Combustion optimisation, efficiency improvements and emission reduction by installation of modern LowNOₓ firing systems at existing bituminous coal and lignite coal-fired steam generators

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1. Introduction
Siemens Energy Sector – Answers for energy supply

Energy products and solutions - in 6 divisions

|-----------|-------------------------|-------------------|---------------|-------------------|-------------------|

- **Energy Service Fossil Region Europe and Africa (REU)**

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1. Introduction
Actual requirements for power plant operation

- Efficiencies, price pressure, lower operation costs
- Meet requirements of European Emission Directive (especially recently EU joining countries)
- Operational flexibilities, e.g. extended load range and fuel properties (coal blends)
- Reduced time of full load operation and optimisation of part load conditions, frequent plant start up and shut down
- Increased load change rates (Primary and secondary frequency control), lifetime extension
Three examples of executed Firing projects within last two years:

2. **Extension of Load Range**

3. Flexibility improvement and reduced operating costs

4. Emission reduction and increase of availability
2. Extension of load range

Main plant figures

Once-through (Benson®) Type Boiler

Main steam flow 260 kg/s (936 t/h)
Temperature (SH/RH) 545 °C / 568 °C
Pressure (SH) 260 bar
Commissioning 1996
Mills for Bituminous Coal 6 Roller Mills
T-Firing, 12 SM-IV-Burner 61 MWth each

Bituminous coal:

<table>
<thead>
<tr>
<th>Unit</th>
<th>Coal before revamp</th>
<th>Coal after revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCV (MJ/kg)</td>
<td>25.0 – 29.3</td>
<td>23.6 – 26.7</td>
</tr>
<tr>
<td>Water (ar)</td>
<td>5.5 – 13</td>
<td>7.4 – 16.2</td>
</tr>
<tr>
<td>Ash (ar)</td>
<td>7.0 – 20</td>
<td>4.7 – 15.5</td>
</tr>
<tr>
<td>VM (daf)</td>
<td>25 – 42</td>
<td>28 – 43</td>
</tr>
</tbody>
</table>
2. Extension of load range
Goals and measures

Goal of retrofit:

- Boiler capacity increase 10 %
- Keep NO\textsubscript{x}-Emissions ≤ 450 mg/Nm\textsuperscript{3}
- Minimise slagging of furnace
- Corrosion protection of furnace walls (O\textsubscript{2})
- Use of import coals

Measures:

- Revamp to SM-V-Burner design (67 MWth)
- Modification of side wall air system
- Optimisation of OFA system
- Retrofit of mills
- Capacity increase of FD Fan
2. Extension of load range

Firing concept

- Over fire air
- Side wall air
- Secondary air 2
- Secondary air 1
- Primary fuel

SM-V-Burner
2. Extension of load range
CFD calculation of furnace

Temperature profile with isosurface 1500 °C

before revamp

Heat input 735 MW
Air ratio 1,18

after revamp

Heat input 799 MW
Air ratio 1,18

improved position of fireball
2. Extension of load range

Measuring results

Measured wall atmosphere after revamp

O₂-Concentration in Vol.-%
## 2. Extension of load range

CFD and measuring results

<table>
<thead>
<tr>
<th></th>
<th>measured before revamp</th>
<th>CFD after revamp</th>
<th>measured after revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Load [%]</strong></td>
<td>100</td>
<td><strong>109</strong></td>
<td><strong>109</strong></td>
</tr>
<tr>
<td><strong>NO\textsubscript{x} [mg/Nm\textsuperscript{3}@6%O\textsubscript{2}]</strong></td>
<td>304</td>
<td><strong>290</strong></td>
<td><strong>297 – 320</strong></td>
</tr>
<tr>
<td><strong>CO [mg/Nm\textsuperscript{3}@6%O\textsubscript{2}]</strong></td>
<td>26</td>
<td><strong>16</strong></td>
<td><strong>0 – 50</strong></td>
</tr>
<tr>
<td><strong>FEGT [°C]</strong></td>
<td>1236</td>
<td><strong>1265</strong></td>
<td><strong>1267</strong></td>
</tr>
<tr>
<td><strong>UBC in fly ash [w. %]</strong></td>
<td>1,7</td>
<td><strong>2,1</strong></td>
<td><strong>1,6 – 3,4</strong></td>
</tr>
<tr>
<td><strong>O\textsubscript{2} &lt; 0,5 [Vol. %]</strong></td>
<td>1,6</td>
<td><strong>0,4</strong></td>
<td><strong>1,2</strong></td>
</tr>
<tr>
<td><strong>Excess-Air-Ratio</strong></td>
<td>1,18</td>
<td><strong>1,18</strong></td>
<td><strong>1,18</strong></td>
</tr>
</tbody>
</table>
2. Extension of load range
Life time experience

