Flexible Coal: An Example Evolution from Baseload to Peaking Plant

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Conference Track: The Evolving Coal Plant
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What are the impacts of cycling coal and gas?

0% wind and solar

16.5% wind and 16.5% solar energy penetration

Generation dispatch for challenging spring week in the U.S. portion of WECC

Source: WWSIS Phase 1 (2010)
Coal ramping increases with wind & solar

Biggest cycling change is that coal units are ramped 10 times more in the 33% cases compared to the 0% case

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html
Emissions impacts of cycling are relatively small

<table>
<thead>
<tr>
<th>Emission</th>
<th>Emission Reduction Due to Renewables</th>
<th>Cycling Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{CO}_2$</td>
<td>260–300 billion lbs, 29%–34%</td>
<td>Negligible Impact</td>
</tr>
<tr>
<td>$\text{NO}_x$</td>
<td>170–230 million lbs, 16%–22%</td>
<td>3–4 million lbs</td>
</tr>
<tr>
<td>$\text{SO}_2$</td>
<td>80–140 million lbs, 14%–24%</td>
<td>3–4 million lbs</td>
</tr>
</tbody>
</table>

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html
From a system perspective...cycling costs are relatively small

33% Wind/Solar Scenarios

Fuel Costs Avoided with Wind and Solar
$7,000 Million

Cycling Costs
$35–$157 Million

Note: Capital costs for wind and solar are not reflected.

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html
Costs can be significant from generator perspective

Fossil plant O&M increases by $0.5-1.3/MWh over no RE case

Source: WWSIS Phase 2 (2013)
http://www.nrel.gov/electricity/transmission/western_wind.html
Case study: Flexible Coal

How baseload plants can evolve to serve other system needs

- Coal plant that cycles on and off, up to twice daily
- Capital modifications critical

But primary savings came from changes to operating procedures

- Flexibility comes at a cost—but costs can be minimized with strategic modifications and maintenance

Source: Cochran, Lew, and Kumar (2013)
http://www.nrel.gov/docs/fy14osti/60575.pdf
Case study: attributes of flexibility at the plant

• Start up and shut down same day
  o Even twice daily (5-10am then 4-8pm)
• Load follow and run at minimum generation levels
  o 480 MW net capacity units running at 90 MW net
  o Down to 60 MW net (up to 6 hours) with gas support
• Provided automatic generation control
• Operated at sliding pressure (increases efficiency and flexibility at part load)
Case study: from baseload to peaking plant

• 1970’s: Commissioned
• Intended to run at 80% annual CF
• Mid-80’s: Nuclear came in lower on the dispatch stack resulting in cycling of coal (50% annual CF)
• 1980s: Extensive research on 2-shifting; modifications implemented
• 2000s: competitive market; initially operated at full output
• YET...significant forced outages due to latent damage from 1990s cycling
• Competitive market → incentive to operate flexibly (2 shift, min gen)

Photo from iStock 72283000
# Experiences with cycling

## Starts

<table>
<thead>
<tr>
<th></th>
<th>Average number of starts over life of unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cold start</td>
<td>523</td>
</tr>
<tr>
<td>Warm start</td>
<td>422</td>
</tr>
<tr>
<td>Hot start</td>
<td>814</td>
</tr>
<tr>
<td>Total</td>
<td>1,759</td>
</tr>
</tbody>
</table>

## Recent Forced Outage Rates

<table>
<thead>
<tr>
<th>Year</th>
<th>EFOR [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>14</td>
</tr>
<tr>
<td>2003</td>
<td>20</td>
</tr>
<tr>
<td>2004</td>
<td>33</td>
</tr>
<tr>
<td>2005</td>
<td>25.5</td>
</tr>
<tr>
<td>2006</td>
<td>22</td>
</tr>
<tr>
<td>2007-2009</td>
<td>16-17</td>
</tr>
<tr>
<td>2010</td>
<td>9</td>
</tr>
<tr>
<td>2012</td>
<td>20.5</td>
</tr>
</tbody>
</table>

