Turndown and Ramp Rate Issues with Utility Boilers

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ABSTRACT

In the United States, most of the utility boilers in the current fleet of coal-fired power plants were designed for base load operation. However, many utilities are now requiring these same units to quickly follow load, cycle on and off line, or periodically operate at much lower loads—all functions that were not part of the original design requirements. Driving the need for flexible operation are several factors, including low natural gas prices, demand softened by economic pressures, environmental issues, and locally installed renewable generation.

Base load boilers were designed for operational conditions that are less demanding than those required for cycling. Cycling operation and ramp rates faster than those recommended by the manufacturer can result in damage to critical boiler components in atypical locations and through unfamiliar mechanisms. Other issues at low loads, such as burner stability, pulverizer operation, and circulation adequacy within the furnace tubes and heat transfer components, could also lead to damage and shorter component design life.

This report describes the experience of one boiler manufacturer, Babcock & Wilcox Power Generation Group, and explains some of the design philosophy behind many of the boilers in the existing fleet. The report provides background information on the possible unwanted consequences of flexible operation, and it serves as a starting point for future research to determine the extent of damage from different types of operation and the modifications that could minimize it, such as physical changes to the boiler and revised operational policies or procedures. The information presented might help utilities identify the best economic solution(s) and design procedures to consider when they address the turndown and ramp rate issues associated with drum and once-through boilers.

Keywords
Base load
Boiler design
Cycling
Flexible operation
Ramp rate
Turndown

CONTENTS

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INTRODUCTION

Many of the utility boilers that are in operation today have been developed for base load operation with relatively slow rate of load change. However, many of the more recent drum type boilers built after 1980 were designed for or converted to operate in a load cycling mode. All drum and once-through boilers have some load cycling ability, although the rate of load change in most cases is relatively slow. Many of the B&W utility drum boilers sold after about 1980 have structural changes to allow on/off cycling. Prior to about 1980, almost none of the utility drum boilers were designed initially for on/off cycling. For the once-through boilers the number of units that were designed for load cycling or on/off cycling is much less.

Several factors have changed within the power industry which is causing utilities to cycle their units to lower loads. These factors include: (1) reduced demand due to the economic downturn, (2) lower natural gas prices and an increase in adding gas firing capability or fuel switching from coal to gas, and (3) the increase in the deployment of wind and solar (renewable) power generation. With the current desire to cycle these boilers, many utilities are concerned with the effects of low load operation and increased ramp rates on the design limits of the boiler and their effect on reliability and design life.

Extending the use of utility boilers especially when the boilers are cycled can result in many boilers operating beyond their normal expected service life. The actual useful life depends upon the boiler type, past care and maintenance, operating conditions, fuels and many other factors. As a result, failures have occurred and may occur in the future in places and on equipment which have provided relatively trouble-free service for many years, such as tubes and tube welds in vestibules, tubes encased in refractory or behind casing, or other areas of pressure parts. B&W Plant Service Bulletin-58 (PSB-58) should be reviewed so that you are aware of the information and recommendations concerning the inspection of pressure parts on boilers that are in advanced years of service or have been out of service for long periods of time where there are potential issues and hazards that need to be identified and addressed before failure occurs.

Base load boilers were designed for operational conditions that are less demanding than compared to those required for cycling. Therefore, cycling operation and faster ramp rates than those recommended by the original equipment manufacturer (OEM) can potentially result in damage to critical boiler components. The potential for creep and fatigue damage depends on the design details of the at-risk components and the operation of the unit for rate of load change. Other issues at low loads such as burner stability, pulverizer operation, circulation adequacy within the furnace tubes and heat transfer components can lead to potential damage and an increased loss of component design life.

