shorter outages and extended outage intervals. Technology hasn't stopped evolving. Advances in machine-learning (ML) and artificial intelligence (AI) increasingly allow utilization of algorithms that learn from data without relying on rules-based programming and require less support from human experts. This is becoming a game changer. As AI and ML technology grew, MHPS sought partnerships with best-in-class software companies to implement these capabilities into the digital power plant. Technology alone is not the answer because it cannot offer the kind of insights that come from many years of plant design and operational experience, so the combination of human and artificial intelligence is essential to success. With years of experience of monitoring fleet operation, MHPS understands the profiles for many different failure modes of critical equipment in power plants. This information serves as the foundation of teaching AI and ML models both acceptable and unacceptable behavior so the technology has a basis to deliver automated decisions. Once this learning process is completed, advanced technologies are leveraged to minimize or displace the model-building processes performed manually today with efficient algorithms that continuously learn and become more accurate as new data is ingested over time.

The ability to identify problems either manually or automatically is critical to any anomaly detection initiative. However, the ability to quickly perform a root-cause analysis is equally or more critical to mitigating an existing or developing issue that could result in major damage or plant downtime. MHPS has successfully applied AI technology that automatically performs analysis on pattern changes and identifies the top contributing factors associated with the change. This capability not only expedites the troubleshooting process but also gives unbiased insight on pattern changes regardless of whether it is a known or unknown condition. The result is “zero-day” failure detection, so that no failure needs to have already occurred in order to be detected and avoided.

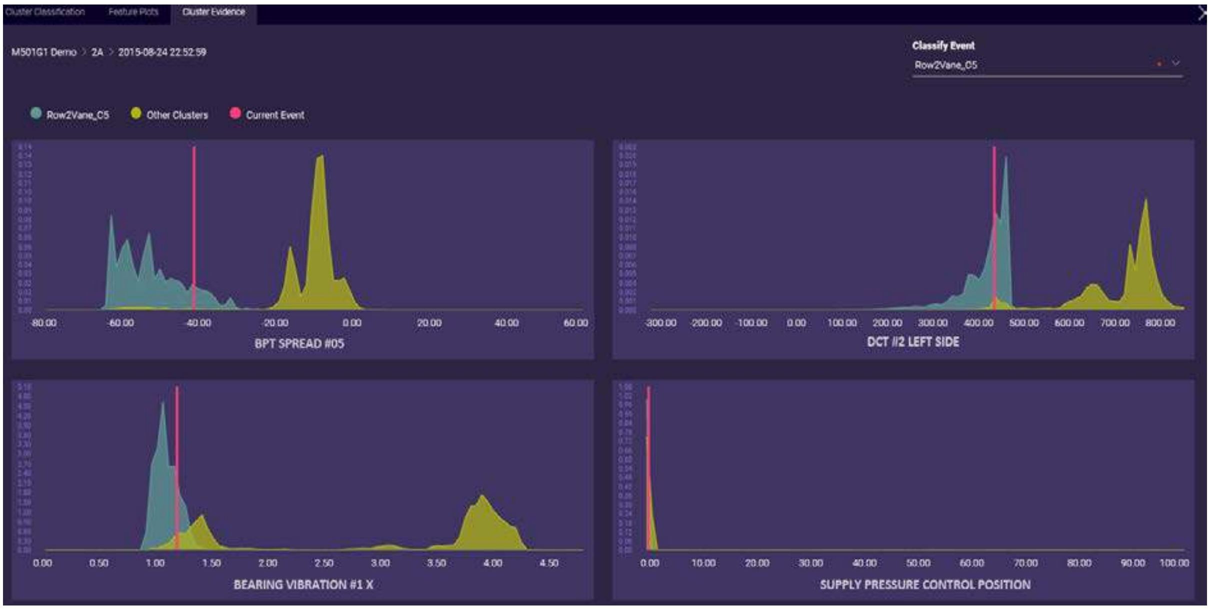

Figure 5: AI-Driven Analytics in Action

VIII. Digitally-Enabled Power Plant

To summarize, a digitally-enabled power plant:

