Flexibility Options for Power Plants – The Flexibility Toolbox
Dr. Claudia Weise, November 3, 2017, Berlin
1. Introduction

2. Flexible Operation of Thermal Power Plants

3. Toolbox

4. Conclusion
1. VGB PowerTech – who we are

- We have **478 members in 35 countries**, over 90% are European based.

- We represent an installed capacity of **466 GW** based on this energy mix:

  - Fossil
  - Nuclear
  - Renewables

VGB is the European Competence Center of Heat and Power Generators. Founded in 1920 it is based on a voluntary association of companies active in the energy business.
VGB facilitates the exchange of experiences between the experts and document and disseminate the results for the benefit of all members.

Over 1,700 experts are active in the VGB network.
1. German power generation in 2016

- Installed net capacity: 210 GW (thereof 104 GW RES)
- Gross power production: 648 TWh (consumption 593 TWh):

Renewables have outsourced lignite as No.1 electricity generation source. More than 50% of RES is coming from volatile sources. Gas has increased by 25% from 2015. Installed capacity has grown by 50% since 2000.
## 1. Installed Capacity in Germany

<table>
<thead>
<tr>
<th>Install. Cap. [GW]</th>
<th>Total</th>
<th>Renewables</th>
<th>Thermal</th>
<th>Nuclear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Solar</td>
<td>Wind</td>
<td>Hydro*</td>
</tr>
<tr>
<td>Germany**</td>
<td>197.3</td>
<td>40.9</td>
<td>49.6</td>
<td>5.6</td>
</tr>
</tbody>
</table>

*including all hydro; **as of December 31, 2016

### Type of coal

<table>
<thead>
<tr>
<th>Type of coal</th>
<th>Calorific value [kJ/kg]</th>
<th>Ash content [%]</th>
<th>Water content [%]</th>
<th>Sulphur content [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>German lignite</td>
<td>7,800 – 11,300</td>
<td>2.5 – 20.0</td>
<td>40 – 60</td>
<td>0.15 – 3.00</td>
</tr>
<tr>
<td>Imported hard coal applied in Germany</td>
<td>~25,000</td>
<td>7.0 – 15.0</td>
<td>9.0 – 12.0</td>
<td>&lt; 1.0</td>
</tr>
</tbody>
</table>
2. What does flexible operation mean?

- **Minimum load operation**
  - important for the provision of residual load and for fast start up in case of high demand (e.g. two-shifting)
  - more economic than shut-down of the whole plant

- **Advanced dynamics by high ramp rates**
  - high ramp rates ensure a fast reaction to changed market condition
  - power plants with dynamic cycling abilities can participate in different markets

- **Short start-up and shut-down**
  - Short start-up and show-down times are beneficial to quickly respond to according market requirements (e.g. two-shifting)
  - thermal stress during start and stop are most severe and causes lifetime consumption

Flexible operation aims at achieving low minimum load, high ramp rates and fast start and stop time. According measures might contribute to one or more targets.
2. Flexibility parameters of thermal power plants

<table>
<thead>
<tr>
<th>Plant type</th>
<th>Hard-coal</th>
<th>Lignite</th>
<th>CCGT</th>
<th>Gas Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load gradient [% / min]</td>
<td>2 / 4 / 8</td>
<td>2 / 4 / 8</td>
<td>4 / 8 / 12</td>
<td>8 / 12 / 15</td>
</tr>
<tr>
<td>in the load range [%]</td>
<td>40 to 90</td>
<td>50 to 90</td>
<td>40* to 90</td>
<td>40* to 90</td>
</tr>
<tr>
<td>Minimum load [%]</td>
<td>40 / 25 / 15</td>
<td>60 / 40 / 20</td>
<td>50 / 40 / 30*</td>
<td>50 / 40 / 20*</td>
</tr>
<tr>
<td>Ramp-up time Hot start &lt;8 h [h]</td>
<td>3 / 2 / 1</td>
<td>6 / 4 / 2</td>
<td>1.5 / 1 / 0.5</td>
<td>&lt; 0.1</td>
</tr>
<tr>
<td>Ramp-up time Cold start &gt;48 h [h]</td>
<td>7 / 4 / 2</td>
<td>8 / 6 / 3</td>
<td>3 / 2 / 1</td>
<td>&lt; 0.1</td>
</tr>
</tbody>
</table>

Source: VDE and own studies
usual value / state of the art / potential
*as per emission limits for NOx and CO

Thermal power plants are able to significantly contribute to a modern energy system. Technology development is focused on realising the flexibility potentials.
3. Flexibility Toolbox – the Approach

A joint endeavor of the Excellence Enhancement Centre (EEC) of India and VGB in the frame of the Indo-German Energy Forum

