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# INTEGRATED PERFORMANCE MONITORING FOR ASSET OPTIMIZATION

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## ABSTRACT:

Utilities need technology that is able to accurately estimate the performance and health of the power plant, and assess and optimize the plant's current generation position for the purposes of generating accurate market pricing and operating cash-flows forecasts. The technology must be able to provide the utility with the required information to support robust power trading and risk management strategies, and ultimately increase the profitability of the business.

This paper will address the utilization of integrated performance monitoring technologies to improve asset optimization at power generating facilities and report on the health of the power plant. Additionally, this paper will provide insight to some specific advanced monitoring technologies, how integration of the technologies can provide increased value for plant operations, and address the impact on key performance indicators that almost all utilities track, formally or informally.

Case studies related to the technical information presented will also be presented.

## INTRODUCTION

**<u>Today's Power Plant Business Needs</u>** – The major drivers for electrical power generating utilities today consist of the following:

- Increasing competition to be the lowest cost producer
  - Minimizing fuel costs (+250% annual price increase in 2008 and fuel represents 77-93% of generation costs)
  - Minimizing operating and maintenance costs
- Improved availability and capacity factors (i.e., increased reliability)
- Emission reduction consistent with increasing regulations for clean air standards--green-house gas initiatives, such as $SO_2$, NOx, CO and $CO_2$
  - (e.g., Regional Greenhouse Gas Initiative [RGGI])
- Maximizing staff productivity--doing more with less
- Integrated technologies providing reliable information for efficient and productive actions driving strong balance sheets (lowest cost generation with accurate cash flow forecasts, enabling robust trading and risk management strategies to increase profitability)

Bottom Line: Utilities need advanced technology representing best practices in today's power plant operations that are able to:

a. Reliably and accurately measure the current performance and health of the power plant and its equipment
b. Readily provide reliable information for efficient and cost-effective actions to control and optimize the plant's current generating status
c. Access the heterogeneous and disparate mountains of data for a holistic and automated solution set with the purpose of optimizing the unit's competitive position

The technology must be able to provide the operating and management team with the required information to address the major plant business needs that include improved equipment reliability, heat rate, capacity factors, staffing levels, maintenance costs, and emission reductions.

This is most effectively accomplished with integrated condition-based monitoring systems incorporating condition-based maintenance (CBM) and applied predictive maintenance (PdM) technologies using advanced monitoring solutions.

This paper will show how integrated, condition-based monitoring systems can provide the sustaining measurable benefits to meet the current plant business needs noted above. An overview of condition-based monitoring systems, i.e., CBM concepts that include PdM practices, advanced thermal performance monitoring and analysis, advanced pattern recognition (APR), data integration and automated condition assessments will be presented.

CBM, a form of proactive maintenance, is defined as maintenance initiated on the basis of a piece of equipment's condition. Physical properties, such as vibration, temperature, oil condition, and ultrasonic sound output, are monitored on a periodic or continuous basis for indications of degradation. CBM is an alternative to failure-based maintenance initiated when assets break down, and time-based maintenance initiated on a schedule basis.

True CBM brings reliability-centered maintenance and predictive maintenance practices into real-time, so that maintenance personnel understand when a component or asset is going to fail based upon the monitored information. For example, detailed condition diagnostics can detect changes in vibration long before traditional operating or historian-based systems would recognize the change as a machine defect. The anomaly is assessed to determine whether a maintenance activity is required, and prognostics can predict when a failure can occur as a result of the fault condition.

CBM allows the workforce to concentrate on productive, timely maintenance activities. Accurate diagnoses and timely maintenance help avoid lengthy shutdowns, secondary failures, and potentially unnecessary maintenance activities. With CBM, that information can then be passed to the enterprise asset management solution where appropriate maintenance and/or problem mitigation activities can be pursued which provides a more efficient maintenance approach with a potentially significant positive financial impact.

