Operational Strategies for Flexing in Thermal Plants

Renewable Integration & Sustainable Energy Initiative

Greening the Grid (GTG) Program

A Partnership between USAID/India and Government of India
Outline

• Steps to flexibility
• Plant equipment with most significant impacts
• Best Operational Practices for flexible operation
• Practical tips for flexible operation
• Retrofits for flexible operation
• Training and skills programs
• Maintenance Strategy
**Steps to flexibility**

- **Mind-set Change: Raise the awareness for flexibility:** Provide background information about the need for flexibility, explain the necessity and impact on the O&M of the plant, and initiate training programs.

- **Check the status of the plant** and identify bottlenecks and limitations with respect to flexible operation:
  - Consult with OEMs to assess the influences of low load operation and temperature and pressure gradients on main components and equipment.
    - Ensure smooth operation of all control loops at base load.

- **Plan and execute test runs** to evaluate the plant flexibility potential with respect to minimal load, start-up and cycling behavior in the current setup.
  - Identify constraints and process limitations as well as improvement potential.

- **Optimize the I&C system:** This is the most cost-effective way to enhance the flexibility of the plant. A certain level of automation is a prerequisite for tapping this potential.
  - Smooth control of major power plant processes is a flexibility enabler; e.g. precise steam temperature control.
  - Optimizing the underlying control loops, i.e. coal supply, drum level and air control, is a basic requirement and plant operators need to consider interlocks coming from logics.
Steps to flexibility

• **Implement mitigation measures** to manage the consequences of flexible / cycling operation. This includes a reassessment of all O&M procedures, with a special focus on water and steam quality, preservation and layup procedures as well as on maintenance strategies. The use of appropriate condition monitoring systems is essential.

• **Optimize combustion**: Stable combustion is the key aspect to ensure minimum load operation. The following aspects are very important:
  – Reliable flame detection for each individual burner
  – Optimized air flow management
  – Operation with a reduced number of mills
  – Adaptation of the boiler protection system to low load operation.

• **Optimize start-up procedures**: In order to ensure a fast and efficient start-up, plant operators should check start-up related temperature measurements and consider replacement. Besides automated start-up procedures, this is a prerequisite to assess admissible temperature limitations and to operate with less conservative set points.

• **Improve the plant efficiency at part load** and the **dynamic behavior of the plant**: This refers to measures using the potential of the water-steam cycle – such as frequency support by condensate stop and HP heater optimization – as well as measures enhancing the performance of important equipment and components, e.g. ID, FD and PA fans or feed water pumps.

• **Improve the coal quality**: The better the coal quality the better the combustion process. Therefore, measures to improve and to monitor coal quality should be considered, such as blending and washing as well as online coal analysis.
Steps to flexibility

Each Unit should be targeted to do different value to the grid.

The decision is to be taken after ascertaining the potential through test runs.

The decision for investment to be taken based on cost-benefit analysis.

- Combustion
- Water-steam cycle
- Turbine
- I&C system
- Auxiliary systems
Impact on Coal Plant

Age & Cycling Impacts Plant Life

Fossil Steam (Coal - >100MW)

- Baseloaded (<10 starts per year):
  - 2000-2017: EFOR: 5-6%

- Extended Shutdown
  (>2000h Reserved Shutdown per year):
  - 2000-2017: EFOR: 7.16%

- Load Following
  (Service Factor >70%, Capacity Factor <60%):
  - 2000-2017: EFOR: 7.06%

- Minimum Load
  (Capacity Factor <50%, Unit Starts <20):
  - 2000-2017: EFOR: 7.19%

- Two Shifting (>50 Starts per year):
  - 2000-2017: EFOR: 11-12%

Lower efficiency
Emission control issues (FGD/SCR requires minimum temperature to operate and avoid fouling)
Trade-off - between value of flexibilization and costs

Source: EPRI
Limitations to be addressed

Ramp Rates-Limitations
- Stresses in thick walled components
- Fuel quality
- Controls and time lag between coal milling and turbine response

Minimum load limitations
- Combustion stability
- Boiler circulation
- DNB
- Minimum feed water flow & BFP
- Last stage blade flutter
- FG Exit Temp./Acid due point
- Vibration issues

