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Elements and Enablers of the Digital Power Plant:
Digital Solutions for 50 Hz. GTCC Responsiveness

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Abstract:

Power plant digitalisation is a key response to the changing market scenario in Europe and competitive power markets elsewhere in the World, especially in areas with increasing penetration of renewable generation. In the last few years, many gas turbine combined cycle (GTCC) power plants have moved from continuous base load operation to frequent daily start/stop operation and have reduced operating hours per year. Mitsubishi Hitachi Power Systems (MHPS) has been developing a range of data-driven digital flexibility solutions that can help plants operate in a more responsive, reliable and economically viable way in this type of dynamic market -- while maintaining the standards of reliability and availability expected from base-load gas turbines.

These and other digital solutions are the elements of what is often called the Digital Power Plant, and many of them can be applied to upgrade existing GTCC plants. This is one of a series of papers around the theme of “Elements and Enablers of the Digital Power Plant” that describes the experiences of the authors’ company in harnessing the potential of power plant digitalisation to improve the economics of GTCC power plants as they respond to changing power markets and grid requirements.

A series of case studies will be discussed where digitalisation of data acquisition, analysis and control led to substantial economic benefits for Owners of GTCC power plants in Europe.

I. Introduction to European Power Market Situation

By 2025, renewable energy sources (RES) within Europe are expected to continue to penetrate the power generation market with a further increase of 185GW and fossil fuel generation is expected to fall by 36GW (ENTSOE, 2015). It is expected that 22 EU countries will have 50% hourly load penetration by RES, whereas 8 countries will have 100% hourly load penetration by RES, meaning each hour, RES will have a tremendous impact on the load profile of the grid. The increased RES penetration poses uncertainty and pressure on grid system flexibility and stability. Based on MHPS experience, natural gas fired or oil fired GTCC power plants are already moving from continuous operation in 2011 to DSS operation and much less number of operating hours per year (Figure 1), which can be attributed to increased penetration of RES. These challenges force equipment designers and power plant operators to explore new means of flexible, sustainable and environment-friendly GTCC operation.