The following information has been developed to identify and help evaluate the concepts and feasibility needed for obtaining turndown solutions to mild (100% to 40% of maximum continuous rating (MCR)), moderate (40% to 25% MCR) and deep (25% MCR to house load, or about 10% load) load cycling/turndown operation on utility boilers. This paper has been organized by boiler components that will need to be investigated to determine best and most feasible solution(s). Many of these components will require analysis in the areas that involve boiler performance, furnace circulation, fuel delivery (pulverizers and burners), combustion and environmental control systems. Other items that go beyond the boiler island are also mentioned but are not expanded upon since these items are usually not provided by Babcock & Wilcox Power Generation Group, Inc. (B&W PGG). They are listed, however, so that they can be considered in a plan to address turndown or ramp rate issues.

The information provided in this document may help utilities identify the best economic solution(s) and design procedures that should be considered when addressing the turndown and ramp rate issues on drum or once-through boilers. An "Issues vs. Load Matrix" is included at the end of this paper to provide an idea of the issues that are involved when considering low load and ramp rate changes that are more liberal than those for which the unit was designed.

Discussions with several utilities occurred at EPRI's Boiler Life and Availability Improvement Program (Program 63) Meeting that was part of the EPRI 2012 Generation Advisory and Council Meetings in Nashville, Tennessee, held on October 2, 2012. Utility boiler operation questions were directed towards low load boiler operation and cycling. Questions that were discussed included the following:

- Who needs to load cycle and why?
- What load is the lowest load they can achieve?
- What are their limitations?
- What are their techniques for achieving low load?
- Who wants to load cycle, but isn't and why?

The response to these questions provided the feedback that was used to develop this paper. The interest in both subcritical drum boilers and once-through boilers (both sub and supercritical) were discussed during this meeting. Therefore, this paper will address both unit types.

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PAST EXPERIENCE WITH LOW LOAD AND CYCLING

In the late 70's and early 80's, B&W received many requests from the industry for operation of their coal, oil and gas boilers at low load and for cycling operation. These requests were prompted by the surge of nuclear power generation and the high cost of natural gas and oil. Many studies were performed to determine the best methods for operating these units. Several units were retrofitted and tested. The results from this past work are the starting point for this paper. The details of this work covered a wide range of boilers and operating conditions. Therefore, only a summary of the results will be presented.

Subcritical and Supercritical Once-Through Boilers

Historically, B&W's once-through boilers that were designed for base load operation have been capable of load cycling down to about 45% load, whereas other boilers can load cycle to lower loads of 25 to 35%. However, the lower load limit is usually set by feedpump and combustion issues. For on/off cycling, the once-through boiler must use the startup system which can be challenging for quick load ramping especially when water quality cleanup is a problem. In an effort to determine the operational problems and equipment cycling limitations, B&W would evaluate the cycling performance of the once-through steam generator to determine boiler system design changes which would permit the boiler to cycle on and off and cycle to low loads with rapid response to load demand.

Experience has been gained on once-through boilers from data taken for the following cycling operations: cold start, hot start after overnight shutdown, boiler-fired turbine off, hot restart after trip, and load cycling from 40% to full load (above the boiler startup system operation) and from 20% to full load (required startup system operation). The test data taken was used to determine the impact and effects of these cycling modes on boiler system components, operational difficulties and system limitations.

Results from the analysis of the test data showed that under nearly all cycling modes of operation (except load changing when operating above 40% load), difficulties were experienced in controlling rates of temperature change in boiler pressure components and in maintaining boiler tube metal and fluid temperatures within design limits. Startup times were also extended due to water cleanup limitations and turbine synchronization difficulties.

Based upon the results from the testing effort, B&W performed several conceptual design studies that were directed at modifications to the once-through boiler such that problems attributed to the level of cycling capability desired could be minimized. However, minimizing the problems was also tied to the rate of load change. The desired rate of load change could affect temperature matching to the turbine. Recommendations were developed for three levels of cycling service: Level 1 is load cycling from 40% to full load, Level 2 is load cycling from 20% to full load, and Level 3 is daily on-off cycling over the full load range. In all cases the once-through boiler would be capable of rapid response to load demand.

