Increasing Asset Availability in the Power Industry:

SmartSignal eCM™ (Equipment Condition Monitoring) Technology

By Brad True,
General Manager,
Power, Energy & Process
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The electric power industry is in the midst of fundamental change. What was once a highly regulated, monopolistic industry with traditionally structured electric utilities is evolving rapidly in a marketplace defined by increasing competition and deregulation. As the industry evolves, so too must business practices — particularly maintenance activities and the acceptance of unplanned downtime as “normal.” But how?

One innovative solution, SmartSignal’s eCM (Equipment Condition Monitoring) system, has emerged to provide power generators with an early warning of equipment problems before traditional control/monitoring systems, allowing enough time to address the issue before actual failure occurs. As a result, power generators can now maximize asset availability and plan ahead for repairs in a way that minimizes both cost and financial loss.

I. Introduction

SmartSignal’s eCM system is a unique, field-proven solution designed and developed to overcome the technical issues involved in detecting subtle deviations from normal operation for any sensor-equipped machinery.

This white paper outlines the current state of the power industry and some key power generation problems, as well as how SmartSignal's eCM software products can help overcome them. Product features, functionality, a cost/benefit analysis, and details of an industry implementation are described in detail to illustrate how power generation companies can leverage this revolutionary technology to minimize downtime and associated costs.

The Key Issue: Asset Availability

In a market defined by increasing competition, power generators of all types must be laser-focused on maximizing efficiencies. Perhaps the most obvious — and costly — drain on operating efficiency is asset unavailability due to a forced outage, sometimes referred to as “unplanned downtime.”

While most manufacturers have excess stock and/or buffers to protect themselves against short-term outages, power generation is one of the few industries where this isn't possible. By its very nature, electricity cannot be stockpiled. As a result, asset downtime for a power generation plant has a direct and immediate impact on revenues. With limited ability to generate electricity, a generator will have to absorb lost revenues, along with the high costs of unplanned repair and maintenance. Even worse, if the generator has a contractual commitment to provide power, the costs of purchasing electricity on the spot market may also be incurred, further eroding revenues.

Yesterday's Solution: “Blind” Preventative Maintenance

Not surprisingly, in an effort to maximize asset availability, power generation companies have embarked upon an intensive program of preventative maintenance. However, the downside of excessive preventative maintenance is increased maintenance costs. What's more, according to the industry research firm ARC Advisory Group, half of all preventative maintenance is unnecessary.
What the industry has desperately needed is a solution that not only provides early warning of potential failures — so downtime, maintenance and associated costs can be reduced — but also gives managers a clear picture of the status of generating capacity. Said differently, a product that describes present asset conditions and, in so doing, provides insight into the enterprise’s ability to generate power in the near future.

That solution is now available.

**Today’s Solution: SmartSignal’s Patented eCM System**

SmartSignal’s eCM technology uses advanced, empirical mathematical techniques to understand the complex relationships between correlated pressures, temperatures, flows, vibration, speeds, voltage, current, and other sensor outputs associated with an equipment system. By recognizing subtle but significant changes in correlated sensor values, SmartSignal’s patented eCM solution provides early detection of abnormal equipment behavior, making maintenance far more effective and focused by enabling operators to fix specific developing problems before a critical equipment or process failure occurs. The software works with existing sensors of all types and is OEM independent.

State-of-the-art functionality enables SmartSignal eCM to:

- Monitor and analyze any correlated data set from sensors and control systems, including vibration sensors
- Monitor a variety of equipment (gas turbines, pumps, fans, compressors, etc.) across OEM manufacturers in a single software application
- Monitor the health of the sensors themselves — condition-based instrument calibration
- Validate data to ensure validity of mission critical sensor-based data
- Provide enterprise systems (ERP, EAM, MES) with real-time information on the health of operating equipment assets
- Recognize the unique performance of each individual asset by developing a personalized monitoring system for each asset as built (or used) for increased sensitivity and accuracy
- Focus attention on equipment exhibiting abnormal performance through a standard screen WatchList™

**II. How the System Works**

While the eCM system uses advanced mathematical techniques to identify deteriorating equipment or processes, the basic approach is actually quite simple. The system’s core functionality is based around three proprietary software “engines”:
• **Set-Up** — It all starts with a set of reference data consisting of correlated sensor readings representing normal machine operation. Typically, much of this information is already being collected and stored in existing information and control systems. In minutes, SmartSignal’s proprietary algorithms use this reference data to create an empirical model of normal operation.

