Efficient operation at part load – The need of hour
Sandeep Chittora, Power Generation Services, Siemens Limited
Plant Optimization
Flexibility is the new efficiency

**Reduced Electricity Production Cost and Increased Competitiveness** *

- **Reducing technical minimum plant load**
  - Down to 30%
  - 16 MW more
  - Improved I&C and combustion for stable operation at lower loads

- **Increasing Efficiency and Performance (MW)**
  - 3x higher
  - Higher ramp rates up to 15MW/min
  - @ 75% load, including aging recovery effects by new hardware in HP and LP turbine at constant coal consumption

- **Improved Ramp Rates**
  - An improved efficiency leads to lower CO₂ emissions!

- **Reducing CO₂ Emissions**
  - Up to 5% lower
  - Reduced startup-times and earlier power productions by improved I&C and hardware measures

- **Reduced Costs for Starting and earlier Power Production**
  - >60min earlier

**A Balance of Plant (BoP) Optimization makes a significant contribution to economic values**

*Values are based on a 500 MW reference steam power plant*
Plant Optimization
Total Plant Evaluation is key for successful operation in deep part load

Balance of Plant (BoP) Assessment for Boiler, Condenser, Steam Turbine & Auxiliaries

Boiler
Fuel Supply
Instrumentation & Controls
Combustion Concept & Operation
Thermal Design
Fans and Pumps

Turbine
Blading
Operation
Steam Seal
Drains

Condenser
Terminal Temperature Difference (TTD)
Condensate Pump

Boiler Feed Pump (incl. Motor or turbine drive)
Feed Water Heaters

Steam Piping System
Cooling Water System
40% Technical Minimum is Possible – NTPC Dadri

UNIT LOAD

MS TEMP & RH TEMP

<table>
<thead>
<tr>
<th>Cond.</th>
<th>M %</th>
<th>Ash%</th>
<th>C %</th>
<th>H %</th>
<th>N %</th>
<th>S %</th>
<th>O %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air dried</td>
<td>4.03</td>
<td>37.29</td>
<td>43.63</td>
<td>3.26</td>
<td>1.01</td>
<td>0.35</td>
<td>10.43</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>GCV (kcal/kg)</th>
<th>VM%</th>
<th>Ash %</th>
</tr>
</thead>
<tbody>
<tr>
<td>3000</td>
<td>22%</td>
<td>35%</td>
</tr>
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</table>
Influence on Ramps on Temperature Transient

UNIT LOAD

\[\Delta T = 1 \text{ K/min}\]

MS TEMP

\[\Delta T = 1 \text{ K/min}\]

HRH TEMP

\[\Delta T = 1.5 \text{ K/min}\]
Lower technical minimum is better than two shift operation

Comparison of life consumption based on cold, warm and hot start

<table>
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<tr>
<th>Start</th>
<th>Life Consumption</th>
<th>IEC 45 permissive</th>
</tr>
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<tbody>
<tr>
<td>Cold Start</td>
<td>23 – 75 hours</td>
<td>100</td>
</tr>
<tr>
<td>Warm Start</td>
<td>15 -17 hours</td>
<td>700</td>
</tr>
<tr>
<td>Hot Start</td>
<td>10 -12 hours</td>
<td>3000</td>
</tr>
<tr>
<td>Load Change</td>
<td>3 hours</td>
<td>-</td>
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Incremental O&M costs

- 100% Base Load
- 120% Technical Minimum
- 140% 2 shift
- 155% 2 shift
- 170% 2 shift
Transient Operation (Ramp Up / Ramp Down)
increased temperature gradient results increased life consumption

Main steam valve

Crack depth: 50% wall thickness
Time for crack initiation

Operational Strategy

- Part load may lead to steam temperature changes, especially hot reheat temperature.
- Thermal stresses due to temperature changes across thick wall components are detrimental to life consumption.
- Careful analysis and suitable modification would lead to improved fatigue behavior and reduce maintenance requirements.
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