Recommendations for improving the cyclic operation of the once-through boiler when operating above 40% load (Level 1) are primarily directed at operational ease and flexibility and require no system or equipment design changes. Depending on actual plant equipment installed these recommendations can include (1) addition of a flame monitoring system, (2) enlarged computer capability for tube temperature monitoring, (3) new or upgraded burners and controls for better fuel input turndown capability, and (4) addition of a method to increase the economizer exit gas temperature (EEGT) for minimizing problems with the air quality control system (AQCS) system (especially for selective catalytic reduction (SCR) catalyst conditions).

Recommendations for improving the cycling operation of the once-through boiler from 20% to full load (Level 2) include Level 1 upgrades, but also require design changes to upgrade the boiler startup system. Furnace circuit modifications can sometimes be done, if the goal is to operate at about 20% load, and not use the boiler start-up system.

Recommendations for daily on/off cycling for the once-through boiler (Level 3) would include the Level 1 upgrades but require extensive design changes that include changing the furnace to a spiral or a low mass flux vertical tube once-through boiler design and replacing the startup system to full pressure separators which include a recirculation pump. Even with these design changes, unless provisions are made for feedwater heating prior to ignition to minimize thermal shocking of the boiler, fatigue damage is likely to occur over the long term.

The recommendations apply to either subcritical or supercritical once-through boilers. The study work did not address the problems that cycling may cause to the turbine-generator or to other plant equipment.

Subcritical Drum Boilers

Operating B&W drum boilers exist in a wide variety of sizes, configurations, and details of construction. This variety is due to a number of design influences that existed at the time of the boiler's design. Sizes or capacities of the drum boilers has increased over the years as utility systems have increased in size. Due to either design necessity or economic pressures, the size changes have dictated different configurations and details of construction.

Drum boilers built before 1980 were essentially designed for base load service, with load cycling down to some contractual lower load (normal control range). The design evaluations of these pre-1980's boilers were made primarily on the basis of operating characteristics at high loads. Competitive pressures at the time dictated that cycling would be considered second when making design decisions. As a result, most of these boilers now in use have details of construction which may not be ideal for cycling service. Boilers built after 1980 were also designed to a normal control range and some were specifically designed for minimum load consideration and had no real limits that would restrict cycling. Some of these units were designed for on/off cycling. However, there were issues with rate-of-change limits.

Because of the wide variety of designs in service, drum boilers cannot usually be considered generically for the effects of cycling. Instead, it is more meaningful to look at certain components of the boilers that are identified by experience and design analysis as potentially being more vulnerable to cycling service. These will be discussed from two standpoints: (1) operating methods to minimize cyclic damage, and (2) design modifications to increase tolerance to cyclic conditions. With an understanding of these options, operators can decide what specific investigations are necessary for choosing the most suitable options for their requirements.

This paper will consider only pressure part components of the boiler. Non - pressure parts, such as casing, vestibules, windboxes, flues and ducts, are also greatly affected by cycling service. While their failure (leaks) is more tolerable than failure of pressure parts, non-pressure part to pressure part connection design is very important to avoid pressure part failures. Construction methods and remedies for non-pressure parts have even more variation than pressure parts and thus, are beyond the scope of this discussion.

Subcritical drum boilers are quite adaptable to cycling service. However, if extended service in such an operating mode is anticipated, each component of the boiler should be reviewed individually for possible "weak spots" in its cycling tolerance. Relatively simple modifications may be engineered to overcome these weak spots which operational changes cannot avoid.

Water shock areas of the boiler's components should always be reviewed. High temperature components should also be reviewed because of the interaction of cycling stresses and creep damage. Dual (constant boiler furnace pressure/variable superheater pressure) or variable pressure operation should be considered because of its advantages for the turbine and boiler cycling. Variable pressure is very important to the turbine, but not an advantage for the boiler furnace, thus dual pressure is best for both the boiler and the turbine. Variable pressure operation may be constrained due to heat absorption changes and other design considerations. But if the boiler furnace is operated at essentially constant pressure with either constant throttle pressure or dual pressure, there should be no issues.