Low back end temperature
Lower Heat Transfer to Convective Heating Surfaces
Combustion-Stability Temp. Distribution NOₓ-Emissions
Feedwater-Temp. ↓
Ventilation, erosion, vibration

DCS

APH

FGD

LS-Temp. ↓
RH-Temp. ↓

Combustion Stability
Temp. Distribution
NOₓ-Emissions

Feedwater-Temp. ↓

Lower Heat Transfer to
Convective Heating Surfaces

Minimum load limitations
- Combustion stability
- Boiler circulation
- DNB
- Minimum feed water flow & BFP
- Last stage blade flutter
- FG Exit Temp./Acid due point
- Vibration issues
<table>
<thead>
<tr>
<th>Plant equipment with most significant impacts</th>
<th>Primary damage mechanism</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Boiler water-walls</strong></td>
<td>Fatigue corrosion, corrosion due to oxygen and chemical deposits (depending on water quality)</td>
</tr>
<tr>
<td><strong>Boiler super-heaters</strong></td>
<td>High temperature differential and hot spots from low steam flows during start-up, long-term overheating failures</td>
</tr>
<tr>
<td><strong>Boiler re-heaters</strong></td>
<td>High temperature differential and hot spots from low steam flows during start-up, long-term overheating failures, tube exfoliation damages IP turbines</td>
</tr>
<tr>
<td><strong>Boiler economizer</strong></td>
<td>Temperature transient during start-ups</td>
</tr>
<tr>
<td><strong>Boiler headers</strong></td>
<td>Fatigue due to temperature ranges and rates, thermal differentials tube to headers; cracking in dissimilar metal welds, headers and valves</td>
</tr>
<tr>
<td><strong>Drum</strong></td>
<td>Thermo-mechanical stress at drum walls</td>
</tr>
<tr>
<td><strong>LP turbine</strong></td>
<td>Blade erosion</td>
</tr>
<tr>
<td><strong>Turbine shell and rotor clearances</strong></td>
<td>Non-uniform temperatures result in rotor bow and loss of desired clearance and possible rotor rubs with resulting steam seal damages</td>
</tr>
<tr>
<td><strong>Feedwater heaters</strong></td>
<td>High ramp rates during starts; not designed for rapid thermal changes</td>
</tr>
<tr>
<td><strong>Air heaters</strong></td>
<td>Cold end basket corrosion when at low loads and start up, acid and water dew point</td>
</tr>
<tr>
<td><strong>Fuel system / pulverizers</strong></td>
<td>Cycling of the mills occurs from even load following operation as iron wear rates increase from low coal flow during turn down to minimum</td>
</tr>
<tr>
<td><strong>Generator</strong></td>
<td>Thermo-mechanical stress on generator components especially at windings and insulation</td>
</tr>
<tr>
<td><strong>Water chemistry / Water treatment</strong></td>
<td>Cycling results in peak demands on condensate supply and Oxygen controls</td>
</tr>
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<tr>
<td>---------------------------------------------</td>
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</tr>
<tr>
<td>Piping</td>
<td>Water ingress, thermal shock, improper drainage</td>
</tr>
<tr>
<td></td>
<td>Thermocouple monitoring and automated drains can help</td>
</tr>
</tbody>
</table>
Measures for low load operation

