Minimal Load Reduction (MLR) and Storage Systems as Flexibilisation Options for coal-fired Steam Power-Plants

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1. **EnBW Power Generation at a Glance**
   - EnBW Power Generation Portfolio
   - EnBW Power Generation Engineering Services
   - EnBW Conventional Power Plant Fleet

2. **Minimal Load Reduction**
   - Background
   - Fuel Supply and Heat Generation Systems
   - Flue Gas Cleaning and Filtering Systems
   - Water-Steam-Cycle and Steam Turbine
   - Summary Minimal Load

3. **Outlook: Thermal and Electrical Storage Systems**
   - Flexibilization of Power Plants by Thermal Energy Storages
   - Electrical Storage for Flexibilization of Power Generating Plants
EnBW Power Generation at a Glance

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EnBW Power Generation at a Glance

**EnBW Power Generation Portfolio**

- Thermal Power Stations / CHP (Coal, Gas, Oil, Biomass, Waste)
- Nuclear Power Plants
- Renewable Energies, i.e. Wind onshore & offshore, Water power, Geothermal Energy
- District Heating, Industrial Power Supply

**EnBW Power Generation Engineering Services**

- Vast experience in engineering, construction, operation and maintenance of power stations
- High professionality and customer orientation
- Tailor-made and individual concepts and solutions
EnBW Power Generation at a Glance

Heilbronn Unit 7
- Power Rating: 812 MW
- Commissioning: 1985
- Boiler OEM: EVT / Sulzer
- Feed Steam Params: 197 bar, 540°C
- Minimal Load: 28%

Altbach HKW1
- Power Rating: 476 MW
- Commissioning: 1985
- Boiler OEM: Steinmüller
- Feed Steam Params: 195 bar, 540°C
- Minimal Load: 30%

Altbach HKW2
- Power Rating (solo/GTE): 335 / 428 MW
- Commissioning: 1997
- Boiler OEM: Steinmüller
- Feed Steam Params: 249 bar, 540°C
- Minimal Load: 31%

Karlsruhe RDK 7
- Power Rating: 536 MW
- Commissioning: 1985
- Boiler OEM: Steinmüller
- Feed Steam Params: 181 bar, 535°C
- Minimal Load: 33%

Karlsruhe RDK 8
- Power Rating: 536 MW
- Commissioning: 2016
- Boiler OEM: Steinmüller
- Feed Steam Params: 285 bar, 603°C
- Minimal Load: 35%
2nd Chapter

- Minimal Load Reduction (MLR)
  - Background
  - Fuel Supply and Heat Generation Systems
  - Flue Gas Cleaning and Filtering Systems
  - Water-Steam-Cycle and Steam Turbine
  - Combined Heat and Power
  - Summary
The Economic Case for Minimal Load Reduction

- Market price often oscillates around marginal cost level
- Revenue/Loss = (market price [€/MWh] - marginal costs [€/MWh]) * P [MW] * Time [h]
- Low ML is economic benefit!

![Graph showing market price oscillations and corresponding PP Load changes.](image)
**Historical Development of Minimal Load**

› **Before 2000: 2-Mills-Operation**
  – ML 30-40% with coal fire only; ML 25% with coal fire with supporting oil fire
  – availability had been a high priority: Minimum load : 2-mill-operation, no plant trip

› **2000-2010: 2-Mills-Operation**
  – ML 25%: with coal fire only (no supporting oil fire), forced circulation

› **2010 – now:**
  – EnBW’s MLR project goal : Minimal Load of 15-20% with coal fire only
  – Further reduction of ML only possible with 1-mill operation because of flame stability

› **Higher ML for lignite-fired steam power plants**
Coal Feeders, Mills and Firing

- Stable range for coal feeders: 60%...85%
- One mills for each of the 4 burner levels, tangential firing system
Flame Stability

› Low load in 2-mill operation, the mill and coal feeder load would be decreased to approx. 40..50 percent or below which result in poor flame stability

› For a comparable PP load in 1-mill operation, the coal feeder and mill load could be ≥80 percent with a stable flame

› Coal feeder/mill load preferable at 60...85 percent
Fuel Supply and Heat Generation Systems

**Burner Levels and Excess Air**
- Minimum load (1-mill operation) preferably with firing of level 30 or 40 (⇒ also positive effect on flame stability)
- Combustion while minimum load preferably with high excess air ($\lambda_{\text{total}} \sim 2$)

