Digital Solutions for Optimizing Gas Plant Operations

Natural gas-fired combined cycle plants (gas plants) steadily replaced coal-fired plants for baseload operation during the past two decades. Traditionally, the plant with the best efficiency and lowest operating costs was dispatched first. This level of predictability no longer exists in the modern power market now undergoing an energy transition. Increasing contributions by variable wind and solar generation now demand that in many cases, gas units operate as a backstop for renewables rather than as baseload resources for which they were designed. As a result, gas plants find that they are cycling more frequently, and operations can span from minimum load to baseload on almost a daily basis. Furthermore, the operating economics in this era of the rapidly increasing cost of natural gas and the growing pressure on reliability of cycling fossil-fueled plants are perhaps the top issues plant owners and operators now face. GE Digital is at the forefront of the digital transformation of the electricity industry, using innovative software solutions that translate industrial data into breakthrough business results.

The electricity market often defines the market rules that drive the plant's operating regime. In some regions, changes in plant dispatch are driven by "must-take" rules that force gas plants to provide load-balancing services. Plants capable of cycling service within a region employing substantial renewable resources are usually placed higher in the region's dispatch order. The outcomes critical to gas plant operators used to be focused on reliability, cost of generation, base load run time. Those are all still critically important but the added complexity of the decarbonization of the grid is making other attributes (e.g. operational flexibility) equally important, yet must be addressed within existing budget constraints. GE Digital's software solutions help orchestrate flexible and robust power generation to deliver reliable and affordable service for your customers.

However, cycling a unit outside its design basis poses a unique problem. Determining the actual cost of operation is beyond the ability of the typical distributed control system (DCS) or plant data recorder, particularly when operating long periods of time below baseload or assessing the effect of cycling on the remaining life of components and equipment. The good news is that software solutions can help manage these risks and improve the plant operating flexibility through advanced performance intelligence and predictive analytics.

Digital operations is the key to enabling this energy transition, particularly with flexible, dispatchable, affordable, reliable, and lower CO2 electricity production. GE Digital can future-proof your power generation infrastructure in this rapidly evolving electricity market by optimizing and gaining flexibility in operations, improving outage response time, and meeting customer reliability expectations. Digitalization of existing power infrastructure promises to expand existing operating limitation, reduce compliance incidents, enable proactive response to asset health condition, and enable the autonomous plant for improved operational flexibility and efficiency.

Flexible Plant Operations

We begin by defining the characteristics of a flexible plant, followed by a brief survey of the effects of cycling on a plant's equipment, and concluding with a discussion of modern data analysis techniques designed to accurately assess the material condition of plant components and systems through performance analytics and work process automation to optimize asset performance and reliability.

Broadly defined, flexible operation is any mode of operation other than baseload, including two-shifting, double-two-shifting (starting up and shutting down a unit twice a day to match the early morning and evening peaks in load demand), load following, and turn down to some minimum load when the demand is low, more frequent startups and shutdowns, and fast startup. Flexible plant operations are characterized as having several of the following, often contradictory, capabilities:

Sustainable minimum load

A plant's minimum load (usually stated as a percentage of full load) is the minimum output that a plant can continuously safely sustain. In general, the lower the minimum load setting of a plant, the lower the cost of operation, thus making the plant more economical in cycling operation. A flexible plant will have a lower minimum load capability than its peers.

Short cold start time

A plant's cold start time is the number of minutes required to ramp to minimum load and synchronize to the grid. A flexible plant will have a faster cold start time to be of value to the grid operator, particularly in the event of a grid emergency. In some locales, the regulatory authorities limit emissions during startup, so a fast startup from cold conditions may avoid emissions permit violations.

Fast ramping capability

A plant's ramping capability describes the rate at which plant generation changes in a minute after a cold startup. An industrial CT can change load at 25-50MW/min, while a central station coal plant may be limited to 5-10MW/min. Wind, however, can change load by 50-60MW/min and solar 200MW/min. A grid operator values a plant that can rapidly increase or decrease its load in the event of a grid disturbance, when a storm blows through (wind), or when the sun is blocked by clouds (solar).

Other gas plants may be required to change to two-shift cycling service, where plants would shut down overnight and then restart to meet daytime loads. Units with 200 to 250 or more starts per year are not uncommon.

