Graph Use Cases in the Electrical Power Grid

Matthias Gebhardt
A moment for safety

Together we provide a safe working environment. We learn from mistakes and sharing ideas, concerns and asking questions are a matter of course.

We also draw attention to the following safety measures in case of evacuation of the premises:

- Follow the escape route as indicated
- Use the stairs instead of the lift
- Go to the assembly point
- Follow the instructions of the in-company emergency responder

Keep 1.5 meter distance

05 Mai 2021
Confidentiality C1
Operating the Electricity Grid at 220 kV and 380 kV
TenneT at a Glance

- **Workforce**: 4,913 Employees
- **EBIT**: 768 EUR million
- **Assets**: 21.8 EUR billion
- **Investments 2019-2029**: 35 EUR billion
- **Grid**: 99.99% Availability
- **Grid length**: 23,555 Km
- **Dutch State**: 100% Shareholder
- **Footprint**: 27.4% Greened
TenneT at a Glance

Germany

Facts & figures

Employees (internal + external) 2,390

Assets

EUR 16,067 bn

Total grid length 12,606 km

Transformer substations 129

Number of end-users 24.3 m
Our tasks
A grid operator’s tasks

Main tasks

**Transmission services**
Ensure a robust and efficient high-voltage grid

**System services**
Maintain the balance of electricity, 24/7

**Market facilitation**
Facilitate an efficient and stable electricity market
Maintaining the balance

Maintenance of the energy balance: the amount of electricity produced must always exactly match the amount of electricity consumed.

- Load variations
- Deviations from prognoses

- Maintenance of the energy balance
- Outage of power plants
- Volatile production of renewable energy sources
Load in Control Area TenneT
Total consumption of a day
Renewable Energy Sources in Control Area TenneT

Generated energy per month

- Wind Onshore
- Wind Offshore
- Solar

Graph showing generated energy in MWh from 2017 to 2020.
Installed Capacity Wind Onshore and Solar

Installed capacity in total 22.8 GW

Installed capacity in total 19.2 GW
Offshore capacity in Germany and The Netherlands

9.832 GW in 2026 (GER)

- DolWin1 – 800 MW – DC
- DolWin2 – 916 MW – DC
- DolWin3 – 900 MW – DC
- DolWin5 – 900 MW – DC
- DolWin6 – 900 MW – DC

alpha ventus – 62 MW – AC
Riffgat – 113 MW – AC
Nordergründe – 111 MW – AC

DolWin2 – 916 MW – DC
HelWin1 – 576 MW – DC
HelWin2 – 690 MW – DC

BorWin1 – 400 MW – DC
BorWin2 – 800 MW – DC
BorWin3 – 900 MW – DC
BorWin5 – 900 MW – DC

Future projects (DE):

- BorWin6
  - 930 MW 2027
- BalWin1
  - 2000 MW 2029
- BalWin2
  - 2000 MW 2030
- BalWin3
  - 2000 MW 2030

16.7 GW until 2030

Future projects (NL):

- IJmuiden Ver Alpha
  - 2000 MW 2027
- IJmuiden Ver Beta
  - 2000 MW 2029

9.6 GW until 2030

5.6 GW in 2026 (NL)

- Borssele Alpha
  - 700 MW – AC
- Borssele Beta
  - 700 MW – AC
- Hollandse Kust (zuid) Alpha
  - 700 MW – AC
- Hollandse Kust (zuid) Beta
  - 700 MW – AC
- Hollandse Kust (noord)
  - 700 MW – AC
- Hollandse Kust (west) Alpha
  - 700 MW – AC
- Hollandse Kust (west) Beta
  - 700 MW – AC
- Ten noorden v.d. W.
  - 700 MW – AC

