Improving Performance and Flexibility of Thermal Power Plants Combined with Advanced Digital Technologies

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1 Introduction

Globally the power industry is undergoing profound structure transformation responding to mega trends in politics, economy, and technology. Thermal power plants, which have been the backbone for power generation all over the world, are expected to remain a leading source of electrical energy in the coming decades. Today these plants are facing growing new challenges to prove their financial and environmental viability. In the United States and Europe the competitiveness of coal-based generation has been eroded for several reasons. New environmental regulations for flue gas emissions as well as for combustion byproducts and wastewater, while making coal power increasingly clean, are contributing significantly to the cost of electricity.

Rapid penetration of wind and solar generation, with their intermittent nature, is the latest disruptive force facing the aging electrical power infrastructure. According to Eurostat renewable energy sources accounted for a 13.2% share of the EU-28’s gross inland energy consumption in 2016 and for a 29.6% share of the gross electricity consumption. The strong growth of wind and solar generation is certain to continue.

The large output from non-dispatchable wind and solar sources means that coal power and other generators need to cycle deeper and more frequently to support grid stability. Cycling includes shutting down and starting up, load ramping, and operating at a low load. On the other hand, most of the old coal-fired power plants in the U.S. and Europe were designed for base load service with limited range and rate for load changes. These plants need to improve their cycling capabilities to compete in the market and attain reasonable operating time and revenue.

As a leading power generation equipment supplier, Mitsubishi Hitachi Power Systems (MHPS) has been developing and implementing new technologies and new operating procedures to improve the flexibility, dispatchability, performance and cost of power plants in key global markets. Over the past decade, OEMs like MHPS and the power plant operators have increasingly adopted digital and communication technologies to improve plant operation. In early 2017 MHPS has unveiled MHPS-TOMONI, a comprehensive family of digital solutions. TOMONI means “together” in Japanese and signifies close interactions with power plant owners and operators in a collaborative manner to effectively unleash the potential of power plant digitalization. It harnesses big data, sophisticated analytics and human insights – the combined power of the equipment design and total plant knowledge of MHPS and the owner/operator’s engineering, operation and maintenance expertise. The MHPS-TOMONI digital platform opens up new possibilities and opportunities for improving power plant flexibility, reliability and productivity in today’s dynamic market.

2 Requirements for Cycling Operation

Figure 1 illustrates the main requirements for existing power plants to operate in the new landscape of electricity generation.

Fast ramping rate: The power output from solar and wind facilities varies from day to day, and often on an hourly or minute scale. In the absence of widespread investment and installation of dedicated energy storage systems, thermal power plants including coal-fired plants will need to provide most of the required load support and other ancillary services such as frequency control through improved operational response and by tapping into the thermal inertial in the steam and hot water in power plant systems.

Reduce minimum load: Most conventional coal-fired boilers were designed with limited turndown range, with a typical minimum load around 40% of MCR rating. To operate in cycling mode, it is desirable to reduce the minimum load without the need of firing support fuel. This will allow the plant to stay online to quickly respond to grid demand and to avoid startups, especially cold starts which are costly and potentially damaging to the plant equipment due to thermal fatigue.

Reduce startup time: Fast and smooth startup will allow the plant to respond to grid dispatch and maximize generation revenue, while reducing the startup fuel usage / cost.

