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Putting Combustion Optimization to Work

By Nancy Spring, Senior Editor

Variable conditions like coal quality, boiler cleanliness and equipment deterioration can affect a coal-fired power plant's performance—and that's where combustion optimization systems come in, to minimize their impact. Even small efficiency improvements can make a significant difference.

New plants and plants that are retrofitting can benefit from combustion optimization. Peter Spinney, director of market and technology assessment at NeuCo Inc., said any unit that's 30 MW or greater and controlled by a digital control system is a candidate for combustion optimization. He estimates a payback in anywhere from a few months to two years based on the NO_X and the fuel efficiency savings.

Power plant operators have several optimization technologies from which to choose. When PPL's Colstrip power plant in Montana replaced its analog controls with digital distributed control systems (DCS), advanced model predictive multivariable control combustion optimization systems were installed. As Tampa Electric modernized its 1,800 MW coal-fired Big Bend plant, a fuzzy neural model-based combustion optimization system was included.

"To many people, burner optimization is not the online closed-loop optimization that NeuCo provides, but is either the tuning of manual settings or testing to provide operator guidance about where to keep dampers under different loads," said Spinney. "All are motivated by the need to operate boilers better and comply with NO_X regulations but there are a variety of ways to go about the problem." NeuCo defines optimization as the automated extraction and application of process knowledge to improve availability, efficiency and emissions.

Technology Choices

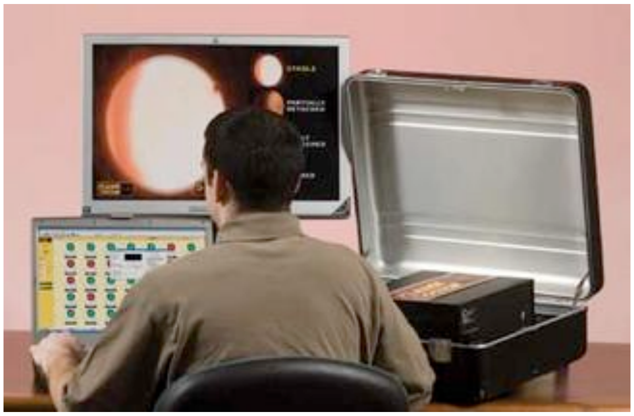
Boiler tuning and optimization don't substitute for one another but rather complement each other, said Spinney. For example, both over-fire air and low NO_X burners have air dampers that can be controlled online through the plant's control system and biased in closed-loop for minimizing NO_X and improving heat rate. There are also other parameters on low-NO_X burners and boiler systems that need to be manually tuned.

Some optimization methods model the furnace and make changes over time while others take measurements directly from the furnace in real time, said Ron Zimmerman, marketing manager, Zolo Technologies. "We're measuring right at the combustion zone."

Zimmerman likened the difference between the two methods to cars with carburetors and cars with fuel injectors.

"With a carburetor you kind of smell the exhaust and tune," said Zimmerman. "Power plant operators without combustion measurements are forced to look at the stack and judge things as best they can. They adjust their fuel mixture and look at the CEMS."

The CEMS—continuous emissions monitoring system—is important because of Environmental Protection Agency (EPA) reporting requirements and it can be used for optimization. According to Zimmerman, however, CEMS is late in the game and not optimum.



Flame Doctor may be used to diagnose and fix coal-fired burner performance issues. Courtesy B&W

"What modern fuel-injected cars do is measure right at the combustion zone, providing an optimal mix of fuel and air all the time," said Zimmerman. "What we offer is an instrument that can measure directly in the combustion zone. We map multiple paths across the fireball; it's not a single point sensor. You know exactly which burner needs tuning."

The tunable diode laser absorption spectroscopy (TDLAS) system can be integrated into existing control systems. Optimizing software solutions that hunger for data, for instance, integrate very well with the technology, said Zimmerman.

Zolo's technology may be laser-based, but for Zimmerman how it's done is not the important thing.

"Who cares if it's lasers?" he said. "Customers don't want to know what the technology is, they want to know if it works."

Using neural network, model predictive control and direct search technologies, NeuCo's CombustionOpt can determine what the optimal fuel and air set points should be for specific goals and constraints and then make the necessary adjustments to available fuel and air variables in real-time.

"There are anywhere from 12 to 96 burners and they can all be controlled individually or in combination," said NeuCo's Spinney. "That has a big impact on NO_X, CO formation, boiler efficiency and other boiler performance parameters. CombustionOpt can control those damper positions. They're the set of levers CombustionOpt uses."

Initially, burners are tuned manually and the standard set point for the secondary air positions is often determined by measurements taken by traversing the boiler with various probes, said Spinney. However, manual tuning of low NO_X burners and the ongoing optimization of low NO_X burners don't really substitute for one another.

