Implementing Sliding Pressure Operation

A Study in Benefits, Challenges, Design and Tuning

Presented by

Don Parker
Provecta Process Automation

Greg Alder
Scientech

August 2015
Overview

- **Historical Setting:**
  - Many base-load drum boilers in 70-90s were designed for
    - fixed pressure,
    - normal operation range 80-100%.

- **The changing operating scene:**
  - Life extension
  - Unregulated renewables
  - Economic imperatives:
    - Wider range operation
    - Fuel cost reduction
    - CO$_2$ reduction
Energy Market Challenges –
Pressures on Capacity and Performance

- Wider, more flexible operation
- Faster Ramping
- Improved efficiency at low load
Range and Performance Changes: 4x500MW Station (Australia)

Original design: 80-100% fixed pressure, 25 year life

Load range extension
Sliding pressure operation; emissions reduction
Range extension, ramp rate, biomass, reduced attendance, FCAS
Further range extension, Mill auto-bias

Possibilities:
Overload
VWO operation
Increased FCAS
Solar augmentation

% Load
0 20 40 60 80 100
1970’s 1990’s: Life extension programs 2012-13 Future
Sliding pressure

Steam Pressure

TV Posn

100%

100%

Steam Flow
Why Sliding Pressure?

- **Benefits in Unit Heat Rate at low load**
  - Reduced turbine throttling losses (wider valve opening)
  - Reduced Feed Pump Power
  - Improved Hot RH temperature attainability

- **Reduced Turbine inlet temperature variations on load changes**

- **Economic benefits:**
  - Fuel costs reduced
  - CO$_2$ emissions reduced
The Challenges

- How do I quantify the benefits?
- How do I optimise the pressure curve?
- What are the potential downsides?
  - Fast ramping → Increased drum saturation temperature changes
  - Greater fuel input variations – impacts on combustion and pulverizers
- How is the control system changed to:
  - Calculate additional fuel input requirements during ramps
  - Minimise pressure overshoot/undershoot
  - Minimise steam temperature deviations from fuel/steam flow imbalances during ramps
A Complete Solution

Known Potential Efficiency Improvement Areas

PEPSE Scenario Modelling

Benefit Determination

Controls Implementation and Tuning

UTILIZING:

Scientech’s wide industry experience

Scientech’s deep knowledge and capability

Cost model (Client); Calculations (Scientech)

Provecta’s wide controls experience
1. Quantifying the Benefits

- **PEPSE model example**
  - 550MW gross, drum boiler, fixed pressure
  - Fixed and sliding pressure comparisons at half load
  - Two pump models applied: Electric and steam-driven
  - Two Hot RH temperature scenarios for 50%, fixed pressure
    - No temperature loss (ie full HRH temperature at 50%)
    - 30 Deg F temperature loss (and recovery in sliding pressure)
  - Six 50% scenarios run:

<table>
<thead>
<tr>
<th>Model</th>
<th>HRH temp loss at 50%?</th>
<th>Fixed Pressure</th>
<th>Sliding Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elec MBFPs</td>
<td>Y</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>Elec MBFPs</td>
<td>N</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Steam MBFPs</td>
<td>Y</td>
<td>✓</td>
<td>N/A</td>
</tr>
<tr>
<td>Steam MBFPs</td>
<td>N</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
GTHR
8511B/kWh
1. Quantifying the Benefits

- **Outcomes: Turbine Net Cycle Efficiency at Half Load**
  - Case 1: Fixed Pressure HRH Steam Temp 970°F
  - Case 2: Fixed Pressure HRH Steam Temp 1000°F
  - Both cases: Sliding Pressure HRH Steam Temp 1000°F

<table>
<thead>
<tr>
<th>MBFP Model</th>
<th>Case</th>
<th>Fixed Prs</th>
<th>Sld Prs</th>
<th>% Improvement</th>
<th>Net Heat rate improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>1</td>
<td>39.88</td>
<td>40.68</td>
<td>2.00</td>
<td>168.4 B/kWh</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>40.09</td>
<td></td>
<td>1.47</td>
<td>123.1</td>
</tr>
<tr>
<td>Steam</td>
<td>1</td>
<td>40.19</td>
<td>40.80</td>
<td>1.52</td>
<td>128.4</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>40.40</td>
<td></td>
<td>0.99</td>
<td>83.86</td>
</tr>
</tbody>
</table>
1. Quantifying the Benefits