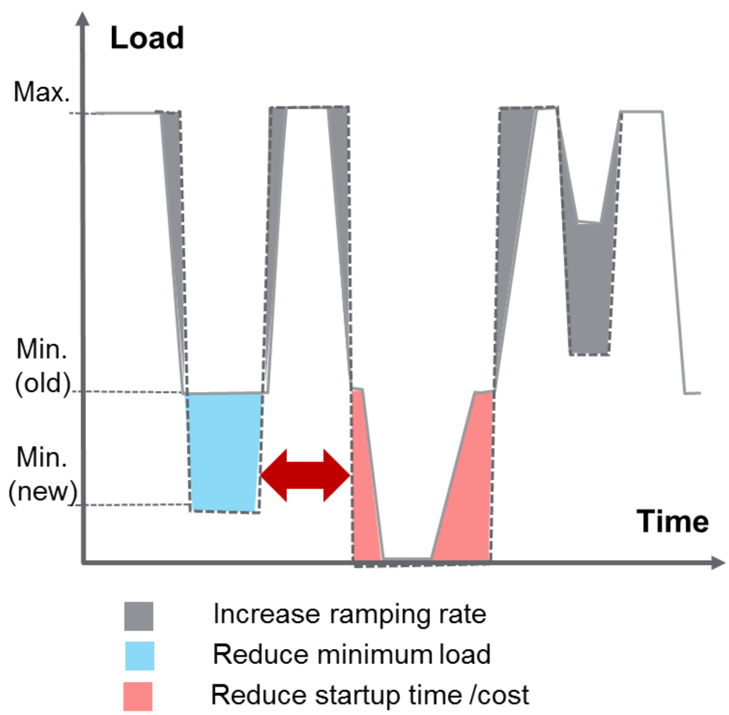


Figure 1: Requirements for cycling operation

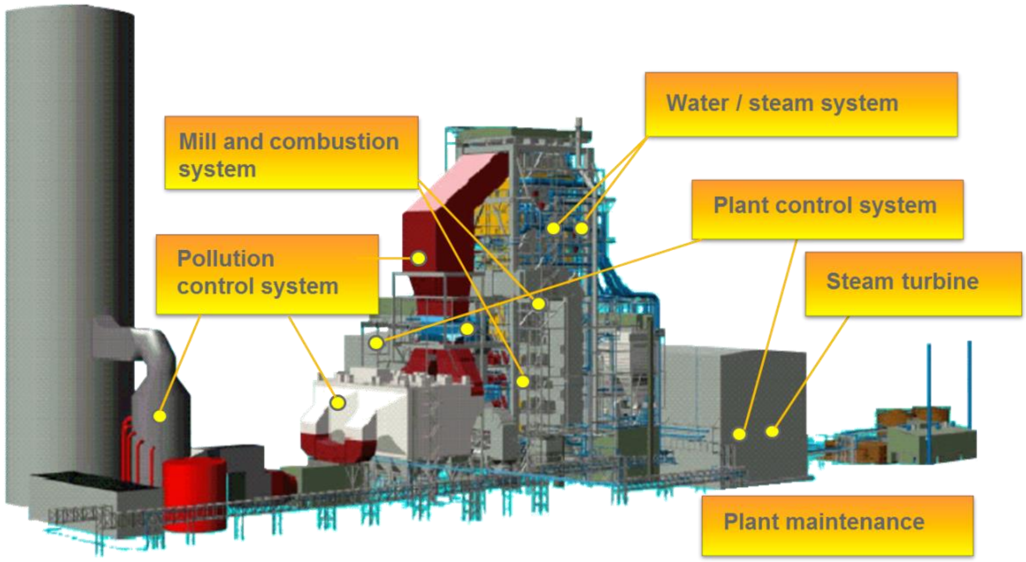


Figure 2: Areas for improving plant cycling capabilities

To meet the cycling requirements, all main subsystems including the combustion system, boiler water/steam system, steam turbine, pollution control system, and control system of the power plant need to be evaluated and possibly improved in equipment and / or operation procedures, as shown in Figure 2. The plant maintenance procedures should also be reviewed and updated to manage the more vigorous modes of operation and their impact on equipment condition and life.

3 Plant Equipment Improvement

3.1 Mill and Combustion System:

Combustion stability is a determining factor in achievable minimum load and ramping rate. Mills and burners must be closely evaluated with attention to the following areas:

- Test and determine turndown ranges of existing coal mills and burners. Operating at very low load requires taking mills and burners out of service in combination with running the in-service mills and burners at reduced output.
- Evaluate the burners for load following and fuel flexibility and upgrade if necessary to latest low NOx burner models with improved flame stabilizer.
- Inspect the flame scanner and upgrade / install if necessary. Properly functioning flame scanners are essential in avoiding false trips due to weak signal strength at low burner load.

- Assess the condition of mills and upgrade them if necessary. For example rotary classifiers can be retrofitted for improved fineness which will help maintaining flame stability at part load conditions and improving combustion efficiency and emissions. Improve the “over-fire” and turndown capabilities of the mills.

Such measures alone implemented in today’s fleet can provide reliable combustion performance at 15-20% MCR as proven via retrofits in plants in Europe; see examples later in this section.

To gain additional operation flexibility for very low load and fast ramping, indirect firing may be considered. As shown in Figure 3, indirect firing is achieved by installation of a pulverized coal bunker between the mill and burner, with the additional piping and valves. An indirect firing system decouples the burner firing rate and the mill output rate, therefore providing a new level of freedom for combustion control.

With indirect firing and burner optimization it is possible to maintain reliable combustion performance at 10% MCR or lower and achieve ramping rate as high as 10% /min. Additionally, this arrangement with pre-ground and pre-dried fuel helps to stabilize the combustion process in a wide operation range and therefore can reduce the startup auxiliary fuel consumption by as much as 95%. It also improves fuel flexibility and reduces plant heat rate by allowing operation at lower excess air levels.

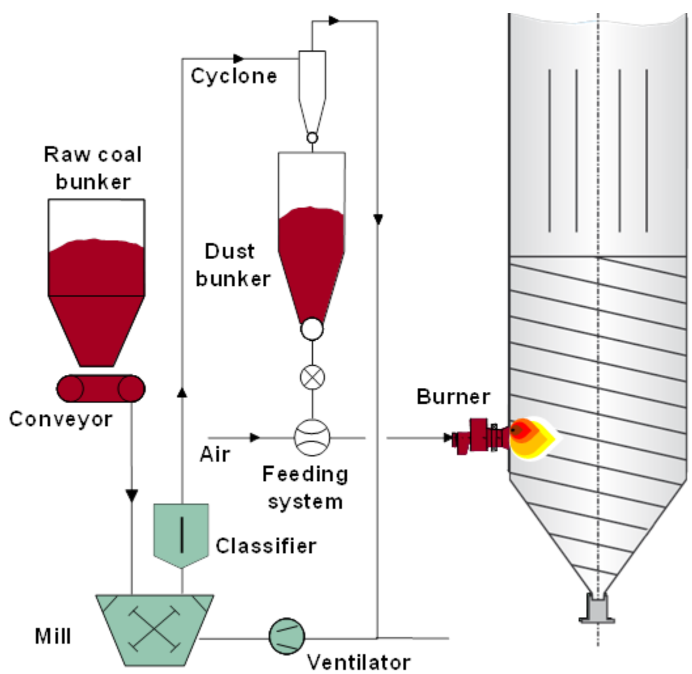


Figure 3: Indirect firing system

Another measure to reduce the startup cost is a fuel switch for the startup burners from fuel oil to natural gas for plants which have access to sufficient natural gas supply. With low cost natural gas available, co-firing natural gas is an effective way to keep a plant operating stably at very low loads and avoid costly shutdown and startups.

Mill and combustion system can benefit greatly from the MHPS-TOMONI digital solutions in optimizing the operation, control and maintenance; see further discussions in Sections 4 and 5.

3.2 Boiler Water / Steam System:

Cycling operation can expose boiler pressure parts to increased risk of fatigue and premature failure. Comprehensive review is required for the heat transfer components and pressure parts to identify and avoid potential areas of over-heating and excessive thermal stress.

