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Charting the Future

Predictive maintenance ensures dynamic NO_x and heat rate optimization

By Don Labbe, Bill Hocking, Bill Ray, Jon Anderson, and Pat Klepper

Electric power producer, Entergy, operates two 800 MW units at their White Bluff Station in Redfield, Ark. Reducing NO_x emissions was a main concern and led to a major project to retrofit the units with distributed control systems for the boiler and auxiliary controls. This retrofit would also extract heat rate benefits while trimming the frequency and duration of high steam temperatures. The results enhanced unit reliability, improved thermal performance, and provided continuous dispatch capability.

Entergy White Bluff Units 1 & 2 are split furnace 800 MW PRB coal-fired drum units constructed in the early 1980s. The units have tangentially fired-drum type dual-furnace boilers with eight coal mills supplying coal from the Powder River Basin mine in Wyoming. Design turbine throttle conditions are 1000°F/1000°F and 2400 psig. The distribution of energy between the superheat and reheat sections of the boiler as the unit varies in load promotes a challenging steam temperature control problem.

We retrofitted the plants with a modern distributed control system (DCS) and achieved significant control and ramp rate improvement. To further improve unit heat rate and lower NO_x emissions while enhancing ramp rate capability, we required a dynamic optimization approach to address unit limitations, such as O₂ and steam temperature control during unit ramping, coal mill changes, and soot blowing. We integrated with the DCS a dynamic optimization system combining model predictive control and neural nets operating at high execution rates.

The comparison of results with a prior project illustrates the contributions of a smart soot blow system to heat-rate performance. Such a system was added to the overall optimization system this summer and achieved an additional 0.1 to 0.2% in heat rate benefits.

The system provides tighter regulation of the critical ramping variables, thus allowing reduction of operator margin for heat-rate improvements approaching 1% and NO_x reductions in excess of 15%. Through the dynamic multi-variable control structure, we can maintain these improvements during dispatch operation, which is nearly continuous for this unit. The system provides the added benefit of lower peak steam temperatures while lowering the standard deviation. This enhances the ramp rate capability while improving heat rate.

Dynamic optimization requirements

Since NO_x reduction was a prime project objective, prior to initiating the optimization project at the station, we retrofitted 152 drives for the air dampers. These pneumatic drives with internal I/P provided independent control of each air damper, resulting in increased flexibility in adjusting the air distribution. We minimized the cost impact for these additions by using a fieldbus interface to the DCS.

The heat rate parameters available to the optimization system included the prime control variables of superheat and reheat steam temperatures, superheat and reheat spray flow, excess O₂, and air heater exit gas temperature. We wanted to drive these parameters towards their optimum values by reducing variability and maintaining adequate margin to alarm conditions.

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The station had assigned a significant performance penalty to high steam temperature conditions due to past experiences with boiler tube failures and issues with high temperature steam components. A paramount objective was to minimize the frequency and duration of steam temperatures above the 1010°F threshold, designated a plant operational excellence limit. Due to these temperature issues, the dispatch rate sometimes went below 20 MW/min. Another objective was to sustain the dispatch rate of 20 MW/min over the load range and extend the target rate to 25 MW/min in the near future.

Our challenge intensified with the recent operating mode transition to wide load swings. A shortage in coal supply had forced the unit into a coal conservation mode. During daily off-peak power periods, the unit loads fell below 50%, and then it rose to near full load during peak periods. The units required quick dispatch between load demands and operated in near continuous dispatch mode at all loads.

This mode of operation amplified the difficulties of steam temperature control. Drum units have a characteristic issue associated with the distribution of energy between superheat and reheat sections as a function of load. The ability to provide sufficient reheat steam temperature at low load conditions requires a large reheat surface area due to the low cold reheat steam temperature. As load increases, the cold reheat steam temperature increases linearly, thereby increasing the hot reheat temperature capability. This can result in excessive reheat sprays at high load to maintain reheat set point. On the flip side, the proportion of energy absorbed by the superheat sections drops as load increases, tending to lower superheat potential. When burner tilts or another direct energy distribution mechanism is provided, it typically functions to strike a balance between superheat temperatures controlled by sprays and reheat temperatures controlled by sprays.

