NORCOWEs viktigste prosjekter og resultater
Frokostmøte 24/8 2017

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Partners

Research partners:
- Christian Michelsen Research AS (host)
- Uni Research AS
- University of Agder
- University of Bergen
- University of Stavanger
- Aalborg University (DK)

User partners:
- Statkraft AS
- Statoil AS
- Acona Flow Technology AS
- Aquiloz AS
- Axys Technologies
- Leosphere
- Norwegian Meteorological Institute
- StormGeo AS
NORCOWE in figures

- PhD 27 (including current students)
- Masters 58
- Post doc 7
- Budget 253 mill NOK (120 mill NOK from RCN)
Why NORCOWE?

• Help to solve current and future challenges for the offshore wind industry
• Help the industry to identify issues that need attention
• Mobilize new Norwegian research groups to address offshore wind
• Joint effort, cooperation towards common goals
• Add value to the partners: Coordination, network and marketing
Relevant time and length scales in offshore wind

<table>
<thead>
<tr>
<th>Scale</th>
<th>Length</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesoscale</td>
<td>10,000 - 10 km</td>
<td>Days - Hours</td>
</tr>
<tr>
<td>Park scale</td>
<td>10 - 1 km</td>
<td>20 min – 20 s</td>
</tr>
<tr>
<td>Rotor scale</td>
<td>200 - 50 m</td>
<td>10 – 2 s</td>
</tr>
<tr>
<td>Blade scale</td>
<td>5 - 0.5 m</td>
<td>0.5 – 0.01 s</td>
</tr>
</tbody>
</table>

Factor of $10^6$ in relevant length and time scales

“Alt henger sammen med alt”

By courtesy of Finn-Gunnar Nielsen
Increased energy production – lower LCoE

The energy production depends on the wind speed cubed – a small difference in wind speed equals a large difference in income

Loss of energy production due to neighbouring turbines is a well known phenomena (wake effect), but not so well quantified

Loss of energy production due to neighbouring wind farms is a phenomena of budding interest
ECN/NORCOWE wake study campaign

- October 2013 – May 2014
- Single turbine row wake
- 2 nacelle mounted LiDARs
- 5 LiDARs in the field
  - 1 scanning
- SUMO flights in May 2014
NORCOWE campaigns – OBLEX-F1
FINO1, German Bight, May 2015 – September 2016 (atmospheric part); May 2015 – October 2015 (oceanic part)
Towards the optimum O&M strategy

- Integrating load estimates, condition monitoring and failure estimates into reliability based O&M strategies.
- Reduce O&M costs
- Improve capacity factor
- Increase lifetime

Courtesy: John Dalsgaard Sørensen, AAU
NORCOWE RWF

- Reference site: FINO3
- Installed capacity: 800 MW
- Number of turbines: 80
- Turbine: DTU 10 MW turbine, rotor 178m, hub height 119m
- Water depth / foundations
  - not in initial focus
  - 22 meter, monopiles
Corrective maintenance policy based partly on *

Failures in 3 categories and regular annual service:

<table>
<thead>
<tr>
<th></th>
<th>Minor Repair</th>
<th>Major Repair</th>
<th>Major Replacement</th>
<th>Annual Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>6</td>
<td>1</td>
<td>0.1</td>
<td>1</td>
</tr>
<tr>
<td>Vessel</td>
<td>Crew transfer vessel</td>
<td>Crew transfer vessel</td>
<td>Heavy lift vessel</td>
<td>Heavy lift vessel</td>
</tr>
<tr>
<td>No. Technicians</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>3</td>
</tr>
<tr>
<td>Duration</td>
<td>6 [h]</td>
<td>18 [h]</td>
<td>48 [h]</td>
<td>35 [h]</td>
</tr>
<tr>
<td>Cost</td>
<td>61,200 [€]</td>
<td>530,000 [€]</td>
<td>3,000,000 [€]</td>
<td>140,000 [€]</td>
</tr>
</tbody>
</table>

- Spare parts available in stock
- 24 hired technicians working 12 h shifts a day
- Major replacements carried out in two 12 h shifts
- Failures lead to turbine shutdown
- Annual service carried out at start of each June

* Iain Dinwoodie, Ole-Erik V. Endrerud, Matthias Hofmann, Rebecca Martin, Iver Bakken Sperstad. 2014. “Reference cases for verification of offshore operation and maintenance simulation models for offshore wind farms”.
NORCOWE RWF – Baseline O&M model