CBM relies on effective use of PdM technologies such as vibration testing, electrical analysis, lube-oil analysis, thermography, and ultrasonics. When utilized in a consistently applied program or process, the value gained in equipment condition understanding can be great. These periodically-applied technologies form the fundamental basis for an effective CBM program.

## ADVANCED CONDITION-BASED MONITORING SOLUTIONS CHARACTERISTICS

In order to control a performance metric (such as heat rate), the monitoring system must have an accurate measurement of the parameter and have an accurate set-point for controlling the indices of performance that drives the specific plant business need.

The monitoring system must provide the operator and engineer responsible for the plant system with improved technology upon which to manage the operation and performance optimization of the plant. In so doing, the monitoring system will provide automated condition assessments given a set of heterogeneous data describing a plant system or component performance condition. The assessment must not be based on a single instrument variable, but on a set of variables that best describe an anomaly or condition status most probably representing the root cause of the performance degradation.

Performance indices are proposed as key performance indicators (KPIs) that drive the plant needs for equipment reliability, heat rate, power output, capacity factors (outage durations, plant availability, EFORs), staffing levels, maintenance costs, and emission metrics.

### Key Performance Indicators - Measurement and Control of Plant Assets

The following specific KPIs are listed as the primary performance parameters to be measured and controlled that have the biggest impact on the optimization of the plant's operation and business success.

- Equipment reliability is the major contributor affecting several of a plant's financial performance metrics, i.e., availability, maintenance costs, capacity factor, outage scope and duration, and staffing levels. With the aging of plant assets, reliability has become increasingly more important and can be represented by the following KPIs:
  - Individual equipment reliability (%)
  - Availability (%)
  - Capacity (%)
  - EFOR (%)
  - Equipment maintenance costs ($)
- Heat rate defines the efficiency of the power plant to convert fuel into electrical energy. Thus a decrease in a unit's heat rate will result in decreased fuel costs and gain in power output, as well as improved Greenhouse Gas (GHG) emissions.
  - Heat Rate (BTU/kWh)
  - Fuel costs ($)
  - Power output (MW)
  - GHG (Tons of CO, $CO_2$, NOx & SOx)
- Doing more with less requires evaluating the staff requirements to maintain the plant at peak conditions. Thus optimizing staff needs results in reduced operational costs both at the plant and corporate level.
  - Plant staff employed to operate a unit of generation (#)
  - Resource Cost ($)

The key element of asset optimization is to implement more efficient operating practices and technologies that reduce the kWh plant operating costs that are measured by the noted KPIs. Applying advanced real-time monitoring technologies is a means to positively affect these key KPIs.

## ADVANCED MONITORING TECHNOLOGIES

Several monitoring and diagnostic solutions are available that allow optimization of the plant KPIs of interest. Advanced monitoring and assessment of power plant equipment performance requires an in-depth understanding of the equipment and systems with their associated mechanisms of performance and their attendant process data and inter-relationships. Transforming process data into measurable business results requires both the acquisition and validation of performance data along with detail mathematical modeling and the interpretation of the process data. Data interpretation has been shown through Information Technology (IT) research to represent 70 percent of the business value in monitoring and diagnostics. The data interpretation component requires plant engineering expertise, specific process knowledge of the operations, and the analysis tools to automate and assist in the diagnostics and examination of the key performance information.

### Thermal Performance Analysis and Monitoring

Off-line thermal analysis and on-line performance monitoring require 1st Principles thermodynamic modeling of the power plant process cycle.

**Off-Line Thermal Performance Analysis**--The off-line thermal analysis provides insight into the detailed performance of the thermal process and utilizes a steady state, energy balance software program that calculates the performance of an electric generating plant's thermal process cycle. A plant analysis model is obtained by the development of a thermal plant schematic that mimics the actual plant component and pipe connections. The plant schematic is developed using a component library that accurately models the component's thermal attributes and hence the entire process cycle. The resultant model can be used for the following:

- Design analyses of an integrated turbine and boiler cycle or individual components
- Analyze boundary condition changes
- Quantify controllable parameter changes
- Automated test data reduction for usable form and studies
- Perform "what-if" studies for predictive evaluation, including evaluation of new or modified plant configuration and process modifications and incremental heat rate reduction studies
- Determining the accurate, best achievable target values for on-line performance monitoring
- Perform plant degradation studies and detailed analysis of boilers and turbine cycles

**On-Line Thermal Performance Monitoring**--On-line thermal performance monitoring and diagnostic applications also require the 1st Principles modeling that allows plant staff to measure, control, and improve plant performance by reducing heat rate and fuel costs, increasing power output, and reducing operating and maintenance costs. On-line monitoring is used by both operators and engineers.

