Flexible, reliable and efficient power plant technology – GE’s Europe Experience

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Power Services delivers a more balanced portfolio across total plant capabilities.

- ~5,900 gas turbines
- ~1,600 aeroderivative gas turbines
- ~9,900 generators
- ~900 heat recovery steam generators

- ~1,600 GW: ~1.5 of installed capacity enough to power 8 million homes
- ~28,000 power generation assets globally ... the world's largest installed base

- ~2,000 boilers
- ~2,600 utility steam turbines
- ~3,400 industrial steam turbines
- ~3,000 air quality control systems
Impact of renewable power on operation profiles
Demand on Flexibilty – Energy Production Germany

January 2016

July 2016

Demand of flexible operation will increase ~ 20 % of volatile power production
**FLEX SUITE™ Steam**

Offering for Steam Plants

<table>
<thead>
<tr>
<th><strong>FLEX SUITE™ for Steam Power Plants</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>START</strong></td>
</tr>
<tr>
<td>Fast, reliable start-up</td>
</tr>
<tr>
<td>Cost optimised start-up</td>
</tr>
<tr>
<td><strong>PERFORM</strong></td>
</tr>
<tr>
<td>Power and Efficiency Increase</td>
</tr>
<tr>
<td>Peak load</td>
</tr>
<tr>
<td>Controlled environmental footprint</td>
</tr>
<tr>
<td><strong>RESPOND</strong></td>
</tr>
<tr>
<td>Frequency response</td>
</tr>
<tr>
<td>Increased ramp rates</td>
</tr>
<tr>
<td><strong>RESERVE</strong></td>
</tr>
<tr>
<td>Improved part load efficiency</td>
</tr>
<tr>
<td>Low load operation</td>
</tr>
<tr>
<td>Hot standby</td>
</tr>
</tbody>
</table>

| **CARE**                             |
| Maintenance concepts                 |
| - Lifetime optimised operation       |
| - Flexible maintenance               |
| - Conservation and preservation      |
| Condition and lifetime monitoring    |
| - Remote component monitoring        |
| - Lifetime assessments               |
| - Site inspection services and condition analysis |
| Commercial solutions                 |
| - Flexible service contracts         |

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FLEET360* STEAM PLANT SERVICES SOLUTIONS – FLEXIBILITY

DIGITAL SOLUTIONS
- Steam Plant Asset Performance Management
- Low Load Optimization
- Part Load Optimization
- Enhanced Fast Ramp/Startup/Response
- BoilerOpt and Digital Boiler +
- Digital Twin

STEAM TURBINE
- Blade Vibration Monitoring
- Valves and Actuator Monitoring
- Enhanced ST Rotor Stress Control

BOILER
- Flame Scanners
- Plasma Burner
- Burner Upgrade
- Smart Mill
- Stability Monitor
- Low Load Boiler Package
- Auto Tune
- Air Preheater Upgrade

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<table>
<thead>
<tr>
<th>Min. Load</th>
<th>Start-up</th>
<th>Load Gradient</th>
<th>Heat Rate</th>
<th>Availability</th>
<th>Nox Emission</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 → 10%</td>
<td>3 → 1.5 h (hot)</td>
<td>2 → 6%/min</td>
<td>-2%</td>
<td>+2%</td>
<td>-20%</td>
</tr>
<tr>
<td></td>
<td>10 → 4 h (cold)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
GE Flexible Steam Turbine Features

- Scroll Inlet with RADAX Stage
- Welded Rotor
- Advanced 3D Blade Design
- Shrink Ring
- Instrumented for Modern ST Control
- Single Bearing Design
- Broad Last Stage Blade Profile
Boiler Flexibility Topics

Practical Examples

- Optimisation / Minor works / Low Load
- Minor Intervention / Efficiency / Upgrade Envelope
- Fuel Change Topic
- Fast Ramp / Upgrade
- Major Retrofit
Optimisation – Conventional Power Plants
Load Range Extension for Bituminous Coal

Min Load Reduction due to Process and Equipment Optimisation

- 4-Mills in Operation
- 3-Mills in Operation
- 2-Mills in Operation
- 1-Mill in Operation

Reduced Min Load

Usual Load Range

Life Steam Production [%]

In cases of extended firing envelope operation, the furnace safety system must be revalidated for safe operation according to the NFPA 85 code.
Small Project
800 MW Bituminous coal unit

- 800 MW hard coal unit
- GE Tower boiler, once through
- Tangential firing
- GE steam turbine
- Unit with district heating (240 MW) and process steam extraction
- Design Low load operation: 30%
Load Range & Efficiency Improvement
Minor Intervention