For on/off cycling, a B&W drum boiler startup system that includes division valves for dual pressure operation (constant pressure in boiler furnace with variable pressure main steam pressure), steam attemperators, and steam drum dump to the condenser for boiler-turbine temperature matching can be added for obtaining optimum startup times with minimum thermal stress to the boiler and turbine. An additional option for on/off cycling could include a turbine bypass (referred by some as a European) system.

Critical components during load or on/off cycling are the following: (1) the inlet and outlet headers of the economizer, (2) the tube/header cracking in the lower furnace due to furnace subcooling that is caused by cooling in the furnace during shut-down and start-up, (3) high stress loadings on the steam drum due to top-to-bottom temperature differentials that lead to drum humping, (4) cracking in the superheater - reheater tube-to-header locations due to temperature differentials between the header and tube, and (5) tube leg flexibility of heat transfer surface that penetrates enclosure walls operating at temperatures (usually saturation) which are different from those of the convective heat transfer surface. Riser connections to the steam drum also need to be reviewed for on/off cycling.

Many of the component problems given above are dependent upon the change of saturation temperature during cycling. The change in saturation temperature is the greatest at low pressures so that thermal and pressure stresses do not tend to peak concurrently.

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TODAY'S CONCERNS WITH LOW LOAD AND CYCLING

The issues identified above would still be relevant for today's boilers that need to load cycle. However, today's boilers have been modified with low NO_x burners, overfire air systems and AQCS to achieve the required emission requirements for the boiler. These systems add a complexity for the boiler to load cycle and ramp at rapid rates. The following items address several of today's needs for load cycling.

Increase Economizer Exit Gas Temperature (EEGT)

For drum or once-through boilers, the necessary system or systems to maintain the economizer exit gas temperature (EEGT) at a level that will not cause problems with the AQCS on the back end of the boiler island will need to be incorporated. Additional boiler testing could be required to more accurately determine furnace exit gas temperature (FEGT) and the cleanliness effects on heating surfaces at lower loads. For boiler load turn-down from 100% to 40% MCR, economizer gas bypass, flue burners or economizer water-side bypass systems such as B&W PGG's V-Temp™ system will be required. For load turn-down from 40% to 25% MCR, the components given above could be required, alone or in combination. B&W PGG's V-Temp™ system could be enhanced in combination with a furnace circulation system. Load turn down from 25% MCR to house load (10%) would require similar combinations of the systems used for operation at 25% MCR.

Combustion and Pulverizer Issues for Flame/Combustion Stability

One of the major issues with load cycling is developing the necessary system(s) to maintain stable combustion during low load operation of the boiler. Boiler heat transfer and heat flux variations at low loads would be affected by the firing system and could require testing or computational fluid dynamics (CFD) modeling to obtain an acceptable design approach for the circulation and performance analysis of the boiler. Items that can be considered include:

- Investigate gas firing for low load conditions
- Operation with only one pulverizer and with lighter support
- Operation with two pulverizers, determine lowest possible load
- Investigate installation of smaller capacity pulverizers
- Investigate half pulverizer operation
- Investigate installing new burners

Combustion and Pulverizer Issues from 100% to 40%

Flame Stability

Essentially all of B&W's PC-fired utility boilers can turn down from 100% to 40% load without further modification and with stable flames (except lignite units). There are only a few exceptions. In many cases this will require taking one or more pulverizers out of service, which is a cost/convenience/reliability/response rate issue, not a technical obstacle. Delta cost is ignition fuel for normal pulverizer shut-down and start-up. Flame stability at 40% load is maximized by operating with fewer pulverizers in service and with burners at higher input. However, weak flames or unsteady flame scanners may require use of igniters in some cases. Dual capacity lighters could be used to save fuel.

NO_x, CO Emissions

Emission performance is slightly improved going from 100% to 40% load relative to NO_x, CO. Unburned Carbon (UBC) tends to decrease as load is reduced and excess air increases, but eventually UBC will increase due to cooler conditions.

