DONG Energy Wind Power

The challenges of connecting offshore wind

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DONG Energy is one of the leading energy groups in Northern Europe

Our business is based on procuring, producing, distributing and trading in energy and related products in Northern Europe.

DONG Energy has 7,000 employees and is headquartered in Denmark.
DONG Energy’s strategy

Doubling EBITDA, DKK billion

Halving CO₂ emissions, g CO₂ per kWh
Offshore Wind Power

Wind Power develops, constructs and operates wind farms in Northern Europe.

<table>
<thead>
<tr>
<th>Under construction</th>
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<tbody>
<tr>
<td>Anholt Offshore</td>
<td>400</td>
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<tr>
<td>Demo projects</td>
<td>12</td>
</tr>
<tr>
<td>Lincs</td>
<td>270</td>
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<tr>
<td>London Array 1</td>
<td>630</td>
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<tr>
<td>West of Duddon Sands</td>
<td>389</td>
</tr>
<tr>
<td>Borkum Riffgrund 1</td>
<td>277</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>1,978</strong></td>
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**Target 2020: 6.5 GW**

### Projects completed with DONG Energy

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<td>1,2 GW</td>
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The challenges of connecting offshore wind

- Larger turbines
- Bigger wind farms
- Further from the power system

100 – 200 km from wind farm to power system
The challenges of connecting offshore wind

A case

how to connect

Wind farm: 1 GW – 100 mile from PCC
The electrical challenges
- HVDC
- Long HVAC Cables

The grid code challenges
- New requirements
- Ancillary services

Harmonic resonance
Harmonic stability
Transient voltages
Voltage control
Protection
Emission

Cost of Energy

Black-start
Artificial inertia,
Stop-to-house-load,
High wind ride through,
High voltage ride through,
Power Oscillation Damping

The challenges of connecting offshore wind
The challenges of connecting offshore wind

Harmonic issues

We need to understand:
- WTG converter
- controller
- array design
- export cable
- power system

1. Emission
   - The WTG converter emits harmonics
2. Amplification
   - The wind farm "amplifies" the background harmonics
3. Harmonic stability
   - The WTG controller and grid becomes unstable

Wind farm & offshore substation

Submarine cable

Land cable

HV/E-HV

Onshore substation

Shunt Compensation
The challenges of connecting offshore wind

Ideas to mitigate the harmonic issue:

(1) Passive filter in wind turbines
(2) Active filter in wind turbines
(3) Active filter in group of wind turbines
(4a) Passive filter at the offshore substation
(4b) Passive filter at the onshore substation
(5) Active filter at the point of common coupling
The challenges of connecting offshore wind

• Areas of interest
  – Harmonic resonance and stability
  – Mitigation of harmonics
  – Wind Farms connected via long AC cables
  – HVDC connected wind farms
  – Multiple HVDC connected wind farms
  – Multi terminal HVDC
The challenges of connecting offshore wind