Diagnostic health monitoring will reduce new technology O&M risk

By Irwin Stambler

Intelligent diagnostic systems help avoid excessive outages and costly component replacement by calling for corrective action before problems have time to become failures.

Many power generators are concerned with the financial risk of unpredictable maintenance costs associated with advanced gas turbines they are purchasing or have placed in service.

However, intelligence-based diagnostic systems are available to monitor those machines from startup on through shutdown to make sure that compressor, combustors, turbine and all related systems are operating within design limitations and expected performance parameters.

System checks start with sensor validation and then progress to performance and condition status. For example:

☐ **Sensors.** Check control and data collection sensor signals against norms to pre-test sensor reliability and signal validity of measured parameters.

☐ **Performance.** Evaluate actual versus expected performance for critical components such as compressor, combustion system and turbine.

☐ **Remaining life.** Compare operating condition against design norms to determine remaining life of hot section, rotor blades and vanes.

The US Dept. of Energy awarded an R&D contract to Electric Power Research Institute (EPRI) to head the development and design of a diagnostics software-based system for industrial gas turbine power plants, assisted by Impact Technologies, Boyce Engineering and Progress Energy.

Program status

Out of that development has come a suite of five modules that can be used separately or in combination to monitor the health of General Electric Fr 7EA, 7FA and Siemens 501FD machines.

Leonard Angello, manager of combustion turbine technology at EPRI says, "users are free to choose any one or all of the modules that best meet their needs for simple cycle and combined cycle power plants."

Modules are currently available for sensor validation and recovery (virtual sensors); performance degradation detection and fault diagnosis; startup and combustion system fault detection; hot section remaining lifes; vibration fault detection and diagnosis.

Ashville plant. Progress Energy peaking plant in Ashville, North Carolina is powered by two dual-fuel Fr 7FA units that served as in-service “test beds” for checking out development of the health management system.

Essentially, the EPRI team has developed a comprehensive array of intelligent tools for insight into the total health of simple cycle and combined cycle gas turbine systems, mechanically and thermodynamically.

Through proper utilization of these health management technologies, plant and engineering staff can make timely decisions regarding unit operation and maintenance practices.

Fuzzy logic

Major software concepts employed in developing the monitoring design include those based on neural network principles and fuzzy logic.

The sensor validation methodology, which relies on neural network techniques, is based on fuzzy logic provisions that continuously check the 'normal' bands (membership functions) associated with each sensor signal at current operating conditions.

When a signal goes outside these membership functions, while others remain within, an anomaly associated with those specific sensors is detected.

Finally, signal correlation and special digital filters are used to determine if even small levels of noise are present on a particular signal.

These approaches are carried out in parallel and then combined in a probabilistic data fusion process to determine the final confidence levels that a particular sensor has failed or has suspect operation.

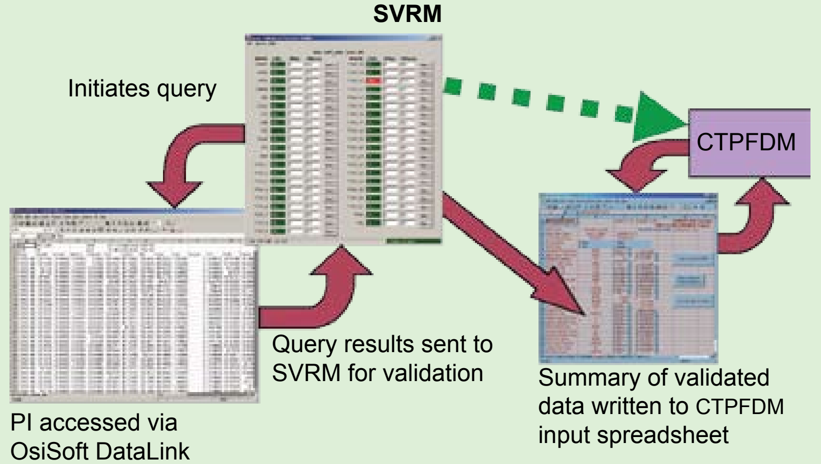
Validation

Operators can check that existing and specially installed sensors integrated into the health monitoring system modules are functional and generating appropriate value signals.