For these boilers, the ratio of superheat to reheat absorption resulted in low reheat temperatures at low load and low superheat temperatures at high load with high reheat spray flow. This characteristic, combined with the dispatch mode of operation, challenged the regulatory steam temperature control system. During dispatch, the steam temperatures would quickly accelerate from a low temperature condition (zero spray) through set point to a high steam temperature as the spray system responded. Similarly, the steam temperatures would drive down with no control as sprays shut off. These characteristics made this unit a prime candidate for a model predictive approach that can anticipate increasing steam temperature and take appropriate control steps in advance and thereby prevent high peaks without excessive spray at lower steam temperatures.

We were to accomplish the commissioning and subsequent operation with the unit operating in dispatch mode with load cycles from near minimum load to near maximum several times per day.

The combination of the load variations and boiler thermal characteristics challenged the ability of the DCS to catch peak superheat temperatures and hold set point.

Steam temperature control response trends present the load, A/B side superheat temperatures and set point, and A/B side reheat temperatures and set point for one week. At low loads the superheat and reheat set points lower to provide temperature control capability. At high loads, reheat temperatures easily make set point, but superheat temperatures fall off due to boiler characteristics.

The high temperature spikes in superheat temperature typically correspond to steep load ramps and usually follow operation with temperatures below set point. Load ramps with mill changes result in over-firing scenarios that require precise control of superheat sprays from zero to very high values. The peak temperatures were 1028/1021°F with standard deviations of 16.5/16.6°F. The superheat temperature is above the threshold of 1010°F approximately 0.51% of the period.

Since superheat temperature translates into reheat temperature in a very short time, the reheat control loop also has a difficult task. The peak temperatures were 1028/1027°F with standard deviations of 35.8/34.3°F. The reheat temperature is above the threshold of 1010°F about 5.4% of the period.

Dynamic optimization methodology

The optimization solution applies a neural net/model predictive control combo.

This system combines model predictive control with its dynamic process models and neural nets with its quasi steady-state gain derivations to provide control and optimization for a dispatching unit.

Model predictive control models are well suited for processes like steam temperature control and O_2 control, where the variables are related by thermodynamic, chemical, or control relationships. Final steam temperature is related to superheat spray with a particular gain based on steam properties and a time response based on metal mass and steam flow.

Neural networks are well suited for processes like NO_x , where the relationship to dampers is dependent on other dampers. The air dampers form a parallel network and are interactive, suggesting a neural network approach.

Neural networks can be dynamic, but this increases the computational overhead dramatically, resulting in a compromise in the size of the solution or the execution interval. Also, neural nets pose no advantage to processes with known physical relationships and can in fact reduce the accuracy of response for such systems. This arises from the statistical characteristics of neural net learning from noisy plant data.

The approach with this system is to combine the two methods and apply each to its strengths: model predictive control to fast dynamic manipulation, and neural nets to variables like NO_x .

The control variables (1, 2, 3, 4, and 5) have model predictive relationships with manipulated variables (A, B, C, and D). Neural net models appear between a subset of these variables and another manipulated variable (E). The combination features models from both the model predictive control and the neural net.

Excess air

Challenges in lowering excess air increase dramatically with dispatch operation. Fuel and air swings due to load changes, and mill starts/stops result in large variability of the furnace exit O_2 . Excessively low O_2 is a great concern to operations. Combine that concern with low O_2 , and the large variability in the O_2 typically results in a significant operational margin in the O_2 control.

By applying a model predictive approach to the control of O_2 , the variability below the low constraint reduces through aggressive constraint control. With less variability, you can reduce the O_2 operating margin with no increase in operational alarms. This results in a lower net O_2 for improved heat rate and lower NO_x .

Smart soot blow potential

One way to address the energy distribution issue is to apply soot blow sequencing in a more effective manner. However, due to budget constraints, we delayed the installation of a smart soot blow system and completed it this summer. Through effective soot blow techniques, a more favorable energy distribution provides increased superheat temperature, lower reheat spray flow, and lower air heater exit gas temperature with preliminary estimates of 0.1 to 0.2% heat rate improvement at the high load condition.