- Creates knowledge from all relevant sensors and data sources
- Has a robust and flexible total plant data foundation
- Utilizes the latest technology for cybersecure connections
- Targets the highest priority business objectives of its Owners using:
    - Advanced control logic
    - Advanced data analytics

It has been clearly demonstrated that making power plants more digital can create many opportunities for their Owners. It is also clear that technology advancements will continue to create more opportunities over the life of the plant, and there will be strong economic incentives to continue to evolve the digital power plant and use the latest digital data communication, management and security foundation elements to facilitate the future application of additional digital solutions as market needs change and as technology advances to make power plants smarter. The digitally-enabled power plant will provide the key foundation elements to allow that evolution as the industry progresses to the smart power plant of the future.

IX. Looking to the Future

Today's plants are already benefiting from control upgrades and analytics that provide O&M optimization, performance improvement and flexible operation. As technology advances, exciting progress is being made on cognitive applications, like artificial intelligence (AI).

Making power plants smarter, more cognitive and ultimately autonomous will be a big part of the solution to future power market challenges.

A smart power plant will be:

- Self-aware of its limits, current operating status and plant-level operational options
- Able to take corrective action during operation
- Able to use real-time analytics to protect itself while maximizing revenue and minimizing emissions
- Able to automatically compensate for the aging of critical components and gradual degradation of performance
- Able to assess and quantify risk, utilizing knowledge from itself and similar plants, to make important trade-offs based on profitability and equipment longevity

- Capable of proactively adjusting important operational parameters to optimally prepare for predicted weather events such as changes in ambient temperature and barometric pressure

Smart power plants will determine and prioritize their maintenance needs based on system-level implications, assess risk and economic trade-offs of run versus maintain, communicate their status and provide risk assessment based on asset criticality, and request human maintenance support when needed to leverage limited human maintenance resources.

The smart power plant will be aware of neighboring plants, grid congestion, power markets and weather forecasts and provide real-time insights and recommendations based on analytics to optimally support the grid and maximize revenue from energy, capacity and ancillary services markets.

In short, a smart power plant will operate as if it had an unlimited number of human experts on site who have full knowledge of the plant, similar plants from a monitored fleet, the transmission grid, the wholesale power market and the surrounding environment.

X. Conclusion

The opportunities created by making power plants more digital will be ever-evolving and plant Owners and Operators will need to proactively adapt to changes and unforeseen circumstances to optimize operation and maintenance, sustain cybersecurity and drive profitability. The goal of this digitalization is to create a smarter power plant. Some of the key digital elements of this smart power plant are already available, and many others are being piloted. They all use real-time data from internal and external to the plant to create actionable knowledge for use by operators and/or autonomous controls. These elements can be applied in whole or part to both new and existing power plants based on the business objectives of the Owner/Operator.

The MHPS vision is to use advancing AI and similar cognitive applications to steadily create individual systems capable of autonomous operation, connect them to work cooperatively and create a smart power plant that can operate largely without direct human control and with far less on-site manpower than today.

Technology is advancing faster than ever and the energy markets continue to evolve. This will require plants to be able to readily incorporate new control strategies and new AI-based advanced analytics. Making them digitally-enabled today provides the foundation for a "future-proof" smart power plant.

References

1. Endo et al. 2015, "Advancement of Remote Monitoring & Diagnostic Service", Power-Gen Asia 2015, Bangkok, Thailand
2. Tanaka et al. 2016, "Modern Predictive Maintenance Technologies and Methodologies for Power Plants' Profitability", Power-Gen Europe 2016, Milan, Italy
3. 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
7. Thomas et al. 2017, "Elements and Enablers of the Digital Power Plant: Enhanced Delivery of Power Plant O&M Support Using Advanced Digital Technologies", POWER-GEN International 2017, Las Vegas, Nevada, USA
8. Bergins et al. 2018, "Improving Performance and Flexibility of Thermal Power Plants Combined with Advanced Digital Technologies", Electrify Europe 2018, Vienna, Austria
9. Imakita 2018, "Digitally-Enabled Power Plant", POWER-GEN Asia 2018, Jakarta, Indonesia