Pulverizer Issues

Ameren (Illinois Power) Havana Station was able to cycle the mills on/off reliably using their late 1970's equipment, so most plants should be able to do it with what they have installed, but it takes training and discipline. There might be some hardware upgrades to make it easier. Havana Station had no problem with pulverizer motors, and do not believe the motor specifications were any different from typical pulverizer motor specifications. Raising the pulverizer outlet temperature set point may decrease the primary air (PA)/coal ratio, while maintaining the required volume and velocity. If the PA flow relative to coal flow at high turndown is too high, an igniter may be required.

Combustion and Pulverizer Issues from 40% to 25%

Many of our utility units, except lignite and small single-wall-fired units, can turn down to 25% load without continual igniter support. Issues with pulverizer starts/stops could be an issue at these loads.

Flame Stability

Smaller units (with 3 or less pulverizers) capable of 25% load without igniters may be forced to do so operating only a single pulverizer - however this is generally unacceptable because of the issues with a black furnace if that one pulverizer trips.

Development issues to consider are: Ignition system upgrades for less than Class I input for flame stability (or to prevent black furnace) to save auxiliary fuel; NFPA 85 issues could be a concern; and pulverizer upgrades to permit prolonged operation at reduced coal rate (to enable two pulverizers in operation) - auto loading system.

Pulverizer Issues

The Auto Spring loading system will definitely help the pulverizers tolerate low load operation. The DSVS® classifier can also increase the inventory in the pulverizer, reducing low load vibration issues, and provide an improved size distribution. Modifications to the pulverizer and PC piping to separate some of the primary air at the top of the pulverizer could be considered to richen up the mixture during half pulverizer firing.

Emissions

NO_x can be controlled by combustion down to about 40% load with proper tuning and controls.

NO_x will increase as load drops from about 40% to 25% - in this case, the SCR goes out of service (or could remain in service with a modified system to increase the exit gas temperature from the boiler); and NO_x from the boiler increases unavoidably due to higher excess air to comply with NFPA minimum air requirements - so over fire air (OFA) systems and low NO_x burners become ineffective. For some units, the NO_x increase will be moderated as thermal NO_x contribution diminishes - especially for large, hot units. NO_x reduction then primarily relies on the SCR.

CO typically will drop from 40% to 25% load. This could depend on burner combustion.

UBC varies - increases due to incomplete combustion as the furnace cools. UBC is also dependent on coal type and furnace size.

Combustion and Pulverizer Issues from 25% to House Load About 10%

Flame stability/incomplete combustion

There are dual issues of minimum pulverizer capability (the issue with 1 or 2 pulverizers described above) and corresponding thermal input to the unit, plus a need for auxiliary fuel for flame stability. There is a continued issue with pulverizer starts/stops, and a related issue with ramp rate to increase firing rate constrained by bringing mills into service. For multi-unit plants, it would likely be better to take one unit to hot standby and keep the operating units at or near 40% load. The turbine heat rate will not be very good below 25% load.

Development items for consideration: Significant scope adder - for a mini-milling system, e.g., 2 B&W® EL pulverizers, feeders, bunkers, PA system - decide on direct or indirect fired, and supplemental burners to reduce coal rate to under 10% of rated boiler input. Use very high fineness to reduce UBC in flyash.

Pulverizer Issues

For low load burners and auxiliary burners, an indirect system could be considered. An indirect system separates pulverization from fuel delivery and combustion, providing flexibility of design and operation that might have great value for low load operation.

Emissions:

NO_x - pre-combustor exhausting into the main furnace to control combustion environment and lower NO_x—still an issue without an SCR.

CO - expected to be similar to values at 25% load or will drop with load. This could depend on burner combustion.

Unburned combustibles - without a precombustor, can expect significant carbon carryover.

Superheater/Reheater Issues

Maintain Acceptable SH/RH Temperature Margins

Keeping acceptable SH/RH temperature margins could require modification of the boiler to minimize the temperature differential between the superheater and reheater as the boiler operates at the lower loads. Boiler heat transfer at low loads below 40%MCR will be affected by the firing system and the design aspects of the heat transfer surface. A means of compensating for the temperature variation will be needed. Minimizing the SH/RH temperature differential across the load range could require a specialized bypass system or other operational changes. Consideration of variable throttle pressure or dual pressure operation might be necessary. Much of the allowable steam temperature variation will depend on the turbine. Variable pressure operation can solve many of these issues but the boiler could require larger superheater attemperators.

