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Supercritical Control

Technologies for supercritical boilers bring new efficiencies to coal-fired power plants, but require specialized control strategies.

Charlie Menten
Emerson Process Management

Because of its abundance and affordability, coal continues to be a major energy source for power producers worldwide. However, as carbon consciousness becomes more prominent, technologies for gaining efficiency and reducing emissions from coal-fired plants become more critical. As boiler technologies grow more sophisticated, their control strategies must keep pace to take advantage of increased capabilities.

Burning coal generates 40% of the world's electricity, according to the World Coal Institute, and it is expected to be the fuel of choice for the foreseeable future as companies deploy technologies that offer cleaner, more efficient coal-fired plant operation. It's also worth noting that U.S. coal reserves represent 29% of global reserves. Supercritical and ultra-supercritical once-through boiler technologies are among those re-emerging as new materials and designs help drive higher efficiency levels and ease of operation.

For supercritical plants, the accuracy and resolution of the DCS (distributed control system) is more important than in subcritical units. A well-designed control system that provides tight regulation and the ability to hit and maintain setpoints can help utilities capitalize on the economic and environmental potential these units offer. Understanding why this is so requires examining key differences in the design and operation of subcritical and supercritical plants.

The term supercritical is used for plants with design operating pressures above where normal boiling occurs. Instead, water simply transitions from liquid to vapor without traditional nucleate boiling. For water, the supercritical point occurs at pressures in excess of 3,207 psi.

Supercritical power generation units feature once-through boilers designed to operate with pressures from 3,500 to 4,000 psi, versus 1,800 to 2,500 psi for subcritical boilers. Higher firing temperatures and pressures translate into better efficiency, defined as more electricity generated per BTU of coal consumed. This is attractive to power producers, as these increased efficiencies translate into reduced fuel costs and emissions.

Lessons of earlier attempts

Supercritical technology dates back to the 1950's but those first generation supercritical units were unreliable and difficult to control, suffering maintenance problems and material failures from operation at higher temperatures and pressures. Because these early designs were unable to move back and forth between supercritical and subcritical operational modes easily, it was necessary to operate continuously in the supercritical range. This introduced overall cycle inefficiencies. For example, even at low loads, the boiler feedwater pumps needed to keep producing pressures in the range of 4,000 psi. Since these use the second largest turbines in the plant, this translated into a significant amount of energy consumption and equipment wear and tear.

Because of these issues, the industry largely turned to drum boilers in the 1970s. In this design, water changes to steam in the drum as water circulates through the water walls. This can translate into slower startup, as well as slower responsiveness to load changes.

Now, thanks to improved boiler design, most notably the Benson once-through boiler, as well as advancements in metallurgy for stronger boiler tubing, a new generation of supercritical units have been gaining popularity over the last decade or so. The Benson design offers a number of advantages, including simplified start up and the ability to operate in sliding pressure mode.

Today's supercritical units can achieve thermal efficiency of more than 45%, compared with a typical subcritical plant's 30-38%. Because they are most efficient when operating at high pressure (units go supercritical at 70% load), supercritical plants typically have been and will continue to be larger, base load units.

World-wide applications

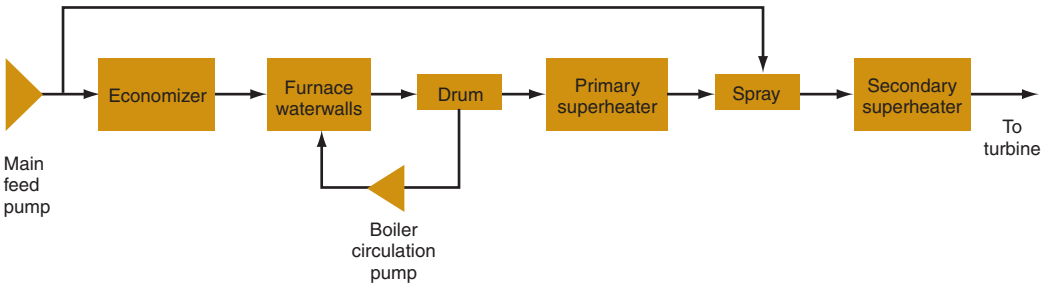
Some of these advanced units are being built in the U.S. as utilities add base load generating capacity. For example, We Energies' Elm Road Generating Station and Xcel Energy's Comanche Unit 3, and others use supercritical boilers.