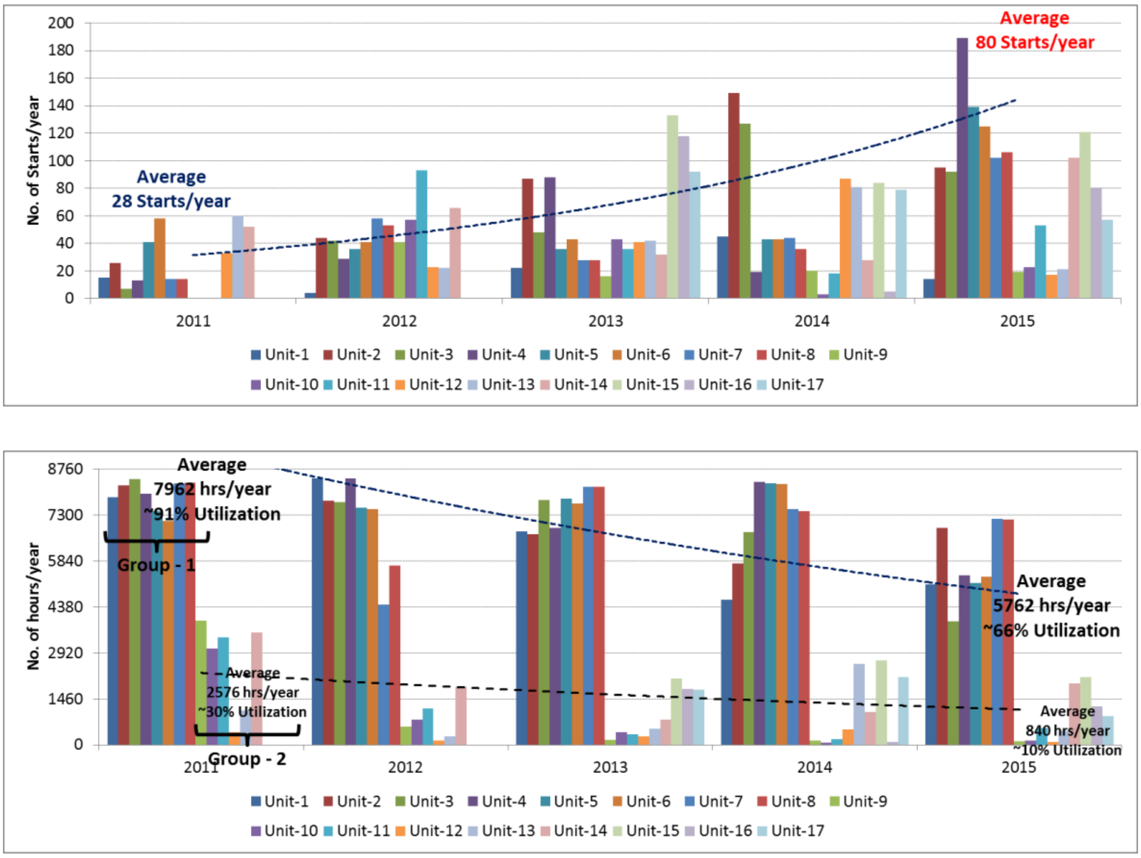


Figure 1: Operational Profile of Various GTCC Plants in Europe

To make plants more flexible and make power generating companies able to sustain in such a challenging power market, equipment designers have developed various digital solutions - including a variety of flexibility elements that allow GTCC plants to more efficiently respond to rapidly varying grid demand. These digital solutions not only promote lower system costs overall but also increase responsiveness of the plant throughout the operation cycle with careful evaluation of the life cycle impact on hot gas path parts and other critical components. This translates to reduced cost and improved performance of the gas turbine and steam turbine fleets. Since 2011, more than 125 cumulative flexibility elements have been implemented in European GTCC plants to achieve faster start-up, lower combined cycle loads and better part load efficiency than previously considered possible. These solutions have placed plants “back into market” with higher utilisation than the recent past. Further development of digital solutions is ongoing to make the power plants more flexible and sustainable to adapt to a dynamic market.

II. 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.

At MHPS, the result of leveraging those steadily advancing digital and communications technologies is called MHPS-TOMONI. TOMONI means “Together” 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 digitalisation. It combines digital technology with extensive equipment designer and User collaboration and comprehensive total plant design, operation and maintenance experience. One of the most important aspects of this approach is the leveraged human insight – the combined power of the equipment design and total plant knowledge of MHPS and the Owner/Operator’s engineering, operations and maintenance experts. Machine analytics and software help with speed and productivity, but they are not enough.

The MHPS-TOMONI concept provides new opportunities for flexible operation, performance improvement and optimized power plant O&M, with the ultimate objective of maximizing total plant reliability and productivity.

An early system-level implementation of massive power plant data acquisition and digitalisation commenced in 1997 when MHPS commissioned the T-Point power plant at the Takasago Machinery Works in Japan, which is an in-house fully operational and heavily instrumented GTCC power plant dispatching into the Kansai Electric grid.

T-Point was followed in 1999 with the full-scale implementation of MHPS's first power plant Remote Monitoring Center (RMC). This RMC is located in the MHPS Takasago Machinery Works and first began monitoring and providing monitored power plants with real-time early warning and fleet benchmarking as well as engineering knowledge to improve reliability, reduce unplanned downtime and implement better outage planning based on predictive analytics. A second RMC was established in 2001, in Orlando, Florida, USA to increase service coverage in the Americas. In 2016, the third MHPS RMC was opened in Alabang, Philippines to increase coverage in Southeast Asia and Oceania. Today, these centers monitor and provide support to power plants all over the World, and their capabilities are being steadily expanded to become a "conduit" for a new and innovative two-way digital information exchange to assure that every connected plant can benefit from the latest design advancements and fleet experience, whether it is fully remotely monitored or not. An early strategic decision was to carefully introduce advanced analytics and software to improve response time and productivity, while also keeping in mind the value of human expert insight and the importance of teamwork with operations and maintenance personnel at the monitored power plants – "Together" with MHPS-TOMONI.