Low startup cost

A plant's startup cost reflects the monetary value each time the plant is started from a cold stop. A complete accounting of startup costs will include the value of the remaining life of the plant consumed with each startup. Every plant experiences wear-and-tear during each startup and consumes fuel before the plant is synchronized to the grid. A flexible plant will be designed for a routine cold startup to minimize its startup cost.

Maintains heat rate at part-load

A plant's part-load heat rate reflects the fuel efficiency at load conditions less than full-load. A flexible plant will maintain high thermal efficiency over a wide operating range, thus allowing the plant to be dispatched more often and for more extended periods.

Plant controls and digital security

Modern, flexible power plants require an intelligent DCS tailored to a plant's emerging capabilities and future planned upgrades. Also, modern control systems must be configured for added cybersecurity protocols, intuitive operative interfaces, advanced data sharing and analysis tools, and context-sensitive on-line diagnostics.

Many gas plants designed initially for baseload operation were not equipped with enhanced instrumentation or advanced data monitoring and analysis capability necessary to detect data anomalies and predict component conditions. In some cases, a vicious spiral has occurred where more cycling leads to more unreliable operation and reduced component life because the actual cost of production is underestimated.

A factor shared by each of the measures mentioned above regarding flexible gas plant operations is the tuning of the combustion turbine (CT). Aeroderivative CTs, in particular, must be regularly tuned to achieve the desired emissions and fuel efficiency performance. Tuning is based on a specific set of site-specific variables. Seasonal adjustment of flame temperatures and fuel splits, post-outage tuning, and tuning to account for changes in fuel and other operating variables are commonplace.

GE Digital offers Autonomous Tuning software that automatically tunes for emissions compliance and ideal performance based upon changes in ambient temperature, fuel properties, and unit performance degradation. The AI-powered solution automatically explores the space of CT operations, builds a machine learning model, and then continuously finds the optimal flame temperatures and fuel splits to minimize emissions and combustion acoustics every two seconds. The digital solution employs machine learning in closed-loop supervisory control. Field test results demonstrate a potential 14% reduction in CO, a 12% reduction in NOx, and a 0.5 – 1.0% fuel/ CO_2 reduction. Further, routine manual tuning of your aero-derivative CT is no longer required (Figure 1).