<table>
<thead>
<tr>
<th>No.</th>
<th>System</th>
<th>Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Pulverizer</td>
<td>Mill operation concept(I&amp;C, protection etc.)</td>
</tr>
<tr>
<td>2</td>
<td>Pulverizer</td>
<td>Mill turn down improvement</td>
</tr>
<tr>
<td>3</td>
<td>Combustion</td>
<td>Adaptation of Flame Scanners</td>
</tr>
<tr>
<td>4</td>
<td>Combustion</td>
<td>Burner modifications</td>
</tr>
<tr>
<td>5</td>
<td>Economizer</td>
<td>Economizer bypass (SCR)</td>
</tr>
<tr>
<td>6</td>
<td>Air Heater</td>
<td>Air heater operation concept</td>
</tr>
<tr>
<td>7</td>
<td>water-steam cycle</td>
<td>Opt. Temp and pressure set-points</td>
</tr>
<tr>
<td>8</td>
<td>water-steam cycle</td>
<td>Change of extraction for boiler feedwater-pump turbine</td>
</tr>
<tr>
<td>9</td>
<td>water-steam cycle</td>
<td>HP-heater valve/bypass</td>
</tr>
<tr>
<td>10</td>
<td>water-steam cycle</td>
<td>Steam extraction from headers</td>
</tr>
<tr>
<td>11</td>
<td>Turbine</td>
<td>Optimization of nozzle sections for partial arc admission</td>
</tr>
<tr>
<td>12</td>
<td>Turbine</td>
<td>IP-valve upgrade (control)</td>
</tr>
<tr>
<td>13</td>
<td>Turbine</td>
<td>Ventilation protection of Turbine</td>
</tr>
<tr>
<td>14</td>
<td>I&amp;C</td>
<td>Tuning of control loops, adding low flow valve</td>
</tr>
</tbody>
</table>
Best Operational Practices for flexible operation

• **I&C optimization is the most cost-effective way to enhance power plant flexibility**

• Use of SCAPH- This will ensure faster PA temp. and guarantee a sufficient drying of coal

• An online pulverized coal and air distribution management system is capable of measuring the air-fuel ratio to coal burners in each PC pipe to coal burners in real time which can be optimized automatically based on the received coal quality

• Reducing the number of mills in service at part load to ensure Minimum load of each mill and proper air-fuel ratio

• To get faster heat output the storage capabilities of mills can be exploited by purposely adapting the classifier’s rotational speed

• Use of heating blankets to keep turbine warm during stand-stills by balancing the upper and lower casing and thus avoiding the bending of the shell- for start-up optimisation
Best Operational Practices for flexible operation

Judicious use of HP/LP bypass, oil guns
Sliding pressure
Deaerator heating and charging of HP heaters
Reliable Temperature measurement for thick walled components-
Accurate and well-placed temperature measurements of thick-walled components (inner wall and middle wall) are inevitable for evaluating the thermal stress (temperature difference) during power plant start-up and shut-down and the corresponding lifetime consumption

Accurate and reliable control of start-up fuel
Optimisation of control loops(tuning for low load operation)
  • Spray water control
  • Feed-water control
  • Drum level control
  • O₂ / air control
  • Circulation control
Areas which would require intervention including retrofits

**Firing System**
- Wind Box
- Coal & Air Nozzles
- Control Philosophy-SA & PA
- Mill Upgrades
- Advanced Flame Scanners
- Mill O/L Temp.
- Two Mill Operation
- Advance Tilt Mechanism

**Pressure Parts**
- RH/ SH Modification
- Second Pass Modification

**Boiler Operation**
- Modify to Sliding Pressure
- Excess air level and burner tilts
- Preferential selection of burner elevation(s)

Some Solutions available in the market: Boiler auto tune, Flexi suite, Combustion stability monitor
Turbine retrofit

Nozzle Control Partial Arc & Control Stage

Welded Rotor

Shrink Rings

Valves & Control System Upgrade

Last Stage Blade Upgrade

Thermal stresses in HP & IP due to temperature variation

Valve erosion

LS.B erosion, ventilation & vibration
Retrofits for flexible operation

Automated start-up – One button start-up
Advanced unit control particularly comprises feed-forward model-based approaches that have proven to be an appropriate measure for improving the dynamic behavior of power plants

Indirect and direct throttling of extraction steam – Advanced frequency control
- Condensate throttling (indirect)
- Throttling of extraction steam to LP preheaters and feed-water tank (direct)
- Throttling of extraction steam to HP pre-heater (direct)

Condition monitoring systems should monitor highly loaded boiler and piping components against creep and fatigue
Coal sampler
Coal analyser
BFP Recirculation valve
Scanners
# Practical tips for flexible operation