III. Requirements Driven by European Power Market Situation

In keeping with the "Together" philosophy of MHPS-TOMONI, MHPS has a customer-first approach that relies on collaboration to identify potential issues, engage on potential opportunities and jointly work to improve power plant performance. Power plant owners and operators today face complicated challenges in an energy market that will continue to evolve at a rapid rate.

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 on target to the needs of the User communities.

European customer support engineers have been very pro-active in engaging with the GTCC Owner/Operators in Europe to understand their problems and their ever changing requirements due to pressure put by market needs (more renewables, less emissions) through a variety of communication processes including:

- Annual Users' Conferences to share experiences and best practices
- Annual Customer Satisfaction Surveys
- Regular meetings with each plant to plan overhaul and other improvement activities.

Through these feedback mechanisms, the key requirements and key digital solutions listed in Table 1 were identified as most important for European GTCC plants to better compete in the challenging market and to increase their dispatch rate.

Table 1: List of Key Requirements and Digital Solutions for European GTCC Plants

No.	Key Requirements	Key Digital Solutions
1	Time Reduction (cost savings)	1. Start-up Time Reduction (6 solutions) 2. ST Variable Start-up Modes 3. Steam Admission Conditions Relaxation 4. Optimized Thermal Stress Settings
2	Plant Flexibility	1. Minimum Load Operation 2. Forced Air Cooling after Shut-down 3. APS Completion Change 4. Simple Cycle Operation
3	Performance Improvement	1. IGV Closing Optimization 2. IGV Tracking Optimization 3. IGV Further Opening 4. TCA Fan Inverter Application

IV. Digital Solutions to Increase GTCC Flexibility

A modern GTCC power plant has thousands of sensors, and new sensor technologies are being steadily introduced to add more data to an already very large flow of available data. The challenge for plant operators is to use advanced data management and analytics to sift through large amounts of operational data in real time to create actionable knowledge and control the plant with increased precision. This will allow plants to run more flexibly without adversely affecting hot parts and key component life, while simultaneously avoiding unplanned downtime and enhancing predictive maintenance.

Based on market-driven requirements and building on nearly 20 years of experience with human and software-based analysis of massive amounts of sensor and control system data, a portfolio of data-driven digital solutions has been developed and proven in cooperation with Users. Many of these elements have been implemented in European GTCC plants and provide benefits in the areas of:

- Flexible Operation
- Rapid Load Response
- Diagnostics and Predictive Analytics
- Fleet RAM (Reliability-Availability-Maintainability) Improvement

After identifying the market-driven requirements, a structured implementation process was used to define and validate the individual digital solutions – elements of the Digital Power Plant.

Figure 2: Structured Implementation Process for Digital Solutions

The preliminary study of the digital solution set the design requirements. Comprehensive plant digital data acquisition and analysis by local owner/operator engineers, manufacturer engineers dispatched to Site add knowledge. This knowledge and further remote digital data acquisition by an RMC accurately suggest the improvement approaches and then validate the results. Subsequent operational monitoring both locally and at the RMC (for connected plants) provides ongoing feedback and supervision of the digital solution for continuing optimization and response to new operational modes.

V. Supporting Role of Remote Connection

Not every GTCC plant is remotely connected with a direct data feed to enable centralized data correlation and more intensive analysis by expert systems and human experts on a fleet wide basis. However, plants that are connected have proven to play a critical role in the development and deployment of new digital solutions. Increasing flexible operation without detrimental effects on critical components requires detailed data acquisition, expert analysis and precise control. Among other things, these are combined to allow operation closer to design limits and reduce the need for conservative margins used to allow for uncertain knowledge of actual operating conditions. To do that requires intensive data analysis of multiple plants under a range of operating conditions to define the design requirements of the proposed digital solution as well as to support its commissioning and subsequent supervision during operation. That intensive data acquisition could be done with temporary local equipment and expert analysis, but it is far more productive and cost-effective to accomplish on connected plants such as T-Point and the plants monitored by the Remote Monitoring Centers (Figures 3, 4 and 5). 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 for targeted monitoring and communication purposes.