- 2 hired work boats (CTVs)
- HLV chartered for major replacements

<table>
<thead>
<tr>
<th></th>
<th>Crew Transfer Vessel (CTV)</th>
<th>Heavy-Lift Vessel (HLV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Limiting weather criteria</td>
<td>Wave 1.5 [m]</td>
<td>Wind 20 [m/s] / 2 [m]</td>
</tr>
<tr>
<td>Mobilisation time</td>
<td>0</td>
<td>40 [days]</td>
</tr>
<tr>
<td>Mobilisation cost</td>
<td>0</td>
<td>680.000 [€]</td>
</tr>
<tr>
<td>Speed</td>
<td>20 [knots]</td>
<td>11 [knots]</td>
</tr>
<tr>
<td>Technician capacity</td>
<td>12</td>
<td>100</td>
</tr>
<tr>
<td>Day rate</td>
<td>3200 [€]</td>
<td>320000 [€]</td>
</tr>
<tr>
<td>Maximum offshore time</td>
<td>1 shift</td>
<td>Unlimited</td>
</tr>
</tbody>
</table>
NORCOWE RWF – Baseline O&M model

Weather:
- FINO3 - 3 h wind and wave time series
  - Limiting factor for farm access

Failures:
- Generated from exponential distributions

Simulations:
- 11 years simulation with 3h resolution – 20 year design lifetime
NORCOWE RWF – LCoE – preliminary results

<table>
<thead>
<tr>
<th>Component</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turnkey</td>
<td>3300 [€/kW]</td>
</tr>
<tr>
<td>OPEX</td>
<td>0.022 [€/kW]</td>
</tr>
<tr>
<td>AEP</td>
<td>3981.3 [GWh]</td>
</tr>
<tr>
<td>$r_e$</td>
<td>8 [%]</td>
</tr>
<tr>
<td>$r_p$</td>
<td>6 [%]</td>
</tr>
<tr>
<td>$T$</td>
<td>20 [years]</td>
</tr>
</tbody>
</table>

Table 3: LCoE input

LCoE = 0.098 [€/kWh]
Case study – NORCOWE Reference Wind Farm

Vessels

<table>
<thead>
<tr>
<th></th>
<th>CTV</th>
<th>HLV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Wave limit [m]</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Wind limit [m/s]</td>
<td>-</td>
<td>20</td>
</tr>
<tr>
<td>Mobilisation time [days]</td>
<td>-</td>
<td>30</td>
</tr>
<tr>
<td>Mobilisation cost [€]</td>
<td>-</td>
<td>250000</td>
</tr>
<tr>
<td>Speed [knots]</td>
<td>20</td>
<td>11</td>
</tr>
<tr>
<td>Day rate [€]</td>
<td>1000</td>
<td>100000</td>
</tr>
</tbody>
</table>

Cost model

<table>
<thead>
<tr>
<th>Activity</th>
<th>Cost [€]</th>
<th>Duration [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inspection</td>
<td>1000</td>
<td>6</td>
</tr>
<tr>
<td>Repair</td>
<td>10000</td>
<td>24</td>
</tr>
<tr>
<td>Replacement</td>
<td>400000</td>
<td>80</td>
</tr>
</tbody>
</table>

Preventive strategy

• Time/condition based
• Risk/reliability based
Case study – NORCOWE Reference Wind Farm

Time/condition based model

- Time interval of inspection
- Repair threshold

Optimal decision

- 2 year interval
- 0.4 [m] crack size

<table>
<thead>
<tr>
<th>Total cost [€]</th>
<th>Downtime [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.25 $10^6$</td>
<td>0.37</td>
</tr>
</tbody>
</table>

11 inspection & 2.3 repairs/turbine

Risk/reliability based

Optimal decision

- 1% failure probability

<table>
<thead>
<tr>
<th>Total cost [€]</th>
<th>Downtime [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.55 $10^6$</td>
<td>0.27</td>
</tr>
</tbody>
</table>

7.2 inspection & 1.9 repairs/turbine

14% cost reduction
The reference wind farm – a platform for testing tools

- Optimum Wind farm design and operation
- Rules for farm design and operation
- Site wind and wave climatologies
- Levelised cost of energy
- https://rwf.computing.uni.no/
Frokostmøte om hav vind

Hør om kommersielle muligheter og forskningsresultater med industrielle anvendelser.
read more >>

Final Report

The NORCOWE final report is now updated with an appendix containing publication lists, lists of PhD students, staff etc.
read more >>

PhDs

Applying their expertise to new fields.
read more >>

Nye konsepter

Nye konsepter skal drastisk redusere kostnadene per kilowatttime.
read more >>

New Mobile Motion Lab at CMR

In cooperation with the University of Agder, Christian Michelsen Research has established a mobile 6DOF hexapod platform solution for performing motion tests and measurements, as extension to the existing Motion Lab facilities at UiA in Grimstad.
read more >>

News

15. 02. 2017
NORCOWE presentations at DeepWind17...
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New laser tracker and cameras in place at the Motion Lab...
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Calendar/Upcoming Events

24. August 2017
Frokostmøte hav vind...
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