

The Value of GE SmartSignal powered by Predix Solutions to Combined-Cycle Plants



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Combined-Cycle Units: High on Outages—and Costs

Many combined-cycle units were designed to operate at base load but now are cycled frequently. It's crucial for these units to meet dispatch commitments each time they're called upon. Unfortunately, issues throughout the units often cause outages that require dispatch of alternate generation resources or purchase of power on the spot market.

The average combined-cycle unit experiences three or more forced outages per year at a total cost of \$1 million plus. These outages are caused by issues that can occur throughout the unit—from the turbines and compressors, to the HRSG, to the generator, to BOP equipment. Failures occur in mechanical rotating devices, such as rotors, bearings, casings, and lube-oil systems. Performance issues also are common. Condenser air inleakage, boiler feed pump seal deterioration, and a number of other issues can lead to expensive derates.

GE SmartSignal Solutions: Early Warning of All Critical Failures

For over 10 years, the GE SmartSignal solutions have been eliminating failures that previously led to expensive forced

outages. The solutions' actionable information, delivered at the very outset of developing issues, provides foresight and advance notice to perform necessary maintenance before these problems compromise operating results.

GE SmartSignal solutions identify slight deviations from expected bearing vibrations that point to developing bearing failures, misalignments, or casing rubs. The solutions detect minute increases in temperature that are indicative of lube oil cooling problems, thereby preventing major failures down the line. Generator damage can be prevented by detection of abnormal H₂ leakage. And, loss of efficiency can be prevented by detection of pressure losses, which can indicate worn BFP seals or condenser air inleakage.

In fact, the GE SmartSignal solutions monitor all major systems of combined-cycle units and identify, well before they happen, all major failure modes across all OEMs. See Figure 1.

Combined-Cycle Plant Systems	Performance	Bearing Failures	Lube	Mechanical Damage / Wear	Leakage / Seal Failures	Fouling	Process Deviations	Electrical	Motor / Drive	Fuel System Diagnostics	Fuel Supply & Gas Control Valves	Cooling
EQUIPMENT TYPES												
Heat Recovery Steam Generator (HRSG)	X				X	X	X					
Fuel Delivery				X	X	X	X					
Combustion Turbine	X	X	X	X	X	X	X			X	X	X
BALANCE OF PLANT												
Steam Turbine	X	X	X	X	X	X	X		X			
Boiler Feed Pump	X	X	X	X	X	X	X		X			
Generator		X	X	X	X		X	X				
Condenser	X			X	X	X	X					
Feed Water Heater	X			X	X	X	X					
Transformers							X	X				
Centrifugal Pumps & Fluid Transport	X	X	X	X	X	X	X		X			
Control Valves				X			X					
Gear Boxes		X	X	X			X					
CT STARTUP MONITORING												
Compressor	X			X	X	X	X					
Fuel System	X						X			X	X	
Combustion	X						X					
Mechanical		X	X	X			X					
Turbine Cooling							X					X

Figure 1 GE SmartSignal solutions identify all major process and equipment failures on all critical rotating and non-rotating equipment across all OEMs.

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Cycle Watch and Shield Solutions: Earlier Warnings, Improved Diagnostics

Continuous innovations in the GE family of solutions ensure that failure coverage improves over time, with even earlier warnings of developing problems and increased diagnostic capabilities.

GE SmartSignal Cycle Watch Solution

For example, the SmartSignal Cycle Watch solution models combustion turbines during the fast-changing conditions of startup cycles. This solution informs users when thermocouples begin to drift, fuel valves begin to act up, and nozzles begin to plug. Addressing these issues during normal downtime will prevent a trip from blade path deviations. The Cycle Watch solution also indicates the low temps from contaminated fuel, preventing a flameout and failed start. When bleed valves begin to stick, the Cycle Watch solution gives advance notice to make repairs and prevent a compressor stall. When vibration at critical frequencies increases, the insight from the Cycle Watch solution lets users address bearing, coupling, and casing issues during the next maintenance opportunity and prevent other problems down the line.