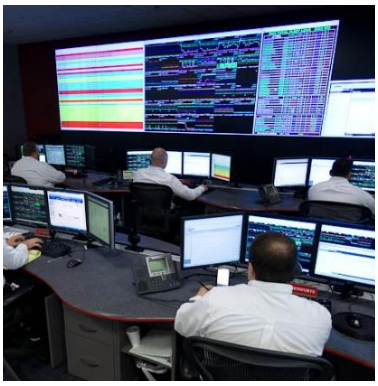


Figure 3: RMC in Orlando, Florida, USA

Figure 4: RMC in Takasago, Japan

Figure 5: RMC in Alabang, Philippines

Connection to the Remote Monitoring Centers has also proven to be very effective in improving GTCC plant reliability. On a self-reporting sample of large 50 Hz. gas turbines conducted by the M701F Users' Group, those plants connected to an RMC had 2.4% higher reliability than those plants that were not connected. Because of the demonstrated benefits of remote monitoring, MHPS now operates three Remote Monitoring Centers and is continually upgrading their capabilities as new technology and best-in-class software becomes available. These Remote Monitoring Centers have proven their value to plants utilizing MHPS OEM equipment and plants utilizing equipment from other OEMs.

VI. Case Studies of Digital Solutions in Europe

Since 2011, more than 125 data-driven digital flexibility elements have been implemented in European GTCC plants to achieve faster start-up, lower combined cycle loads and better part load efficiency. These solutions have placed plants "back into market" and increased their utilisation. Discussed below are three examples:

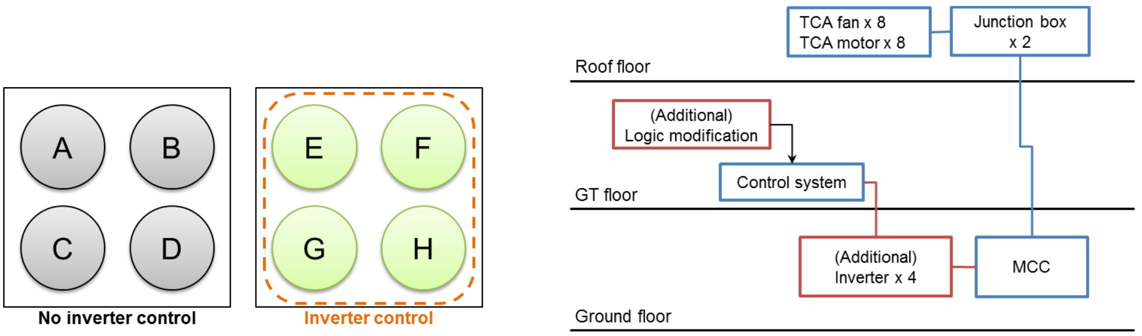
Plant A

Digital Solution – TCA Fan Inverters

Plant A located in Europe wanted to increase performance of the GTCC units. Out of more than 15 data-driven flexibility elements implemented in this plant, one such item which helped increase the performance of the GTCC units by up to ~0.5% relative is discussed herewith.

Turbine Rotor Cooling Air (RCA) is cooled by a TCA cooler and is used to cool turbine hot gas path parts (HGPP). Traditionally, the TCA cooler has fixed controllability with fans which operate at fixed speeds and when the RCA temperature goes beyond the allowable range. The digital solution in this case was aimed to provide more flexible controllability by varying the speed of the fans through use of inverter-based variable speed drives and closed loop digital control of these fans based on RCA temperature. Since TCA temperature is correlated to GTCC performance, this flexible control enables continuous optimization of GTCC performance.

