How does Wind affect Coal (Cycling, Emissions and Cost)
Outline

- Analysis of cycling costs
- Why analyze cycling damage and costs
- Damage mechanisms of cycling
- Cycling costs
- Reducing cycling costs
- Locating failures
- Cost of cycling estimates
- Study scope with protocols(Psco)
- Mitigation strategies
Analysis of cycling costs

- What is cycling?
- This process is damaging to power generation equipment.
- A comprehensive analysis conducted on more than 150 coal fired units shows that the financial costs associated with cycling operation are very high. Analysis of selected older coal fired plants has found them to be more cost effective to cycle than the newest combined cycle units.
- Even if a unit is designed for cycling, there are external factors that lead to cycling costs.
- Cycling units should be subjected to a thorough analysis of their cycling operations to optimize and determine the true cost of each operation.
Why analyze cycling damage and costs?

- Knowledge of operating costs in real-time is critical to the competitive power business.
- High profit times and low power price periods.
- Passing the high cost to cycle power plants on to competitive utilities, by not cycling on/off or going to two-shift operation for specific units with low cycling costs, is an effective competitive strategy when cycling costs are analyzed.
- APTECH has analyzed the cycling costs in more than 300 power-generating plants, Many of the units were being operated at or above the unit’s maximum continuous rating operation (MCR).
- Although running a plant above MCR may be costly, it can save a rapid costly start up on another unit in the fleet.
Damage mechanisms of cycling

- Definitions of cycling have varied from on/off starts, (normally defined as hot, warm, and cold starts)
- Hot starts—700 to 900F boiler turbine temperatures—8 to 12 hours offline.
- Warm starts—250 to 700F—12 to 48 hours offline.
- Cold starts—<250F—48 to 120 hours offline.
- Often the damage mechanism is fatigue and corrosion of the boiler tubes.
- The time to failure from cycling in a new plant-5 to 7 years; older plants-9 months to 2 years after start of significant cycling.
Relative damage caused by cycling steam plants; Courtesy: Intertek-Aptech
When plant loads change, the consequences are numerous. All of these consequences can force the unit to operate away from the original design point. A few important material damage mechanisms are responsible for the majority of the financial impacts caused by operating coal plants in flexible modes. Examples of these damage mechanisms follow:

- **Thermal Fatigue**: This phenomenon can produce cracking in thick-walled components, especially castings such as turbine valves and casings.

![Cracked header. Cold feed water introduced to a hot header caused the crack in this economizer header; courtesy: EPRI](image-url)
• Thermal expansion: Several systems in a coal plant consist of components that undergo high thermal growth relative to surrounding components. The most important example of this phenomenon is the large movement of boiler structures relative to the cooler support framework.

Tube-to-header cracking caused by thermal transients is shown in this photo. Variation in tube thermal expansion, caused by differences in tube length, increases stress in some tubes; Courtesy: EPRI
Two-shifting, or any other operation that challenges the ability of a plant to maintain water chemistry, can lead to increased corrosion and accelerated component failure. Increased levels of dissolved oxygen in feed water can be the result of condenser leaks, aggravated by more-frequent shutdowns.

Waterwall damage caused by corrosion fatigue is often found in steam generators.;Courtesy: EPRI
Cycling Costs

- The overall range of cycling costs, compared with commonly assumed costs is shown in Figure:

  ![Study Objective](image)

  **“Quantify True Unit Cost Per Cycle”**

<table>
<thead>
<tr>
<th>Unit Type</th>
<th>Typical Industry Value (without consideration of true costs)</th>
<th>Potential Range of Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small Drum</td>
<td>$5,000</td>
<td>$3,000 – $100,000</td>
</tr>
<tr>
<td>Large Supercritical</td>
<td>$10,000</td>
<td>$15,000 – $500,000</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>$100</td>
<td>$300 – $80,000</td>
</tr>
</tbody>
</table>

Quantifying true unit cost per cycle

- This includes all types of cold, warm and hot starts for the units of the system.
The increased incremental costs attributed to cycling fall into the following categories:

- Increases in maintenance and overhaul capital expenditures.
- Forced outage effects, including forced outage time.
- Cost of increased unit heat rate, long-term efficiency and efficiency at low/variable loads.
- Cost of startup fuels, auxiliary power, chemicals and additional manpower required for unit startup.
- Long-term generation capacity costs increase due to a shorter unit life.
Reducing cycling costs

- The plant’s signature data is analyzed during cycling operations and recommendations are made for

  - Operational changes - include modifying temperature ramp rates of key components; to increase unit response and to decrease damage and costs, the ramp rate during cycling should be decreased.

