Flexible operation of Thermal Power Plants – OEM Perspective and Experiences

Sandeep Chittora, Power Generation Services, Siemens Limited
# Table of content

- Technology Development at Steam Power Plants
- Capacity, Demand and Supply
- Market requirements for flexible operation
- Technical background: transient operation
- ST measures to improve transient operation
- ST measures to improve part load operation
- Measures for fast load ramping
- Monitoring systems
- reference
## Technology development of steam parameters

Reference examples state-of-the-art efficiency

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPP Bergkamen</strong></td>
<td>747 MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SPP Boxberg</strong></td>
<td>906 MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SPP Yuhuan</strong></td>
<td>1,000 MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Lünen</strong></td>
<td>812 MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Pingshan II - Double Reheat</strong></td>
<td>1350 MW</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure (bar)</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190 bar</td>
<td>530 / 530</td>
</tr>
<tr>
<td>260 bar</td>
<td>540 / 580</td>
</tr>
<tr>
<td>262 bar</td>
<td>600 / 600</td>
</tr>
<tr>
<td>270 bar</td>
<td>600 / 610</td>
</tr>
<tr>
<td>325 bar</td>
<td>610 / 630 / 630</td>
</tr>
<tr>
<td>350 bar</td>
<td>700 / 720</td>
</tr>
</tbody>
</table>

1) Gross efficiency achievable with this technology – offered

Restricted © Siemens AG 2017
Market requirements
Generation scenario in Germany and India

Development of capacity of renewables Germany

Installed capacity ~ 50% in 2014!

Installed Generation Capacity India (GW)

<table>
<thead>
<tr>
<th>Month</th>
<th>Coal</th>
<th>Nuclear</th>
<th>Gas</th>
<th>Hydro</th>
<th>Renewables</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mar-01</td>
<td>61</td>
<td>10</td>
<td>3</td>
<td>25</td>
<td>45</td>
</tr>
<tr>
<td>Mar-11</td>
<td>94</td>
<td>18</td>
<td>38</td>
<td>40</td>
<td>186</td>
</tr>
<tr>
<td>Jan-14</td>
<td>139</td>
<td>40</td>
<td>20</td>
<td>43</td>
<td>304</td>
</tr>
<tr>
<td>Jul-16</td>
<td>186</td>
<td>43</td>
<td>25</td>
<td>6</td>
<td>193</td>
</tr>
<tr>
<td>Oct-17</td>
<td>330</td>
<td>25</td>
<td>6</td>
<td>60</td>
<td>330</td>
</tr>
</tbody>
</table>
Anticipated Scenario in 2022 with 100 GW Solar & 60 GW Wind

<table>
<thead>
<tr>
<th>Lower Technical Minimum</th>
<th>Primary and Secondary frequency Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faster Ramp up</td>
<td>Faster Ramp down</td>
</tr>
</tbody>
</table>
Technical background: Transient Operation
Recent Findings at a Highly Cycling Unit (operated outside limits)

Main steam valve

Crack depth: 50% wall thickness
Siemens Fleet in India

<table>
<thead>
<tr>
<th>KWU 200 / 210 MW</th>
<th>HP</th>
<th>M30-25</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>IP</td>
<td>M30-25</td>
</tr>
<tr>
<td></td>
<td>LP</td>
<td>N30-2x5m²</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>KWU 500 MW</th>
<th>HP</th>
<th>H30-63</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>H30-100</td>
<td></td>
</tr>
<tr>
<td></td>
<td>IP</td>
<td>M30-50</td>
</tr>
<tr>
<td></td>
<td>M30-63</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LP</td>
<td>N30-2x10m²</td>
</tr>
</tbody>
</table>

Modernize existing plant with flexible operation as key element to them
Market requirements:
Changed operational regimes require highly flexible products

- Fast Start-up
- Primary Frequency Response
- Secondary Frequency Response
- Peak Power & Off-Frequency
- Part-load
- Fast shutdown
- Prepare for start-up

- Flex Operation Line
- Standard Operation Line

- Power on Demand
- Grid Services
- Minimum Part Load
- Maintenance Flexibility

- 30+ Products

- ST Stress Controller
- SPP Hot Start On The Fly
- HP internal bypass cooling
- Advanced Fast Loading
- ST EOH Counter 4.0
- Low Loss Start
- Fast Start / Hot Start

- Advanced Fast Loading
- Primary Frequency Response
- Condensate throttling
- Dispatch Control
- Maximum Load Plus

- HP Turbine with Last MS-Valve
- Partial Bypass Concept
- Part Load Optimization Package
- Minimum Load Reduction
- Top Feedwater Heater

- Fast Preservation
- Fast Cooling
- ST Hot Standby
- FMS

- Power Generation Services
Power on Demand
Reduction of Wall Thickness to Improve Start Up & Cycling Capabilities

Example: Reduced Casing thickness & reduced thermal piston loading by HP bypass cooling

Significant improvement in LCF

![Diagrams and graphs showing load in % over time with and without internal bypass cooling.](image-url)
Power on Demand
Monitoring of flexibility consequences: steam turbine EOH counter 4.0

Task
• Part load may lead to steam temperature changes, especially hot reheat temperature
• Thermal stresses during operation are not considered in standard counting of equivalent operating hours (EOH counter)
• Maintenance needs may not be recognized

Solution
• Evaluation of operational history
• Implementation of a state of the art EOH counter considering load changes

Benefits
• More accurate EOH counting
• Improved outage planning
• Enhanced operational flexibility