Four (4) out of eight (8) fans were controlled with TCA fan inverters with a speed range of 50-100%. Final acceptance testing followed by stand-alone commissioning of each TCA fan inverter control panel and corresponding fan motor was carried out during a scheduled outage of the GTCC unit. Figure 6 shows the implementation strategy for the TCA fan inverters:



(a) Strategy for fans with inverter control (b) Floor plan for TCA fan inverter implementation

Figure 6: Implementation Strategy for TCA Fan Inverters

Figure 7 shows the actual installed panel in the switchgear room of Plant A, and Figure 8 shows the controllability of RCA temperature gained by utilizing TCA fan inverters. Based on the increased control, the efficiency of the unit was increased by up to ~0.5% relative.

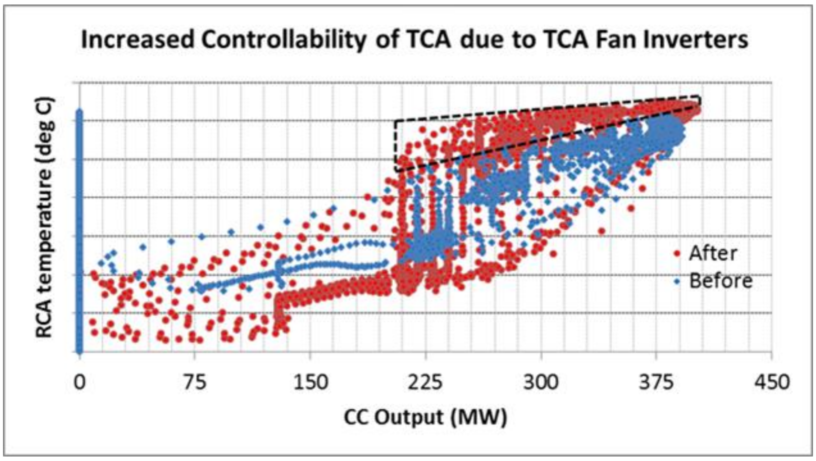


Figure 7:
TCA Fan Inverter Panels
(in the Switch Gear Room)

Figure 8:
Increased Controllability
enabled by TCA Fan Inverters

Plant B

Digital Solution – IGV Further Opening

Plant B located in Europe wanted to increase power output of the GTCC units to earn more revenue during peak demand periods. The digital solution proposed and implemented accomplishes this by opening the inlet guide vanes (IGV) to full position at base load operation.

Usually, IGV position at base load is determined and set during EPC commissioning to achieve an optimal balance between power output and efficiency at base load. Hence, IGV position at base load need not necessarily be full open depending on GT frame and design conditions. For this plant B, there existed the possibility to open IGV more at base load to obtain additional combined cycle (CC) power output. The owner of Plant B wanted the option to select IGV opening between the original setting (optimized for efficiency at EPC commissioning) and full open (100%) as part of the requirements to select between optimized performance when load demand is not beyond the designed base load and maximum CC power output when load demand is peaking. The reference concept for IGV further opening is illustrated in Figure 9.

