Efficiency Improvement on Steam Power Plants at Flexible Load Conditions

Thorsten Strunk

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Today’s and tomorrow’s Load Requirements
Energy from Renewables has feed-in priority in the grid

Situation 2011

Scenario 2020

Tomorrow (Scenario 20XX)

Energy market of tomorrow requires flexible fossil fired power plants

<table>
<thead>
<tr>
<th></th>
<th>Nuclear</th>
<th>Hard Coal</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>Base Load</td>
<td>Base - Intermediate Load</td>
<td>Intermediate Load</td>
</tr>
<tr>
<td>2020</td>
<td>Intermediate Load</td>
<td>Intermediate Load</td>
<td>Peak load</td>
</tr>
<tr>
<td>20XX</td>
<td>Phase out</td>
<td>?</td>
<td>?</td>
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</tbody>
</table>
Conventional Power Plants need to be able to supply full power demand in times of non-availability of renewable energy

India Demand Scenario for 2022

[Diagram showing energy sources for 2022]
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 shut-down
- Prepared for start-up
- Fast start-up
Increased flexibility leads to two main issues for Steam Power Plants

**Increased number of starts & load changes**
- High stress in component
- Increased wear and tear
- Reduced Reliability & Availability
- Increased maintenance cost

**Decreasing number of generated Power**
- Low efficiency in Part Load
- Lower number of generated MW
- Lower income

Stein Turbine Modernization can increase Part Load Efficiency and provide higher stress resistance.
Steam Turbine configuration for 500MW coal-fired power plants (KWU-design)

Turbine initially designed for fixed pressure operation!

\[ \approx 167 \text{ bar} / 538 \, ^\circ C \]

- **HP**
- **IP**
- **LP**

4 valves and inlets

2x10m²
Full Arc HP at Fixed Pressure Operation
Heat Rate loss of approx. 200 kcal/kwh at 40% load

Heat-Rate vs. Load

Fixed pressure mode 538°C
Ageing 240 months
Turbine in “new and clean” condition
VWO
Water-Steam-Cycle
- Full load

Thermal Energy to Water-Steam-Cycle

1250 MW\textsubscript{th}

\[ \eta \approx 40\% \]

\[ \text{Thermal Energy to Atmosphere} \]

500 MW\textsubscript{el}

750 MW\textsubscript{th}
Water-Steam-Cycle
- Part Load (40%) with Fixed Pressure Operation

Thermal Energy to Water-Steam-Cycle

540 MW_{th}

\eta \approx 36,3\%

\approx 21 \text{ MW}

Large "exergetic losses" occur due to throttling in HP control valves

196 MW_{el}

344 MW_{th}

Thermal Energy to Atmosphere
Water-Steam-Cycle
- Part Load (40%) with Sliding Pressure Operation

Reduced Average Temperature of Heat Supply results in large “exergetic losses” ≈ 17 MW

η ≈ 37,0% → difference in exergetic losses: 4 “green” MW*

* compared to fixed pressure mode
Heat-Rate vs. Load (Fixed-pressure vs. Sliding pressure)

- **fixed pressure mode 538°C**
- **Ageing 240month**
- **sliding pressure mode 538°C**

Approximately 4 „green“ MW*

Turbine in “new and clean” condition

* Additional Power output due to better performance
HP Steam Turbine with Control Stage

Drum blades (reaction)
Rotating blade ring (impulse)
Stationary Nozzles
Wheel Chamber

Valve operation Full Arc vs. Control Stage

full load

part load

Valve closed
Heat-Rate vs. Load (incl. Control Stage)

- **fixed pressure mode 538°C**
- **Ageing 240month**
- **sliding pressure mode 538°C**
- **Control stage + 3DS blades 538°C**

Valve point (open: x/4 valves)

$x=1$
$x=2$
$x=3$
$x=4$
$x \approx 3\text{DS}$

Load of ST (relative to rated load)

Half-net Heat-Rate [kJ/kWh] (SPAT considered (variable speed))

- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%
- 110%

Heat Rate vs. Load (incl. Control Stage)
HP Stage Bypass Valve

→ Variation of swallowing capacity of the turbine
Heat-Rate vs. Load (incl. Stage Bypass)

- **Half-net Heat-Rate [kJ/kWh]**
  - (SPAT consired (variable speed)

- **Load of ST (relative to rated load)**

- **fixed pressure mode 538°C**
- **Ageing 240month**
- **sliding pressure mode 538°C**
- **OLV 538°C**

Approximately 3DS
Heat-Rate vs. Load (incl. Stage Bypass & Control Stage)

- fixed pressure mode 538°C
- Ageing 240month
- sliding pressure mode 538°C
- Control stage + 3DS blades 538°C
- OLV 538°C

Valve point (open: x/4 valves)

Load of ST (relative to rated load)

Half-net Heat-Rate [kJ/kWh] (SPAT consired (variable speed))

- 3DS

40% 50% 60% 70% 80% 90% 100% 110%

38,3% 38,8% 39,3% 39,8% 40,3% 40,8% 41,3% 41,8% 42,3% 42,8%
Additional “green” power (sliding pressure and Control Stage) can save up to 55,000 tons CO2 emission / year

![Graph showing power difference relative to fixed pressure mode - as designed “green” MW vs load of ST (relative to rated load).]

- Benefit of control stage + 3DS blades
- Benefit of sliding
- Ageing 240 month

Power difference relative to fixed pressure mode - as designed "green" MW

Load of ST (relative to rated load)

Expected aging after 20 years of operation
Scenario: Control Stage

Levelized Cost of Electricity (LCOE)

"Real Case"

Focus: Europe
Source: VGB 2015

Costs of additional gained „green“ Electricity much lower compared to new power plants
Lower technical minimum is better than two shift operation

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

<table>
<thead>
<tr>
<th>Start</th>
<th>Life Consumption</th>
<th>IEC 45</th>
<th>VGB R105M</th>
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</thead>
<tbody>
<tr>
<td>Cold Start</td>
<td>23 – 75 hours</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Warm Start</td>
<td>15 -17 hours</td>
<td>700</td>
<td>400</td>
</tr>
<tr>
<td>Hot Start</td>
<td>10 -12 hours</td>
<td>3000</td>
<td>1600</td>
</tr>
<tr>
<td>Load Change</td>
<td>3 hours</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

Incremental O&M costs

- 140% at 210 MW
- 155% at 500 MW
- 170% at 660 MW
Transient Operation (Ramp Up / Ramp Down)
increased temperature gradient results increased life consumption

Low Cycle Fatigue

- Temperature Gradient [K/min]
- Allowable Load Cycles

Main steam valve
Crack depth: 50% wall thickness
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

mixed steam
cooling steam
main steam

Design with internal bypass cooling
Design without internal bypass cooling
Primary Frequency Control
- Situation in Germany

For allocating (positive and negative) Power for Primary Frequency Control specific prices of 2000 – 2500 € per MW and week are paid.

„Primary Control Power“ → to be activated within 30 seconds

Demand ≈ 600MW (for Germany)

Cost for Primary Control Power (weekly e-auction)

Mio €

PRL

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HP Steam Turbine Solution

• The Heat Rate increases in part load operation which results in higher CO2 emission and coal consumption
• Boiler Sliding Pressure Operation reduces the losses, however to the disadvantage of controllability.
• HP with Control Stage provides the lowest heat rate losses and maintains controllability.
• HP Modernization is required to implement the Control Stage
• With a HP Modernization the aging will be reversed and additional efficiency improvement can be gained by using state of the art blading and sealing technology.
• HP design update can reduce the stresses in cycling operations.
• The return of investment for the Steam Turbine modernization is lower than all other Cost of Electricity measures.
• Condensate throttling allows for fast load ramp rates.
• ST Mods and Flex-Power Services™ solution (e.g. I&C) can provide additional improvement in Flexibility and Efficiency