Flexible Operation of Coal Fired Power Stations

Marinus Tabak
Agenda

1. Introduction of RWE
2. The German *Energiewende* and the need for flexibility
3. What is power station flexibility
4. Conclusion
Agenda

1. Introduction of RWE
2. The German *Energiewende* and the need for flexibility
3. What is power station flexibility
4. Conclusion
The New RWE: Our energy for a **sustainable life**

Clear goal: CO₂ neutral in 2040 and -70% CO₂ in 2030

- We are the second largest electricity producer in Europe with #1 position in Germany and the Netherlands, and #2 in the United Kingdom.
- We consistently reduce our CO2 emissions in order to be **carbon neutral by 2040**.
RWE has a large global presence in renewables
Growth ambition 2 – 3 GW per year with a project pipeline >18GW

Focus markets

Focus markets
Europe  Americas  Asia-Pacific

Growth ambition
~2.0-3.0 GW gross p.a.

Funds available for investment
~€1.5 bn net p.a.

1 Size of bubble indicates current approximate growth ambitions in GW.
Agenda

1. Introduction of RWE
2. The German *Energiewende* and the need for flexibility
3. What is power station flexibility
4. Conclusion
Energiewende: analysis of the German model
What can we learn from a frontrunner

80 million inhabitants, total energy consumption 13.550 PJ of which 13% renewable

Electricity consumption
40.000 MW (night)
80.000 MW (day)

56.000 MW installed capacity wind

44.000 MW installed capacity solar

90.000 MW installed capacity conventional, however: nuclear phase out: +/- 9,5 GW and +/- 6 GW old capacity will be phased out.
Electricity production in Germany in an average week

We had some excellent sunny days, wind was average, conventional steady
All the 15 min. data points of the year 2017 of wind + solar
The peak was 52.410 MW production, but half of the data points are below 20.000 MW

[Graph showing solar and wind power production]
In the winter time we see days of no sun and wind
Longest period without sun and wind is about two weeks
Calculation: how many batteries do you need?
Variables: +/- 60.000MW for 14 days, capacity of 1 tesla power wall 6,4 kWh @ € 3.000

14 days x 24 hour  = 336 hour
60.000MW x 336 = 20.160.000 MWh
20.160.000 x 1000 = 20.160.000.000 kWh

20.160.000.000 / 6,4 kWh  = 3,15 billion power walls

Capital needed: 9.450 billion euro

Gross domestic product Germany: 3.500 billion euro

The main challenge is to store electricity, we need to use all options, batteries, flexible CO2 neutral power stations, hydro, hydrogen etc.
Agenda

1. Introduction of RWE
2. The German *Energiewende* and the need for flexibility
3. What is power station flexibility
4. Conclusion
What is power station flexibility?

- **Technical Design**
  Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

- **Technology**
  Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

- **Fuel Flexibility**
  Ability to run on diverse blend and alternative fuels like biomass, waste etc.

- **Maintenance strategy**
  Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

- **Organisational set-up**
  Depending on the operating mode you have different organisational models that suit the situation best

- **Flexibility Products**
  There are different flexibility products like balancing, black-start, reactive power, frequency control
What is power station flexibility?

**Technical Design**
Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

**Technology**
Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

**Fuel Flexibility**
Ability to run on diverse blend and alternative fuels like biomass, waste etc.

**Maintenance strategy**
Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

**Organisational set-up**
Depending on the operating mode you have different organisational models that suit the situation best

**Flexibility Products**
There are different flexibility products like balancing, black-start, reactive power, frequency control
Due to the set-up of the electricity market, we see a demand for a wide variability of flex products that can be commercialised.
Overview of the several reserve products and their timescales

**Primary reserve**
- Reaction time: 30 seconds (100%)
- System: UCTE\(^1\)
- Activation: Automatic and decentralised activation via governor control
- Reserved capacity: 3,000 MW in UCTE (600 MW in Germany)
- Auction: Weekly
- Remuneration: Pay-as-bid
- Typical suppliers: Synchronised generators\(^2\), run-of-river plants, storage and pumped storage hydro plants, large-scale battery storage systems

**Secondary reserve**
- Reaction time: 5 minutes (100%)
- Control area: Centralised (TSO); active call through IT
- Reserved capacity: Decided by TSO (2,500 MW in Germany)
- Auction: Weekly
- Remuneration: Pay-as-bid
- Typical suppliers: Storage and pumped storage hydro plants; gas turbine power plants; CHP; large-scale battery storage systems

**Tertiary reserve**
- Reaction time: 7 - 15 minutes (100%)
- Control area: Centralised (TSO); active call through phone / IT
- Reserved capacity: Decided by TSO (2,500 MW in Germany)
- Remuneration: Daily
- Typical suppliers: Storage and pumped storage hydro plants; gas turbine power plants; CHP

A sudden drop in frequency triggers automated response to correct the frequency, followed by manual interventions by power system operators.