However, the majority of these new super-

critical units are being built in Asia, especially China, which is building power plants at a rapid pace. These new plants will provide infrastructure to support booming economies and bring electricity to areas previously unconnected to the grid. In support of China's growing power requirements, 90 gigawatts of new capacity is planned over the next two years.

Two noteworthy fast-track projects in China are Huaneng Power Intl.'s Huaneng Yuhuan plant and China Huadian Group Corp.'s Zouxian units 7 and 8. Both use Emerson's Ovation expert control system.

Subcritical drum boiler flow



Source: Control Engineering *with data from Emerson Process Management*

The steam drum makes subcritical units easier to control, but sacrifices efficiency.

The first two units of the four-unit, 4,000 MW Huaneng Yuhuan plant synchronized to the power grid eight months ahead of schedule: Unit 1 successfully completed the 168 hour performance test, a significant milestone for new plants coming online, on Nov. 28, 2006, making it China's first 1,000 MW ultra-supercritical unit in commercial operation. Unit 2 synchronized to the power grid on Dec. 15, 2006, and completed the 168 hour performance test on Dec. 30, 2006. It is estimated that about 11 billion KWh of electricity will be generated by these two ultra-supercritical units annually. Start-up of units 3 and 4, Phase 2 of the project, is slated for 2008.

Units 7 and 8 at the Zouxian Power Plant are among the first ultra-supercritical units in China to have a 1,000 MW output rating. Unit 7 of the Zouxian facility successfully completed the 168-hour performance test on Dec. 4, 2006, roughly nine months ahead of schedule. The Zouxian units also represent the first installation of FOUNDATION fieldbus technology at a power generation facility in China. When Phase IV is completed, the Zouxian Power Plant is expected to be the largest coal-fired plant in China, with eight units having a total generating capacity of 4,540 MW.

A well-designed, advanced control system from a vendor with the expertise and understanding of the nuances of controlling drum versus once-through supercritical boilers can contribute to the smooth start up and commissioning of new units. This same combination of proven automation technology and know-how is also extremely beneficial for keeping these units operating at peak efficiency.

For supercritical units, the control system's accuracy and resolution is paramount, as better control allows power generators to capitalize on the heat capture capabilities of supercritical unit designs. Unlike a drum-type boiler, the once-through, supercritical boiler does not have a large steam drum to store energy. Because there is no energy reserve, the control system must match, exactly and continuously, feedwater flow and boiler firing rate (both fuel and air) to the turbine's steam energy needs, to deliver the desired generator power. The ability of the control system to control operations more tightly, and to hit and maintain setpoints, leads to stable, steady-state operation, without oscillation. This is critical, as steady-state, base load operation is key to achieving supercritical unit efficiency.

Real-life application

With the confidence that a control system is able to keep plant operations tightly controlled without the need for frequent operator intervention, power generators can augment plant efficiency by applying other complementary advanced automation and control technologies. This was the experience at Yonghung Thermal Power Plant units 1 and 2, where results included, but were not limited to, heat rate improvement via a reduction in CO and LOI (loss of ignition).

The plant is located in Inchon, 35 miles southwest of Seoul, South Korea, and has a generating capacity of 1,600 MW. Yonghung units 1 & 2 came online in 2004; units 3 & 4, each capable of 870 megawatts, are currently under construction and slated to be operational by June 2008 and March 2009, respectively. Each supercritical unit has a 5,325,000 lb/hr once-through, single-reheat boiler and a tandem-compound, four-flow, single-reheat, regenerating and condensing turbine.

