State-of-the-Art Offshore Power System in the German Bight and Technical Mid-Term Expansion Options

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Energy Economy and Grid Operation
Transmission Grids
Content

- North Sea Overview
- Cluster Concept for Offshore Connections
- Transmission Technology
- Status in the German Bight
- Redundancy Options
- Reliability Analysis
- North Sea Offshore Network
North Sea Overview

Installed Capacity
- United Kingdom 4.9 GW
- Germany 2.4 GW
- Denmark 1.2 GW
- Belgium 0.7 GW
- Netherlands 0.2 GW
- Sweden 0.2 GW

Source: 4C Offshore (http://www.4coffshore.com) February 2015
The Cluster Concept for Offshore Connections

Offshore Wind Park
(~ 300 MW each)

155-kV Three-phase System
(~300 MW, max. 20 km)

Offshore Converter Station
(+/- 320 kV, 900 MW)

HVDC Submarine/Land Cable

Onshore Converter Hall/Switchgear

155-kV Three-phase System (~300 MW, max. 20 km)
Connection to Shore

Grid

2 x 155 kV submarine cable

AC link

Wind farm

33 kV collector network

Source:
Dr. Felties, RWE Innogy
Submarine Cables

- HVAC
  - Three-Core
  - Single-Core
- HVDC
  - Oil-Paper
  - XLPE

Source: ABB
HVDC Devices

IGBT Technology (currently up to 6.5 kV)

- IGBT Module
  - Soldered bond contact
  - Infineon
  - Mitsubishi
  - ABB
  - Semikron
  - ...

- Press-Pack IGBT
  - Ceramic bond
  - Toshiba
  - Westcode/IXYS
  - ABB
  - Fuji
  - ...

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HVDC Converter Topologies

- 2-level Inverter
- 3-level Inverter
- MMC
- 2-level Rectifier
- 3-level Rectifier
- MMC

- Filter losses
- Trafo losses
- Switching losses
- Conduction losses

Source: Creative Common Licence
Gas Insulated Lines (GIL)

- 400 kV
- > 2000 MVA
- Low Losses
- SF6 gas insulation
- Self Healing after fault
- > 300km distances
- No outer magnetic field
- No compensation required

Source: Prof. Hofmann, University Hannover
Gas Insulated Lines (GIL)

Source: Prof. Hofmann, University Hannover
Low Frequency AC Transmission

Source: Prof. Erlich, University Duisburg-Essen
North Sea Development Stage

Alstom (2017/19)
MMC-Converter
"MaxSine"

ABB (2013)
2-Level-Converter
"HVDC Light"

SIEMENS (2015)
MMC-Converter
"HVDC Plus"

SIEMENS (2015/19)
MMC-Converter

ABB (2015)
CTLC-Converter

Alstom (2017/19)
MMC-Converter
"MaxSine"

ABB (2016)
CTLC-Converter

Source: Maximilian Dürrbecker
North Sea Development Stage, German Bight

- **In Operation (DC)**
  - BorWin 1, 400 MW, 2010
  - BorWin 2, 800 MW, 2015
  - DolWin 1, 800 MW, 2015
  - HelWin 1, 576 MW, 2015
  - HelWin 2, 690 MW, 2015
  - SylWin 1, 864 MW, 2015

- **In Operation (AC)**
  - alpha ventus, 62 MW
  - Riffgat, 113 MW

- **Construction commissioned**
  - BorWin 3, 900 MW, 2019
  - DolWin 2, 916 MW, 2016
  - DolWin 3, 900 MW, 2017
  - Nordergründe (AC) 111 MW

- **Planned (DC)**
  - BorWin 4, 900 MW, 2019
  - BorWin 5, 900 MW, 2023
  - DolWin 4, 900 MW, 2025
  - SylWin 2, 900 MW, 2024

Source: TenneT Offshore GmbH
Redundancy Options

- Ring closure
- 155-kV Interconnection
- HVDC Interconnection (Multi-Terminal)
# Reliability Analysis for Parallel HVDC – Case A