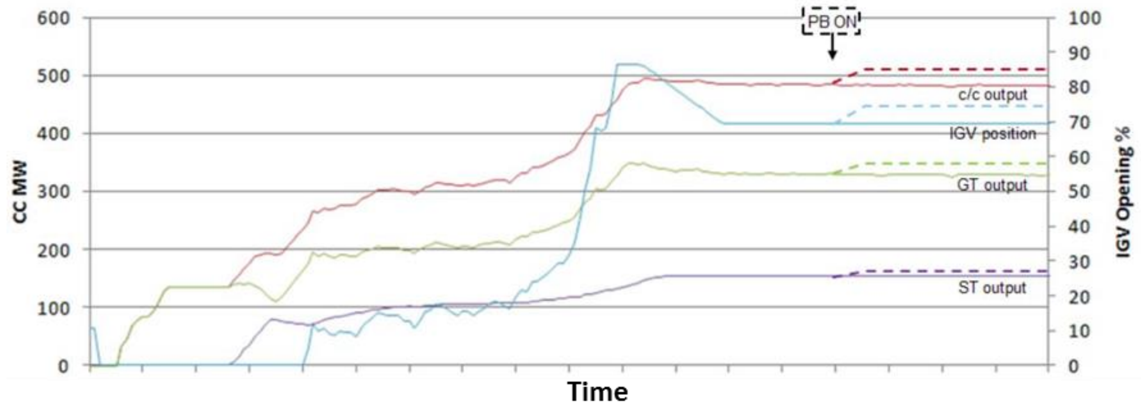


Figure 9: Operation Concept of IGV Further Opening (Reference)

When the IGV is opened to full open position, inlet air flow increases, and it affects various parts of plant, including the bottoming cycle. As part of feasibility study, the effect of opening IGV to full open position was studied in detail on (a) GT Compressor, (b) Hot Gas Path Parts, (c) Combustion condition, (d) Shaft mechanical limit, (e) ST, (f) HRSG and (g) BOP including interlocks during the operation. Based on the results, two different cases, (1) IGV 100% Open and (2) IGV 90% Open, were proposed for Plant B. Figure 10 shows the effect of IGV 100% open (Case 1) on CC Output and CC Efficiency.

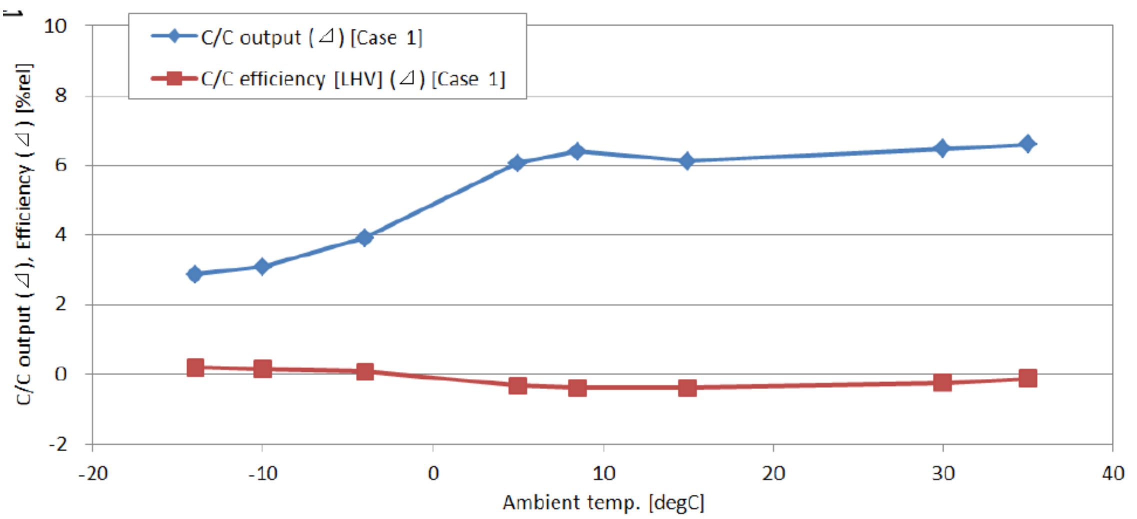


Figure 10: Effect of IGV 100% Open on CC Output and CC Efficiency

Figure 11 illustrates the relative increase in CC Output and GT Output on three units of Plant B.