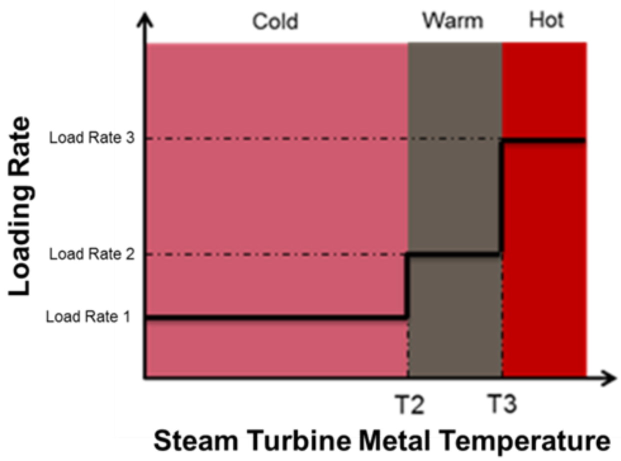
- Evaluate heat balance of all boiler heat exchangers over entire load range.
- Check flow stability (both static and dynamic) in all heat exchangers.
- Determine temperature differences at outlet end of all heat exchangers.
- Improve attemperation system operation and control range, especially for the reheater side.
- Assess stress range and permissible fatigue damage for critical parts under anticipated load change rates during cold, warm, and hot starts. Upgrade if necessary.
- Monitor critical parts for temperature difference and life consumption accumulation. Further discussions about remote monitoring and diagnostics, an integral part of MHPS-TOMONI, are included in Section 5.

Thick-walled components such as steam headers can be the limiting factor for ramping rate. They need to be evaluated accurately using modern calculation tools. For new builds and where it is justifiable to retrofit an existing unit, number of headers can be increased for superheater and reheater sections to reduce the wall thickness and therefore allow faster ramping. Alternately, replacing header material with an alloy having higher allowable stress can also reduce wall thickness and enable higher ramping rate.

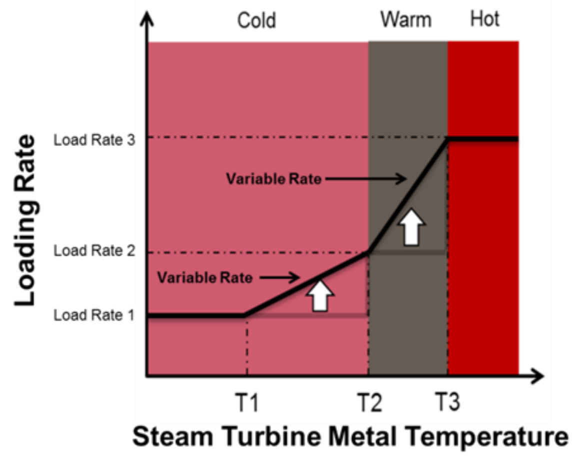
3.3 Steam Turbine:

Similar to thick-walled boiler components, steam turbine components such as rotors, casings, and valve bodies are subjected to more frequent and ever higher levels of thermal stress in order to remain competitive with regard to operational flexibility. Traditional startup procedures require hold time durations and load ramp rates based on discrete cold, warm, or hot start definitions (Figure 4a).

MHPS has applied “Variable Startup” technology at numerous plants, allowing for interpolation between definition of cold, warm and hot start based on measured turbine metal temperatures. This approach allows for shortened durations and faster ramping rates for many startups which previously would have been unnecessarily conservative (Figure 4b). While the Variable Startup technology does remove some conservatism from the traditional steam turbine starting and loading procedures, it does not result in thermal stresses in critical turbine components, such as rotors and casings, beyond the assumed limits associated with the original procedures.



a)



b)

Figure 4: a) Standard cold, warm, and hot start definition; b) Variable cold, warm, and hot start definition.

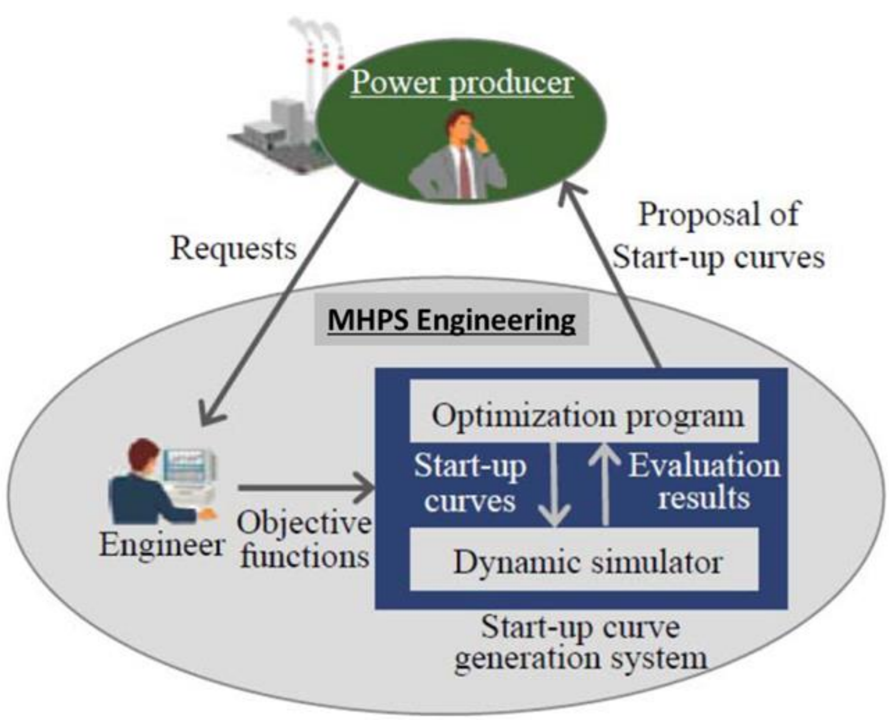


Figure 5: Real time startup curve optimization

Additional technology is being developed by MHPS which would allow users to generate startup curves in real time by applying multi objective evolutionary algorithms to optimize rotor life consumption and fuel consumption within the constraints of rotor stress and internal clearance limitations. As illustrated in Figure 5, real time startup curve optimization is an example of the MHPS-TOMONI concept applied to enhance plant cycling performance. This technology has been piloted on combined cycle applications where ability to reach full plant load is limited by steam turbine capability. Many coal fired plants may currently be limited by the capability of the boiler (due to thermal stress or combustion system limitations) in terms of cycling operation; however continuous improvements in boiler technology are driving the need for a more synergistic approach to overall plant starting and loading optimization.