<table>
<thead>
<tr>
<th>States</th>
<th>Probabilities</th>
<th>h/year</th>
<th>Yield without outage [MWh]</th>
<th>Yield with outage [MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without line (Base Case)</td>
<td>300 MW line</td>
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<tr>
<td>No outage</td>
<td>95,028%</td>
<td>8324,44</td>
<td>7491992,6</td>
<td>7491992,6</td>
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<tr>
<td>One HVDC out of service</td>
<td>4,859%</td>
<td>425,61</td>
<td>383047,4</td>
<td>191523,7</td>
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<tr>
<td>Two HVDC out of service</td>
<td>0,063%</td>
<td>5,48</td>
<td>4933,9</td>
<td>0</td>
</tr>
<tr>
<td>HVDC and AC Interconnection out of service</td>
<td>0,051%</td>
<td>4,47</td>
<td>4026,4</td>
<td>2013,2</td>
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<tr>
<td>Sum</td>
<td>1,00</td>
<td>8760,00</td>
<td>7.884.000,33</td>
<td>7.685.529,52</td>
</tr>
</tbody>
</table>

| Difference (MWh)                      | 0,00           | 127.682,47 | 191.523,71                |
| Cost savings                          | 0,00 €         | 12.768.247,06 € | 19.152.370,59 € |

| Energy costs €/MWH                    | 100            |

- **Onshore** → **Offshore**

**Diagram:**
- VSC 1
- HVDC 1
- L1
- OWP 1
- VSC 2
- OWP 2
- HVDC 2
- L2
- OWP 3
- VSC 3
- OWP 4
- L5

**Text:**
- **450 MW installed (each OWP)**
- Ø 50% in-feed

**Fraunhofer IWES**
Reliability Analysis for Parallel HVDC – Case B

<table>
<thead>
<tr>
<th>States</th>
<th>Probabilities</th>
<th>Yield without outage [MWh]</th>
<th>Yield with outage [MWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Without line (Base Case)</td>
</tr>
<tr>
<td>No outage</td>
<td>95,028%</td>
<td>5993594,1</td>
<td>5993594,1</td>
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<tr>
<td>One HVDC out of service</td>
<td>4,859%</td>
<td>306437,9</td>
<td>153219,0</td>
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<tr>
<td>Two HVDC out of service</td>
<td>0,063%</td>
<td>3947,1</td>
<td>0</td>
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<tr>
<td>HVDC and AC Interconnection out of service</td>
<td>0,051%</td>
<td>3221,1</td>
<td>1610,6</td>
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<tr>
<td>Sum</td>
<td>1,00</td>
<td>6.307.200,26</td>
<td>6.148.423,61</td>
</tr>
</tbody>
</table>

| Difference (MWh)                           | 0,00          | 127.682,47                | 153.218,96              |
| Cost savings                               | 0,00 €        | 12.768.247,06 €           | 15.321.896,47 €         |

Energy costs €/MWH 100

450 MW installed (each OWP)
Ø 40% in-feed (3500 full-load hours)

interest rate 8%

| savings (20 years) | 125,4 Mio € | 150,4 Mio € |
| savings (25 years) | 136,3 Mio € | 163,6 Mio € |
North Sea Offshore Network (NSON)

European Commission\(^1\) treats offshore power system as priority corridor between North and Central Europe

North Sea Offshore and Storage Network (NSON)

NSON could be first step towards European “SuperGrid“ (Overlay-Network)

NSON project objectives:
- Analysis of different market and power system options
- Quantify the effect on German and European energy supply system
- Quantify the effect on power system infrastructure
- New developments in mathematical optimization methods for power system planning and operation purposes

## NSON Potential Benefits

<table>
<thead>
<tr>
<th>NSON as additional power system expansion in the north sea region</th>
<th>Security of supply</th>
<th>Market and competition</th>
<th>Integration of renewable energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Improvement of interconnection between load centers</td>
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<tr>
<td>Reduced imports of fossil fuels</td>
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<td>Transmission of offshore wind energy to load centers</td>
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<tr>
<td>Avoiding of transmission system congestions</td>
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<tr>
<td>Increase of exchange capacity between countries, increase trading and competition</td>
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<td>Containment of peak prices</td>
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<tr>
<td>Driving force for standards for offshore wind and suppliers</td>
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<tr>
<td>Beneficial for integration of offshore wind capacity</td>
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<tr>
<td>Power balancing due to spatial extension</td>
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<tr>
<td>Integration of Scandinavian hydroelectric capacities</td>
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<tr>
<td>Integration of offshore storage technologies</td>
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<td></td>
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<tr>
<td>Contribution to CO₂ reduction</td>
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