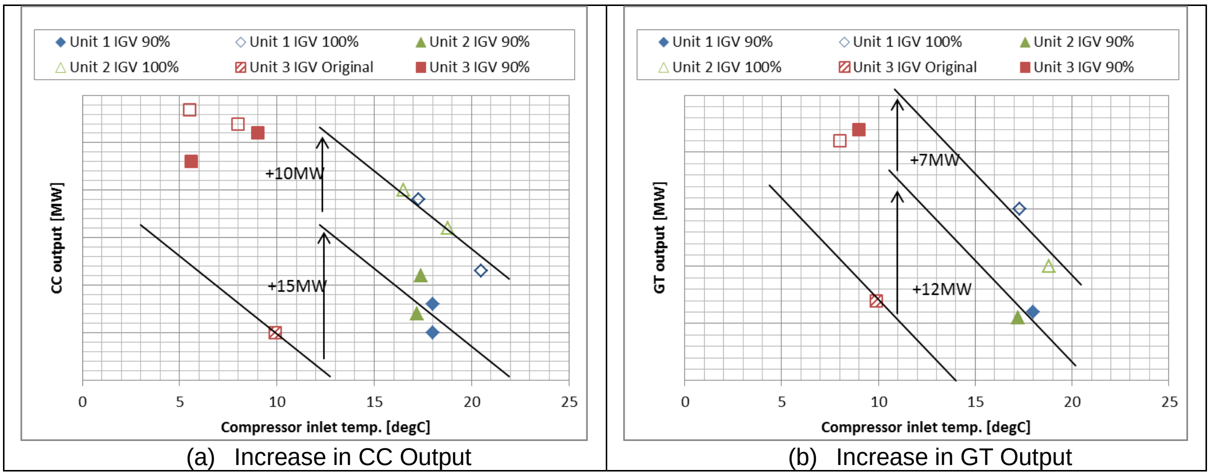


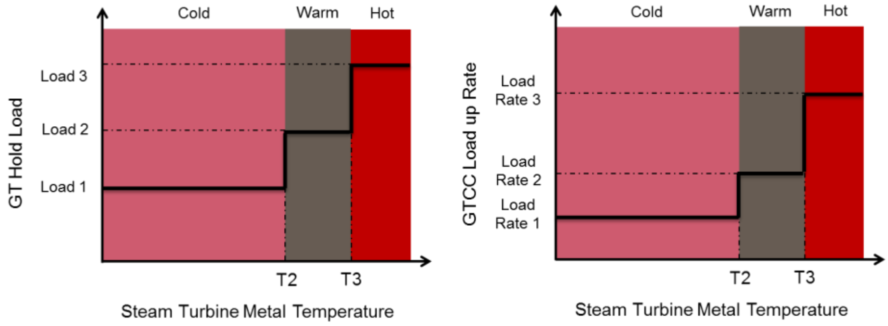
Figure 11: Actual Increase in CC and GT Output for three units of Plant B

<u>Plant C</u>

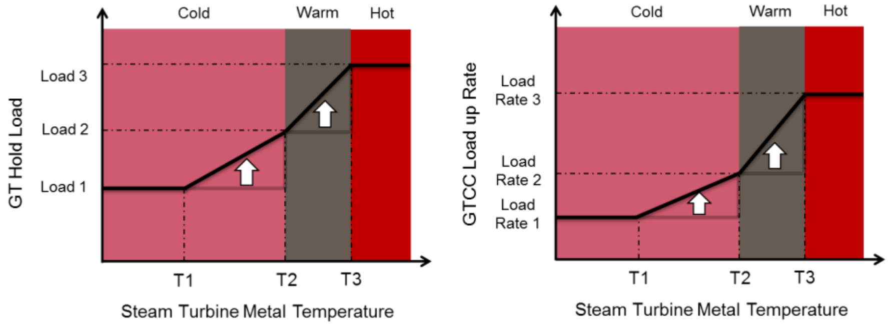
<u>Digital Solution – ST Variable Start-up Modes</u>

Plant C located in Europe wanted to reduce starting time for their GTCC units. In addition to various digital solutions to reduce starting time of the gas turbine (GT), MHPS also implemented digital solutions aimed to reduce starting time of the steam turbine (ST), thus enabling the plant to get shorter GT and ST starting times. This helps in minimizing fuel cost in starting the units as many plants do not get paid for the start-up period from the respective national grids.