These improvements in steam temperature and O_2 control, along with air damper optimization, improve NO_x and heat rate performance. We applied the Delta heat rate methodology to provide an on-line assessment of the benefits. The components include variables the optimization system controls or influences— NO_x excess air (O_2), superheat and reheat temperature, superheat and reheat spray flow, and air heater exit gas temperature.

The trend presents the data from the 20-day dispatch period. We derived the baseline values from periods of steady load operation prior to the installation of the optimization system. Since these comparisons occur dynamically during dispatch operation, transient periods exist when benefits are negative. During load increases when the unit is firing up, superheat and reheat spray flows increase sharply over steady load values. However, other periods of operation offset these. The key assessment is to determine the average or mean benefit

over extended periods.

About the Authors

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FAST FORWARD

- An electric producer in Arkansas sees NO_x emissions as a main concern.
- A major retrofit project would help optimize NO_x and build heat rate benefits.
- The results led to better unit reliability and thermal performance.

Expert Systems Keep Goods on Rail, Energy Company Connected

Railway oil analysis laboratories handle anywhere from 300 to 1,000 samples per day to sample oil from each diesel engine and compressor once every 10 days. The potentially overwhelming volume of analyzed samples is not the only challenge the labs face. The typical diesel engine fleet comprises different makes and models, and each one has unique metallurgy and performance characteristics. "This means the fault signatures for each class of machine are unique," said John K. Turner, manager of software development at GasTOPS, a control system and condition assessment products and services provider for defense, aviation, power generation, oil and gas, marine, and wind energy applications based in Ottawa, Ontario, Canada. "Combine this with the fact condition indicators frequently relate to multiple fault modes and multiple engine component parts. Multiple faults can and do occur at the same time," he said. "The resulting fault matrix is complex, and human experts are hard pressed to untangle the patterns of indicators to explain which failure modes are at play in a real-world situation." Each person also has a different experience and may make different decisions depending on the data and how it relates to their experience. In the last two years, Turner's team has implemented expert systems for the Canadian Air Force, Panama Canal Authority, and BNSF Railway.

Suncor Energy is a growing integrated energy company focused on developing Canada's Athabasca oil sands. The company's oil sands operations, located near Fort McMurray, Alberta, get support from businesses providing exploration and production of natural gas and renewable energy, energy marketing, and refining. Suncor's growth plans target production capacity of 500,000 to 550,000 barrels per day in 2010 to 2012.

After making major investments in ERP and plant maintenance, Suncor faced a common situation; the company had invested millions of dollars in operations and maintenance, and yet the systems were completely disconnected. Instead of allowing a one-off, custom solution that would be risky to maintain in the future, Suncor demanded a solution that leverages the MIMOSA open standard for integrated operations and maintenance. The company also wanted to leverage the intelligence in its operations systems for predictive maintenance. The integrated solution, built on the MIMOSA standard, lays the groundwork for a roadmap of future use cases beyond predictive maintenance (such as capability forecast, optimized O&M planning).

An expert system can incorporate rules to analyze valid combinations of the parametric measurements to resolve the specific failure mode or conditions at play using physical concepts, such as the molecular ratio of atoms in a compound, the percentage of elements in an alloy, and the statistical correlation of elemental ratios or unique elemental patterns with the specific maintenance or repairs. "These rules ensure the expert system will always render the same decision for the same set of conditions," Turner said. As a result, an expert system can

analyze each sample passing through the lab to the same level of detail, and with a consistency and accuracy impossible for a human expert to achieve. The volume of data and the complexity of the fault matrix are no longer an issue, and the expert system becomes a resource to support and empower human experts.

Introducing the expert system at GasTOPS has led to the transition from a test parameter based diagnostic system to a machinery failure-mode-based process, Turner said. "Experts now raise predictive maintenance recommendations in the context of the diagnosed failure mode and the associated maintenance action." The new system has reduced the number of locomotive shutdowns, thus increasing availability, which helps meet customer delivery times for goods delivered by rail.

Other oil & gas companies, such as Chevron and BP, are taking an active role in the MIMOSA organization to leverage Suncor's efforts as well. One high-level type of information the company is leveraging for predictive maintenance includes instrumentation alerts (when a device is out of calibration), which automatically generate work requests. Another is rotating equipment alerts (based on statistical vibration analysis), which also generate work requests when the equipment degrades beyond pre-defined health thresholds.

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