The on-line thermal performance monitoring and diagnostic application is a real-time, data base management, performance monitoring, testing, and analysis system. The system is designed to use plant instrumentation to detect performance trends and determine their associated costs. APR technology may be incorporated to validate data inputs, allowing the system to detect instrument fault, drift, and calibration errors earlier than conventional data validation.

The on-line monitoring system must be capable of detecting performance abnormalities at the system, individual component, or instrument level. The on-line system may be configured to present these abnormalities as deviations from their desired conditions, with the deviations expressed typically in heat rate penalty or megawatt effects with their attendant costs.

Distributing the on-line information throughout the plant and utility on computer networks for graphical display and further analysis is essential for making thermal performance improvement part of everyone's job. More utilities today are implementing remote monitoring and diagnostic centers that are staffed with senior engineering, operations and maintenance staff to support plant staff with increased visibility into plant performance and diagnostics.

Operations staff (who are the first line of defense for heat-rate improvement) can use the on-line monitoring system to monitor deviations of key operating parameters from an optimum point, to predict unit response to proposed operational changes, and to increase operator awareness of the effect operating control and maintenance decisions have on plant performance.

- Controllable Losses displays provide guidance to plant operators by graphically presenting target values, deviations from targets, and costs for those deviations for operator controllable parameters.
- Operators are provided with on-line plant performance information to assess current plant operations to detect and correct problems, such as condenser fouling and boiler fouling.

Maintenance staff can use the on-line monitoring system to determine when maintenance is cost-effective, to verify the effectiveness of maintenance actions, and to provide economic justification for proposed maintenance actions.

Engineers can use the on-line monitoring system to optimize plant heat rate and component performance and to determine the impact of proposed changes on plant performance and economics.

- Performance data is available to validate plant equipment vendor claims.
- Trending of critical plant component performance allows users to monitor component degradation and optimize their maintenance efforts to minimize unscheduled downtime.
- By utilizing an off-line thermal analysis application link engineers can establish best achievable target values, as well as perform diagnostic "what-if" analysis of performance issues.

Management can use the on-line monitoring system to obtain instantaneous and cumulative costs of performance changes and to help ensure the optimum economic dispatch of the monitored units.

On-line thermal performance monitoring integrated with off-line analysis will allow plant staff to reduce fuel costs ($), increase power output (Megawatt - MW) and minimize GHG (tons). Additionally maintenance of equipment and systems will be reduced ($).

## Advanced Pattern Recognition

APR is defined as a real-time, continuous, on-line monitoring application that utilizes existing data signals available thru installed Distributed Control System (DCS) systems, data historians, and other monitoring systems. The signals available from these systems feed the APR application for the intention of in-depth review of normal and abnormal operating conditions.

APR functions by discerning data patterns associated with normal system operation and comparing the learned characteristics with subsequent monitored system behavior. APR performs its analysis by learning the patterns associated with normal system operation from archived numeric data values, monitoring the current numeric data from continued process operation, identifying discrepancies between learned patterns and the monitored data, and presenting results graphically. The value for each signal in the monitored state is compared to its corresponding predicted value to identify signal failure, calibration drift, component performance changes, and condition degradation.

Adding additional modeling and signal handling capabilities, the APR application is utilized for predictive monitoring of a system and/or equipment. The models created from various related signals are routinely evaluated (typically every 2-5 minutes) for pattern changes and digressing symptoms. These results provide more in-depth insight as to a developing condition and fault assessment at a much earlier stage than traditional monitoring systems.