Usually, for GTCC plants, GT load hold and CC load-up rate increase are fixed based on discrete functions of ST HP inlet metal temperature. Variable start-up modes enable implementation of a linear function of HP inlet metal temperature for GT load hold and CC load-up rate in warm start mode as well as cold start mode. This concept is illustrated in Figure 12.



(a) ST Start-up Modes (Cold, Warm, Hot)



(b) ST Variable Start-up Modes (Cold, Warm, Hot)

Figure 12: ST Variable Start-up Modes

Figure 13 illustrates the time savings due to implementation of ST Variable Start-up Modes.

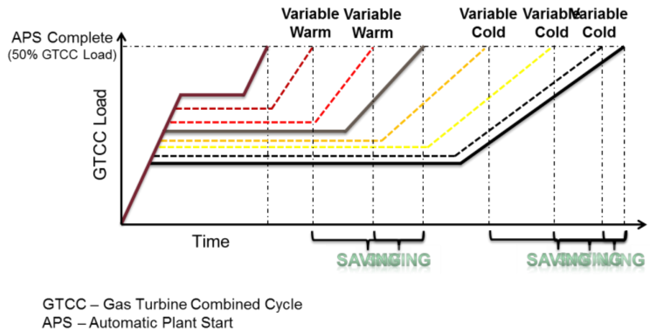


Figure 13: Time savings through ST Variable Start-up Modes

After implementation, Plant C has gained fuel savings of ~7000 Nm^3 during hot start by reducing automatic plant start (APS) completion time up to 15 min in warm start. Since then, this item has been applied to more than 10 units in 5 plants over the last 3 years.

VII. Conclusion

Evolving competitive power markets need existing power plants to operate reliably with duty cycles that require responsiveness that is often beyond the original plant design basis.

Substantial experience has been gained by working closely with GTCC power plant Owners and Operators in Europe, proving that the latest digital data acquisition, communication and analytics technologies can be leveraged to greatly improve the flexibility and responsiveness of existing 50 Hz. GTCC plants.

Figure 4 shows the cumulative number of flexibility elements which have been implemented in European GTCC plants to improve their responsiveness.

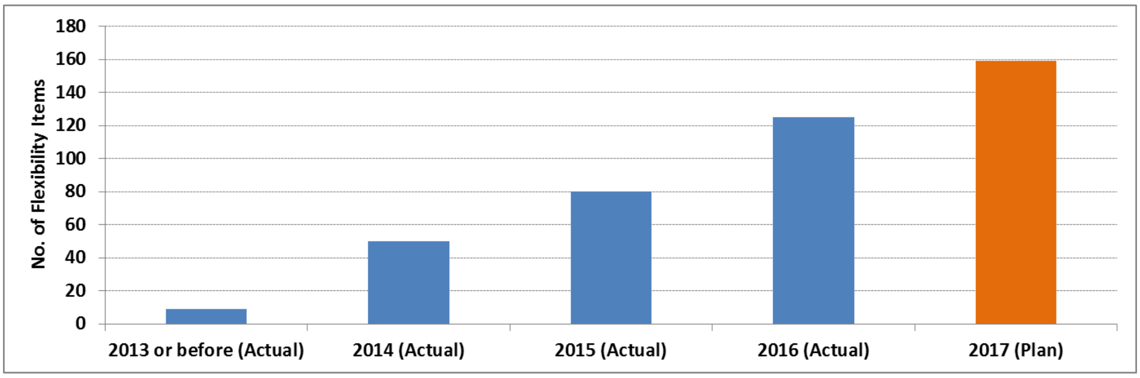


Figure 14: Digital Flexibility Elements Implemented on European GTCC Plants

New and existing power plants are becoming increasingly digitalised 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 large. Communications and knowledge sharing through MHPS-TOMONI (Japanese for “Together”), that includes 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.

References

1. A. 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. entsoe – Scenario Outlook & Adequacy Forecast 2015”, European Network of Transmission System Operators for Electricity, 2015, Europe