# Cycling Baseload Plants

Driving to better understand, manage, and mitigate the impacts

## THE STORY IN BRIEF

Baseload coal-fired plants have been designed for consistent, round-the-clock operation at full load. But today's low natural gas prices and increased dispatch of intermittent renewable generation are encouraging the use of baseload plants for cycling duty, which can lead to component damage and reliability problems. EPRI is working with member utilities on an integrated framework of analysis, operating strategies, and design modifications that will help minimize these impacts.

In a sense, operating a coal-fired power plant is akin to driving a modern car. Both will be most reliable and efficient if steady operation is sustained. A car consistently driven on extended trips at a steady 55 miles per hour can be expected to operate more efficiently and reliably over the long term than a car driven an equal number of miles with the continual acceleration and deceleration of stop-and-go traffic. For a coal-fired power plant, the impact of acceleration and deceleration of electrical output takes a similar toll on efficiency and reliability.

For baseload, coal-fired power plants, today's low natural gas prices, increased renewable generation, and economic downturn have created the utility equivalent of heavy traffic. The existing U.S. fossil-fired generation fleet, designed for long stretches of "freeway" operation, now must cycle, or "follow the load"—frequently reducing output or even shutting down for brief, unscheduled intervals.

This new duty cycle forces the plant and equipment to be operated closer to—or beyond—nominal design limits and through more cycles than originally anticipated. The result is increasing rates of damage to a variety of plant systems that could lead to more equipment reliability problems in the long term.

### A Growing Problem

Cycling and load following are not new. In recent decades, EPRI workshops and studies have evaluated and addressed impacts of cycling operation, such as accelerated damage to boilers and turbine problems associated with boiler water chemistry. Top-down empirical analyses using industry data have correlated plant cycling with operating costs.

Nevertheless, there are gaps in knowledge about the impacts of cycling, and current knowledge of cycling effects needs to be better integrated with decision making. Studies are needed to quantify the impacts of cycling on environmental control equipment, such as particulate controls, post-combustion $NO_x$ controls, FGD systems, and waste management systems. Impacts of cycling on heat rate (plant efficiency) as well as on many damage mechanisms, such as boiler circumferential cracking and fireside corrosion, need to be considered.

Changes in plant operations also pose new challenges. "Some baseload capacity is being replaced by gas-fired units and heat recovery steam generators," said Kent Coleman, a senior project manager in EPRI's Boiler Life and Availability Improvement program. "Baseload dispatching traditionally taps nuclear plants first and then the least costly coal plants," Coleman said. "But as gas prices have come down, gas plants have displaced more of the coal plants."

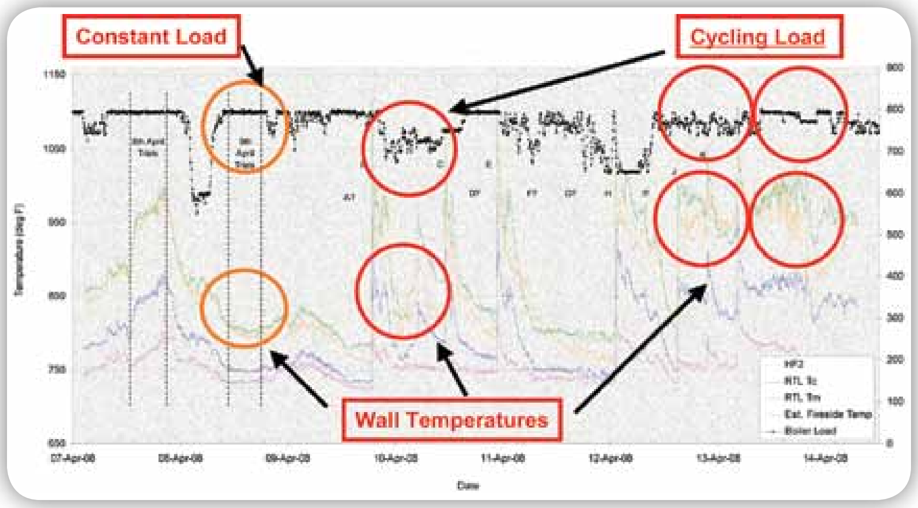
Also important are the effects of variable resources, such as wind and solar energy. "When the output from a wind farm abruptly goes down, dispatchers have to come up with more generation from somewhere, so they dispatch the coal units to follow that load," Coleman said.