Flexibility Toolbox

Retrofit

Operation & Maintenance

Training

Management

Advanced I&C Environment

Flexibility needs technology, people and leadership
The toolbox includes technical retrofit measures for main systems of the power plant – combustion, water-steam cycle, turbine, I&C, flue gas cleaning and auxiliaries – as well as storage technologies.
### General

#### Evaluation of process limitations in co-operation with OEM

<table>
<thead>
<tr>
<th>Flexibility impact</th>
<th>Minimum load reduction, start-up optimization and ramp rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitations</td>
<td>General (in particular boiler and turbine)</td>
</tr>
</tbody>
</table>
| Description        | ▪ Evaluation should include a boiler calculation to assess the influences of low load operation and temperature- and pressure gradients on the boiler components and equipment  
▪ An inventory review is required to assess the plant status in detail and to derive a schedule for test programs  
▪ Establish transparency about the technical boundary conditions for flexible plant operation |
| Investment         | Depending on the OEM, no investment needed in the first place |
| Timeline           | 1 month                                                      |
| Best Practice      | N/A                                                          |
3. Example for a Retrofit Measure 2/4

### Combustion

#### Coal stockyard – Thermographic detection system

<table>
<thead>
<tr>
<th>Flexibility impact</th>
<th>Minimum load reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitations</td>
<td>Self ignition of coal on coal stockyard</td>
</tr>
</tbody>
</table>
| Description        | - A reduction of the minimum load together with a more frequent operation in minimum load leads to an increased storage period of the coal favouring its self-ignition.  
- Beside installing a detection system, an appropriate coal handling of the stockyard (compaction) is recommended to avoid self-ignition. |
| Investment         | A /B and additional O&M costs |
| Timeline           | 1 – 3 months |
### 3. Example for a Retrofit Measure 3/4

#### I&C System

**Model-based thermal stress calculator**

<table>
<thead>
<tr>
<th>Flexibility impact</th>
<th>Start-up optimization, ramp rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitations</td>
<td>Thermal stress</td>
</tr>
<tr>
<td>Description</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Using a dynamical wall model with physical parameters, e.g. for heat transfer and heat distribution, it is possible to compute the temperature difference from the steam temperature, which usually is measured anyway.</td>
</tr>
<tr>
<td></td>
<td>▪ The available margin with respect to the thermal stress can be used as a feedback signal to the start-up controller in order to keep the temperature difference in its admissible range.</td>
</tr>
<tr>
<td></td>
<td>▪ Less conservative than measuring the temperature difference be means of dedicated measurements.</td>
</tr>
<tr>
<td>Investment</td>
<td>B</td>
</tr>
<tr>
<td>Timeline</td>
<td>12 month depending on number of start-ups available</td>
</tr>
<tr>
<td>Best Practice</td>
<td>H. Lens, PowerGen Europe 2014, Mid-Load Operation of Large Coal-Fired Power Plants</td>
</tr>
</tbody>
</table>
### Lithium Batteries

<table>
<thead>
<tr>
<th>Flexibility impact</th>
<th>Enhancing the dynamic behaviour</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limitations</td>
<td>Market options</td>
</tr>
</tbody>
</table>
| Description        | Electrochemical storage systems ranging from 1kW to 5 MW. The discharge time is from 10 min to 4 hours. It provides:  
  - Provision of control power and control capacity  
  - Supply of back-up power  
  - Peak Shaving  
  - Black start of power plants  
  - Even fluctuating generation  
  - Control of grid voltage  
  - Time shifting and self-consumption of locally produced PV energy |
| Investment         | up to 1,500 Euro/kW               |
| Timeline           | Depending on the size             |
| Best Practice (large scale) |  
  - STEAG Large Battery Systems (90 MWel, 6 x 15 MW)  
  - Enercon & partners; Feldheim (10 MW) |
An optimized mixture of monitoring and diagnostics provides useful information for adapting the plant to flexible operation including modern maintenance strategies.
## 3. O&M: Critical components

<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 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>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>
</tbody>
</table>
### 3. O&M – Practical Tips

#### O & M

<table>
<thead>
<tr>
<th>Plant Area</th>
<th>Issue / Special focus</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Water-Steam Cycle</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Water chemistry</strong></td>
<td>▪ Proper water and steam quality at all load conditions in order to avoid corrosion</td>
<td>Strict adherence 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”</td>
</tr>
<tr>
<td></td>
<td>▪ Cycling results in peak demands on condensate supply and oxygen controls</td>
<td></td>
</tr>
<tr>
<td><strong>Evaporator</strong></td>
<td>▪ Differences of wall temperatures and material stress</td>
<td>▪ Ensuring sufficient steam flow</td>
</tr>
<tr>
<td></td>
<td>▪ Avoidance of overheating</td>
<td>▪ Optimize operation procedures or methods to reduce the ramp rate to the required or necessary minimum</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Check for design buffer in minimum feedwater flow</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Use circulation mode</td>
</tr>
<tr>
<td></td>
<td></td>
<td>▪ Condition monitoring</td>
</tr>
<tr>
<td><strong>Super-heater</strong></td>
<td>▪ Differences of wall temperatures and material stress</td>
<td>▪ Ensuring sufficient steam flow</td>
</tr>
<tr>
<td></td>
<td>▪ Temperature spread at life steam discharge</td>
<td>▪ Condition monitoring</td>
</tr>
</tbody>
</table>