---

\(^1\) The Union for the Coordination of the Transmission of Electricity.

\(^2\) Primary regulating units are required to reserve ~2% of their nominal power ("primary control reserve", updated every year).
What is power station flexibility?

- **Technical Design**
  Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

- **Technology**
  Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

- **Fuel Flexibility**
  Ability to run on diverse blend and alternative fuels like biomass, waste etc.

- **Maintenance strategy**
  Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

- **Organisational set-up**
  Depending on the operating mode you have different organisational models that suit the situation best.

- **Flexibility Products**
  There are different flexibility products like balancing, black-start, reactive power, frequency control.
Eemshaven power station: 2x800 MW ramping up and down with 22 MW per minute – min. load at 224 MW

Eemshaven is the cleanest and most efficient hard coal fired power station of western Europe, at the same time it can ramp up and down with >22MW a minute and start up in a matter of hours.

<table>
<thead>
<tr>
<th>Component</th>
<th>30 min average</th>
<th>Day average</th>
<th>Year average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stikstofoxide (NOx)</td>
<td>200 mg/nm³</td>
<td>100 mg/nm³ (1)</td>
<td>60 mg/nm³</td>
</tr>
<tr>
<td>Zwaaveldioxide (SOx)</td>
<td>200 mg/nm³</td>
<td>50 mg/nm³ (1)</td>
<td>40 mg/nm³</td>
</tr>
<tr>
<td>Stof (Staub)</td>
<td>20 mg/nm³</td>
<td>5 mg/nm³ (1)</td>
<td>3 mg/nm³</td>
</tr>
<tr>
<td>Waterstofchloïde (HCl)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>1.2 mg/nm³</td>
</tr>
<tr>
<td>Fluorwaterstof (HF)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>0.5 mg/nm³</td>
</tr>
<tr>
<td>Cadmium (Cd) en thallium (TI)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>0.05 µg/nm³</td>
</tr>
<tr>
<td>Kwik (Hg)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>2.8 µg/nm³</td>
</tr>
<tr>
<td>Overige zware metalen (2)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>14 µg/nm³</td>
</tr>
<tr>
<td>Dioxinen/furanen (PCDD/PCDF)</td>
<td>n.a.</td>
<td>n.a.</td>
<td>0.0026 ng/nm³</td>
</tr>
<tr>
<td>Koolstofmonoxide (CO)</td>
<td>n.a.</td>
<td>100 mg/nm³</td>
<td>50 mg/nm³</td>
</tr>
<tr>
<td>Totaal koolwaterstoffen (C-H) (3)</td>
<td>n.a.</td>
<td>5 mg/nm³</td>
<td>1 mg/nm³</td>
</tr>
</tbody>
</table>
## Boiler design

### Technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HP</th>
<th>RH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam flow</td>
<td>2,171</td>
<td>1,782</td>
</tr>
<tr>
<td>Steam pressure</td>
<td>285</td>
<td>59</td>
</tr>
<tr>
<td>Steam temperature</td>
<td>600</td>
<td>610</td>
</tr>
<tr>
<td>Feedwater temperature</td>
<td>308</td>
<td></td>
</tr>
<tr>
<td>Cold RH temperature</td>
<td></td>
<td>359</td>
</tr>
<tr>
<td>Flue gas temperature</td>
<td></td>
<td>115</td>
</tr>
<tr>
<td>Boiler efficiency</td>
<td></td>
<td>95.3</td>
</tr>
</tbody>
</table>
Flue gas cleaning

### Technical data

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiler fuel</td>
<td>Hard coal</td>
</tr>
<tr>
<td>Plant capacity</td>
<td>2 x 800 MW</td>
</tr>
<tr>
<td>FGD process</td>
<td>Wet limestone-gypsum</td>
</tr>
<tr>
<td>Flue gas discharge</td>
<td>Wet stack</td>
</tr>
<tr>
<td>Gas flow rate</td>
<td>2,116,000 m³N/h</td>
</tr>
<tr>
<td>Inlet gas temperature</td>
<td>115 – 140 °C</td>
</tr>
<tr>
<td>Inlet SO₂ concentration</td>
<td>max. 4,100 mg/Nm³ dry</td>
</tr>
<tr>
<td>SO₂ removal efficiency</td>
<td>98.5 (5 levels)</td>
</tr>
<tr>
<td>Absorber type</td>
<td>Single-loop in-situ oxidation process</td>
</tr>
</tbody>
</table>

- ESP 5 cells
- Ash collection and transport
- ID fan
- FGD
- Waste-water treatment plant
Flue gas cleaning
Flue gas cleaning: SCR
What is power station flexibility?