3.4 Air Quality Control System:

All emission limits must be met when the plant is operated at very low load / fast ramping conditions. Coal-fired power plants commonly use electrostatic precipitators (ESP) or fabric filters (FF) for particulate control, flue gas desulfurization (FGD) scrubbers for removing SO_2 and other acid gases, and selective catalytic reduction (SCR) for NOx reduction.

ESP and FF can generally accommodate a wide range of load. In the case of ESP, higher dust removal efficiency can be expected at reduced loads because of the lower flue gas flow rate and longer treatment time. However, it is important to maintain flue gas inlet temperature at above the acid dew point to prevent corrosion of ESP or FF components.

Wet FGD can operate in a wide load range to capture SO_2 effectively. However, fast load cycling and low load operation will require robust response and proper tuning in process control to ensure optimum SO_2 removal, reagent utilization, and by-product quality. Operating at low load can also change the oxidation reduction potential in the FGD slurry, which can in turn shift the speciation of metals such as mercury and selenium that have secondary effects in mercury emissions and selenium removal from the FGD wastewater.

Dry scrubbers, both the spray dryer absorber (SDA) and the circulating dry scrubber (CDS) types, generally can also have turndown ranges. Very low flue gas temperature can limit SDA performance because the reagent is introduced in the form of water slurry and the absorber outlet flue gas must stay well above the saturation temperature. For the CDS type, low turndown ratios can be achieved by taking absorber modules out of service and / or by recirculating clean flue gas to the absorber inlet.

SCRs are sensitive to operating temperature and must be evaluated for reduced load operation when both flue gas temperature and flow rate are lower. SCRs need to operate above the minimum operating temperature (MOT) to ensure adequate NOx reduction and to prevent the formation of ammonium bisulfate (NH_4HSO_4, or ABS), which is a corrosive, sticky liquid at the temperature range, from the ammonia reacting with the SO_3 in the flue gas. ABS can deactivate the catalyst NOx reduction performance by clogging the pores and cause fouling, pluggage, and corrosion to downstream equipment such as air preheaters.

To avoid ABS formation, gas side or water side bypass around the economizer can be installed or retrofitted to raise the SCR inlet temperature. On the other hand, to support cycling operation by customers, MHPS has been able to lower the recommended MOT based on extensive low load operation testing and field experience. As shown in Figure 6, lower MOT or boiler (economizer) outlet temperature enables a wider load range for the SCR operation and significant savings in operating fuel cost.

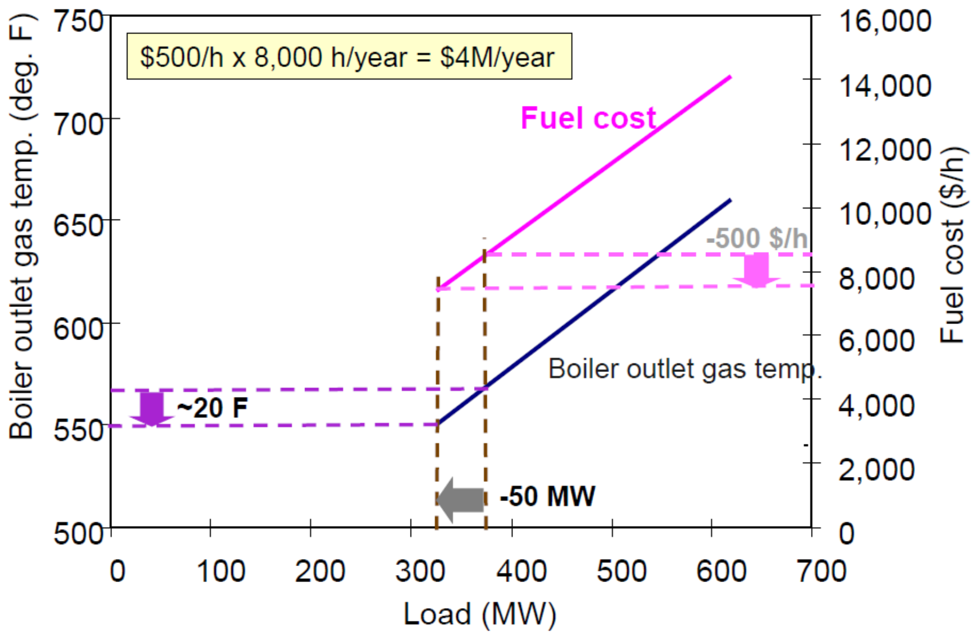


Figure 6: Minimum operating temperature for SCR and its impact on plant operation

To further extend the operating range of SCR, MHPS has also been reducing the minimum injection temperature (MIT). MIT gives a plant the additional flexibility to operate the SCR with ammonia injection and NOx reduction at temperatures 20 - 30 °F below the MOT for a short duration before operating for a longer duration at normal operating temperatures, without causing irreversible catalyst deactivation. MHPS is currently working with U.S. utility customers to investigate other ways to further mitigate and eliminate the ABS constraint.

3.5 Examples of Cycling Operation:

Europe is one of the first large power markets that already have widespread installation of both wind and solar power generation and its power grid has had to absorb the output variability of renewable sources. Germany as a leading market for renewable energy also has a relatively small natural gas-fired generation capacity in operation (many gas plants are currently mothballed) due to high natural gas price compared to low electricity market price (as a consequence of large generation capacity from renewables), so that its coal-fired power plants must do more to support grid stability. Figure 7 shows two examples of bituminous coal fired power plants in Germany that are able to perform deep cycling operations. Plant A is a small subcritical unit and Plant B is a large supercritical unit. After implementing some of the improvement measures for plant equipment and operation as discussed in the previous sections but without adopting indirect firing, both plants were able to cycle on a daily or intra-day basis with minimum load in the 15 - 20% range with one mill in operation.