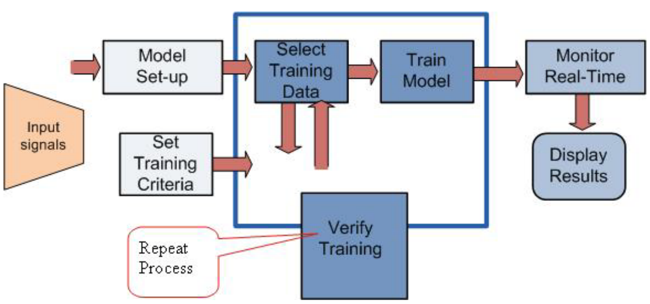


**FIGURE 1 - ADVANCED PATTERN RECOGNITION INFORMATION PROCESSING**

Model-result accuracy is enhanced through an analysis based upon operating state conditions, as opposed to an assessment based upon one common operating condition. The APR tool goes beyond other traditional condition monitoring applications. It provides enhanced features with additional fault identification, condition understanding, and problem mitigation capabilities.

The application utilizes uniquely configured models that focus on specific systems and/or equipment types for which the following outputs are available:

- Overall model condition status
- Individual signal condition status
- Data/signal details related to model condition change
- Data trends for time series review and event correlation

The APR technology offers an in-depth real-time equipment advanced condition monitoring solution for affecting equipment reliability. APR affords unique capabilities that differentiate this application from other condition-based monitoring applications. They include:

- Models configurable upon multiple operating states
- Selectable data processing per model
- Signal displays of individual and/or collective model results
- Ability to handle large numbers of models without sacrificing processing capability
- Seamless integration with on-line thermal performance applications
- Imbedded technology for signal validation capability
- Condition assessment and predictive information

**Data Integration -** Data integration of both thermal performance and APR technologies into a combined advanced condition-based monitoring system has seen limited application throughout the electric power generation industry. Only recently have some utilities appreciated the value of integrating these and other available technologies as a more informative approach to CBM. Additionally, integration with PdM program activities with these real-time condition applications provides an even more thorough approach. More forward thinking and progressive utilities have and are establishing best practices that include advanced condition-based monitoring systems with PdM, with CBM, with risk analysis and financial review as noted above.

There are advantages in the integration of not only these data sets but all the available data that includes both real-time process data as well as off-line information. Comprehensive condition-based monitoring requires the use of all possible data to best evaluate the condition and health of plant equipment. Condition-based applications that use all the information available will provide the most reliable information for subsequent action in the optimization of the plant KPIs that further supports the financial interest.

The actions resulting from integrated condition-based systems' output information must be efficient and cost-effective in terms of attaining and maintaining the best achievable performance as measured by the power plant KPIs. It is imperative that the reference KPIs be established by prior reference validation using high-fidelity models representing the specific equipment configuration as well as the plant mode of operation. The models must be unit-specific and go beyond the use of standard original equipment manufacturer (OEM) curves that are based on one size fits all.

Evaluating and interpreting all of the plant data that is available in data historians, DCSs, operator rounds, and other plant databases is monumental and requires advanced computational technology. Fortunately, there are advanced condition-based applications today that integrate all available plant data and provide results that when evaluated as a combined set of data provide insight into the equipment condition and potential root cause assessments.

Characteristics of integrated condition based applications include computer models as well as best practices for interpreting the mountains of data existing in a variety of formats. These databases may be process information, e.g., from temperatures, pressures and flow rates to thermography, vibration and lube-oil databases. Off-line databases such as operator rounds and plant enterprise resource project (ERP) data are equally important in establishing the health of plant operations and interpreting the behavior of plant equipment and performing predictive analysis.

Integrated condition-based technology must include the 1st Principle models that establish the reference target for accurate, best achievable metrics for both the thermal monitoring as well as the reference for APR applications.