05 Mai 2021
Confidentiality C1
# Offshore Grid Connections (DE)

<table>
<thead>
<tr>
<th>Project</th>
<th>Capacity (MW)</th>
<th>Commissioning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Operational</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>alpha ventus</td>
<td>62</td>
<td>2009</td>
</tr>
<tr>
<td>BorWin1</td>
<td>400</td>
<td>2010</td>
</tr>
<tr>
<td>BorWin2</td>
<td>800</td>
<td>2015</td>
</tr>
<tr>
<td>DolWin1</td>
<td>800</td>
<td>2015</td>
</tr>
<tr>
<td>DolWin2</td>
<td>916</td>
<td>2016</td>
</tr>
<tr>
<td>DolWin3</td>
<td>900</td>
<td>2018</td>
</tr>
<tr>
<td>HelWin1</td>
<td>576</td>
<td>2015</td>
</tr>
<tr>
<td>HelWin2</td>
<td>690</td>
<td>2015</td>
</tr>
<tr>
<td>Nordergründe</td>
<td>111</td>
<td>2017</td>
</tr>
<tr>
<td>Riffgat</td>
<td>113</td>
<td>2014</td>
</tr>
<tr>
<td>SylWin1</td>
<td>864</td>
<td>2015</td>
</tr>
<tr>
<td>BorWin3</td>
<td>900</td>
<td>2019</td>
</tr>
<tr>
<td><strong>Under construction</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DolWin6</td>
<td>900</td>
<td>2023</td>
</tr>
<tr>
<td>DolWin5</td>
<td>900</td>
<td>2024</td>
</tr>
<tr>
<td>BorWin5</td>
<td>900</td>
<td>2025</td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td>9,832</td>
<td></td>
</tr>
<tr>
<td><strong>To be built</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BorWin6</td>
<td>900</td>
<td>2027</td>
</tr>
<tr>
<td><strong>Σ</strong></td>
<td>10,732</td>
<td></td>
</tr>
</tbody>
</table>
Planning Processes and Congestion Forecast

Keep your assets safe

Use forecasts of the generation and consumption to determine possible congestions in the grid.
Planning Processes and Congestion Forecast

- **Input**
  - load
  - conventional generation
  - generation from wind power plants
  - generation from solar power plants
  - planned outages
  - horizontal exchange

- **Output**
  - grid and market activities to ensure a congestion free grid
  - redispatch
  - grid reserve
  - possible short term redispatch
  - curtailment

Congestion forecasts are national and European processes.
Planning Processes and Congestion Forecast
Redispatch and curtailment

220/380 kV TSO Grid

110 kV DSO Grid

OVERLOAD
Planning Processes and Congestion Forecast
Redispatch and curtailment

220/380 kV TSO Grid

110 kV DSO Grid

OVERLOAD

generate more

generate less
Planning Processes and Congestion Forecast
Redispatch and curtailment

220/380 kV TSO Grid
110 kV DSO Grid

- OVERLOAD
- generate more
- curtailment
- generate less
- curtailment
Grid Node Forecast
Map geographical generation to 110 kV busbar

220/380 kV

grid topology

110 kV

geographical information
Impact on Wind Forecasts

Squall line

Storm cut-off

Icing

Curtailment
Negative Prices
Trading Behaviour
Impact on Solar Forecasts

- Sahara Dust
- Sun Eclipse (10.06.2021)
- Fog
- Snow
Grid Node Forecast
Misty graphs

How to map the geographical generation and sensitivity to the busbars?
Grid Node Forecast
Misty graphs

How to map the geographical generation and sensitivity to the busbars?
Grid Models and other Graphs

- Grid models are exchanged between the operators using the Common Grid Model Exchange Standard (CGMES) Library or in UCTE format on different forecast (d+2, d+1, intraday, snapshots) horizons.
- The different models are merged and grid security analysis is performed.

- How to store the grid models like a time series for e.g ex-post analysis?
- Are there typical switching states in dependency of the weather?
- Where to set new assets?
- How to performe grid restoration and synchronisation?
- ...
Disclaimer

This PowerPoint presentation is offered to you by TenneT TSO B.V. (‘TenneT’). The content of the presentation – including all texts, images and audio fragments – is protected by copyright laws. No part of the content of the PowerPoint presentation may be copied, unless TenneT has expressly offered possibilities to do so, and no changes whatsoever may be made to the content. TenneT endeavours to ensure the provision of correct and up-to-date information, but makes no representations regarding correctness, accuracy or completeness.

TenneT declines any and all liability for any (alleged) damage arising from this PowerPoint presentation and for any consequences of activities undertaken on the strength of data or information contained therein.
TenneT is a leading European grid operator (Transmission System Operator (TSO)). We design, build, maintain and operate the high-voltage electricity grid in the Netherlands and large parts of Germany and facilitate the European energy market. We are committed to providing a secure and reliable supply of electricity, today and in the future, 24 hours a day, 365 days a year and to playing our role in driving the energy transition. We transport electricity over a network of approximately 23,500 kilometres of high-voltage connections, from wherever and however it's generated, to over 42 million end-users while keeping electricity supply and demand balanced at all times. With close to 5,000 employees, we achieve a turnover of 4.1 billion euros and a total asset value of EUR 23 billion. TenneT is one of the largest investors in national and international onshore and offshore electricity grids. TenneT makes every effort to meet the needs of society. This will require us all to take ownership, show courage and connect with each other.

www.tennet.eu