<table>
<thead>
<tr>
<th>Plant area</th>
<th>Issue / special focus</th>
<th>Mitigation</th>
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<tr>
<td>Mills</td>
<td>Minimum number of mills / burners / burner level ensuring a sufficient ignition and respectively combustion</td>
<td>Optimized combustion control based on the test run experiences in part load operation; special focus on reaction time and mill switch over; note: It is better running fewer mills at higher load than more mills at low load – the combustion stability increases.</td>
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<td>Air distribution control</td>
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<td>Inertia and smooth switch over</td>
<td>Optimized grinding: enables better usage of the fuel – improving the combustion process, precondition is the use of washed coal, respectively coal without stones, rocks and other hard impurities</td>
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<td>The control criterion for taking the first mill into operation should be the temperature inside the respective coal mill (classifier). This temperature should be higher than 70°C in order to avoid water dew point in the mill and, consequently, to avoid corrosions and blockings inside the coal mill caused by wet coal dust</td>
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               ▪ Minimum coal flow  
               ▪ Air distribution control  
               ▪ Inertia and smooth switch over | ▪ Optimized combustion control based on the test run experiences in part load operation; special focus on reaction time and mill switch over; note: It is better running fewer mills at higher load than more mills at low load – the combustion stability increases.  
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| **Burner** | ▪ Flame stability (flame pulsation and blow-off)  
▪ Air distribution | ▪ Reliable flame detection  
▪ Improve air-fuel ratio  
▪ Increase mixture and swirl  
▪ Ensure equal coal dust distribution to burners  
▪ Reduce cooling air flows  
▪ Improve positioning accuracy of air control flaps  
▪ To keep required steam temperatures at low load, use the upper burner levels in order to shift heat transfer from the evaporator to the superheater / reheater sections |
## Practical Operational Tips

### Water-steam cycle

#### Water chemistry
- Proper water and steam quality at all load conditions in order to avoid corrosion
  - Cycling results in peak demands on condensate supply and oxygen controls
- Strictly adhere to proven quality standards such as VGB-S-010-T-00; 2011-12.EN “Feed Water, Boiler Water and Steam Quality for Power Plants/Industrial Plants

#### Evaporator
- Differences of and material stress
- Avoidance of overheating
- Ensuring sufficient water / steam flow
- Optimize operation procedures or methods to reduce the ramp rate to the required or necessary minimum
- Check for design buffer in minimum feedwater flow, especially in once through boilers
- Use circulation mode
- Monitor conditions
## Practical tips for flexible operation

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<tr>
<td><strong>Super-heater</strong></td>
<td>▪ Differences of wall temperatures and material stress</td>
<td>▪ Ensure sufficient steam flow</td>
</tr>
<tr>
<td></td>
<td>▪ Temperature spread at life steam discharge</td>
<td>▪ Monitor conditions</td>
</tr>
<tr>
<td>Drum</td>
<td>▪ Minimum level</td>
<td>▪ Adhere to allowable temperature differences</td>
</tr>
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<td></td>
<td>▪ Differences of wall temperatures and material stress</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Inertia during start-up</td>
<td></td>
</tr>
<tr>
<td><strong>Once-through circuit</strong></td>
<td>▪ Switching point – from once-through to circulation mode</td>
<td>▪ Optimize mode change procedure between once-through and circulation operation</td>
</tr>
<tr>
<td>Feed water pump</td>
<td>▪ Minimum flow control</td>
<td>▪ Optimize part-load operation regime</td>
</tr>
<tr>
<td></td>
<td>▪ Switch over (if more than one pump)</td>
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## Practical tips for flexible operation

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<td><strong>General</strong></td>
<td>▪ Introduction of heating blankets</td>
<td>▪ Keep the turbine warm during standstills</td>
</tr>
<tr>
<td><strong>HP and LP turbine</strong></td>
<td>▪ Ventilation (reverse steam flow in the exhaust steam zone)</td>
<td>▪ Implement protective functions in the HP and LP turbine</td>
</tr>
<tr>
<td></td>
<td>▪ Vibration excitation at the last-stage blades</td>
<td>▪ Extend vibration monitoring</td>
</tr>
<tr>
<td></td>
<td>▪ Water droplet erosion</td>
<td>▪ Cool blades and casing (LP a, controlled flow and fast evacuation via direct link to condenser)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Improve condenser vacuum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Optimize drainage</td>
</tr>
<tr>
<td><strong>Chasing, bearings and shaft</strong></td>
<td>▪ Vibration and expansion due to thermal stress</td>
<td>▪ Optimized start-up procedures</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ EOH (Equivalent Operating Hours) counter to quantify the lifetime consumption due to thermal stress</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Improved condition and temperature monitoring</td>
</tr>
<tr>
<td><strong>Generator</strong></td>
<td>Thermo-mechanical stress on generator components especially at stator windings</td>
<td>Integrate online monitoring and diagnosis: control of the cooling temperature, partial discharge measurement and stator end winding vibration measurements</td>
</tr>
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</table>
Need for preservation or lay-up procedures