Spray Attemperator Issues

Spray attemperators are another component within the superheater and reheater system that is exposed to severe thermal cycling duty. Cracked and broken nozzles and liners can introduce material into the steam lines that can result in unexpected down-time. Pieces of broken attemperator can become lodged in the piping and block tube openings in downstream headers. Blocked flow paths can result in tube overheating and failures. Broken attemperator components also reduce spray water/steam mixing efficiency.

Header Ligament Cracking

Header ligament cracking is another problem that can be associated with heavily-cycled boilers. Superheater and reheater headers subject to load cycling have exhibited extensive ligament cracking. Creep swelling and thermal fatigue are two major failure mechanisms that contribute to ligament cracking. Although failures and life cycle of the component are related to both mechanisms, examination techniques are available for evaluating each one separately.

Superheater/Reheater Flexibility

Units provided today for cycling duty have many elements designed into them that reduce the effects of thermal cycling. "Flexibility" refers to the ability of a component to move, either expanding or contracting. Greater flexibility will result in less restraints and lower operating stress levels. Units that have been designed for base load operation may have relatively inflexible designs, especially at the junction of pressure parts that may have significantly different temperatures during start-up/shut-down operation. Fatigue failures have occurred in header tube legs and drum connections with relatively inflexible designs. Tube leaks near the tube-to-header connection are indicative of tube leg flexibility problems. In many cases failure occurs on the tube side of the tube-to-header weld. Outboard tubes are often more susceptible.

In determining the cyclic life of an existing boiler, the limiting factor is the effect of differential expansion between the header and the roof or wall tubes on the header's tube legs. This difference in motion occurs due to the temperature difference between the header and the roof or wall tubes at the various load conditions. The headers and roof tubes are usually made of two different materials which will expand at different rates. The tube legs also experience the external forces and moments which act on the header due to the expansion of the steam piping.

Circulation Issues with Minimum Flow/Furnace Protection

At the lower operating conditions, the circulation of the boiler must be capable of safely operating without tube failure issues. Drum and once-through boilers will need to be investigated for different burner firing combinations and variable pressure operating conditions. Drum boilers may be susceptible to flow stability issues at low loads especially below 40% load. For the older open pass units with roof burners in the furnace, stability can be an issue with the slag screen wall when operated at lower loads. Also the oil- and gas-fired drum units may experience corrosion failures due to flow stability in the baffle wall. These problem issues with flow stability can be easily resolved through a low load boiler circulation analysis.

Once-through boilers will be susceptible to minimum flow issues at low loads especially when the units have been retrofitted with low NO_x firing systems. For once-through boilers considering lower load and/or cycling operation, the items that would be considered are: (1) furnace replacement with MLR tubing, (2) incorporate multiple (doubling) furnace passes, (3) upgrade the startup system, (4) convert to spiral enclosure with vertical separators and circulation pump, and (5) convert the vertical tube unit by installing vertical separators and pump.

Other circulation related issues are furnace sub-cooling and economizer thermal shocking. Both of these issues are more common on drum boilers.

<u>Furnace Subcooling</u>

Several boilers have suffered tube cracking in the lower furnace area after a period of on/off cycling operation. Generally, tube leaks have occurred after about 400 cycles. The longitudinal cracks form on the cold, inside surface of the tube and propagate through the wall, resulting in leaks on the casing side of the tube. Usually the first area where tube leaks occur is in the lower windbox or vestibule attachment. Cracking has also occurred at the upper windbox attachments where lugs have been welded on tubes and at hopper tube bends.