This software's innovative and patented Variable Similarity-Based Modeling (VBM) technology dynamically compares all the data at each point in the cycle to similar expected behavior from reference "golden" starts. Accounting for and removing the expected variation leaves clear indications of the subtle changes from cycle to cycle. This extends the coverage of steady-state monitoring to give even more insight—and more opportunity to address developing CT problems before they cause trips and forced outages.

GE SmartSignal Shield Solution

The SmartSignal Shield solution is the industry's first predictive-diagnostic software. It gives users a complete understanding of the status of their equipment: *what* is going to fail; what is the *apparent cause* of the failure, and what is the *priority* of the impending failure. The Shield solution builds upon our core early failure detection and provides proactive notifications containing specific diagnostic guidance and clear prioritizations.

After analyzing data from hundreds of millions of machine hours and tens of thousands of avoided failures, we were able to identify the fault patterns, in context of operating behavior, that are important to combined-cycle plants and incorporate them into the Shield solution. All critical failures, both mechanical and performance, are incorporated into this solution and are diagnosed on all key operating assets: boiler feed pumps and generic pumps, condensers, cooling water circuits, combustion turbines, generators, HRSGs, and steam turbines.

Case Studies: Proof of Success

The three sample case studies below illustrate actual problems identified and solved by combined-cycle customers using SmartSignal solutions.

Customer Success Story #1

Lube Oil Temperature Threatens Bearing Life

Problem: A gradual but steady increase in combustion-turbine and corresponding generator bearing temperatures was observed over a period of two weeks. The increase progressed beyond the model estimate based on "normal" historical operation. Evaluation of this situation revealed that the turbine bearing oil-drain temperatures displayed a similar increase above the model estimate. In addition, the cooling water outlet temperature from the oil coolers was not reflecting a corresponding temperature increase.

Solution: Based upon evaluation of the relevant data, the SmartSignal solution sent a notification to the customer with a diagnosis of a potential performance issue with the lube oil cooler. Station investigation of the incident determined that the cooler was in good functioning condition. However, the component cooling water bypass valve around the cooler had failed in the open position. Furthermore, there was a corresponding false indication of valve position on the DCS system. Erroneous valve-position readings led operations staff to believe the valve was fully closed. While sensors indicated adequate flow to the oil cooler, the failed open bypass valve resulted in starving the cooler of water, thus providing insufficient oil cooling.

The lube oil cooler bypass valve operation was restored and valve position indication in the DCS was corrected, returning the system to proper operation.

Value Derived: This particular condition allowed the turbine and generator bearings to run at elevated temperatures, but still under the radar of the plant alarm settings. Early detection by the SmartSignal solution afforded quick identification and resolution of a condition that may have gone undetected for quite some time. Continued operation at elevated bearing temperatures will significantly reduce the life expectancy of a bearing. Resolution of the condition prevented accelerated bearing wear and possible premature replacement or possible bearing failure during operation—which would have resulted in a forced outage.

The value of the SmartSignal detection was anywhere between \$50,000 (the cost of shutting to change the bearing) to \$5 million, the cost of a catastrophic failure.

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Customer Success Story #2:

Attemperator Valve Control Thermally Shocks HRSG

Problem: On numerous occasions, a dramatic decrease in HRSG desuperheater outlet line temperatures was detected by a SmartSignal solution. The magnitude of these temperature swings was in excess of 400° F, and the transient typically would last four to six hours. The observed temperature decreases were well below the SmartSignal model projections based upon normal historical data. The occurrences were intermittent, on the order of once or twice per week. These events appeared to occur while the plant was operating on duct burners.

Solution: A review of additional sensor charts available in the SmartSignal model revealed that these temperature swings were due to steam attemperation and apparent overspray. Clouding the events was the fact that attemperator flow readings and flow valve position indications provided inconsistent information relative to each other. The customer was notified of this situation, and an investigation was initiated at the plant. The investigation revealed the attemperator flow control valve had sustained erosion damage to the plug and seal. This made flow control difficult and, at times, allowed for leaks by causing unwanted attemperation. Additionally, the flow control sensor was found to be out of calibration, which caused erroneous sensor readings. The valve was repaired, and the system was restored to normal operation.