**Heat Transfer and Feed Steam / RH Steam**
- Heat transfer from flue gas to water-steam-cycle is at higher levels, thus less heat input to the evaporation; more heat input to the superheating
- Feed steam und RH steam temperatures remain at high levels (approx. 20K lower compared to full load)
- Sliding pressure curve not to apply at very low part load
Temperature in Flue Gas Duct Channel

- No essential temperature drops compared to previous minimal load (30-40% load case)

SCR-DeNOx

- Temperature before DeNOX were sufficiently high in all but one case. This has been corrected with a ratio change of secondary air
- Precise control of NH3-injection is challenging
**HP Turbine (HPT) Ventilation**

- HP turbine tends to ventilate when mass flow (identical to low pressure drop across HPT)
- Keeping RH pressure through IPT valves make situation worse.
- HPT exhaust temperature may drastically increase within seconds ⇒ hazzard of turbine trip or damage
- steam extraction, e.g. for district heating, increases the tendency towards ventilation
RH Massflow
› Ensure minimal RH massflow (steam extraction from cold RH may be critical)
› Low RH massflow can result in damage of RH heat exchanger piping.

IP / LP Turbine Ventilation and Condenser
› LP turbine tends to ventilate when mass flow / pressure gradient is low
› Water injection off to prevent erosion
› Ensure low condensor back-pressure (last stage vibration excitation)
› Droplet erosion not an issue (wet steam regio unchanged, lower flow velocities)
Boiler Feedwater Pump and Steam Use

› Superheated Steam for BFP
› Also applies for CHP-PP
› Lower Pressure / higher volumetric expansion: steam from extractions: check the smallest Diameters ("vena contracta")

Boiler Circulation Pump

› The 1-mill-operation requires to operate the boiler circulation pump (forced circulation). The pump control is automated
› the load regime for which the circulation pump is operated at low part load should be avoided
Water-Steam-Cycle and Steam Turbine

**Combined Heat and Power (CHP)**

- Heilbronn Unit 7: steam extraction for district heating / process steam from cold reheat
- Karlsruhe RDK 7: steam extraction for district heating from hot reheat ⇒ higher cogeneration ratio
Summary MLR Project

MLR Project Management

➢ Thorough planning prior to field experiments essential
➢ Close cooperation with plant operators and turbine OEM has been beneficial
➢ Power plant has to examined as a whole
➢ Individual technical/physical limitations for each power plant
➢ Minimal Load Reductions as specified in the project objectives have been achieved

Achievements

<table>
<thead>
<tr>
<th></th>
<th>Altbach HKW 1</th>
<th>Heilbronn Unit 7</th>
<th>Karlsruhe RDK 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power Rating, elec.</td>
<td>476 MW</td>
<td>812 MW</td>
<td>536 MW</td>
</tr>
<tr>
<td>Minimum load, previously(^1)</td>
<td>28%</td>
<td>30%</td>
<td>33%</td>
</tr>
<tr>
<td>Minimum load, achieved</td>
<td>14-18%</td>
<td>approx. 15%</td>
<td>15-18%</td>
</tr>
<tr>
<td>Co-Generation / CHP max.</td>
<td>80...100 MW th</td>
<td>15 MW th(^2)</td>
<td>70...80 MW th</td>
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\(^1\) ETG 2012
\(^2\) 1-mill operation
\(^3\) 2-mills operation
3rd Chapter

Thermal and Electrical Storage Systems (Outlook)

- Flexibilization of Power Plants by Thermal Energy Storages
- Electrical Storage for Flexibilization of Power Generating Plants
Thermal and Electrical Storage Systems (Outlook)

“KRAFTWERKSFLexibilisierung durch Thermische Energiespeicher” (“FLEXITES”)

› Flexibilization of Power Plants by Thermal Energy Storages
› Integration into thermal coal-fired power plants
› 2017-2020

Sample concept of thermal storage to increase operational flexibility as PP integrated system (courtesy of Siemens AG)
“KRAFTWERKSBATTERIE HEILBRONN”

› Joint venture between Bosch AG and EnBW AG (*2017)
› Electrical energy storage for flexibilization of power generating plants / primary/secondary control energy
› First storage system (20 MWh, 20 MW) at the Heilbronn Unit 7 power plant
  - erection started in November 2017
  - commissioning spring 2018
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