At the heart of the Yonghung Thermal Power Plant is an integrated control and monitoring system (ICMS) based on Emerson's PlantWeb digital architecture with the Ovation control system. This manages all plant systems, including

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coordinated boiler and turbine control, burner management, data acquisition, motor control, and balance-of-plant processes. The Ovation system fully integrates the units' processes and seamlessly interfaces to the FGD (flue gas desulphurization), ESP (electrostatic precipitator), and auxiliary systems.

The ICMS incorporates high-fidelity simulators that use Ovation hardware and software in conjunction with modeling software to simulate startups, verify operating procedures and test new applications software. The simulator design offers a realistic opportunity to train and prepare plant staff to handle any situation, which paved the way for easier commissioning and tuning, as well as earlier completion of the plant by approximately three months.

The ICMS uses AMS Suite: Intelligent Device Manager, which monitors the plant's intelligent pressure, temperature, and level transmitters, and control valves. With it plant personnel can predict and preemptively correct potential problems with Yonghung's devices, reducing maintenance costs and contributing to plant reliability.

Another important component of the ICMS is Emerson's SmartProcess optimization software. Since each power plant is different, effective operation is affected by a different set of variables, internal and external. Optimization software tailored to plant-specific needs can improve opportunities for achieving desired results.

SmartProcess software, for instance, optimizes process control and monitoring using advanced control techniques, fuzzy logic, advanced multi-regional model networks and model-based predictive controls to ensure attainment of increased plant efficiencies and decreased operating costs within operational and regulatory limits.

Incremental efficiency gains

The SmartProcess software was implemented approximately three months after Yonghung units 1 & 2 became operational. This enabled operators to measure plant performance first at "design conditions," theoretically when a plant should be most efficient, then compare this baseline to plant performance after the optimization software was up and running. Comparing the data painted a clear picture of efficiencies directly related to the optimization software.

The Yonghung Thermal Power Plant, the largest coal-fired plant in South Korea, is part of Korea South-East Power Co.'s strategy to maintain low-cost, high-quality electricity for Seoul's metropolitan area.

At Yonghung units 1 & 2, SmartProcess software optimizes two processes that impact plant performance: steam temperature and combustion. Minimizing steam temperature variations increases efficiency by reducing boiler tube leaks and turbine blade fatigue, resulting in significantly reduced maintenance costs and outage requirements while improving ramp rates, which contribute to increased revenue.

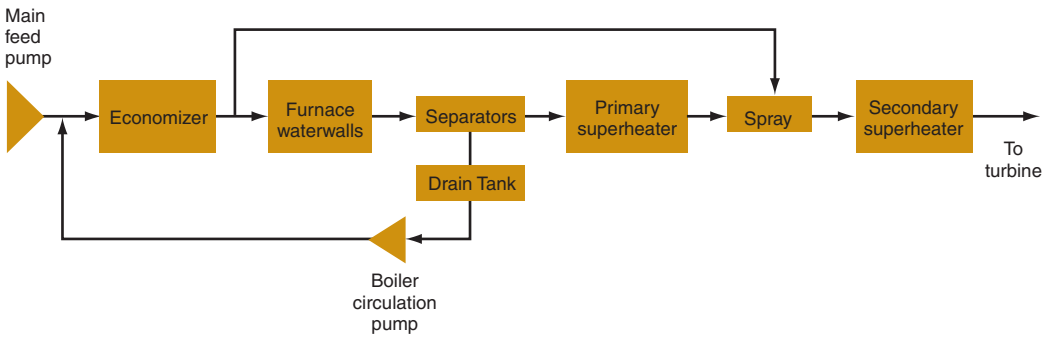
Optimizing combustion control improves heat rate (boiler efficiency), which translates into reduced costs, as well as reduced emissions and controlled opacity levels. Emerson was asked to focus on minimizing CO and LOI while controlling NOx below limits to meet the Yonghung plant's objective of improving plant efficiency and maintaining good control response.