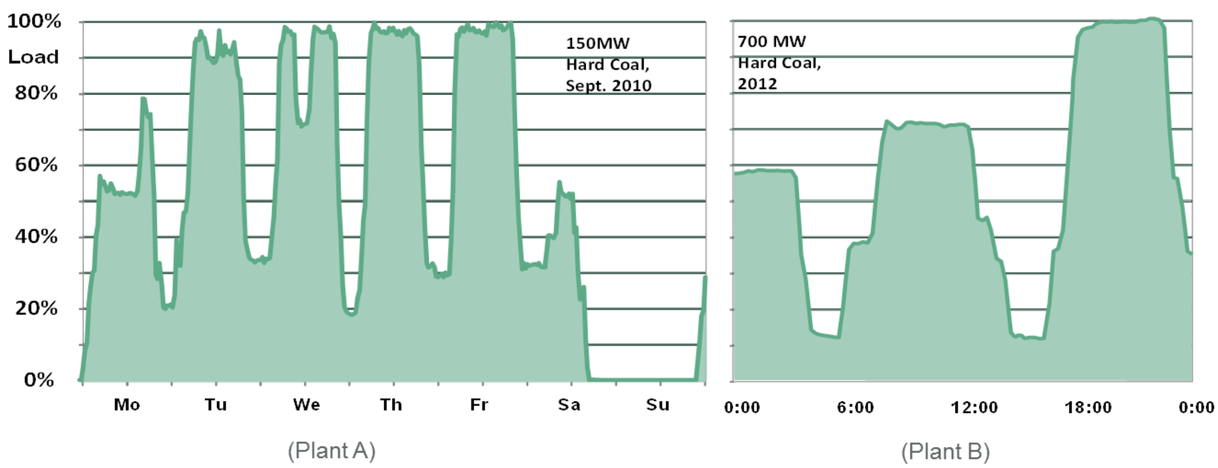


Figure 7: Examples of two German plants in cycling operation

4 Maintenance Technologies

Cycling operation of today's coal fleet demands more vigorous, knowledge-based maintenance practices to prevent unplanned outages and preserve the useful life of equipment. A single unplanned unit outage due to a boiler component failure can cost tens of millions of dollars in lost power generation and repairs. Typical failures can be caused by material overheating, creep damage, fatigue, fire side corrosion, steam / water site corrosion, and ash erosion, as illustrated in Figure 8 for various pressure part components of a boiler.

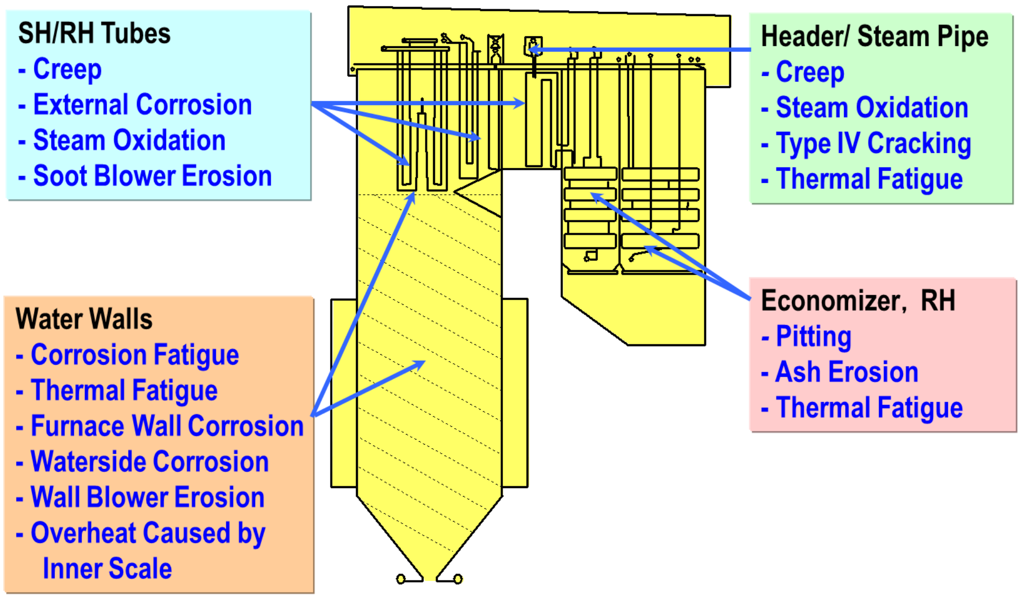


Figure 8: Typical boiler components damage / failure mechanisms

4.1 Risk Based Maintenance:

Based on extensive boiler inspection and maintenance experiences and large metallurgical and failure assessment database with historical information from a wide range of designs, fuel properties, and operating conditions,