  - Hardware modifications - include short term monitoring of thermocouples and additional monitoring of equipment; include longterm modifications such as boiler tube supports, pump valves/orifices, pulverizer monitor.
Locating Failures

- Few conventional steam plants were designed to follow load, cycle from minimum to full load every day, or shut down and start up daily.
- The challenge for owners of plants required to operate in this way is to fully understand the effects on plant and component life expectancy, and the actual costs, of these new operating profiles.
- If the actual costs are unknown, making a profit becomes a matter of luck rather than good management.
- In a competitive electricity market, not knowing the true generating costs could place the plant or the company in economic jeopardy.
- For example, if the actual cost of cycling a unit is not included in the bid price, and the plant must cycle, not only there is no compensation for unknown damage to plant equipment, but also the plant is not being compensated for future maintenance and unplanned repair outages.
Common problems in cycling plants. A survey of 215 steam plants found many common equipment problems; Source: Intertek-Aptech
The following are examples provided to show magnitude of systems and components within a typical coal-fired plant designed for base load operation that are affected by cycling and load-following service.

1. Tube bending. Thermal forces bowed and permanently bent this boiler super heater tubing, including the water-cooled support tube and clips; Courtesy: Intertek-Aptech
2. Corrosion fatigue damage in the steam-cooled wall in the heat recovery area is evident in this photo. The steam-cooled sidewall has a damaged economizer header penetration. Cycling caused differential thermal growth, and the penetration is badly damaged.

3. Bending corners. Boilers are typically rectangular boxes rather than round or spherical. This photo shows water wall corrosion fatigue damage at the lower furnace seal. It is an example of cycling damage at a corner or a change in shape. Courtesy: Intertek-Aptech
4. Leaky heaters. This HRSG feed water heater tube was one of many failures that resulted from cold-end corrosion during cycling. There were numerous leaks at the tube to header connection due to thermal cycling damage.
The Intertek-Aptech staff has developed two approaches to develop cycling cost estimates, the top-down estimate and the bottom-up estimate. 

Top-down estimate: Top-down estimates use historical unit operating data and historical cost data to determine the costs of cycling operations.

- The first step is to determine operating costs that include the operating, maintenance, and capitalized maintenance costs incurred by the unit, cost of fuel and chemicals for water treatment used for startups, and costs related to the increased outages caused by cycling.

- These costs are then analyzed, processed, and tallied to create annual “candidate” cycling costs for the unit.
The second step is to add cycling damage to the maintenance cost estimates. The damage the unit accumulates from cycling is determined by examining the plant’s operating records. Specifically, the hourly average power output of the unit’s generator is analyzed to count cycles (all types of cycling and load-following) and determine the historical damage that the unit has accumulated versus base load operation.

Finally, the accumulated damage and historical costs are taken to calculate a statistical “best estimate” of the cycling costs and calculate the upper and lower bounds using statistical regression techniques.
- Bottom-Up Estimates: The other cost-estimating process is the bottom-up analysis. It is referred to as a bottom-up because it starts with the detailed work order history and a review of failure events and analysis completed earlier.

- The bottom-up review includes seven to 10 years’ worth of plant work orders which include a detailed analysis of work orders by a subject matter expert (SME), Actual failure reports, overhaul records, and prior inspection reports are also checked to determine the root cause of previous failures so that the costs can be properly classified.
Psco’s Study

- The study looks at two levels of installed wind on the PSCo system.
- The 2GW case represents the approximate level of wind PSCo expects to have on the system by 2013.
- A 3GW scenario was also studied to understand the cost of adding an incremental 1GW of wind to the PSCo system by the year 2020. The study period includes the years 2011 through 2025.
- Coal unit cycling costs were calculated for each level of installed wind under two cycling protocols.
Protocol 1 – Referred to as the “Curtail” Protocol:

- All PSCo coal units are dispatched to follow changes in net load, where the net load is the obligation load minus wind generation. Each coal unit would be cycled down to its economic minimum before any wind generation is curtailed.

- If the net load decreased below the aggregate coal fleet economic minimum capacity, curtailment of wind would be required to effectively increase the net load back to the economic minimum capacity.
Protocol 2 - Referred to as the “Deep Cycle” Protocol

- Rather than curtail wind at this point if net load falls further, one or more coal units would be called upon to deep cycle.
- Wind curtailments may still be required if net load falls below the aggregate coal fleet minimum deep cycle level.

Results:
- The first result is that cycling costs do not change linearly with changes in wind penetration.
- For a fixed level of wind, cycling costs are forecast to generally decline over time.
Larger levels of wind penetration increase the size of the wind wedge (the shaded area between the load and net load lines) in the chart which increases the size, intensity and frequency of cycling event.
Strategies to mitigate cycling costs

- Operating procedures
- Maintenance procedures
- Equipment upgrade
- Wind curtailment
- Energy storage

- The first three listed above require extensive knowledge of the component history and most probable failure mechanisms.
- Equipment upgrades cover a broad spectrum of options based on initial design, current age and unit operating mode.
- Energy Storage helps reduce the rate of load change and variability over time.
Thank you!