I. Generation
EOH consumption is a function of actual thermal stress

II. Generation
Introduction of three start-up modes with fixed EOH consumption

III. Generation
EOH counting also considering load changes

IV. Generation
EOH counting also considering load changes
Grid Services
Measures for fast load ramping

1. Throttling
2. Additional valve
3. Condensate throttling
4. HP heater
5. Fuel increase

Diagram showing the process flow with various components such as steam generator, extraction steam valves, fast control butterfly valves, fast condensate control station, condenser, feed water pumps, and HP feed water heaters.
Grid Services
Increase turbine swallowing capacity to use boiler storage

a. Remove throttling of control valves
b. Opening of last main steam valve

![Diagram showing the process of grid services with flowchart and graph]

[Graph showing efficiency with labels for different states of the main steam valve and different throttling states.]
First Condensate throttling based primary frequency control in India

- Enlarge storage volume
- Fast condensate control valve
- Fast control valves in LP extractions

NTPC Dadri Stage II – Unit #6  490 MW
Grid Services
Example for grid code compliance

![Graph showing grid code compliance](image)

- Opening of CV
- Condensate throttling
- Fuel increase
- Closing extractions #8 & #7
- Additional Spray Flow (1.0% MS, 3.5% RH)
- Sum of Measures

95% Load; with Condensate Throttling

2.5%
Further solutions for flexible operation
Minimum Load Reduction

Task
To upgrade the plant so that the specified minimum load level can be reduced and to make the plant capable of fast and low-stress load increases on demand in accordance with market requirements.

Solution
- Use of robust state space controller for unit control
- Adaptation, optimization and setting of lower-level controls for new minimum load level
- Adaptation or addition of control sequences, burner and mill scheduler
- Provision of additional instrumentation where necessary

Benefits
- Reduced financial losses during off-peak periods
- Faster response to increased load demands as unit does not need to be shut down
- Avoidance of unnecessary startups and shutdowns

The Minimum Load Reduction solution results in savings for minimum load operation through optimization of lower-level controls.
Part Load: Efficiency improvement
Top heater for improved heat rate and lower NOx emissions

- Steam from stage bypass connection
- Is activated at part load
- Final feed water temperature vs. load constant or even increasing
- HR improvement of ~ 0.6% @ 50% load

Wai Gao Qiao 3, China 2008, 1040MW
Part Load Optimization:  
Centralized frequency variable power system

Solution: feed frequency variable turbine from main turbine extractions, supply frequency variable power to motors of fans and pumps.

- House power rate has been reduced from 3.5% to less than 2% (SCR and FGD included)
- Higher reliability compared to conventional electronic frequency convertors
Online calculation of Boiler Fatigue Components is possible

Both Creep Fatigue and Low cycle fatigue calculated

Depending upon the actual operating mode, residual life of critical components is determined
Maintenance Flexibility
Fatigue Monitoring System

How much fatigue is it?

Don’t Guess when you can actually measure it
## Further I&C solutions for flexible operation

Reference case: DCS Retrofit in Neurath Units D and E

- **2 x 600 MW units, lignite fired**
- **Built 1975**
- **Originally designed and run as base-load plants**

### Reference Case: DCS Retrofit in Neurath Units D and E

#### Starting Situation

<table>
<thead>
<tr>
<th>Load Gradient</th>
<th>Minimum Load (Gross)</th>
<th>Primary Frequency Control (PFC)</th>
<th>Secondary Frequency Control (SFC)</th>
<th>Simultaneous PFC and SFC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 MW/min</td>
<td>440 MW</td>
<td>18 MW by throttling of inlet valves</td>
<td>n.a.</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

#### Contract

- Primary Frequency Control (PFC): 18 MW by throttling of inlet valves

#### Proven (Trial Run)

- Minimum Load (Gross): 290 MW
- Primary Frequency Control (PFC): 18 MW by condensate throttling

#### Further Possible Potential

- Minimum Load (Gross): 270 MW (w/o bypass operation)
- Primary Frequency Control (PFC): 45 MW
- Secondary Frequency Control (SFC): 66 (75) MW

### Load Gradient

- **Minimum Load (Gross)**
  - (w/o bypass operation): 250 MW
  - (with risks, e.g. minimum fire interlock): 270 MW

### Frequency Control

- **Primary Frequency Control (PFC)**: 18 MW by throttling of inlet valves, 18 MW by condensate throttling
- **Secondary Frequency Control (SFC)**: 66 (75) MW, 100 MW

### Simultaneous PFC and SFC

- **Still under investigation**

### Contractual targets considerably exceeded!
Further I&C solutions for flexible operation
Selected references

### Frequency & Dispatch Control

**Altbach, Germany**
420 MW, hard coal:
5% in 30 s up to 100% load
(with turbine & condensate throttling + partial deactivation of HP preheaters)

**Dingzhou, China**
600 MW, hard coal:
Boiler delay reduced from 180s to 40s for load ramps up to 4%/min (with throttling)

**Dadri, India**
490 MW
35 MW (~7%) in 20 s
(with condensate throttling + HP reserve)

### Reliable and efficient start-ups

**Franken I, Germany**
383MW, gas, built 1973:
20% reduction of start-up costs

**Steag Voerde, Germany**
700 MW, hard coal, built 1985:
Minimum sustainable load w/o oil support and bypass reduced from 280 (40%) to 140 MW (20 %)

### Reduced minimum load

**Callide, Australia**
420 MW, hard coal:
Max. load +10 %
1,400 h/year max. load through controlled HP bypass deactivation
Contact information

Sandeep Chittora
Advisory Expert – Steam Turbine Performance
Siemens Limited, India

Phone: +91 124 2842650
Mobile: +91 9971170337
E-mail: sandeep.chittora@siemens.com

siemens.com