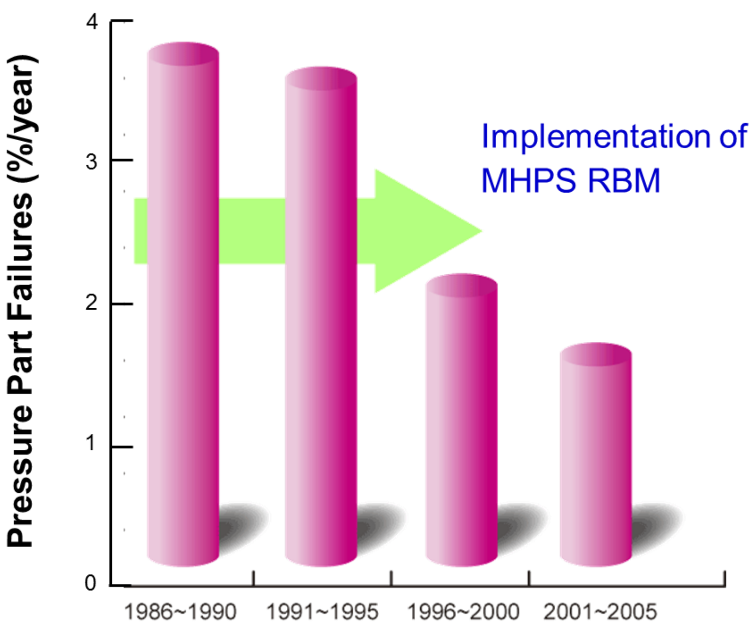


Figure 9: Pressure part failures over two decades for 55 boilers

MHPS has developed and implemented advanced preventive maintenance / Risk Based Maintenance (RBM) programs for many power plants. The key elements of RBM are optimized inspection planning, advanced assessment, long term cost-based maintenance scheduling. The preventive maintenance / RBM programs have resulted in large improvement in availability, efficiency, and significant long term cost savings. Figure 9 shows the boiler pressure part failure rates of 55 boilers monitored by MHPS over two decades of time. By application of preventive maintenance / RBM, pressure parts failure rates were drastically reduced.

4.2 Condition-Based Predictive Maintenance:

One of the latest developments in MHPS' maintenance techniques is the Component Condition Monitoring Tool (CCMT®), an example of the MHPS-TOMONI digital solutions for plant maintenance. CCMT® is a software application for digitalizing, monitoring and forecasting of the condition of power plant components to allow plants to implement a condition-based maintenance strategy, based on the combined knowledge, experience and data by both MHPS and the customer. Continuous and reliable monitoring of component condition can be achieved by both "offline" measurement / inspections during outages and "online" calculation by using databases and empirical correlations in the software. CCMT® provides real-time condition indication and forecasting by combining both offline and online data and using offline checks to verify online calculations by the software.

For online calculations, CCMT® uses correlations that consider the damage mechanisms of each individual component such as erosion, corrosion and thermal fatigue. The software provides constantly updated data of component condition based on real time operation data and history, a database for all online and offline measurements, as well as recommendations, alarms and warning for the plant engineer to make data-based decisions for inspection, repair, or replacement of a component. The database also can provide the needed instructions and drawings for the specific service actions to enable quick action. Figure 10 is an example of monitoring graphics for a roller in a MPS coal mill, showing offline measurement, online monitoring and a roller replacement event. CCMT® can cover all subsystems of a boiler plant such as mills, burners, pressure parts, and air preheaters. CCMT® is now ready for the first full scale installation at a 675MWe supercritical power plant in Europe.

Similar MHPS-TOMONI digital solutions are applied to maintenance of other power plant subsystems such as the steam turbines. The effectiveness of a condition-based maintenance program depends heavily on the accuracy of digital life consumption models and the ability to reliably predict (and prevent) premature component failure. Life consumption models developed by MHPS rely on the data collected as part of remaining life evaluations completed across the fleet of steam turbine users.

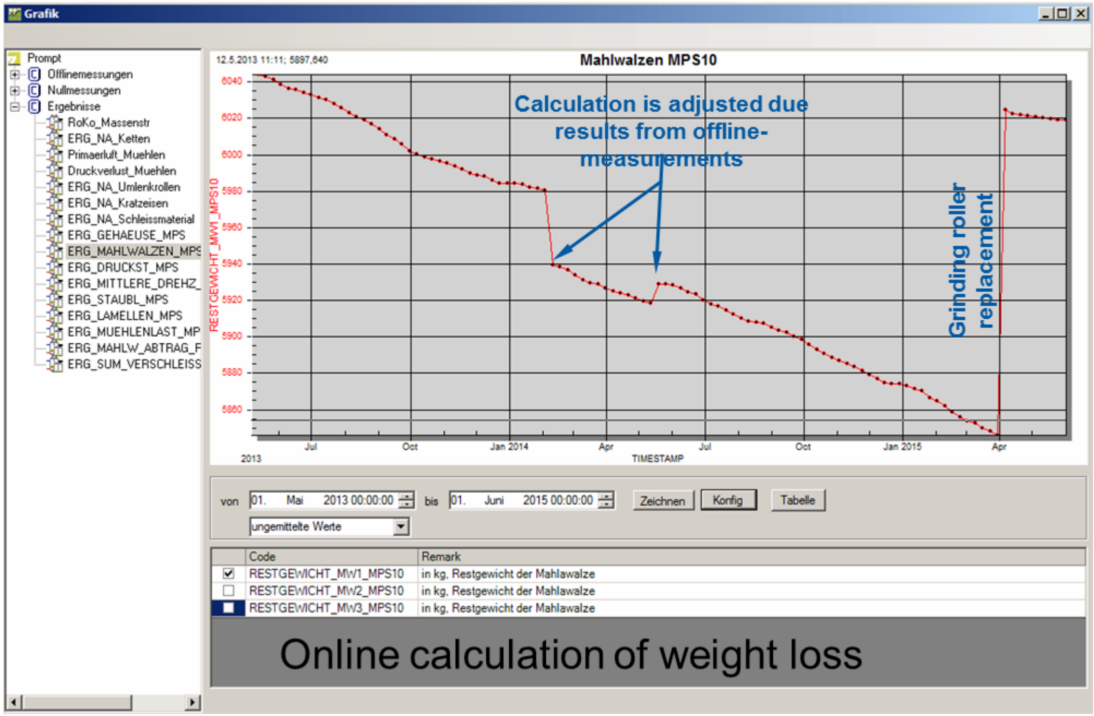


Figure 10: Condition monitoring graphic for a pulverizer roller

Leveraging advanced life assessment technologies for individual users combined with remote monitoring and diagnostic capabilities allows MHPS to calibrate digital life consumption models and ensure optimized and customized implementation of condition-based maintenance strategies.