The cause of the problem is typically a combination of thermal cycling and high stress areas. The thermal cycling is the result of cooling in the furnace during shut-down and start-up. When the boiler is shut-down and bottled up for the off-line period, the entire furnace is at, or near, saturation temperature. During the bottled-up period, some heat will be lost and the boiler water will cool off, with cooler (subcooled) water collecting in the lower section of the furnace tubes. Thus, there will be a temperature gradient from the lower to upper furnace. When flow in the furnace is initiated after the shut-down period, the hot water displaces the cold water – resulting in a thermal cycle. The greater the temperature difference, the greater the shock. The magnitude of the temperature stratification, the number of cycles, and water treatment problems can all help to shorten the time to failure. Residual stress from welding and the degree of restraint on the tube act together to cause and determine the time of failure. Design modifications are available to solve this problem.

Economizer Thermal Shocking

Another area of the boiler that is susceptible to thermal cycling and fatigue failures is the economizer inlet header. During shutdown periods, the economizer temperature equalizes to the boiler outlet temperature. To maintain drum level, colder water is periodically fed through the economizer to the drum. The temperature difference between the economizer components and the cooler feedwater produces a thermal cycle. This temperature cycling may result in thermal fatigue failures, which have primarily occurred in the economizer inlet header-to-tube stub areas. Economizer inlet header crack initiation and propagation can be enhanced by the presence of oxygen pitting on the inside surface of the header. Design and operational solutions for this problem are available.

Ramp Rates and Other Issues with Turndown

Issues due to increased ramp rates become important when turndown and load cycling are used for a unit to quickly respond to changes in the grid. Investigating the effects of increased ramp rates would require extensive evaluation of all the areas discussed in this paper. It is expected that different rates could be acceptable depending on the load point from which the ramp is started and the desired end point. Issues with the startup system, feedpumps and steam temperature matching will need to be addressed. For better reliability, duplicate startup system valves could be required if the unit is to operate daily or frequently on the startup system. Control system improvements to better accommodate good control of rapid load change could also be required.

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CONCLUSIONS

Conventional fossil fuel-fired boilers can meet the demands of utility systems for rapid and wide variations in load, including complete shutdown and restart. One should expect that the heat rate will suffer at low loads, especially at very low loads. There is not much that can be done about this issue; therefore one should expect low load operation to be inefficient. In addition, cycling of the unit will reduce the operational life of the components. To minimize the damage of each cycle, proper design and operation is required so that the unit can operate effectively for an expected number of cycles.

For optimum results, some new strategies, equipment, controls and operating methods will be required. The emphasis of this paper is on cycling and load change. Each boiler will require a special evaluation to determine the best modifications to meet the cycling requirement weighed against the cost of modification of the unit. In most cases, operation of the boiler down to 40% load will require minimal modification for reliable and successful operation.

For lower loads and an increase in load change rates, testing and an investigation of the boiler to identify the critical components of the boiler will be required. Many features of the current design for start-up and the boiler's startup system will very likely be retained but could require additional supplemented provisions. These boiler modifications will be more extensive and development of new strategies could be required.

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ISSUES VS. LOAD MATRIX

Boiler Load %

	Component/ System	100-75	75-40	40-25	25-0		0-25	25-40	40-75	75-100
Boiler	Fans			?	X		X	?		
	Pulverizers			?	X		X	?		
	Burners			?	X		X	?		
	Air Heaters			?	X		X	?		
	Furnace			X	X		X	X		
	Superheater		?	X	X		X	X		
	Reheater		?	X	X		X	X		
	Economizer				X		X	X		
	Drum				X		X	X	?	
	Start-up System				X		X	X		
	Attemperators			X	X		X	X		
	Control System			X	X		X	X		
Environmental	SCR		?	X	X		X	X		
	Particulate Collection				?		?			
	Precipitator				?		?			
	Baghouse				?		?			
	SO_2 Control				?		?			
	Wet FGD				?		?			
Balance of Plant	Turbine				X		X			
	Condenser				X		X			
	Feedwater Heating				X		X			
	Boiler Feed Pumps				X		X			
	Water Quality						X			
	Fuel Handling				X		X			
	Cooling Water				?		?			
	Duct Work and Expansion Joints			X	X		X	X		

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