- 2 x 500 MWe, Tilting Tangential Burners. GE OEM.
- Coal Preparation by 6 x Vertical Spindle GE pulverizers
- Fired on high ash Bituminous coal
- Problem, high unburnt loss, minimum load ~50%
- Minor modification to burners to target low load and UBC reduction.
# Load Range & Efficiency Improvement

## Minor Intervention

<table>
<thead>
<tr>
<th>UBC Performance (lower = better)</th>
<th>Lowest Load with coal only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual pre-conversion</td>
<td>8.6%</td>
</tr>
<tr>
<td>Predicted post conversion</td>
<td>6.8%</td>
</tr>
<tr>
<td>Actual post conversion</td>
<td>3.8%</td>
</tr>
</tbody>
</table>

### Performance Values:
- **Actual pre-conversion:** 8.6% (50%)
- **Predicted post conversion:** 6.8% (25%)
- **Actual post conversion:** 3.8% (25%)
Change of Fuel – Fuel Flexibility

- Original Domestic Fuel
- Domestic Fuel, Enlarged Range
- Historical Range of Bituminous Fuel

Ash [%] vs. Moisture [%]
Fuel and load Flexibility - Bituminous Coal

- Faster Start-Up
- Low Load Operation
- Fuel Range Extension
- Fast Load Changes
- Fuel Range Extension
- Fuel Range Extension

Source: REBURNFLAM® Kanal-/Flächenbrenner; Pillard Feuerungen GmbH
Source: ROTAMILL GmbH
Indirect Firing System
Reduction of dynamic Response Delay

**Fast Load Changes**

**Reduction of dynamic Response Delay (Secondary Control)**

- Grinding Process causes Delays due to Storage Capacity of Mill
- Indirect Firing separation of Grinding and Storage
- Significant Reduction of System Response Time

**Graph:**
- **Indirect Firing:** Load Ramps up to 10 % / min
- **Conventional Firing:** Load Ramps up to 2 % - 5 % / min
Optimisation of Conventional Firing Option for Dynamic Response Improvement

| Mill → Burner | Mill → PF Separator / Silo → Burner |

Direct Firing System (Conventional)  (Partly) Indirect Firing System
Optimisation of Conventional Firing
Start up with – Dried Coal – eliminates support energy
Niederaußem K: 8 x 90 MW$_{th}$

• Start-up/Support Firing

• Operation since 2003

Dried Lignite Burner

Dried Lignite Storage Silo
Large Retrofit Project

Superheaters & Reheaters
- Performance Adjustments
- Material Upgrades
- Cleanability

Economizer
- Performance Improvements
- Cleanability
- Erosion Protection

Ducts & exp. joints
- Material Upgrades
- Repairs

Air heater
- High Efficiency Heating Elements
- Air Leakage reduction
- Cleanability

Waterwalls
- Cleanability
- New Burner openings

Overfire air (OFA)
- Two stage OFA

Burners
- Low NOx burners

Bottom ash handling
- Modified After Burning Grate

Coal pulverizers
- Improved classifiers
- Advanced wear parts

<table>
<thead>
<tr>
<th></th>
<th>before</th>
<th>after</th>
</tr>
</thead>
<tbody>
<tr>
<td>NOx</td>
<td>&gt;400</td>
<td>&lt;200  mg/Nm³</td>
</tr>
<tr>
<td>Power</td>
<td>370</td>
<td>394   MW</td>
</tr>
<tr>
<td>Cycle Eff</td>
<td>38%</td>
<td>41.30%</td>
</tr>
<tr>
<td>Feed temp</td>
<td>255</td>
<td>275   °C</td>
</tr>
<tr>
<td>Live Steam</td>
<td>540</td>
<td>570   °C</td>
</tr>
</tbody>
</table>
### Summary

<table>
<thead>
<tr>
<th></th>
<th>State of the Art</th>
<th>Further Development (Newly built and existing Plants)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time for Start-up</strong></td>
<td>2 - 6 Hours Depending on Startup Conditions</td>
<td>1 - 4 Hours Depending on Startup Conditions</td>
</tr>
<tr>
<td><strong>Minimum Load</strong></td>
<td><strong>Newly built Plants: 25 %</strong></td>
<td><strong>Conventional Firing 15 - 20 %</strong></td>
</tr>
<tr>
<td><strong>Bituminous Coal</strong></td>
<td><strong>Existing Plants: 40 %</strong></td>
<td><strong>Indirect Firing 10 % - 15 %</strong></td>
</tr>
<tr>
<td><strong>Load Ramps</strong></td>
<td>ca. 2 - 5 % / min</td>
<td>Up to 10 % / min</td>
</tr>
<tr>
<td><strong>Biomass</strong></td>
<td>10 % CoCombustion</td>
<td>100 % Combustion</td>
</tr>
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