5 Remote Monitoring and Control Technologies

5.1 Remote Monitoring and Diagnostics:

A key enabler of the MHPS-TOMONI benefits is remote monitoring and diagnostics technology. An early system-level implementation of massive power plant data acquisition and digitalization began 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' first power plant Remote Monitoring Center (RMC). This RMC is located in the Takasago Machinery Works and it first started monitoring and providing 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 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.

For coal-fired power plants, the RMCs can monitor the boiler, steam turbine, and generator for efficiency, operating conditions, creep life evaluation, fuel flexibility, stress / life consumption, performance degradation, etc. Advanced Pattern Recognition (APR) models have been developed that enable the MHPS remote monitoring team to identify potential operational concerns and work with plant personnel to proactively address issues that could lead to unplanned outages. The APR models look for statistically significant deviations in operating parameters, for example, deviations in parameters such as control valve position, control valve demand, turbine load, and inlet pressure pointing to potential root causes such as improper valve calibration, degradation of servo motors, or blade path fouling of a steam turbine. The APR models in conjunction with expert engineering support can provide advanced notice along with recommended course of action to troubleshoot and resolve problems before they lead to costly unplanned maintenance.

5.2 Advanced Control Technologies:

Since the 1950s, coal-fired power plant technologies have progressed from subcritical steam cycle with drum boilers to supercritical systems with constant pressure once through boilers, to supercritical and ultra-supercritical systems with sliding pressure boilers. The next generation advanced ultra-supercritical power plants are currently being developed. Similarly, control technologies have evolved from pneumatic control systems, to analog control systems, to digital control systems. The widespread use of digital technologies has enabled the emerging application of artificial intelligence (AI) in power plant controls.

MHPS is developing AI-based control systems, as a new area of the MHPS-TOMONI, to enhance performance, efficiency and flexibility for power plants. By analyzing large volumes of complex data acquired during plant operation, these systems with machine learning can provide a wide range of functions such as cost optimization (operating costs, maintenance costs, etc.) and early detection of anomalies.

Recently, MHPS has deployed an AI-based combustion tuning system on Unit 2 at the Linkou Power Station of Taiwan Power Company. MHPS had supplied boilers and steam turbines for three identical 800MWe ultra-supercritical units for Linkou, with Unit 1 and Unit 2 already in service and Unit 3 currently under construction. In early 2017, verification test of the AI-based combustion tuning system on Unit 2 was successfully completed.

In conventional combustion tuning, control parameters such as the position of wind box dampers, burner tilt angle, and rotation speed of the mill classifier are adjusted to achieve optimum boiler operating conditions including steam temperature, carbon burnout, and exhaust gas compositions (O_2, NOx, CO) etc. In the combustion tuning with AI technology, a machine learning model is used to predict boiler operating conditions corresponding to various settings of control parameters. The AI model can propose a set of process values to achieve optimum boiler condition considering also external parameters such the fuel cost and fuel quality fluctuations.

It was successfully verified that the control parameters proposed by the AI model were essentially the same as those set by experienced boiler combustion engineers through the conventional, more labor-intensive method of combustion tuning. As a part of the TOMONI program, MHPS continues to enhance the AI-based combustion tuning system at the Linkou plant, and plans to extend AI-based control to other subsystems and apply to other power plants globally.

6 Fuel Switch Towards Lower Carbon Footprint and Improved Operational Flexibility

MHPS has performed several projects in recent years for retrofitting existing power plants towards lower CO_2 emissions combined with improved operational flexibility, mainly through coal-to-natural gas and coal-to-biomass conversions.

6.1 Conversion from Coal to Wood Pellets:

Driven by financial incentives and the target of lowering the use of coal in UK, Denmark, the Benelux countries and Canada, multiple power plants up to 660MWel in size were retrofitted to burn wood pellets over the last decade. In most cases a few modifications were done:

- a low NOx burner upgrade, taking into consideration the different particle sizes and ignition behavior of wood dust
- modifications of the mill and classifier and their control system to ensure release of coarse particles
- (parallel) fuel feeding and storage system for wood pellets
- Injection of corrosion prevention agents to the furnace in order to avoid excessive high temperature corrosion of tube bundles and to reduce slagging
- additional safety measures (explosion detection and suppression systems) due to low self-ignition temperature of wood and risk of explosion for wood dust

MHPS has successfully demonstrated that after a retrofit on-the-fly fuel change (from coal to wood pellets and reverse) is possible without any support firing and load reduction.

Provided some incentives like tax reduction or feed-in tariffs the retrofits can pay off quickly. In recent years in Europe such retrofits were done mainly in the case of combined heat and power (CHP) installations serving city heating grids and industry in Denmark as well as under special subsidy schemes and/or in capacity markets for power only installations in Belgium, Netherlands and UK.

6.2 Conversion from Coal to Natural Gas:

There are two main drivers for retrofits of coal plants for natural gas combustion: globally prices for natural gas and LNG became stable (or even reduced) by more diverse sources and (in the US) a plentiful supply of natural gas as a “by-product” of oil exploration. On the other hand the above mentioned legislative requirements for flue gas cleaning have put pressure on decision makers to consider fuel switching:

- Small steam units (~50MWe range), serving mainly heat markets on a seasonal basis rarely can afford tens of m$ investment for environmental equipment. Such plants in many cases were already shut down or retrofitted for gas firing as the easiest and also the cheapest option to comply with current and future emission legislations. Due to extreme low natural gas prices in the US even plants >500MWe are retrofitted this way nowadays.
- MHPS has also retrofitted medium scale coal fired units towards CCGT operation by major modification of the boiler itself plus adding a gas turbine. Such retrofit provides higher generation efficiencies and fits well for industrial users with higher specific self-consumption of electricity.
- In markets with high peak prices of electricity also a third variant can be considered: Gas turbines can be easily integrated in existing coal fired power stations by utilizing the flue gas waste heat in the feed water preheaters of the existing steam cycle and/or providing steam to the existing turbine. Several such projects have been done in Europe in the last 15 years.