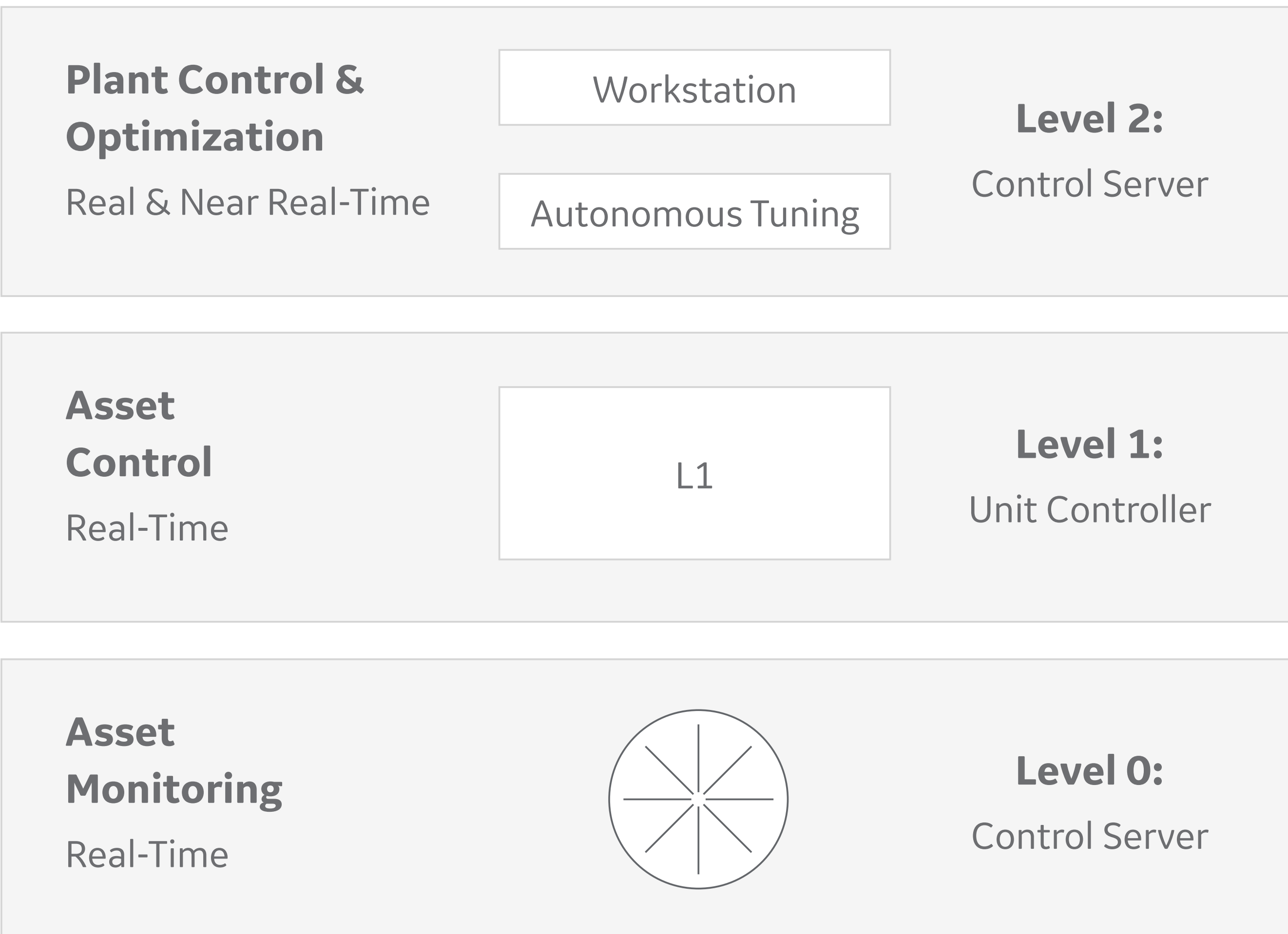


Figure 1. *GE Digital's Autonomous Tuning solution builds on the aero-derivative CT real-time asset monitoring capability. The Level 1 Turbine Control interfaces with the CT's qualified core software. The Level 2 Control Server provides the supervisory combustion control based on turbine-specific machine learning models. Source: GE Digital*

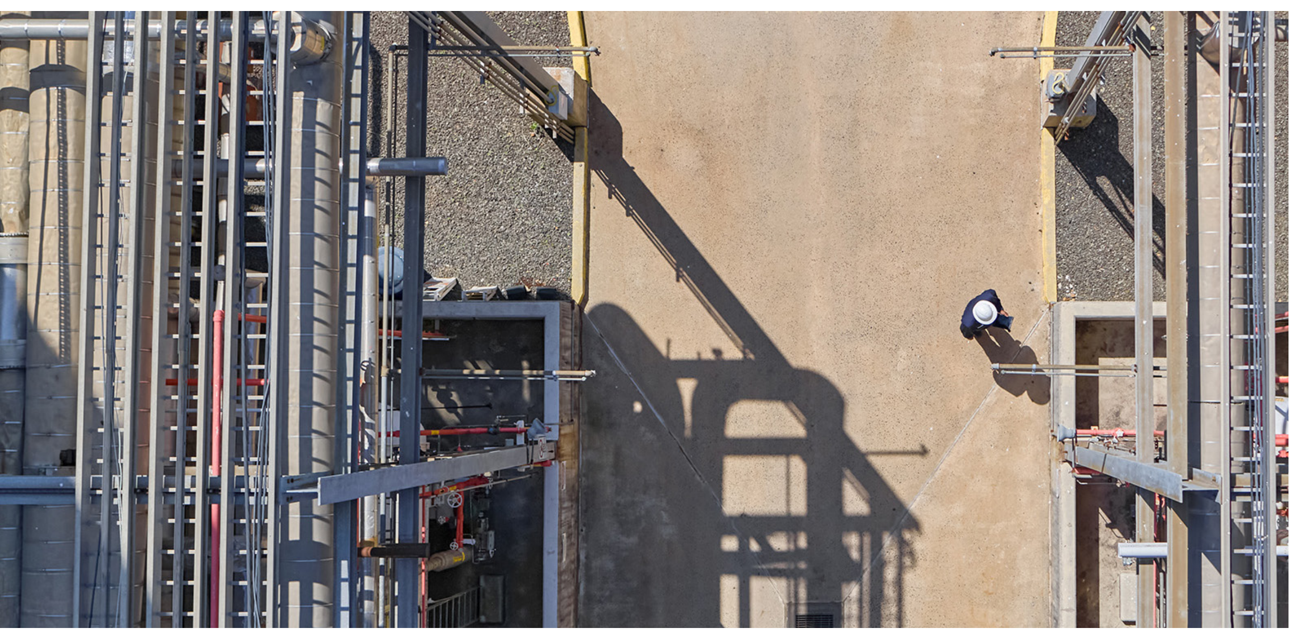
GE Digital's Autonomous Tuning solution also adds to the plant balance sheet, with the typical plant enjoying simple payback of less than one year. Heat rate optimization will save a typical plant hundreds of thousands of dollars annually. One LM6000 plant reported that the need for seasonal tuning was eliminated, no acoustic events were experienced, and the plant produced an additional $300,000 in electricity sales revenue. Further, the solution reduced NOx emissions by 10% while avoiding the need for a $2 million and 12-week outage.