An enhanced diagnostic system fuses information from multiple sensors to provide more reliable readings. It also enables the system to estimate confidence and severity levels associated with a particular diagnosis.

Purpose of the validation module is to confirm the reliability of measured parameters. "When automated algorithms identify a performance or vibration fault, the diagnostic system must be confident that the faults are indeed occurring and are not the results of normal system transients or faulty sensors."

Module integration. The sensor validation and recovery module (SVRM) accesses on-line operating data and validates files for thermal performance calculations by the separate combustion turbine performance and fault diagnostic module (CTPFDM).



On the advice of utility service engineers, says Angello, the sensor validation module has been given both automated and manual modes of operation.

In the automated "batch data" mode, users set a timer to initiate a systems-wide analysis in the early hours of the morning (when network traffic is at its low point) on data from the previous day's operation.

In the manual mode, users selectively choose sensors and data for analysis over a specified time period under control of a user interface. Either way, the system generates graphs that will show raw data, sensor errors and recovered values.

A validation summary view plate displays findings of specific sensors for any detected errors, along with their average severity (see figure on next page).

Performance

The performance evaluation module (CTPFDM) builds on the EPRI sensor validation diagnostic software already developed for simple cycle gas turbine and combined cycle plants. (see figure above)

For compressor analysis, diagnostic capabilities have been enhanced to calculate both the actual and expected values of compressor efficiency and air flow for an indication of how well the compressor is operating.

This is important because most current technology gas turbines use compressor discharge air to cool the combustion liner, transition pieces and the first several rows of nozzles and blades in the expander section.

As a consequence, any evidence of increasing compressor fouling means hotter air is used to cool the hot section parts, which results in hotter metal temperatures and reduced life.

Internals

The remianing life module uses gas turbine firing temperature (first turbine rotor inlet temperature) and logs the amount of time the machine spends at a given firing temperature so that operators can track its service history.

For future module capabilities, EPRI wants to integrate on-line performance and fault diagnostic software with hot section life assessment software to provide an automatic evaluation of the remaining life of the hot section parts.

Another key factor in assessing overall engine performance, says Angello, is monitoring turbine or expander section performance. This is done by calculating actual against expected turbine section efficiency, and by trending changes over time.

Though there is no way (so far) of rapidly restoring turbine section efficiency, the extent and rate of decrease may require an earlier than scheduled major overhaul. Same is true of changes in compressor and combustor performance.

These performance values are displayed in what designers refer to as an "easy-to-read" table that enables users to see at a glance potential problems (or faults) in critical components while they are developing.

Analysis

While the analytic procedure for simple cycle gas turbines differs from that for combined cycle plants, both use standard thermodynamic formulas to monitor actual performance.

For predicted performance analysis, the modules apply correction curve data to calculate base load gas turbine performance; part-load performance and turbine section efficiencies are based on curves fitted to test data.

The modules employ diagnostic algorithms for common combustion turbine faults that use measured data and calculated performance faults (actual versus expected).

With that information in hand, the user then specifies threshold values for the faults to indicate "alert" and "action" status.

Angello notes that the performance monitoring and diagnostics software is Excel-based and runs under Windows 98/2000/XP operating systems.

Spreadsheets derived during its application permit a user to access and modify model parameters. Excel charts are used for trending key parameters in a technique that permits importing on-line or historical data.

Power plants

Performance diagnostic modules have been developed for simple cycle and combined cycle gas turbine analysis.

Although "expected performance" profiles are already built in for Fr 7EA, 7FA 501FD machines, Angello notes, users can create their own profiles for other gas turbine models if OEM correction curves are available.