**TABLE 1 - INTEGRATED CONDITION-BASED MONITORING APPLICATIONS BENEFITS**

| Condition-Based Application | Function | Database Attributes | Integration Role & Benefit |
|---|---|---|---|
| Off-Line Thermal Performance Analysis | Provide granular assessment of system and component performance | Off-line with link to On-Line thermal performance monitoring application | Provide accurate, best achievable thermal performance metrics for other monitoring applications |
| On-Line Thermal Performance Monitoring | Provide real-time monitoring of process conditions | Plant data historian and On-Line Application database | Provide real-time assessment of heat rate, power level, controllable losses and equipment thermal efficiencies |
| APR Monitoring | Provide real-time monitoring and prediction of key process parameters | Plant data historian and APR Application database | Provide reliable and predictive information on critical plant equipment metrics |
| Rules Engine | Provide automated interpretation of equipment condition | Plant data historian and Rules Engine Application database | Automated knowledge assembler using integrated database information for directing meaningful action |
| Lube-Oil | Provide information on lube-oil condition | Plant Lube-Oil database | Provide lube-oil information |
| Thermography | Provide information on component thermal state | Plant Thermography database | Provide thermography information |
| Vibration | Provide real-time information on rotating equipment | Plant data historian and On-Line Vibration Application database | Provide vibration information |
| Ultrasonics | Provide high frequency sound information | Application database | Provide insight to sound-borne problems |
| Operator Rounds | Provide information on non-instrumented and qualitative operating information | Off-line “flat-file” information | Provide process information not instrumented or included in the data historian or other databases |
| Risk Analysis | Provides mechanism for consistent risk assessment | Self-contained database | Utilizes all available data to support the decision process based on risk probability and magnitude |
| Computerized Maintenance Management System (CMMS) | Provide maintenance management information | CMMS database | Provide work orders, equipment reliability data, master equipment list, etc. |
| Financial Modeling | Provide financial data for management control | ERP database | Provide financial data being tracked by KPIs |
| Supply Chain Modeling | Provide procurement and warehouse information | ERP database | Provide purchasing and warehouse data for maintenance planning |

## Automated Condition Assessments

An automated condition assessment application (rules engine) that incorporates pre-configured and user-developable rules is essential for providing insight as to what the APR and on-line applications or other application results indicate. This automated assessment is performed when an exception condition (alarm criteria are exceeded) is identified in the on-line monitoring application. The rules and calculations provide condition assessments based on actual monitored signals as related to the equipment component or system being assessed. The rules engine can also incorporate information from other analytical applications and integrate them with the on-line thermal monitoring and APR databases.

The rules engine affords its users the following advantages:

- Collects advanced decision-making logic and analysis with data sets larger than normally used effectively by operators and engineers or management who already have full work loads
- Supports a dynamic data model (i.e., being able to classify failure modes having different plant operating modes

- Simplifies applications results interpretation by translating data to text messages of actual assessment information.
- "Logic tree" decision tree analysis capability for both diagnostic purposes as well as understanding anomaly findings
- Facilitates knowledge transfer to centralized repositories and technical knowledge capture to help combat issues due to the loss of key specialists, decision makers, managers, and highly creative employees

When combined with other real-time monitoring applications, APR, on-line monitoring, condition-based monitoring, and periodic APR monitoring systems, a very thorough condition assessment can be obtained with clear textual messages and detailed drill down insight. The rules engine increases the capabilities and effectiveness of advanced real-time monitoring applications.

**Benefits of Integrated and Automated Conditioned-Based Monitoring System -** The following are benefits of advanced integrated, condition-based monitoring systems:

- Ability to use more than one database for evaluation
- Accurate, best achievable performance parameters for on-line, real-time monitoring
- Knowledge base incorporating prior histories of abnormal operation for reference in diagnostics using all possible database information
- Prioritizing maintenance activities for optimization with PdM planning and outage schedules and scope
- Improved equipment reliability resulting from more thorough real-time data processing
- Reduced maintenance staff affected by improved data for PdM and outage scheduling
- Improved availability by increased equipment reliability
- Improved knowledge of equipment (Mean Time Between Failure (MTBF) allowing focusing maintenance budgets on the right equipment
- Prioritizing maintenance on high risk equipment as established by integrated APR and thermal performance data
- Minimizing false alarms and improving operator and maintenance staff utilization
- Improved risk assessments of equipment condition given more complete information
- Improved resource effectiveness through consistent advanced analytical tools
- Demonstrated ROI from industry case studies