3. Implementation of Flexibility Measures

- Analysis of the status quo
- Test Program
- Performance Analysis
- Flexibility Assessment
- Flexibility Deployment Cycle
- Implementation
- Action Plan
3. New Leadership

...it is a new culture
3. How to deploy the cultural change?

**Motivation:**
- Raise awareness for flexibility and the need for a change

**Training for power plant personnel:**
- New operating regimes – simulator training modules to familiarise with new processes and features
- New maintenance routines – specific training to familiarise with new inspection, repair and spare part management
- Specific for different types of personnel but aiming at a intensive co-operation across departments (operation, maintenance and controlling)

**Deriving a fleet approach:**
- Installing *Flexibility Cells* to sustain and to transfer know-how and to implement train-the-trainer-concepts

The planning and implementation of flexibility measures in the power plants should go hand in hand with a profound training concept taking the staff aboard for the change.
3. Fleet approach for maintenance

Fleet approach to realise synergies

Define power plant types
- market driven – must-run, reserve, etc.
- technology driven – similar equipment (e.g. turbine / boiler)

Assessment and definition of maintenance strategies for different power plant types

Overall fleet is equipped with a uniform automation technology ensuring data transparency and advanced data assessment as well as benchmarking.

Standardization, harmonized working and reporting procedures and exchange of experiences and lessons learned are benefits of the fleet management approach.
3. New requirements for personnel

- New skills
- New work flows
- New organisation
- New maintenance
- New operation regimes
- New job profiles

...it is a new culture
3. New requirements for personnel

- Management
  - Senior Engineer
  - Trainer

- Operational Staff
  - Supervisor
  - Operator

- Maintenance Staff
  - Mechanical
  - Electrical

- Coordinators
  - Operation
  - Grid

Legend:
- AT: Apparatus technology
- MT: Machine technology
- ET: Electrical technology
- C&I: Control & Instrumentation technology
- IF: Instrumentation and Faulty

80 to 90 employees typically work in a 1-unit hard-coal power plant.
### Flexibility-Training-Program “Operation Personnel“

<table>
<thead>
<tr>
<th>Types</th>
<th>Target group</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparation Operation Training</td>
<td>Operating personnel (local and control room)</td>
<td>Qualified Prep-op-certificate (compulsory for the Flexibility Training modules) (optional: recommendation for further promotion)</td>
</tr>
<tr>
<td>Flexibility Operation Training</td>
<td>Control room personnel, shift supervisors and shift engineers</td>
<td>Qualified Flex-op-certificate (compulsory for the Simulator Training modules) (optional: recommendation for further promotion)</td>
</tr>
<tr>
<td>Simulator Training</td>
<td>Control room shift groups</td>
<td>Sim-Flex-certificate (optional: recommendation for further promotion)</td>
</tr>
</tbody>
</table>
3. Training – Overview of Modules

- Preparation
  - Boiler (once through and circulation)
  - One-Mill operation
  - Turbine
  - Electrical components
  - Instrumentation and control
  - Renewables
  - Power plant design and operation
  - Post black out
  - Economical aspects
  - Simulator training (power plant, grid)

- Flexibility
  - Train the trainer
  - Maintenance coordination

- Simulator

- Competency
  - Grid coordination
4. Conclusions

→ The Flexibility Toolbox provides an overview of measures enhancing the flexibility potential of power plants.

→ Toolbox includes technical aspects – retrofits and O&M recommendations, recommendation for the training of power plant personnel as well for management issues.

→ The Toolbox is a joint endeavor of EEC and VGB in the frame of the Indo-German Energy Forum – it will be finalized at the end of 2017.

Flexible power plant operation implies many challenges: technically and organizationally. A holistic approach is needed to address the complex tasks and requirements.
Thank you

for your interest!

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3. Thermal Storage – Example: GKM Mannheim

Not-pressurized flat bottom tank
Hedbäck design:
- Simple design
- Water/steam as medium
- Max. temperature < 100 °C
- High volumenas (> 1000.000 m³)
- High output and capacities up to 300 MW, > 2.000 MWh per tank)