Technical Design
Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

Technology
Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

Fuel Flexibility
Ability to run on diverse blend and alternative fuels like biomass, waste etc.

Maintenance strategy
Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

Organisational set-up
Depending on the operating mode you have different organisational models that suit the situation best

Flexibility Products
There are different flexibility products like balancing, black-start, reactive power, frequency control
Biomass the CO₂ neutral fuel and feedstock
Biomass is much more than wood, we also look towards agricultural residues

Biomass is:

- Stored solar energy: for example, nature is 20x as efficient in storing energy than us using batteries (in other words: 1kg of biomass contains the same energy as 20kg of lithium ion batteries)

- CO₂ neutral fuel and feedstock

- Abundantly available - but the Netherlands needs to import e.g. from the USA

- Crucial source of carbon to make industry fossil free and according IPCC key in developing CO2 negative sources (Bio-Energy Carbon Capture)

- Valuable and therefore we need to use it in an intelligent way e.g. cascading the biomass in refineries
With the same power station, we can go from fossil, to green and from green to CO2 negative...

Fossil CO₂ emissions  

Sustainable and green

- **Coal**  
  - 22Mton CO₂
  - 1/3

- **Gas**  
  - 14Mton CO₂
  - 2.5x

- **Biomass**

- **BECCS**  
  - 15 Mton CO₂
  - 4x

= 1 Mton CO₂ reduction
And biomass comes in many shapes and forms...

Example:

Millions of tons of biomass are simply burned, having negative consequences.
What is power station flexibility?

**Technical Design**
Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

**Technology**
Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

**Fuel Flexibility**
Ability to run on diverse blend and alternative fuels like biomass, waste etc.

**Organisational set-up**
Depending on the operating mode you have different organisational models that suit the situation best.

**Maintenance strategy**
Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

**Flexibility Products**
There are different flexibility products like balancing, black-start, reactive power, frequency control.
Becoming „Best in Class“ means reaching optimal costs and optimizing availability and efficiency with available resources.

Schematic: most optimal structure of maintenance cost and “cost of unavailability”

Eemshaven aims at implementing the most optimal maintenance strategy and excelling in operational performance based on a multilayered approach. The approach consists of several initiatives all of which focus on the highest impact the available resources can deliver and on a continuously improving performance culture.
Taking probabilities, HSE risks, unavailability and cost into consideration, the objective of the two-step “IBC” initiative is to ultimately be carried out for the whole installation.

1. Overall Risk Assessment

The decision tree gives guidance whether preventive or corrective maintenance is the more favorable option for (sub-)aggregates of the respective system. It can also give a hint to modify the installation if neither is acceptable.

2. Detailed Decision Tree

Effect of defect

<table>
<thead>
<tr>
<th>Danger</th>
<th>Bottleneck</th>
<th>Delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>High probability</td>
<td></td>
<td>Low probability</td>
</tr>
<tr>
<td>Medium probability</td>
<td></td>
<td>Medium probability</td>
</tr>
<tr>
<td>Low probability</td>
<td></td>
<td>High probability</td>
</tr>
</tbody>
</table>

Probability of defect

<table>
<thead>
<tr>
<th>Low</th>
<th>Medium</th>
<th>High</th>
</tr>
</thead>
</table>

The decision tree gives guidance whether preventive or corrective maintenance is the more favorable option for (sub-)aggregates of the respective system. It can also give a hint to modify the installation if neither is acceptable.

All areas define the most important systems within their part of the installation. Systems/sub-systems rated within the dark blue areas of the matrix are the first to be further evaluated using the decision tree.

1 A=unlikely; B=rarely; C=barely; D=frequently; E=often
2 0=none; 1=slight; 2=limited; 3=serious; 4=severe; 5=calamitous
The “Cost Driver” initiative focuses on reducing the highest costs for both preventive and corrective maintenance

Objective:
• Reduce the highest unnecessary costs for both
  • Preventive maintenance
  • Corrective maintenance

Logic:
• Identify highest historical maintenance costs for systems/aggregates that...
  • Preventive: have never/hardly caused corrective action
  • Corrective: are not maintained preventively or/and are maintained preventively but still cause corrective action
• Analyze root cause, develop and implement strategies to lower costs, e.g:
  • extend/reduce time between preventive maintenance activities
  • switch to corrective/preventive maintenance
  • Improve/develop monitoring strategies for condition based maintenance (usage of PQQO and/or SPC system)
  • improve operating procedures of installation
  • consider modification of installation