Value Derived: Large temperature fluctuations within the steam-supply system cause low cycle thermal fatigue of piping and components up to and including the steam turbine, which can have significant adverse impacts on life expectancies. These temperature fluctuations will increase the frequency and extent of maintenance required to keep the steam-supply system functioning properly. Reducing these transients will result in reduced CAPEX and OPEX expenditures, along with increased plant availability. Additionally, restoring the attemperation system to proper operation will improve the plant heat rate.

The SmartSignal solution saved the customer up to \$1 million in lost revenue and expenses, the cost of an estimated three days of forced outage during peak power production.

Customer Success Story #3:

Burner Debris Fouls Environment and Degrades Combustion

Problem: Higher than normal blade-path temperatures were observed during startup and steady-state operation of a combustion turbine.

Solution: An analysis by the SmartSignal solutions revealed that abnormally high temperatures were appearing at certain blade-path locations at certain loads. The Cycle Watch solution was able to detect the high temperature swing from one blade path location to the next as the generator was loaded during startup. The Shield solution also noted NOx-positive residuals. It picked up that the high temperature settled at a specific blade-path location once operating load was reached. The Shield solution sent a notification to the customer with a diagnosis of a problem on a specific burner basket on the engine. The plant scheduled an inspection and discovered an extra shim left in the combustor. Pieces from this shim had entered a burner basket and were disrupting air flow, causing damage to the combustor basket and fuel nozzles. Repairs were carried out, and the engine was returned to service four days later.

Value Derived: Detection by the two SmartSignal solutions enabled a quick identification of a problem on a specific area of the engine. If left to deteriorate, the problem would have caused a full load trip and forced outage. The accurate diagnosis enabled the customer to plan and execute a quick repair and return the combustion turbine to normal operation within a short period of time.

The estimated value of the SmartSignal solutions' detection was \$100,000 plus avoidance of environmental sanctions.

\$679,048: Total Annual Value of SmartSignal Solutions to a Typical Combined-Cycle Plant

A Solution Value Assessment (SVA) for combined-cycle customers using SmartSignal solutions shows an annual benefit of \$679,048 for a typical 550 MW (2x1 unit) CCCT plant.

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An SVA is conducted jointly with key plant personnel to develop a solid understanding of the effective operations and maintenance activities used by the plant before acquiring SmartSignal solutions. This information then is used to identify how the SmartSignal solutions can be integrated with best practices to achieve a higher level of plant performance. Using statistics from EPRI data (EPRI AP 2071, Component Failure and Repair Data for Coal-Fired Units) and information from key plant personnel, we calculate a value of using SmartSignal predictive-diagnostic solutions.

The results of the SVA for a typical 550 MW CCCT plant (2x1 unit) are detailed below and summarized in the table and chart. The assessment provides a breakdown of value obtained from the solutions, as divided into three categories:

1. Maintenance Expense Reduction
2. Fuel Expense Reduction
3. MW Hour Revenue Improvement

These categories are further partitioned among several sub-categories of savings:

- **Shift of Unplanned Maintenance to Planned Maintenance.** Advance warning of equipment problems, on the order of days, weeks, or months, allows maintenance activities to be planned so resources are used efficiently. This then minimizes production loss and equipment damage. The Cycle Watch solution can extend the value of these savings by eliminating unplanned maintenance associated with failed startups.
- **Maintenance Duration Reduction.** Advance warning of equipment problems provides opportunities to combine maintenance activities, use resources more efficiently,

and improve identification of minor maintenance problem locations.

- **Interval Extension.** The information provided by the SmartSignal solutions across all assets of a fleet provides an opportunity to limit maintenance activities to only those assets that have current problems. This eliminates the need for time-based maintenance in many cases.
- **Heat Rate Reduction.** The information provided by the SmartSignal solutions across all assets of a unit provides an opportunity to reduce heat rate. Auxiliary power then can be saved by operating pumps, fans, and other systems at their normal functional levels. The Cycle Watch solution can improve heat rate by eliminating failed startups.
- **Reduction in Startup Failures.** Costs from CT startup issues can easily run several hundred thousand dollars per year. The information provided by the SmartSignal Cycle Watch solution for the combustion turbines during startup provides an opportunity to limit accelerated maintenance costs due to trips or aborted startup attempts, along with the costs of lost production capability after these events.