Cycling Side Effects

Generally, the fast start or cycling performance of a gas plant is limited by the CT, heat recovery steam generator (HRSG), steam turbine (STG), or the plant's distributed control system (DCS). Every time a power plant is turned off and on, the boiler, steam lines, turbine, and auxiliary components go through unavoidably significant thermal and pressure stresses, which cause damage, usually by the interaction of creep and fatigue.

Accurate measurement of the extent of the damage is critical to predicting a component's life cycle. Shorter component life expectancies will result in higher plant equivalent forced outage (EFOR) rates and increased maintenance of components near the end of their service lives, and reduce the plant's overall life span. How soon these detrimental effects will occur will depend on the amount of creep damage present and the specific types and frequency of the cycling. EPRI research has identified many common damage mechanisms related to cycling that can trigger fatigue and fatigue-related damage mechanisms.

Each plant's component(s) that limit performance is unique, although general conclusions are possible. Further, the performance of the gas plant systems is highly interrelated. A very brief examination of the limitations of each of these components is in order before we examine the data collection and analysis techniques that allow plant operators to detect and avoid component damage.



Combustion turbines

The CT can start and be on-line, producing electricity much faster than the HRSG can respond. Thus, the CT must follow a restricted load profile based on the HSRG tube and drum temperature transients and the manufacturer's STG temperature ramp rate limitations. Further, the emissions produced during CT idling are limited in some locales.

Heat recovery steam generators

The most common cause of HRSG failures (after malfunctioning equipment such as sprays or duct burner controls) is a change in operating profile, typically from base load to daily cycling, especially in markets with must-run generation.

The problem with HRSG cycling is magnified as the higher operating pressures in modern HRSGs require increased tube wall thickness, increasing the thermal transient component stress. High-stress regions are typically found in the superheater and reheater outlet headers and manifolds, high-pressure steam drums, downcomers, and risers.

HRSGs also often require the CT to hold at a low load for a time so that the thick-walled components, such as the high-pressure evaporator drum, may be heated gradually before ramping the CT. Cycling HRSGs also subject cold components, such as superheaters and reheaters, to rapid heating, producing significant thermal stresses. The HRSG produces significantly less steam at low CT load than at full-power conditions, which can also damage HRSG components.

Catalyst-based systems for control of CO, NOx, and volatile organic compounds (VOC) are strongly affected by the conditions of the turbine exhaust gas. Oxidation catalysts are passive catalysts used to oxidize CO and VOC to CO2. Selective catalytic reduction (SCR) systems are active catalyst systems that require injecting a reagent containing ammonia (NH3) to reduce NOx to N2 and H2O. Older catalyst systems were designed primarily for steady-state, baseload operation with slow startup times, typically one to three hours, and operated in the 80% to 100% load range. Cycling changes the flow distribution across the catalyst, impacting gas velocity, ammonia concentration, and temperature variations across the catalyst inlet. Thus, CT exhaust NOx and CO can spike during load changes, as can ammonia slip.