The risks of integrated and automated condition-based monitoring systems include:

- Investment without ROI
- Increased applied resources for effective use, i.e. "care and feeding"
- Inaccurate information and data
- Non-use, i.e. proverbial "sits on shelf"
- Complexity causing increased time to learn, use, and obtain usable results
- Application limitations preventing effective data information integration

## CASE STUDIES

The electric power industry has reported that advanced condition-based technology has provided minimally a >3:1 return on investment within the first two years of implementation. Recent case histories have indicated the following:

- Cost avoidance in several APR prediction events have resulted in more than $100,000 savings.
- A Scientech client identified eight APR findings with conservative cost savings greater than $190,000 in the first year.
- Detecting improper indication of a valve position resulting in more than $300,000 cost avoidance annually.
- On-line thermal performance monitoring has resulted in the following:
  - Two to four percent improvement in heat rate at individual plants
  - Over $150,000 savings by detecting improperly configured equipment in the steam cycle
  - Over $460,000 increase in revenues resulting from increased electrical power output.

The latest EPRI Fleet-Wide Monitoring Interest Group (FWMIG) meeting reported the following experience:

- More fossil utilities are applying APR technology and realizing a business case for the investment.
- APR is the primary advanced monitoring technology for fleet-wide monitoring.
- Advanced technology does require an investment with dedicated staffing support as well as software and systems infrastructure.
- Integrated APR with thermal performance monitoring is the direction many FWMIG members are proceeding.
- APR is a key technology for identifying sensor problems.

Integrated condition-based technology financial results are continuing to be documented as the implementation of this approach grows. Investment and operational costs vary depending on the degree of implementation at a specific utility. However, payback for an integrated monitoring project is less than one year in most instances.

## CONCLUSIONS

The information generated within an integrated performance and condition-monitoring system, coupled with condition assessment information, can be used to design a more precise and realistic operating scenario and maintenance management strategy for the power plant. Such a system can also provide support to allocate resources more effectively. Ultimately, the utility management can more confidently make use of the real key performance parameters of its plant assets and assess risks to increase their business profitability and reduce operating costs.

- There is a business case for integrated performance monitoring systems using existing technology.
- Industry groups have noted that integrated thermal performance monitoring and condition monitoring systems are being pursued by many utilities and provide significant payback.
- Scientech is a supplier that has integrated performance monitoring applications.

Mitigating failures require application of best practices as well as using advanced technologies to evaluate and predict performance and incipient failures. Some performance degradation and condition problems are allowable and have minimum impact on a plant's financial performance or safety. Others may be catastrophic to personnel safety, environment, and financial performance. Hence, it is important to perform a risk assessment of potential failures that must be mitigated because of the risk probability and the magnitude of the consequence. Using advanced condition-based monitoring systems, the degree of risk is reduced and acceptable actions can be taken in advance of the event that will mitigate a major impact.

In the current economic conditions, equipment catastrophic events are even more important to minimize and/or eliminate. Many companies have realized the importance of mitigating risk of catastrophic failure and have implemented these types of advanced technologies, however, may have not integrated them for more in-depth interpretation of the available plant data.

These technologies, when integrated, allow management to have improved control of their destiny and provide intelligence into the KPIs driving their business success, including PdM and outage planning. Companies incorporating the best practices noted herein may take advantage of advanced technology for reliability analysis, preventative maintenance, and training that improves asset management and optimization. No one wants a catastrophic event that bankrupts the plant operations because of the slim margins that are being operated on due to economic conditions. There are state-of-the-art advanced, integrated technologies with a business case to avert this possibility.