SM-V-Ultra Low NO\textsubscript{x} Burner

after 8 years of operation - 03/2005

after 13 years of operation - 05/2010
Three examples of executed Firing projects within last two years:

2. Extension of Load Range

3. Flexibility improvement and reduced operating costs

4. Emission reduction and increase of availability
3. Flexibility improvement and reduced operating costs

Main plant figures

Benson type steam generator

Fuel: Bituminous Coal
Steam flow: 420 kg/s / 1512 t/h
Temperature (SH/RH): 535 °C / 541°C
Pressure (SH): 254 bar
Fuel heat input: 1278 MWth
FEGT: 1250 °C
Opposite firing system, 12 MSM-Burner, 100 MWth each
Mills: 3 Tube Mills
Commissioning: 1989

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Ref. coal before revamp</th>
<th>Coal range after revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCV</td>
<td>MJ/kg</td>
<td>25,1</td>
<td>16.7 – 26.4</td>
</tr>
<tr>
<td>Ash (a.r.)</td>
<td>Mass -%</td>
<td>7,1</td>
<td>6 – 30</td>
</tr>
<tr>
<td>Moisture (a.r.)</td>
<td>Mass -%</td>
<td>13,5</td>
<td>7 - 18</td>
</tr>
<tr>
<td>Volatiles (a.r.)</td>
<td>Mass -%</td>
<td>32,9</td>
<td>21 – 36,5</td>
</tr>
</tbody>
</table>
Goal of retrofit:

- Simplification of firing system by removing the secondary fuel system (reburning)
- Extension of coal quality range (Import Coal with high volatile matter)
- Keep / Slight Reduction of primary NO\textsubscript{x} emissions
  - Reduction of ammonia consumption
- Reduction of excess air ratio from 1.25 down to 1.18
  - Reduction of flue gas losses and lower power consumption of fans
- Avoid furnace wall corrosion and slagging

Measures:

1. Firing system
   - New burners
   - Adding a new side wall air system
   - Implementation of Over fire air
2. Pulverising system (3 tube mills)
   - Shut-off of secondary firing system (including flue gas recirculation system)
   - Optimisation of PF distribution
3. Flexibility improvement and reduced operating costs

Combustion air system

complex and flexible, use of existing equipment as much as possible
3. Flexibility improvement and reduced operating costs

Burner design

Primary air
Coal
Retention zone
Guide vane
Rope breaker

„Uniform“ coal - air mixture

CFD calculation of primary air flow
3. Flexibility improvement and reduced operating costs

Burner modification

minimum hardware replacement and scope of work
3. Flexibility improvement and reduced operating costs

CFD calculation

O₂ concentration at furnace walls

before revamp ($\lambda_{\text{tot}} = \lambda_{\text{BB}} = 1.25$) after revamp ($\lambda_{\text{tot}} = 1.18$, $\lambda_{\text{BB}} < 1.0$)
### 3. Flexibility improvement and reduced operating costs

CFD and measuring results

<table>
<thead>
<tr>
<th></th>
<th>measured before revamp</th>
<th>CFD before revamp</th>
<th>CFD No. 7 after revamp</th>
<th>measured after revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coal</strong></td>
<td>VM ~ 25% a.r.</td>
<td>Colombian coal</td>
<td>blend with low cont. of VM</td>
<td></td>
</tr>
<tr>
<td><strong>FEGT [°C]</strong></td>
<td>1211</td>
<td>1215 (1320)</td>
<td>1209 (1312)</td>
<td>~ 1225</td>
</tr>
<tr>
<td>(Mean / Maximum)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Excess-Air-Ratio [-]</strong></td>
<td>1,25</td>
<td>1,25</td>
<td>1,18</td>
<td>1,18</td>
</tr>
<tr>
<td><strong>NO\textsubscript{x} [mg/Nm\textsuperscript{3}, @ 6%O\textsubscript{2}]</strong></td>
<td>520 (±30)</td>
<td>528</td>
<td>315</td>
<td>350 – 480</td>
</tr>
<tr>
<td><strong>CO [mg/Nm\textsuperscript{3}, @ 6%O\textsubscript{2}]</strong></td>
<td>&lt; 10</td>
<td>15</td>
<td>8</td>
<td>&lt; 25</td>
</tr>
<tr>
<td><strong>UBC in Fly Ash [w. %]</strong></td>
<td>ca. 3,2</td>
<td>3,1</td>
<td>1,8</td>
<td>~ 2,5</td>
</tr>
</tbody>
</table>
3. Flexibility improvement and reduced operating costs