GE Digital addresses these many HRSG performance concerns with its Duct Burner Optimizer. Many operators of gas plants report that the duct burner ramp rate is too slow, resulting in missed market opportunities. Also, not all duct burners are capable of modulating output; some can operate only at full load. Off-design operation of duct burners drags down the heat rate of a gas plant which impacts electricity market bid prices, particularly in regions where the incremental revenue for operating duct burners for ancillary services is small. Finally, net emissions from a gas plant increase when duct burners are in service, and higher gas temperatures can lessen the life of SCR catalysts over time.

The Duct Burner Optimizer solves this challenge by automating operation and optimizing when to turn on, ramp or turn off the duct burners by dynamically modeling the plant and use of duct burners. The AI-enabled optimizer predicts the maximum likely demand over the next 30 minutes and the plant capability with and without duct burners, given the current material condition and operating history. Suppose the maximum estimated demand in 30 minutes exceeds the maximum capability without duct burners. In that case, the Optimizer tells the DCS to add just enough duct burner fuel to generate the requested MWhrs (Figure 2).

[1] EPRI. Impact of Cycling on the Operation and Maintenance Cost of Conventional and Combined-Cycle Plants. https://www.epri.com/research/products/3002000817. Damage to Power Plants Due to Cycling https://www.epri.com/research/products/1001507. Descriptions of Past Research: Impacts of Cycling on Existing and Future Fossil Assets. https://www.epri.com/research/products/000000003002012469