Finally it should be noted that a combination of a flexible fuel switch to wood pellets and natural gas (in varying shares) is always possible to increase the local security of energy supply. Most of the Danish power plants have this option.

7 Solutions in a Complex Energy World

To reach the maximum flexibility of serving electricity and heat markets in the meanwhile it also becomes a standard practice in many European countries to integrate large scale hot water energy storage (0.5 GWh scale) and/or electric heaters and other generation equipment in large heating grids. Figure 11 shows all the above mentioned options for operational and fuel flexibility. The gradual increase of intermittent energy sources in Europe leads to higher volatility and more dynamic market conditions. The establishment of the 15min "intraday market" further to the hourly "day ahead market" as a part of the European electricity market target model is considered a response of the European Union to tackle the increasing need on flexibility and to ensure system stability at competitive conditions. Within this increasing complexity of the electricity market systems, it becomes clear that even smaller players, like small utility companies of cities operating a small fleet need to improve their capabilities on prediction of electricity prices, electricity and heat demand and weather conditions. Furthermore, this information needs to be utilised in an effective way, so that it can support operators to have a continuous calculation of the optimum way of operation for the next hours based on the conditions which are continuously changing within the day.

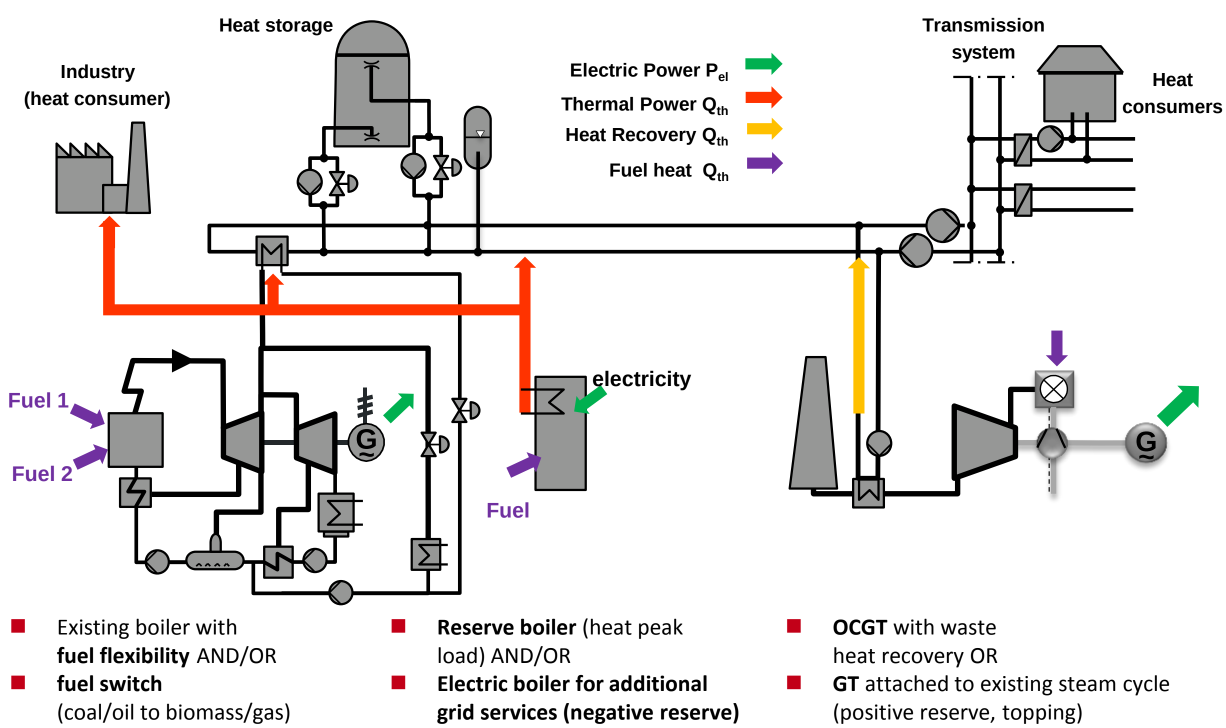


Figure 11: Tailor-made solutions for future oriented CHP and energy systems

Starting from January 2018 MHI and MHPS have established the Power & Energy Solutions Business (PESB) which will utilize proprietary AI/IoT technologies (MHPS-TOMONI & MHI ENERGY CLOUD®) to provide comprehensive services in optimising operation and maintenance of existing power plant assets. Furthermore, through the use of IT tools a better evaluation of future investments in the dynamically changing European energy market will be possible. In addition new flexible and efficient products for integration in energy systems and existing plant infrastructure will be offered, including:

- Waste heat recovery systems in large scale such as organic Rankine cycles (ORC)
- Gas engine power technology
- Solid oxide fuel cells (SOFC)
- High temperate heat pump (for heating grids and/or industrial steam demand)

8 Summary

Thermal power plants, while projected to remain as a leading source of electricity generation, can no longer expect to operate at base load with high capacity factors. Plants will need to be able to operate in a wide load range with fast ramping and potentially frequent starts and in the meantime maintain efficiency, equipment durability, fuel flexibility, environmental compliance, and low cost of electricity. Based on its technology capability and experience as a leading supplier of state-of-the-art power generation equipment, MHPS has developed new technologies and new procedures for thermal power plants include all subsystems such as combustion system, boiler, turbine, pollution control system, and BOP equipment to enhance overall plant dispatchability and flexibility. The MHPS-TOMONI digital solutions platform and MHI ENERGY CLOUD®, with its focus on the fusion of the latest digital technologies and human insights and the collaboration between MHPS and power plant owners / operators, opens up new possibilities and opportunities for improving power plant flexibility and productivity in today's dynamic energy market. With constant technology innovations, thermal power will continue to play a central role in supplying clean, reliable and affordable electrical energy to the society.