- Preservation or lay-up procedures are another important aspect. Boiler tube failures and other corrosion fatigue effects can be reduced by defining lay-up procedures, depending on the duration of the plant being off-line. For implementing suitable preservation procedures to protect equipment, the VGB Standard “Preservation of Power Plants” and “Preservation of Steam Turbo-Generator Set” could serve as a guideline.
Training and skills programs

• To implement flexible operation regimes, it is essential to prepare a plant's personnel for this new situation. Whereas the ultimate goal in the past was to operate a plant in base load at highest efficiencies, this has changed completely in this time of energy transition. Therefore, it is strongly recommended to set up a suitable training program for power plant staff aiming at achieving:

• In-depth technical understanding for flexible operation and its consequences for O&M
• Understanding of the requirement and need for flexibility and change of operating paradigm and
• Changed mindset and motivation to tackle new challenges.

• Management
  – Senior level
  – Trainer

• Operational staff
  – SCE/Desk operators/locational staff

• Maintenance staff
  – Mechanical
  – Electrical & C&I

• Coordinators
  – Operation
Training and skills programs

Power plant simulator....to go hand in hand with workshops

• Operation procedures for quick start-up, shut-down, load ramps, limitation of minimum load
• Methodologies for mitigating the effects of malfunctions
• Plant efficiency during minimum load conditions and load ramps
• Risk management during plant operation
# Water chemistry issues

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Chemistry Issues</th>
<th>Source: EPRI</th>
</tr>
</thead>
</table>
| Load Following               | • Feedwater chemistry control  
                             • Dissolved oxygen in condensate  
                             • Sampling issues                 |              |
|                              | • Phosphate Hideout  
                             • Carryover (level control)  
                             • Corrosion Product Monitoring |              |
| Cycling (weekend off)        | • Reheater pitting  
                             • Chemistry on startup            |              |
|                              | • General Steam Path pitting  
                             • Carryover (swell)               |              |
| Cycling (two-shifting)       | • Boiler chemistry control  
                             • Carryover Issues                | • Feedwater chemistry control     |
|                              |                                                                              | • Carbon dioxide ingress           |
| Extended Layup               | • **Turbine Pitting (leading to Stress Corrosion Cracking or Corrosion Fatigue)**  
                             • Chemistry System return to service | • Oxygen pitting boiler tubing     |
|                              |                                                                              | • Water Treatment Layup            |
|                              |                                                                              | • Instrumentation layup            |
| Sustained Minimum Load       | • **Increased steam path deposition**  
                             • FAC in economizers / IP Evaporator  
                             • FAC in BFP recirculation lines  
                             • Steaming in Economizer (two-phase FAC) | • DNB and Hydrogen Damage          |
|                              |                                                                              | • High level of attemperating sprays |
|                              |                                                                              | • Sampling / Monitoring            |
|                              |                                                                              | • Air-inleakage control            |
Maintenance planning - scope & schedule

- Systematic records of all components
- Optimise maintenance expenditure
- Overhauling duration, timing and scope - Greater OH frequency in later years of life and cycling
- Failure statistics

**Failure faults-independent of operation**
- Due to construction, design, operating errors etc.

**Predictable faults and dependent on service time**
- Wear and tear of ageing component
- Corrosion, erosion and distortion
- Creep and fatigue damage
- Cycling

It is necessary to tailor the overhauling and maintenance intervals for the particular unit on the basis of data available. The analysis of component-wise cost data is important. Metrics of equivalent operating hours, EHS is helpful.

Component-wise maintenance decisions can be taken on the importance, redundancy, safety etc.
Thank You

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