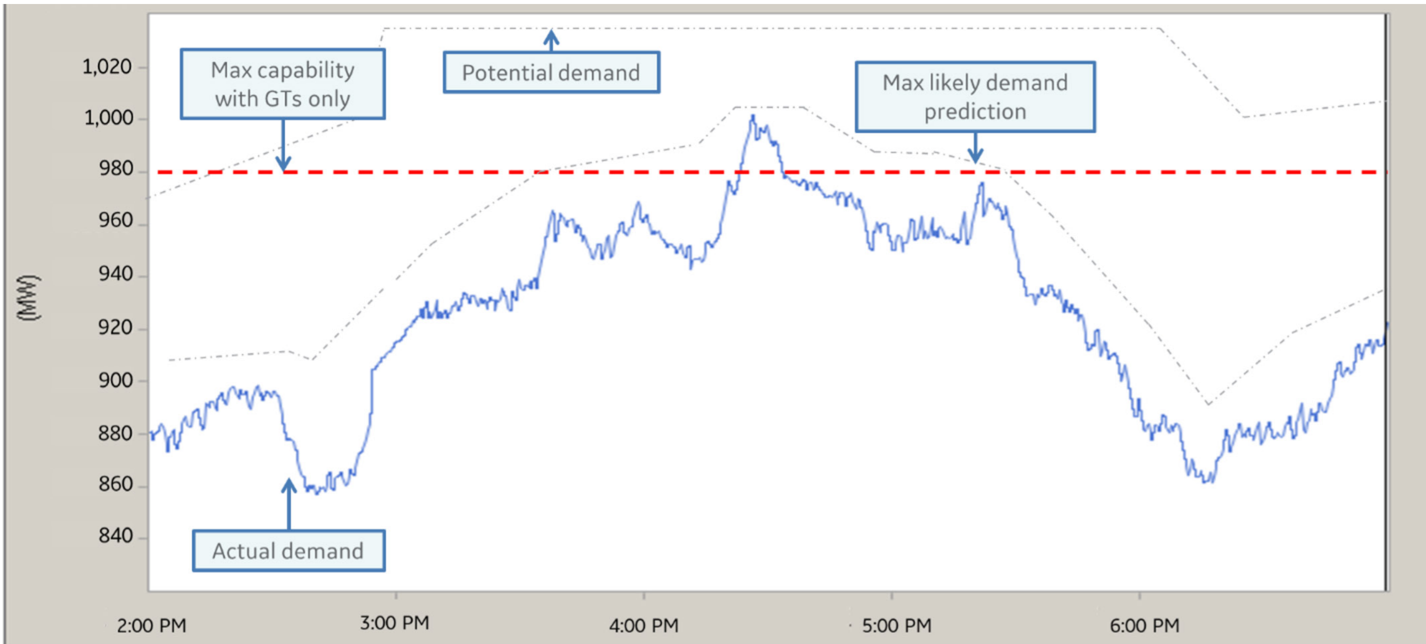


Figure 2. *The example time period shows the Duct Burner Optimizer's prediction of maximum likely demand and the short period that the duct burners should be operated. The Duct Burner Optimizer can be tuned to be either more or less conservative with its predictions. This performance mode is beneficial when duct burners are used during fast ramping and cycling operations. Source: GE Digital*

The potential fuel savings with the Duct Burner Optimizer can be significant. One customer's 2x1 7F combined cycle experienced fuel savings of $250,000 per year per duct burner. The fuel savings were achieved because the Optimizer reduced the number of times the duct burner was turned on too early or shut off too late. Further, by pre-positioning the duct burners, the Optimizer allows the plant to ramp at the GT rate up to the duct burner output limit, extending the range of regulation services that can be supported.

Steam turbines

The steam turbine is typically the most restrictive element of combined cycle startup because of its large thermal inertia. During startup, the steam turbine casing thermally expands slower than the rotor and blades. To prevent blade rubbing and turbine degradation, the rate at which steam energy is admitted is restricted. In conventional combined cycle plants, this restriction in steam temperature and mass flow is controlled by slowing down the load ramp rate of the combustion turbine. The rotor stress monitor is typically capable of limiting or reducing the steam turbine load or speed increase and is designed to trip the turbine when the calculated rotor stresses exceed allowable limits.

The floor pressure of HRSG operation at low loads is critical for steam turbine operation. At low loads, steam pressure is reduced, and the steam flow increases. But so do the steam velocities in the HRSG and piping, which may decrease stability in evaporator circulation. However, the additional low-pressure (LP) steam flow improves the power production by the LP steam turbine, although at lower turbine efficiency. Localized heating may also occur due to internal flow distribution and recirculation changes. The life of an STG is directly related to the number of thermal transients over time.

Distributed Control System

An essential function of the DCS is to start or cycle the plant as quickly as possible but within the many operating constraints noted above. Compared to a manual or semi-automated startup control system used in a conventional start plant, fast-start plants typically utilize a fully automated control system. As a result, more plant instrumentation is required in automated plants to allow the plant control system to monitor system status, minimize times between sequential steps, and provide consistent startups.

Asset Management Principles

Plant operators must clearly understand their plant's thermal performance and equipment reliability to compete successfully in the electricity marketplace (Figure 3).

Figure 3. *The needs of gas plant operators for managing performance are changing*

Capability	Description	APM Performance Intelligence	Legacy Performance Tool
Automated KPI calculations & reporting - Thermal Perf Data	Visibility to fleet/plant/equipment thermal model-derived data for Output, Heat Rate, Capacity, including multi-op modes	**yes**	**yes**
Automated KPI calculations & reporting –Flexibility Perf Data	Visibility to fleet/plant/equipment data for Min Load, Starts, Ramp Rates	**yes**	no
Min Load	Automated minimum load operations detection and evaluation	**yes**	no
Starts	Automated power plant startup detection and evaluation	**yes**	no
Ramp Rates	Automated power plant ramp rate detection and evaluation	**yes**	no
Automated KPI calculations & reporting –Carbon Perf Data	Visibility to real-time production and historical aggregations of actual plant CO_2 emissions from actual plant fuel data	**yes**	no
Data Health	Module to assess sensor / data quality	**yes**	**yes**
What If	Interactive thermal model interface for user to evaluate the plant performance impacts for specific scenarios of interest	**yes**	**yes**
Automated Alerts	Automated alerts on performance deltas versus expected, providing alert source and description	**yes**	**yes**
Automated Diagnostics	Automated analytic rule engines providing root-cause analysis; delivered with alerts	**yes**	no
Economic trade-off Advice	Advice based on actual degradation, expected recoveries and plant financials, maximizing profitability	**yes**	no

Figure 4. *APM Performance Intelligence and Legacy Performance Tool Capabilities*

Legacy performance monitoring and diagnostic tools fall short of addressing the changing needs of gas plant operators. They focus on baseload heat rate, output, reliability but do not readily address the incremental risks incurred by changing operating profiles. However, GE Digital's Asset Performance Management (APM) solution uses predictive diagnostics and data analysis to provide plant operators with real-time visibility of plant thermal performance, diagnostic analysis for actionable insights that expedite remediation of identified problems, and optimization of plant economics across the entire spectrum of operations for reliability and performance (Figure 4).