In total, Figure 2 shows that, in the typical plant, significant annual savings are achieved across all three major categories. This typical plant has annual savings attributed to the SmartSignal solutions of \$320,971 in maintenance expense reduction, \$118,624 in fuel expense reduction, and \$239,453 in MWH revenue improvement. While the actual values achieved at a particular plant are likely to be somewhat different than these numbers, one can get a clear idea of the distribution of value from early warning of failures that are hidden in the data that most plants already are collecting.

	Maintenance Expense Reduction	Fuel Expense Reduction	MWH Revenue Improvement	Total
Shift Unplanned to Planned				
Catastrophic Failure	\$103,172		\$32,865	\$136,037
Major Failure	\$79,151		\$22,097	\$101,248
Minor Failure	\$73,220		\$15,499	\$88,719
Maintenance Duration Reduction				
Duration Reduction Minor Failure	\$3,386		\$49,351	\$52,737
Interval Extension				
Interval Extension Major Inspection	\$2,042		\$19,641	\$21,683
Heat Rate Reduction				
Heat Rate Reduction 0.25%	\$0	\$118,624	\$0	\$118,624
Reduction in Start-Up Failures				
Accelerated Maintenance & Trips	\$60,000		\$100,000	\$160,000
PLANT - ANNUAL TOTAL	\$320,971	\$118,624	\$239,453	\$679,048

Figure 2 Typical 550 MW CCCT Plant (2x1 unit)—Annual Value

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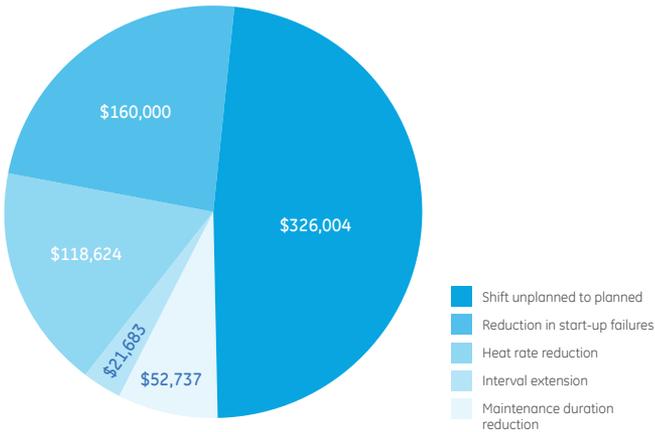


Figure 3 Typical 550 MW CCCT Plant (2x1 unit)—Annual Value

The distribution of benefits across subcategories is presented graphically in Figure 3. All subcategories clearly provide significant contributions to the savings.

Summary

GE SmartSignal powered by Predix solutions eliminate failures that previously led to expensive forced outages. The solutions' actionable information, delivered at the very outset of developing issues, provides the foresight and advance notice

to perform necessary maintenance before these problems compromise operating results. SmartSignal solutions monitor all major systems of combined-cycle units and identify, well before they happen, all major failure modes across all OEMs.

Continuous innovations ensure that failure coverage improves over time, with even earlier warnings of developing problems and increased diagnostic capabilities. The Cycle Watch solution models combustion turbines during startup cycles, extending the coverage of steady-state monitoring to give even more foresight—and more opportunity to address developing CT problems before they cause trips and forced outages. And the Shield solution provides a complete understanding of the status of combined-cycle equipment: *what* is going to fail, *what* is the *apparent cause* of the failure, and *what* is the *priority* of the impending failure.

Finally, the three sample case studies illustrate some major failures identified by SmartSignal solutions, with representative values derived. And, the Solution Value Assessment shows the benefit of the SmartSignal solutions to an average combined-cycle plant—over \$679,000 per year.

About GE

GE (NYSE: GE) is the world's Digital Industrial Company, transforming industry with software-defined machines and solutions that are connected, responsive and predictive. GE is organized around a global exchange of knowledge, the "GE Store," through which each business shares and accesses the same technology, markets, structure and intellect. Each invention further fuels innovation and application across our industrial sectors. With people, services, technology and scale, GE delivers better outcomes for customers by speaking the language of industry. www.ge.com

Contact information

Americas: 1-855-YOUR1GE (1-855-968-7143)
gedigital@ge.com

www.ge.com/digital



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