• **Signal Engine** — Based on real-time signals and the model created from the previous step, estimated signals are produced. These signals indicate the estimated value of each sensor during normal operation.

• **Alert Engine** — In the final step, a comparison is made between the estimated signals and real-time signals. Very fine differences between the two indicate when a system or sensor is operating abnormally. The data reveal which signal or signals are at fault, in turn pointing out the parts of the process or equipment where problems are occurring or are about to occur. Once these faults have been screened to reduce the risk of false alerts, the equipment system is put on SmartSignal’s WatchList.

Unlike conventional threshold alarming systems, which alert when a set point is passed, the eCM system’s higher sensitivity is able to identify a fault while the equipment is still well within the normal operating range and noise band of a given parameter. What really distinguishes the eCM system is its ability to detect potential problems early on, yet not trigger myriad false alarms. And unlike some neural network systems that are set up to continue “learning” the operating of the instrumented system, SmartSignal’s empirical modeling engine doesn’t “drift” with the underlying system or its sensors. Consequently, it can detect very subtle, long-term failure trends that can often be missed in neural net-based systems. The engine also can be quickly retrained to adjust to new equipment or processes that are still “breaking in.”

By leveraging the invaluable information currently invisible to existing threshold-based monitoring approaches, the eCM system can deliver dramatic results with the potential to significantly improve the bottom line for the power generation industry.
III. Cost/Benefit Analysis

As Figures 1 and 2 illustrate, when costs are compared against the value generated by implementing the eCM system, the return on investment is substantial. This is made possible by: (1) validating sensor data and detecting performance degradation early so planned maintenance can address potential problems, and (2) reducing forced outages, planned downtime, and spending on maintenance and diagnostic services.

While SmartSignal’s eCM system has great potential to deliver a significant return on investment, real-world performance is what really counts. As the following example shows, eCM technology is already delivering tangible business benefits.

### Assumptions

<table>
<thead>
<tr>
<th>Assumptions</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average monthly capacity</td>
<td>600 MW</td>
</tr>
<tr>
<td>Capacity factor</td>
<td>70%</td>
</tr>
<tr>
<td>Annual electricity sales</td>
<td>$3.7 Million MWH</td>
</tr>
<tr>
<td>Average unplanned maintenance outage rate — 2% of calendar hrs</td>
<td>$175 HR/Y</td>
</tr>
<tr>
<td>Average planned maintenance outage rate — 4% of calendar hrs</td>
<td>$350 HR/Y</td>
</tr>
<tr>
<td>Annual maintenance spend</td>
<td>$8 Million/YR</td>
</tr>
<tr>
<td>Annual diagnostic services spend</td>
<td>$200,000/YR</td>
</tr>
</tbody>
</table>

**Figure 1: Cost/Benefit Assumptions**

### Typical 600 MW Plant

<table>
<thead>
<tr>
<th>Benefits</th>
<th>Annual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shift unplanned maintenance to planned (10% of unplanned)</td>
<td>$33.0 HR/Y</td>
</tr>
<tr>
<td>Margin on hours shifted from unplanned to planned</td>
<td>$15/MWH</td>
</tr>
<tr>
<td>Reduction in planned maintenance (5% of planned)</td>
<td>17.5 HR/Y</td>
</tr>
<tr>
<td>Margin on increased availability hours through reductions in planned maintenance</td>
<td>$10/MWH</td>
</tr>
<tr>
<td>eCM value generated by reducing planned maintenance outages</td>
<td>$100,000</td>
</tr>
<tr>
<td>eCM value generated by shifting from unplanned outages to planned</td>
<td>$300,000</td>
</tr>
<tr>
<td>eCM value generated by 5% reduction in annual spend on maintenance</td>
<td>$350,000</td>
</tr>
<tr>
<td>eCM value generated by 25% reduction in spend on expert diagnostic services</td>
<td>$50,000</td>
</tr>
<tr>
<td>eCM value generated by 1 saved catastrophic failure every 5 years @ $1 million per save</td>
<td>$200,000</td>
</tr>
<tr>
<td><strong>Total benefit value generated (before costs of SmartSignal eCM)</strong></td>
<td><strong>$1,000,000</strong></td>
</tr>
</tbody>
</table>

**Figure 2: Value Generated by eCM**
IV. SmartSignal eCM Implementation Example: U.S. Steel

U.S. Steel’s Gary, Indiana, steel manufacturing complex provides a significant portion of its own power via a co-generation plant consisting of a steam turbine driving a 161-megawatt generator. A boiler burning a mixture of natural gas and excess gas from the coke oven and blast furnace supplies the steam driving the generator. Unfortunately, the steam became contaminated with “salts” which were carried to the turbine blades where they began to adhere.