"You need to tune those burners when they're initially installed and you probably need to tune them once a year or every couple of years whether you have a closed-loop optimizer or not," he said. "What the optimizer does is adapt for all the things that change in between the intervals during which the manual tuning takes place."

NeuCo's first CombustionOpt installation was in 1997 at a generating system where new low NO_X burners had been installed. The distributed control system opened and closed the secondary air burners as a function of load but the operator also had the ability to "tweak" the damper positions. With 32 burners controlled in pairs, there were 16 controls the operator could tweak.

Spinney did the math. "If by trial and error an operator was to find which exact combination of those 16 pairs of burner damper positions was going to provide for the lowest NO_X and highest efficiency, they'd have to try 21 trillion different combinations," he said.

While NeuCo's software doesn't have the computational power to predict 21 trillion different damper positions, it uses the knowledge of the neural network models and takes some shortcuts to approximate the best combination in less than a minute and makes the damper movements through the control system.

Controlled Chaos

Babcock & Wilcox Power Generation Group Inc.'s (B&W PGG) optimization technology, Flame Doctor, can be used in conjunction with other optimization systems like neural network-type technology to provide information about the individual burners.

"It's not an either/or technology," said Tim Fuller, technology manager, asset performance products, B&W PGG.

Flame Doctor is a portable hardware and software package its field engineers use to diagnose and correct coal-fired burner performance issues. It was developed jointly by B&W and Oak Ridge National Laboratory and funded by the Electric Power Research Institute (EPRI), which owns the technology and licenses it to B&W.

Flame Doctor can be permanently installed but a portable tuning service is just what the doctor ordered for some applications. For example, one of B&W's customers in the Northeast recently experienced flame impingement problems on the rear wall of the boiler and was trying to modify combustion to address that.

The plant's burners were two or three generations old, said Rich Conrad, manager, asset performance products, B&W PGG. "The tuning work reduced the flame impingement and we were able to balance the oxygen across the unit, getting better NO_X numbers, which cut the urea injection rate in half."

Flame Doctor produces a flame "quality map" for the furnace that shows how individual burners can be adjusted to optimize overall performance.

"A boiler might have 50 to 100 or more burners on it," said Conrad. "We can pinpoint the ones who are the 'bad actors' and pinpoint the problem with the burner. Traditional techniques would have been to put an O_2 grid on the back, which is also good information, but this technology can give you more resolution on the combustion process."

The heart of the system is a set of mathematical tools derived from chaos theory that are used for identifying flame patterns. Chaos theory is a way of modeling a system that bridges the gap between two more traditional techniques, linear and statistical, said Fuller, who was one of the system's inventors. "Chaos theory is well-suited for real world complex analysis."

Flame Doctor uses signals from a burner's existing optical flame scanners to diagnose individual burner operation. Conrad said the electrical representation of the optical emissions of the flames they produce turned out to be a very good source of information.

"There was already a device there, we just had to figure out how to use it," he said.

Flame Doctor is appropriate for wall-fired and cyclone-fired applications, although plans exist to expand its capabilities to include corner-fired units. State Space Model

The 2,094 MW Colstrip power plant in Colstrip, Mont., comprises four coal-fired generating units. Owned by PPL Montana with five other utilities, Colstrip's Units 1 and 2 began commercial operation in the mid-1970s, with Units 3 and 4 coming online about 10 years later.

Each unit recently replaced its analog controls with digital distributed control systems (DCS) and combustion optimization systems based on advanced model predictive multivariable controls (MPC). The MPCs at Colstrip, ABB's Predict&Control tool, were designed to be a coordinating supervisory layer on top of the basic single-loop proportional integral derivative (PID) controller's controls.

"They did a full control system upgrade," said Rich Vesel, product manager, eBoP energy efficiency, power generation, ABB North America. "They went from analog controls to a third generation distributed control system and then we put a combustion optimization system on top of each one of those."

Predict&Control's MPC-based system uses an algorithm that identifies accurate state space models from plant test data, wrote Vesel in "The Million Dollar Annual Payback: Realtime Combustion Optimization with Advanced Multivariable Control at PPL Colstrip," a paper he presented at POWER-GEN International in 2008.

"State space models contain dynamic process information, whereas neural nets are like a huge collection of snapshots of various state processes," said Vesel. "The advantage of a state space model in a model predictive control is that it captures all of the process dynamics and the model knows how to take the process in the most efficient path from where it is now to where it's supposed to be based on the input demand signal."

For instance, if a plant is operating at 420 MW and receives a load demand signal for 470 MW, the neural net knows how to operate at each level of output. However, it "has no clue on how to get from point A to B and relies on the base control loops to take it between those two operating points," while the state space model knows the optimal path between the two and guides the process all along the way.