With this information, plant management can make wise decisions about maintaining and improving equipment performance and overall plant heat rate, maintaining capacity for peak dispatch, managing minimum load capability, and improving startup performance. Further, the APM provides economic trade-off advice for optimal timing of future activities to maximize plant performance and "What If" scenario modeling tools to evaluate the impact of variable operating conditions, equipment conditions, and plant configurations to improve plant operations and economics.

SmartSignal, long a favorite industry solution, is an integral component of GE Digital's APM and provides plant predictive maintenance decision support by employing predictive analytics that delivers early detection of pending issues for plant components and equipment. SmartSignal can also indicate probable cause and suggest maintenance alternatives, estimates when an alarm limit will be reached to optimize O&M assets, and monitors sensor status and current failure mode diagnostic coverage per asset to ensure continuous optimal results (Figure 5)

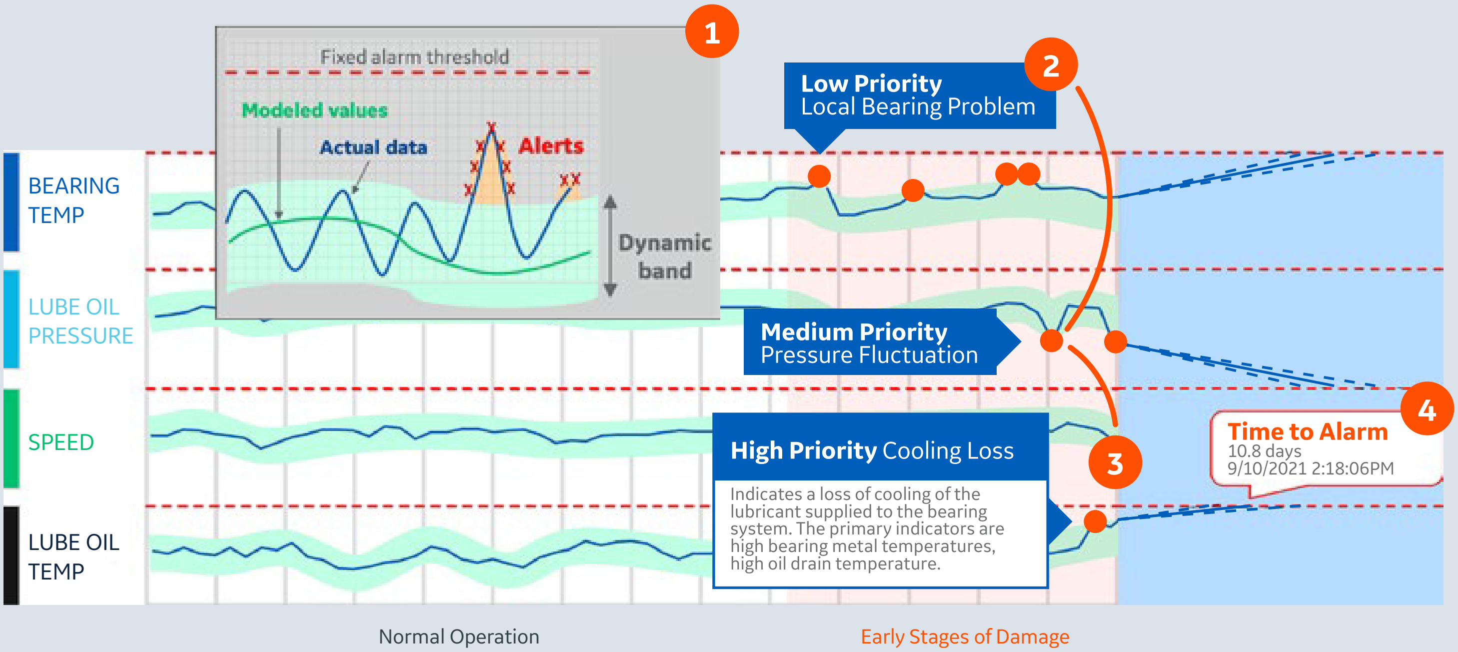


Figure 5. GE Digital's SmartSignal continuously analyses equipment operating performance against its historical data to produce unique O&M recommendations. Source: GE Digital