The combined cycle module is a simple extension of the gas turbine unit. It contains an add-on spreadsheet program that can be used off-line through manual data entry, or on-line through automatic real-time data input using links to a data historian system.

Like the simple cycle module, the combined cycle analysis also has Excel and Windows capabilities. In addition to monitoring combined cycle equipment, it can simultaneously monitor multiple gas turbines.

The combined cycle module monitors both 1x1 gas turbine and steam turbine configurations and 2 x 1 combined cycle configurations (two gas turbines and one steam turbine).

For 2 x 1 layouts, it's emphasized, both gas turbines must be identical. The module is capable of performing those studies for full base load output and part-load operation.

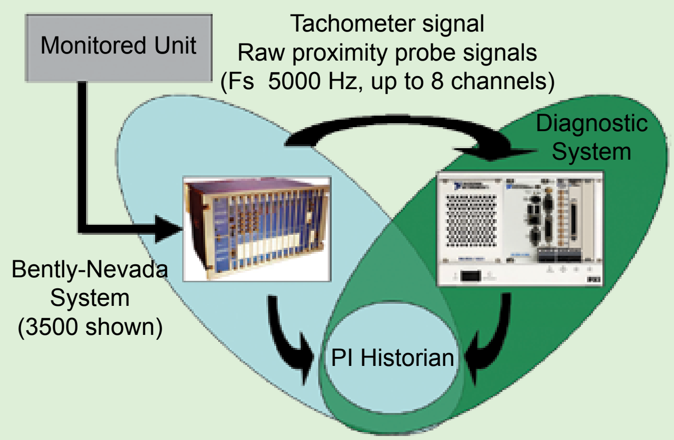
Faults

Project members point to four major plant components that could impact combined cycle performance: the combustion turbine (CT), heat recovery steam generator (HRSG), steam turbine (ST), condenser and cooling water system (COND).

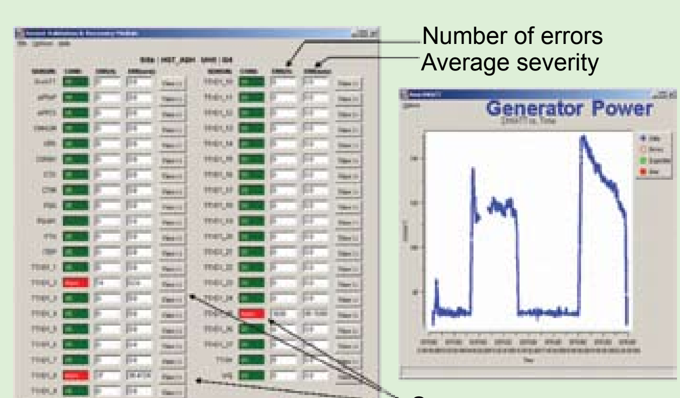
Degradation in the performance of any of these components will cause a decrease in steam turbine output. This means that a drop in expected output may not indicate a problem with the physical condition of the steam turbine. It may be caused by other factors.

The performance monitoring and diagnostics module employs a technique developed to isolate the cause that is based on applying a series of correction curves to account for changes in total plant output, heat

Vibration diagnostics. The vibration fault diagnostics system (VFDS) is a stand-alone autonomous device consisting of a computer running the developed software and data acquisition cards collecting the data. Configuration shown here allows communicating with the Bently-Nevada system and PI Historian.



Sensor validation. The sensor validation and recovery module (SVRM) screen at the right shows the number of errors and the average error severity. Module has two operating modes: automatic analysis at regular intervals and manual analysis of selected data.



rate, and steam turbine exhaust flow.

For some analyses, where correction curves like those provided by OEMs are not available, "the plant owner (or others) could derive them by creating a model of the plant using combined cycle simulation software and executing a series of runs to simulate the impact of changes in ambient conditions."

Start-up diagnostics

A key need for any system is achieving reliable, repeatable start-up operations.