Plant operators responded to changing market conditions. Decisions to modify the plant, replace parts, and lower EFOR were evaluated piecemeal, based on profit potential.
Cycling impacts

- **Thermal fatigue**, e.g., from cold feedwater entering boiler on startup, steam heating up, materials heating up at different rates
  - Boiler tube failures
  - Cracking in dissimilar metal welds
  - Tube cracks in condenser
- **Cracking** in generator rotors
- **Stresses** from changing pressure, e.g., turbine shells
- **Wear & tear** on cycling-only auxiliary equipment
- **Oxidation** from exposure to air on startup and draining
- **Corrosion** caused by $O_2$ entering system and changes to water quality (falling pH)
- **Condensation** from cooling → corrosion, water leakage, increased need for drainage

Photo: Cochran, Lew, and Kumar (2013)
http://www.nrel.gov/docs/fy14osti/60575.pdf
Modifications to minimize cycling impacts

Operating procedural changes

• Natural cooling
• Temperature monitoring of economizer inlet headers, turbine parts, etc.
• Changes to layup procedures
• Pressure part management
• Changes to boiler operating procedures
• Water chemistry maintenance
• Breaker maintenance
• Gap review with best practices

~90% of plant savings (post physical modifications) came from changes to operating procedures
Modifications to minimize cycling impacts

Physical changes

- **Boiler**, examples:
  - Added metal overlay to water walls to minimize oxidation
  - Replaced dissimilar metal welds
  - Strategically replaced corner tubes
- **Pulverizers** – converted water deluge system to steam inert
- **Turbines** – added drains, upgraded lubrication system
- **Rotors** – insulated key parts to reduce rotor cracking from rubbing
- **Condenser** – sacrificially plugged tubes at top of condenser due to low loads

*Note that plant had horizontal, not pendant, boiler designs and automated drains*

*Source: Lefton 2013*
Can my coal plant do this?

- **Physical distinctions**: boiler design is horizontal, improving drainage

- **Operating distinctions**: Much higher EFOR rates than most operators are comfortable with; tradeoff between maintenance costs and EFOR

- **Regulatory distinctions**: Can run plant without SCR up until SCR minimum generation level

- TVA is cycling coal because of cheap gas and lighter loads. e.g., 1420 MW Kingston plant:
  - More starts
  - More ramps
  - Increased $ for preventive and corrective maintenance
Conclusions

- Flexibility in plant operations is an increasingly desired service as RE penetrations increase.
- Coal plant in this case study was modified to access this flexibility.
- **Key to success:** changing operational practices; tolerance for higher EFOR rates.
- Success also due to plant-specific factors, e.g., better design for drainage.
- Coal can be operated flexibly—at a cost—but these costs can be minimized through rigorous inspection and training programs.
Recently published analyses

Documents diverse approaches to integration of variable RE among 6 countries—Australia (South Australia), Denmark, Germany, Ireland, Spain, and the US (Colorado and Texas)—and summarizes policy best practices. [www.nrel.gov/docs/fy12osti/53732.pdf]

Reviews the international suite of wholesale power market designs in use and under consideration to ensure adequacy, security, and flexibility in a landscape of significant variable renewable energy. [http://www.nrel.gov/docs/fy14osti/57477.pdf]

**Flexibility in 21st Century Power Systems**
Flexibility of operation—the ability of a power system to respond to change in demand and supply—is a characteristic of all power systems. Flexibility is especially prized in twenty-first century power systems, with higher levels of grid-connected variable renewable energy (primarily, wind and solar). [http://www.nrel.gov/docs/fy14osti/61721.pdf]

**Flexible Coal: Evolution from Baseload to Peaking Plant**
This case study reviews how power plants intended to run at baseload can evolve to serve other system needs. The CGS case illustrates the types of changes that may occur in global power systems, especially those with legacy plants. [http://www.nrel.gov/docs/fy14osti/60575.pdf]
Thank you!

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