"You can see these difficulties playing out in the Midwest, where a lot of wind is coming on line," said Tony Facchiano, a senior program manager and one of the leaders of EPRI's environmental controls research. "The problem is, the wind typically picks up at night just as the load drops. You have all this renewable energy just when you need it least, so the baseload plant shuts down at night. In the morning, you get a one-two punch—the load picks up and the wind dies—and you have to get the plant back on line.

"Load following, low loads, and turning units off and on all present operational problems," Facchiano said. "Plants are designed to operate at full load. Everything is optimized for a full load, and when you operate at lower loads, you're compromising performance. In all three cases, your heat rate goes up, which means the operating efficiency of your plant goes way down. And there are issues with emissions and keeping your environmental controls operating properly.

"If you take a plant off line, you have to make good guesses about when it's going back on. Do you send people home or have them stay on site? Do you keep the plant on hot standby? Do you go for a cold start or a hot start? A lot of folks think that if you need power at 8 o'clock in the morning, you just press a button and out comes the power. It doesn't work that way."

"In normal operation, there's a certain amount of time when you're letting things




*Operational trials at PPL's Brunner Island Unit 3 showed steep temperature excursions in the boiler's front wall under cycling duty. Such rapid heat variations can lead to thermal fatigue and component failure.*

heat up and expand at a slow, uniform rate to control the stresses," Coleman explained. "You're not making any power, but you are burning fuel, so some utilities have tried to shorten that time as much as possible by ramping up quickly. But the shorter you make that warm-up, the more damage you can do to your unit. It's a trade-off between spending money on fuel and spending money on maintaining equipment throughout the plant."

"When you talk about load following, you're talking about rapid increases and reductions in temperatures and velocities, and a lot of thermal stress is created," Facchiano said. "When loads change in a plant, the consequences are numerous—pulverizers or mills go off and on, fans speed up and slow down, furnace temperatures and heat profiles are altered, pollution control requirements change, steam and flue gas velocities vary, and so on. All of these changes create stresses. Things are unsteady, and there's a transient period when things are out of sync."

## Taking the Long View

Coleman said today's decisions about which plants to operate and how to use them often come down to minimizing fuel costs or emissions—which plant produces less carbon dioxide, for example. Many decisions do not take into account longer-term life-cycle costs. Facchiano cited the car analogy to help explain.

"If I run my car at 70 miles per hour at a mostly constant speed, my car might last 15–20 years. But if I am doing a lot of starting and stopping, that car may last only 5–10 years. After the first year, I might think everything is fine, but I'll see the impacts later on. The same thing applies to the impacts of cycling on power plants today. A lot of the consequences are long term. Thermal fatigue, for example, develops over a long period," Facchiano said.

"All the top failure mechanisms for the boiler and turbine generator are effects of cycling," Coleman said. "We're already seeing a lot of corrosion fatigue and thermal fatigue in boilers as a direct result of this kind of operation. Industry maintenance costs have increased quite a bit over the last few years because of it. Power plant owners are changing out waterwalls and boiler headers because the units are old and they've been run hard. It increases the risk of unplanned outages, equipment failure, and personal injury."

"And all this is happening at the same time orders for new units are being canceled, so now you have older units that are being asked to run longer," Facchiano added. "Cycling only increases the wear and tear, so it's kind of a perfect storm."

In order to manage plants and fleets effectively, it's important to understand the critical risks, such as higher costs, increased probability of failure, and rate of equipment degradation. Past research has demonstrated that the detrimental effects of cycling operation might not show up in the short term and that unique unit characteristics (age, design, metallurgy, etc.) and operational regimes make it difficult to accurately quantify and predict cycling impacts. Quantifying these impacts inherently entails a high degree of uncertainty. Plant design, cycling regime, equipment condition, changes in operating practices, and changes in fuel all make it unlikely that a one-time assessment will produce an accurate result that can be used in the long run.

## An Integrated, Real-World Approach

EPRI is looking at a long-term approach for studying the impacts of cycling. Because these impacts differ from plant to plant, the research will use members' generation assets as "laboratories" to study cycling impacts over several years. The work has three objectives:

- Develop and validate an integrated framework to quantify the cost, performance, and reliability impacts of various fossil plant cycling scenarios;
- Define critical operating practices and design modifications that mitigate or better manage these impacts; and
- Develop and demonstrate an approach for modeling the response of generation assets to various dispatch scenarios that optimizes fleet deployment on the combined basis of generation cost and equipment degradation.