To cover this part of system operation, the module suite offers users a Start-Up Diagnostics Module (SUDM) which contains a computer program that facilitates the comparison of trends from one gas turbine to another.

Start trends can be compared to a different start-up on the same gas turbine being monitored or against a start-up on a different engine. Trends can be plotted against time or against other important turbine parameters such as rotor speed or fuel flow.

The system maintains a database of various start-up performances so that if start-up problems do occur, a user can compare the event to one in which a successful start-up was achieved.

EPRI developed the SUDM to be a simple tool that can assist gas turbine engineers in diagnosing start-up related problems.

Basic premise is that you can identify at least one "good" start which can serve as the gold standard, officially designated as a "reference start," by which all other starts are judged.

Fault detection

The module is designed to provide insight both into start-up equipment shortcomings and related functions that can cause start-up malfunction.

For instance, if data show the system takes too long to reach purge speed, it may indicate the starter motor on the turbine has degraded and needs maintenance attention.

In related possibilities, such as where a failure to light-off occurs, the project team cites at least two scenarios leading to that problem: the first is a failure of the flame eye to detect an actual flame, while the second "is an actual failure to light-off."

In that case, say the researchers, the difference between the two scenarios can easily be determined by examining an overlay chart of the trends of the fuel valve position and exhaust gas temperature versus time.

If temperature ramps up quickly in the analyzed start, as it does in the reference start, then the problem lies in the flame detector. On the other hand, if the exhaust gas temperature doe not ramp up at all or is delayed, the problem is somewhere else.

This is an indication of a true failure to light-off. The root cause of the problem could be the igniter or the fuel nozzles or the fuel supply system.

Remaining life

The next module in the series, Remaining Life Module (RLM), comprises a spreadsheet based software tool that uses blade life algorithms to calculate the remaining life of combustion turbine hot section components.

The analysis begins by using an OEM remaining life formulation technique built into the RLM module. This is used to calculate remaining life for hot section components (hours and starts-based).

In addition, EPRI blade life algorithm software is used to carry out "batch wise" analysis at the end of each gas turbine start-stop cycle.

Remaining life analysis can be carried out in two different modes: initialization and run-by-run.

In the initialization mode, the user manually enters the current operating history of an engine in terms of fired hours, number of starts, number of trips, etc.

Where necessary, the user will input estimates to characterize the nature of the operating history such as percentage of total hours operated in part load, base load and peak load operation.

OEM-based calculations are carried out to define the current equivalent (factored) run hours and starts for the hot section, the rotor, and the combustor.

This then forms the basis for future calculations on a run-by-run basis using both the OEM algorithms and the EPRI algorithms.

Vibration faults

The final component of the new diagnostic monitoring suite is the Vibration Fault Diagnosis System (VFDS) that enables users to detect incipient mechanical fault conditions and plan appropriate maintenance actions.

The VFDS module "uses high bandwidth vibration data to extract low bandwidth feature data" which are used by diagnostic reasoning to identify actionable failure modes.

Time domain features include maximum amplitude, RMS, crest factor, kurtosis, peak to peak, shaft orbits, and baseline comparison. Identifiable faults include unbalance, misalignment and rubs.

The module has an analysis component that extracts features, and a display component that presents those extracted features in an intuitive manner to identify actionable failure modes.

Syngas operation

With the growing emphasis on gasification technology, the question arises about the EPRI/DOE concept's relevancy for syngas fired facilities.

The overall concept serves as a starting point for syngas health monitoring, says Angello, but modules need to be focused on coal-syngas operations.

Taking sensor validation and data recovery as an example, he says the current equipment is generically applicable to IGCC, but its extension to the gasification train use would require operating data sets for neural net training. ■

Footnote. EPRI is looking to adapt these modules for different gas turbine models worldwide. Interested parties should contact Leonard Angello at EPRI by phone at (650) 855-7939 or by e-mail to: Langello@epri.com