"State space takes you along the optimal path based on the objectives, which could be economics, fastest ramp rate or least emissions. It is similar to PID control loop, but it's multivariable in terms of quantity of inputs and outputs and it knows where the process is supposed to be five or 10 minutes into the future."

Results from Colstrip demonstrations show how the combustion optimization systems managed NO_X simultaneously with the reduction of excess O_2 and the major heat rate improvement that came from management of reheat spray flows, one of the top three heat-rate killers in a subcritical plant, according to Vesel.

"On one of the larger 740 MW units at Colstrip, we got a 15 percent NO_X reduction, 15 percent excess O_2 reduction and a 40 percent reduction in reheat spray flow, all at the same time," he said.

Vesel estimates that between NO_X control and heat rate improvement, financial benefits could pay for the controller in less than a year.

CO More Important than NO_X

Tampa Electric Co. (TEC) has undertaken several major projects at its Big Bend site in Apollo Beach, Fla., to reduce emissions at the plant's four units. As part of the move to control emissions and to find optimal positions for various parameters in the boiler combustion process, TEC is also installing combustion optimization systems.

"Big Bend is one of the few coal-fired power plants in Florida," said Harry Winn, senior optimization engineer, Emerson Process Management, Power and Water Solutions.

As part of the project scope, Big Bend put in new distributed control systems to get tighter controls and then they put in equipment for emission reduction. "They thought the third piece of the puzzle was to optimize the combustion even further, to minimize what the selective catalytic reduction equipment has to do to get the final emissions below the levels where they need to be."

Emerson's SmartProcess fuzzy neural model-based combustion optimization system was installed and configured on Big Bend 4 in 2007. TEC plans optimization systems for all four units as each new DCS is completed, said Winn.

"Their plans are to do it over a four-year period," he said. "Right now, we are still working on Unit 3." The remaining projects could be completed by 2010 or 2011.

Big Bend Unit 4 is a Combustion Engineering tangentially fired boiler design while Units 1, 2 and 3 use Riley Stoker boilers. "They are completely different boilers, so Emerson is using a different optimization strategy," Winn said.

The fuzzy neural model in the controller is characterized as a Takagi-Sugeno-type fuzzy model, based on "piecewise linear systems," according to the paper, "Optimizing the Boiler Combustion Process in Tampa Electric Coal-fired Power Plants Utilizing Fuzzy Neural Model Technology," written by Winn with George M. Bolos, principal engineer, Tampa Electric Co., and presented at POWER-GEN International 2008. "Fuzzy logic is used to overcome sharp switch between neighbor models."

Winn said with a regular control system, normally only one thing is controlled, while "in a fuzzy neural model, you control many things at the same time and use more than one target goal to control the variables."

There are several goals and they work together—the goals of efficiency improvement, NO_X improvement or CO improvement, for instance. The user can allocate weights to the goals that can be modified.

"In Maryland, we did an optimization project where the primary goal from May to October was NO_Xreduction, but from October to May, the utility modified the weights to allow the optimization system to concentrate primarily on increasing unit efficiency," said Winn.

At Big Bend 4, the weight for CO was modified as the project progressed. Engineers discovered that the CO formed from the combustion process was very unpredictable and on some occasions it was difficult to maintain CO within acceptable limits. Winn said what started out as a NO_X reduction project "morphed into a CO project and we didn't expect that when we started. That was an extra benefit. The SCR could always reduce the NO_X to acceptable ranges, but there wasn't really anything to control CO so we gave CO more weight."

Other retrofit plants Emerson has worked on have shown cost-saving benefits. "There's a plant in Illinois that we did that has been able to keep under its state emission limits with a combination of tuning and optimization without putting SCRs in," said Winn. Emerson is working with several new coal plants, too.

Coming Optimization Improvements

"In CombustionOpt, we've added a different type of optimization technology that complements the adaptive neural networks," said NeuCo's Spinney. "It's called model predictive control, and it helps to manage some of the more dynamic aspects of combustion optimization."

Another area where CombustionOpt has made improvements is in transparency for the user.

"If an operator is under the belief that management bought a combustion optimization system to reduce NO_X," said Spinney, "and happens to be paying attention to what NO_X is doing and sees that the optimizer is turned on and NO_X is going up, he might believe that the optimizer is not doing what it is supposed to do." In fact what may have happened is the boiler got a big slug of wet coal and the optimizer is backing off on NO_X because it's more important to deal with the wet coal and pump more O_2 in there to avoid slagging or high CO or opacity. "In the older versions of CombustionOpt, there wasn't that level of visibility," he said.

ABB's Predict&Control launched in 2005 and Vesel said upgrade plans include refining the algorithms for additional speed and accuracy, but there is "nothing in the R&D pipeline besides model predictive control." MPC used to be limited by computing power but no longer.

"Taking the MPC and putting it into standard controllers instead of running it on separate PCs that are layered on top of the DCS could be the next generation," he said.