This integrated framework would include information and analyses from various EPRI programs and experts. The effort would entail the following steps:

- Define all sources of costs resulting from cycling—impacts on power-block equipment, emissions controls, coal feed processing, and overall heat rate penalties—that can manifest themselves as reduced service life, increased forced outages, compliance violations, higher operating costs, or lower efficiency.

- For each unit, determine the first-order causes likely to contribute most significantly to costs.
- On a unit level, quantify costs as a function of all major operational and design parameters believed to be critical, including ramp rate and a comparison between historic (baseload operation) costs and the increased cost due to cycling.
- Define additional unit data that need to be acquired, along with instrumentation necessary to monitor and/or quantify the critical impacts.
- Evaluate plant simulator technology with system-level cost functions as a possible analysis "test bed."
- Develop and demonstrate a fleetwide optimized cycling dispatch model, using unit-level cost functions associated with various modes of cycling operation. It might be possible to create scenarios that could demonstrate the subtle changes in dispatch that have unexpectedly large benefits for the cost of cycling. Tracking and optimizing asset life consumption could be a new role for the emerging fleetwide monitoring centers. Information could be sent to a central location, where all monitoring, trending, and analysis could be done.

This approach will require an up-front assessment for each generating asset faced with cycling duty and then periodic follow-up assessment of impacts over a period of two or three years. The goal is to develop a validated approach and framework for quantifying the impacts of cycling at the unit level and for developing an asset deployment strategy for the fleet. It is likely that a mix of top-down empirical analyses and engineering calculations using physics-based models will be required.

"There are two key needs we have to address," Facchiano said. "One is to be able to better quantify the cost of cycling. Utilities need that information to make a decision when asked to cycle a unit. What's the break-even point? It doesn't make sense to generate power if I'm going to lose money, so I need to factor in the impacts of cycling to know where that point is.

"Our R&D should also focus on the other need: identifying tools and technologies that can minimize the impact if units must be cycled. There's a lot that can be done in this area. For example, a more responsive control system could help minimize the impacts of transients, or an improved boiler design could reduce stresses due to thermal transients.

"We've already started. A lot of work EPRI has been doing for some time is applicable to understanding and advancing the resolution of this issue," Facchiano said. "What we need to do now is compile what we already know and figure out what we still need to learn. Much of our work in 2010 will apply to cycling; we already have a lot of tools we can apply. And we're going to get smarter as we go."

*This article is based on a white paper being developed by EPRI's Generation Sector. Background information was provided by Norris Hirota, nhirota@epri.com, 650.855.2084; Tony Facchiano, afacchia@epri.com, 650.855.2494; and Kent Coleman, kcoleman@epri.com, 704.595.2582.*

**Norris Hirota**, a director in the Generation Sector's Operations and Maintenance program area, has overall responsibility for the development and deployment of technology for improving plant performance and reliability. Hirota joined EPRI in 1980 and has managed numerous programs in both the Nuclear and Generation Sectors relating to equipment and plant reliability and O&M cost reduction. He has also led several large initiatives to apply EPRI-developed technologies at member companies. Hirota received B.S. and M.S. degrees in mechanical engineering from the University of Santa Clara.

**Anthony Facchiano**, senior program manager for environmental controls in EPRI's Generation Sector, manages research on boiler performance, in-furnace and postcombustion NOx control technologies, and boiler operability issues associated with low-NOx combustion. Before coming to EPRI in 1993, he worked at Coen Company, Bechtel Power Corporation, and Exxon Research and Engineering Company, where he specialized in product development, emissions testing, and full-scale demonstration of combustion systems. Facchiano holds B.S. and M.S. degrees in mechanical engineering from Manhattan College.

**Kent Coleman** is a senior project manager in EPRI's Boiler Life and Availability Improvement program, focused on the development of non-destructive examination methods, reduction of boiler tube failures, and development of remaining-life tools for boiler pressure parts and piping. Before joining EPRI in 1999, he was a specialty engineer for Western Resources (WR) for 17 years and administered boiler repair and life assessment programs for Kansas Gas and Electric Company, a WR subsidiary. Coleman received a B.S. in mechanical engineering from Wichita State University.