Measuring results

NOx Emissions vs. Volatile Matter

UBC ~ 3%

UBC = 2.6%

CO ~ 10 mg/Nm³

measuring points during commissioning
Three examples of executed Firing projects within last two years:

2. Extension of Load Range

3. Flexibility improvement and reduced operating costs

4. Emission reduction and increase of availability
4. Emission reduction and increase of availability

Main plant figures

Boiler type: Natural circulation

Fuel: Bulgarian lignite
Steam flow*: 192 kg/s / 690 t/h
Temperature (SH/RH): 540 °C / 540°C
Pressure (SH): 130 bar
Fuel heat input: 660 MWth
FGET: 1100 °C
Tangential firing, 8 mills
Commissioning 1981
*Retrofit (8% load increase) 2009

<table>
<thead>
<tr>
<th>Unit</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>NCV (a.r.)</td>
<td>MJ/kg</td>
</tr>
<tr>
<td>Ash (a.r.)</td>
<td>w.%</td>
</tr>
<tr>
<td>Moisture (a.r.)</td>
<td>w.%</td>
</tr>
<tr>
<td>Volatiles (daf.)</td>
<td>w.%</td>
</tr>
</tbody>
</table>
4. Emission reduction and increase of availability

Goals:
• Reduction of the NO\textsubscript{x} emissions from 375 to below 180 mg/Nm\textsuperscript{3} @ 6% O\textsubscript{2}
• Increase of effectiveness of the combustion chamber by reduction the excess air from 1.2 to 1.15 (at furnace outlet)
• CO emissions below 180 mg/Nm\textsuperscript{3} @ 6% O\textsubscript{2}
• Preventing water wall corrosion
• Decreasing slagging formation -> increase of availability

Measures:
• Burner outlet modification
  • Stabilise the ignition close to the burner outlet
  • Improve the release of volatiles
  • Optimisation of the furnace cross-section air distribution
  • Protect membrane walls against corrosion

• Modification of burner PF distribution
  • Staging the combustion more effective, reduce burner belt Excess Air Ratio
  • Influence the residence time inside the furnace
4. Emission reduction and increase of availability
New OFA system

- Increase of residence time
- Increase furnace burnout zone
- Decrease loss of ignition
- Equalise furnace outlet temperature
- Create downstream mixing of flue gas
4. Emission reduction and increase of availability
Additional PF concentrator

% of PF distribution

- Vapor burner
- Upper main burner
- Lower main burner

before / after revamp
4. Emission reduction and increase of availability
Burner modification

Stable and early ignition,
Preventing water wall corrosion

before revamp

after revamp
4. Emission reduction and increase of availability
Air / Coal mixture, Radial Air Staging

Preventing water wall corrosion
4. Emission reduction and increase of availability

CFD calculation of combustion temperatures

Isosurface 1200 °C

before revamp

after revamp
4. Emission reduction and increase of availability

CFD calculation of furnace temperature

Lower main burner

before revamp

after revamp

Temperature

[°C]

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### 4. Emission reduction and increase of availability

CFD and measuring results

<table>
<thead>
<tr>
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<th>measured before revamp</th>
<th>CFD after revamp</th>
<th>measured after revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler efficiency</td>
<td>84</td>
<td></td>
<td>84 + ~ 1,5</td>
</tr>
<tr>
<td>( \text{NO}_x ) [\text{mg/Nm}^3, @ 6% \text{O}_2]</td>
<td>350 - 400</td>
<td>195</td>
<td>150 – 180</td>
</tr>
<tr>
<td>( \text{CO} ) [\text{mg/Nm}^3, @ 6% \text{O}_2]</td>
<td>&lt; 50</td>
<td>270</td>
<td>30 - 100</td>
</tr>
<tr>
<td>Excess-Air-Ratio at Boiler Outlet [-]</td>
<td>1,2</td>
<td>1,2</td>
<td>1,1</td>
</tr>
<tr>
<td>UBC hopper [%]</td>
<td>15</td>
<td>-</td>
<td>~ 12</td>
</tr>
<tr>
<td>UBC fly ash [%]</td>
<td>3</td>
<td>4,8</td>
<td>~ 2,5</td>
</tr>
</tbody>
</table>
4. Emission reduction and increase of availability

Measuring results

Air ratio vs NOx emissions
Full load

NOx emissions [mg/Nm³@6%O₂]

Air ratio burner belt [-]

λ_{boiler outlet} ≈ 1.15-1.20

λ_{boiler outlet} ≈ 1.20
5. Summary

The three presented retrofit projects show that the following goals were achieved:

- Load range extension
- Reduction of primary NO\textsubscript{x} emissions
- Cost reduction by improved efficiency and simplification
- Increase of operating flexibility

Thank you for your attention