For illustration, consider a lube oil pump with instrumentation that monitors bearing temperature, lube oil pressure and temperature, and pump speed (Figure 5).

The following presents the process used by SmartSignal for its predictive maintenance recommendations

1 The software uses empirical models of equipment or "digital twins" that have been built from and "trained" on historical data. The models use physics-based models of your power plant equipment that replicates the equipment design and plant process. To ensure the models are relevant to the current plant condition, it uses as-running performance data to tune the model predictions of plant capability across the entire load range.

Predictive analytics provide early warnings by comparing actual data to expected values within a dynamic band. During monitoring, one algorithm assembles a single snapshot from the readings of all individual sensors in the model. This "actual" snapshot is then compared to the model, which uses data embedded in it to create estimates of the usual readings expected to be produced by sensors with the equipment in its current operating state,

SmartSignal uses all available sensor readings to determine the current state of the equipment. For example, the instruments dedicated to independent drivers (controllers, material inflow, ambient conditions, etc.) and those monitoring dependent responses of the system (exhaust gas temperature, material outflow, etc.) are grouped in a single model.

2 The difference between the actual and estimated standard values is called the residual. Another algorithm tests the residual to determine whether it is reasonably small—in other words, whether the real value is close to the expected standard value. When the residual is relatively small, the sample is considered normal. When the residual is relatively large, the data sample is considered suspect and triggers either of two actions. If only one parametric reading yields a high or low residual, the system signals an "alert" for that moment in time and notes it on that parameter's graphic display. Suppose persistent deviations in multiple sensor readings match a known fault pattern. In that case, the system determines that an "incident" is occurring and creates an item for addition to the Alert Dashboard.

3 Algorithms in the SmartSignal system determine whether any parametric behavior is questionable and post anomalous results to an "Alert Dashboard" The detected anomalies generate prioritized alerts and diagnostic information.

4 Time-to-action forecasting provides timeframe requirements for remediation. An analyst can then judge whether any item represents a problem that warrants immediate corrective action—while the piece of equipment and its generating unit remain on-line. In the present case, diagnostic analysis across readings indicates a correlation to bearing lubrication as a possible cause.

Strong Economic Benefits

The value proposition for performance monitoring that produces an incremental improvement in average heat rate adds significantly to the plant's balance sheet. Consider a 2x1 7HA combined cycle with a 1,200 MW nameplate operating at a 52.8% capacity factor. If the plant experiences a 0.5% improvement in plant heat rate through performance analytics, the fuel savings alone are $1,000,000 yearly at a very conservative $5.00/mmBtu fuel cost. Further, the plant support productivity will add further savings when using the full spectrum of services offered by GE Digital's APM.

Conclusion

Owners of gas plants subjected to cycling service are experiencing accelerated equipment degradation, and the typical plant cannot put an accurate dollar value on lost equipment life caused by excessive cycling. Still, operators must continue to cycle the asset to remain competitive in the power market. So, renewable resources connected to the grid will continue to grow, and gas plants will continue to cycle.

Give your plant operators a clear picture of the thermal performance and reliability of the entire plant, as well as discrete plant components and equipment, so that data-driven decision-making is made possible. Operating data and digital diagnostics provide an automated response to performance shortfalls and advance notification of impending equipment problems. Imagine the efficiencies gained when O&M becomes proactive and planned rather than reactive and haphazard.

GE Digital's solutions empower your operations staff to make data-driven decisions to maximize plant economics and improve performance across the entire operational load range. Give your plant the market advantage that will keep your plant "in the money."

If you're interested in learning more about how GE Digital Grid's Visual Intelligence solution can help your utility, please **contact us.**