Plant personnel noticed a variety of symptoms and attempted to diagnosis the problem. However, plant loads vary greatly as various processes go on and off line and product changes occur. The varying loads hid trends of increasing vibration levels in the turbine and fading heat transfer efficiencies in the heat exchangers. By the time vibration levels and heat exchanger efficiencies hit alarm limits, the only course of action was to shut down the co-gen plant and rebuild the turbine. This resulted in a four-week rebuilding process costing U.S. Steel approximately $2,000,000 in parts, man-hours, and electric power purchases. To avoid this situation again, U.S. Steel evaluated the eCM system as a potential solution.

Project Results

The nearly new co-generation facility already had state-of-the-art control and protection systems in place to monitor turbine, extraction, generator, condenser and bearing functions, including pressures, valve positions, temperatures, current, voltages and vibrations (rms displacement). As such, it was a simple task to obtain data from the plant’s 62 sensors for analysis. The first data set, representing the problem period prior to the decision to shut down, spanned three time periods at five-minute intervals leading into the shutdown. The second set of data came from seven different days after the rebuilt generator was up and running.

SmartSignal’s engineers used proprietary algorithms to create an empirical model of normal operation. The supplied data was run through SmartSignal’s fault detection software to identify any subtle differences in performance by comparing actual signals to the estimated “normal” signals.

Sure enough, the eCM technology identified a problem on several key sensors on day one of the “problem” set. In this instance, had SmartSignal’s eCM software been installed, the enormous costs associated with turbine blade plating due to steam contamination—more than $2,000,000 in parts, man-hours, and electric power purchases—could have been mitigated, through advanced warning and a planned shutdown. Based on this performance, U.S. Steel decided to implement the eCM system.
Technical Results

The graphs shown here illustrate the eCM software’s ability to identify abnormal machine behavior long before critical equipment or process failure occurs. Figures 3 and 4 show the generator output and high-pressure steam flow from the USX co-gen plant. For each graph, the Y-axis represents the signal values and the X-axis represents time in hours. The actual parameter value is blue, the eCM estimated signal is green, and the “alerts” — time-slices that indicated problems — are red stars or black bars (constant alerts).

In the following examples, the eCM software started alerting on the earliest data set for key vibration (bearing) temperature and pressure signals. The HP/LP Crossover Pressure signal, Figure 5, and the Bearing 5B Vibration, Figure 6, demonstrate a state of near-constant alert starting with the initial data points.
While the actual signal levels are within accepted operating limits, the estimated signal level based on normal, post-maintenance operating conditions shows that the crossover pressure and bearing vibration levels are higher than they should be. Therefore, the alerts indicate a potential maintenance issue.

Based on the eCM system’s ability to provide advanced detection of abnormal sensor values within the maximum and minimum sensor threshold levels, U.S. Steel selected the software for installation, which has been operating successfully for more than one year.

V. Conclusion

SmartSignal’s patented eCM software has the unique capability to provide early warning of abnormal behavior that could lead to system failures for heavy capital equipment and processes. By understanding the complex relationships between correlated pressures, temperatures, flows, vibration, speeds, voltage, current, and other information, SmartSignal eCM provides earlier detection of abnormal equipment behavior compared to traditional threshold-based alarming. In the increasing competitive power generation business, this capability can provide operators with a significant advantage.

For the first time, companies can greatly reduce unplanned downtime and the potential for catastrophic failure. Instead, using the advanced functionality inherent in the eCM system, developing problems can be addressed as part of a coordinated and efficient condition-based maintenance strategy. As a result, power generators can significantly reduce the costs associated with downtime, maintenance, and diagnostic services. With a highly favorable cost/benefit ratio and a payback period typically less than one year, the eCM system is a viable solution to maximizing asset availability.
About SmartSignal

SmartSignal is a venture-backed, start-up software company based in Lisle, IL. The company closed second round financing in September 2001. The core technology, originally developed at Argonne National Laboratory, is the result of a multimillion-dollar U.S. Department of Energy (DOE) research effort. SmartSignal has thirty-one issued or licensed patents pending/owned and broad foreign coverage. SmartSignal recently won Control Engineering Magazine's “Editor's Choice” award as one of the top new products of 2000; and a Best of Sensors Expo new product “Gold Award.”

Contact Information

For more information on SmartSignal and its eCM products, contact us at 630-245-9000, or visit our web site at www.smartsignal.com.