Method:
• RATIO (root cause analysis)

In addition to savings on maintenance costs, we expect an even better condition of the installation. The initiative is not planned as one-off but will become part of our Eemshaven heartbeat. Shifting employees from the E&M department own the initiative, our RATIO facilitators (ambassadors) support. This way, not only will we improve on cost and performance but also further develop our continuous improvement mindset and culture.
The “Performance Killer” initiative focuses on reducing the highest “costs of unavailability”

Objective:
• Reduce the highest unnecessary costs of unavailability

Logic:
• Identify highest historical unavailability’s (duration of unavailability x limitation of maximal output, e.g. based on ProPer)
• Screen for “unnecessary” unavailability
• Analyze root cause, develop and implement strategies to lower costs, e.g:
  • improve operating procedures of installation
  • Improve/develop process monitoring strategies (usage of PQQO and/or SPC system)
  • Train employees
  • Improve maintenance concept (see “Cost Driver” initiative)

Method:
• RATIO (root cause analysis)

Same as the “Cost Driver” initiative, this initiative is not planned as one-off but will become part of our Eemshaven heartbeat. Shifting employees from the Operations department own the initiative, our RATIO facilitators (ambassadors) support. In addition to generating a higher income due to higher availability, this way we will also further develop our continuous improvement mindset and culture.
The “Bad Actor” initiative focuses on reducing the number of M5 notifications, particularly priority 1 notifications.

**Objective:**
- Reduce the number of “unnecessary” M5 notifications in order to:
  - Reduce maintenance costs
  - Improve on plant performance
  - Reduce interference of processes (e.g. number of work orders, planning, throughput time)
  - Enable people to transform wasted time into value adding time

**Logic:**
- Identify systems/aggregates with highest historical number of (priority 1) M5 notifications
- Analyze root cause, develop and implement strategies to lower number of (priority 1) notifications, e.g.:
  - Improve operating procedures (see “Performance Killer” initiative)
  - Improve maintenance concept (see “Cost Driver” initiative)
  - Improve/implement usage of PQO and/or SPC system
  - Consider modification of installation

**Method:**
- RATIO (root cause analysis)

Same as the “Cost Driver” and “Performance Killer” initiatives, this initiative is not planned as one-off but will become part of our Eemshaven heartbeat. Shifting employees from the E&M department own the initiative, our RATIO facilitators (ambassadors) support. A big surplus of this initiative is to enable employees to use their time in a planned rather than an ad-hoc way and thus creating time for value adding topics.
The “SPC” initiative focuses on taking the next step towards predictive maintenance and next level plant performance

Objective:
- Expand usage of Statistical Process Control functionality in addition to well established Process Quality Optimization (PQO) tool for thermodynamic process optimization in order to
  - Improve plant performance (increase availability and efficiency)
  - Make steps towards predictive maintenance (reduce cost, reduce (unplanned) unavailability)

Logic:
- Identify KPI’s that reflect
  - Condition of the thermodynamic process
  - Condition of the installation
- “Train” the SPC with historical data related to KPI’s (knowledge of physical context of neural network not required)
- Automatically identify performance and plant related issues
- Where needed, analyze root cause and develop strategies and
  - Improve plant performance
  - Plan and execute maintenance

Method:
- KPI development and SR::SPC based RATIO (root cause analysis)

Other than pure corrective or preventive maintenance and “manual” analysis based on PQO tool only, the big advantage of SPC is that “only” knowledge of the most optimal KPI’s is needed as basis for good results. Based on “supervised learning”, the system analyses interdependencies and automatically alerts the user in case of relevant deviations. This way, maintenance needs can be met more precisely.
Agenda

1. Introduction of RWE
2. The German *Energiewende* and the need for flexibility
3. What is power station flexibility
4. Conclusion
What is power station flexibility: many things, but above all a mind-set that we can deliver it!!

**Technical Design**
Operating window of the power station, ramp up/down, material abilities, boiler design, start-up sequence etc.

**Technology**
Automation of the power station, flexibility tools like heat storage, batteries, hydrogen etc.

**Maintenance strategy**
Different load regimes require different maintenance strategies – increased start-stop or load flexibility requires different maintenance.

**Organisational set-up**
Depending on the operating mode you have different organisational models that suit the situation best

**Fuel Flexibility**
Ability to run on diverse blend and alternative fuels like biomass, waste etc.

**Flexibility Products**
There are different flexibility products like balancing, black-start, reactive power, frequency control
Thank you very much!

Marinus Tabak
Marinus.tabak@rwe.com
+316-46164276

Our energy for a sustainable life