- **Cost Benefits**
  - Based on typical fuel costs $2.27/MMBTU

<table>
<thead>
<tr>
<th>MBFP Model</th>
<th>Case</th>
<th>Net Heat rate improvement</th>
<th>Saving/hr 298MW</th>
<th>Sav per unit per year @ 4h/day low load (* .85)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electric</td>
<td>1</td>
<td>168.4 B/kWh</td>
<td>$114</td>
<td>$140k</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>123.1</td>
<td>$83</td>
<td>$80k</td>
</tr>
<tr>
<td>Steam</td>
<td>1</td>
<td>128.4</td>
<td>$87</td>
<td>$85k</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>83.86</td>
<td>$57</td>
<td>$55k</td>
</tr>
</tbody>
</table>
2. Optimising the Sliding Pressure Curve

- PEPSE can quantify all scenarios

- Required load change rate will determine drum metal temperature change rate for any given pressure profile.

- Sliding pressure setpoint will be lagged:
  - To reflect boiler milling/heat release delay and steam energy storage delay.
  - Delayed pressure setpoint also minimises temperature deviations.
  - Ensure delayed pressure setpoint curve does not cause turbine governor to reach maximum at fastest ramp rate.
3. Modifying the Controls

- **Main areas affected**
  - Boiler Demand (dynamic feedforward; pressure controller)
  - Pressure setpoint
  - Steam temperature (gain adaptation and feedforwards)

- **Design changes**

- **Response analysis tests**

- **Simulation and tuning**
Unit Coordinated Mode (BF+MW)
Load changes in Fixed and Sliding Pressure (simulations)
Design Basis: 2-DOF Controller

- A 2-Degree-of-Freedom structure provides control parameters to independently manipulate both setpoint and disturbance responses.
- Simpler structures do not model the expected process response into the setpoint, nor provide model-based feedforward dynamics.

![Diagram of 2-DOF Controller](image-url)
Model-based Sliding Pressure Control

- **Simulation results showing the effect on pressure response (light blue) when**
  - a feedforward to fuel (green) is added to the fuel demand and
  - the pressure setpoint is passed through a second order lag.

Basic control structure (left) and 2-DOF structure (right).
Pressure Setpoint (Response Model) Dynamics

- **Simplified pressure model:**

  ![Diagram of pressure model](image)

  - Turbine CV position
  - X
  - Steam flow
  - Fuel Demand
  - Grinding and Heat release delay
  - Boiler energy storage
  - Steam Pressure
  - Integ.

- **Field Data:**

  ![Graph 1](image)  
  Step change in fuel flow (CV fixed)

  ![Graph 2](image)  
  Step change in Throttle Valve position
Pressure Setpoint Formation

- **The sliding pressure setpoint is dynamically modified to minimise:**
  - Pressure controller over-correction
  - Steam temperature disturbances.

- **Three setpoint model components:**
  - Initial pressure change as governor moves before fuel has any impact on steam production (pressure direction reversal)
  - Delay to pressure changes due to energy storage in metal and waterwalls as the saturation temperature changes
  - Delay in heat input from the additional fuel due to milling, combustion and heat transfer processes
Pressure Setpoint Formation

- **Model-based pressure setpoint**

- Identification tools used to determine parameters

- Need to ensure sufficient throttle valve ‘headroom’ for fastest ramp rate.
System Identification: Boiler Energy Storage
Unit Master Modifications

- Add static Setpoint curve
- Delay P-SP
  - (model based)
- Add overfiring transient component

** Dyn - adaptive transient overfiring
Tuning

- **Pressure-ramp tuning – overfiring calibration**
  - Initial settings from energy storage models
  - Set procedures followed to optimise

- **Load-ramp tuning – dynamic setpoint calibration**
  - Low/mid/high range ramps
  - Load-based adjustments around model data

- **Steam temperature – attemperator outlet temperature setpoint feedforward calibration**
  - Based on steam/fuel dynamic mismatch
  - Iterative: spray flow affects pressure response
Load ramping

SH and RH Temps
Fuel Demand
Main Steam Pressure and SP
Turbine Master
Overfiring signals
Conclusion

- Low load operation is expected to become more prevalent as renewable penetration increases.

- PEPSE has shown Sliding Pressure can provide significant
  - Cost savings
  - CO₂ reduction
  - Reduction in turbine inlet thermal cycling.

- Model-based DCS design provides fast ramping with minimal disturbances.

- Use of advanced identification and tuning tools minimises optimisation time.