At Yonghung units 1 & 2, SmartProcess optimization software receives data updates from the ICMS every second and operates on a dynamic basis. The software models the dynamic plant characteristics, optimizing on a continual basis, regardless of current unit activities like load ramping, mill swing and sootblowing. The modeling and optimization software dynamically generates optimal process setpoints and biases, integrated in real time with ICMS process controllers. The software incorporates safety features and operational limits so that recommended setpoints and biases provide safe operation.

The SmartProcess software automatically

Supercritical once-through boilers do not have a steam drum to cushion demand changes. This increases efficiency, but the DCS must regulate fuel and boiler feedwater precisely to follow turbine loading.

Supercritical once-through boiler flow



Source: Control Engineering *with data from Emerson Process Management*

adjusts a number of variables, including opening of auxiliary air dampers, opening close coupled overfire air and secondary overfired air (SOFA) dampers, biasing forced draft and induced draft fans, positioning SOFA tilts, biasing pulverizer outlet temperature setpoint, O_2 setpoint bias, positioning burner tilts, biasing feedwater to fuel ratio, and biasing the primary superheater, finishing superheater and reheat sprays demands. It is important to note that although the optimization software manipulates numerous variables, operators are kept "in the loop" at all times. They are able to view a diagnostic of all the control loops affected, as well as the permissive conditions for optimization activation, on one screen.

Yonghung's ICMS permits operators to control and monitor critical plant processes from a central location, while providing data to the plant's main computer.

Optimizing steam temperature considers two factors. The first is the dynamic characteristics of heat exchange rates between the flue gas and steam during changes in the combustion process such as changes in the fuel delivery system or burner configurations, or changes in unit heat transfer characteristics. The second is the time delay that is experienced between when these disturbances are initially introduced and when the final effect upon steam temperature is realized. Two types of optimization techniques were used to model, predict and optimize these process dynamics effectively to minimize steam temperature variations:

- A model predictive controller models the process and generates supervisory level setpoints and biases for attemperation water sprays; and,
- Fuzzy feed-forward models of the energy exchange are used for improved steam temperature control.

Combustion optimization decreases boiler NOx, CO emissions and opacity, and increases megawatt revenue through improved ability to respond to load changes, mill changes, and unforeseen events. The modeling and optimization software addresses non-linear or linear process dynamics to maximize quick and effective responses to disturbances and static process characteristics, and accurately predict steady-state responses.

The utilization of SmartProcess optimization software as part of the ICMS enabled the Yonghung plant to meet its objectives for improving heat rate and reducing CO formation and LOI. The project illustrates how performance improvements can be achieved even on a well-tuned, modern boiler within a highly efficient new plant.

The optimization software improved boiler efficiency by improving heat rate under some conditions by 0.44%. While that might not sound like a huge difference, an improvement of half a percentage point for an 870 MW boiler has major cost implications. Additionally, CO was slashed from 350-500 ppm to 50-60 ppm, a 90% improvement, while unburned carbon and LOI were reduced by 10% to 30%. Furthermore, flue gas temperature decreased 1 to 3 °C, a telltale sign of improved boiler efficiency.

These improvements also benefit plant personnel because the software automatically optimizes boiler control, reducing an operator's need to move the O_2 bias to avoid CO formation. Therefore, not only is the automated system more accurate than manual adjustments, it also translates into a better and more efficient personnel deployment.

Because of the efficiency and environmental benefits they bring, supercritical technologies should continue to figure prominently in new base load plants being built in the U.S. and around the world. Power generators that choose this option must consider the control strategy carefully for these units. As recent projects demonstrate, leveraging such an advanced automation and control strategy can put power generators on the super-critical path to smooth, efficient unit start up, the highest levels of unit reliability and availability. **ce**

Charlie Menten is a power generation consultant for Emerson Process Management. Reach him at charles.menten@emersonprocess.com.

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