Design with internal bypass cooling
Design without internal bypass cooling

Interstage admission
mixed steam
cooling steam
main steam
Performance at lower part load factor

210 MW modernization leads to 25 paisa savings in cost of generation with payback period of ~3 years
Part Load Efficiency: Turbine hardware upgrade

HP Turbine

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<th>Load</th>
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<th>75%</th>
<th>Full load</th>
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<tr>
<td>Savings (coal) *</td>
<td>≈ 1.3%</td>
<td>≈ 1.3%</td>
<td>≈ 1.5%</td>
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* Relative to aged condition (both in fixed pressure operation)
### Part Load Efficiency: Turbine hardware upgrade
#### HP + LP Turbine

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* Relative to aged condition (both in fixed pressure operation)
Part Load Efficiency: **Turbine hardware upgrade**

HP Turbine with control stage

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<td>≈ 2.9%</td>
<td>≈ 1.0%</td>
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* Relative to aged condition (both in fixed pressure operation)
Part Load Efficiency: **Turbine hardware upgrade with control stage**
HP + LP Turbine with control stage

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<tbody>
<tr>
<td>Savings (coal) *</td>
<td>≈ 4.7%</td>
<td>≈ 4.1%</td>
<td>≈ 2.2%</td>
</tr>
<tr>
<td>Savings (coal) **</td>
<td>≈ 2.7%</td>
<td>≈ 3.2%</td>
<td>≈ 1.3%</td>
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* Relative to aged condition (both in fixed pressure operation)
** Relative to new and clean conditions
Part Load Efficiency: **Turbine hardware upgrade with control stage**

HP + LP Turbine with control stage

- **Base - T2 - Fixed Pressure** *
- **Base - T2 - Sliding Pressure** *
- **HP-CS/3DS - Fixed pressure** **
- **HP-CS/3DS_LP 3DS - Fixed Pr.***

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* Aging applied to HP/IP&LP-section
** Aging applied to IP/LP-section
*** Aging applied to IP-section
Return on investment with hardware upgrade

Potential Benefits

For the corresponding 500MW steam power plant the modernization of the Turbine Hardware (new HP module with control stage / new LP rotor and inner casing) would result in significant savings for coal.

Taking this into account, the return of invest period accounts to 4 - 5 years. Additional benefits like the avoided CO₂ and the enhanced ability for fast load changes are not even considered here.

* This example is based on a modernization of a 500MW-coal-fired power plant in India (KWU-design)
Reduced Startup-times: Heating blankets
ST Warm Standby Operation to prepare for fast start-up

Technology
- Electrical heating system for ST in turning gear
- Maintains rotor shaft temperature at warm startup conditions

Benefit
- Significant reduction of startup time
  - > 60 min. earlier power production
- Reduction of EOH consumption per start
- Less energy is bypassed to condenser
  - Reduced costs per start up

Electric heating coils to keep HP/ IP Turbine casing and shaft in warm start conditions
Key Takeaway

- Lower Technical Minimum is better operation than two shift operation
- Subcritical fleet is more suitable for flexible operation with respect to loss in performance
- Lower Technical Minimum with part load performance improvement is possible, unit specific changes needs to be applied
- Means of improving part load efficiency by upto 4% are available
- Need based R&M is the approach for part load performance improvement
Contact information

Sandeep Chittora
Head – Portfolio Consulting
Siemens Limited, India
Phone: +91 124 2842650
Mobile: +91 9971170337
E-mail: sandeep.chittora@siemens.com
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 counter 4.0

Introduction of three start-up modes with fixed EOH consumption
Maintenance Flexibility
Fatigue Monitoring System

How much fatigue is it?

Don’t Guess when you can actually measure it
Maintenance Flexibility
Fatigue Monitoring System

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

Typical components:
- Headers, Manifolds (HP superheater, Reheater)
- Drums
- Separators
- Piping (e.g. elbow after HP / HRH final stage attemperator)
- T-Pieces (e.g. HP bypass station)
- Y-Piece (e.g. before HP turbine)