Risk-Based Operation and Maintenance of Offshore Wind Farms

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Motivation

• O&M costs account for around 25 – 30 % cost of energy

Cost drivers of a typical 5MW offshore wind turbine

• A significant portion of annual maintenance budget is ‘wasted’ on reactive maintenance or unnecessary inspections/repairs

• Risk based inspection methods can minimize cost of preventive maintenance
Motivation

Traditional approaches
- Corrective (unplanned): exchange / repair of failed components
- Preventive (planned):
  - Timetabled: inspections, and evt. repair after predefined scheme
  - Conditioned: monitor condition of system and decide next on evt. repair based on degree of deterioration

Risk-based approach
- Uncertainty modelling
- Include unknown results from future inspections and monitoring but applying a decision rule for decisions on maintenance and repair

Repeating inspection/maintenance

Initial design $z$

Inspection/monitoring plan $e$

Inspection/monitoring result $S$

Maintenance / repair plan $d(S)$

State of nature $X$

Total costs $W(z, e, S, d(S), X)$
Risk-based maintenance

- Achieve safe operating conditions with a minimum maintenance effort
- Used in a wide range of industries (e.g. aerospace, oil & gas, railway infrastructure)
- Requirements and guidelines for offshore structures (e.g. DNVGL-RP-C210, DNVGL-RP-0001, API RP 580)

- Applicable on elements susceptible to fatigue failure

![Risk-based maintenance diagram]

Schematic development of inspection plan with respect to fatigue (DNVGL-RP-C210)

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Overview

• Selection of component & failure mode
• Degradation and reliability modelling
• Inspection & model updating
• Decision rule
• Optimal inspection planning
• Case study on NORCOWE RWF
Risk-based maintenance – Critical component/failure

Bladena, 2014
Risk-based maintenance – Damage modelling

- cracks generated at random locations on trailing edge blondline
- size of cracks generated using lognormal distribution
Risk-based maintenance – Damage modelling

- One dimensional fracture mechanics model

- Loading based on mean wind speed and turbulence intensity
Risk-based maintenance – Damage modelling

Initial cracking → Development → Failure

Monte Carlo simulations

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Risk-based maintenance – Model updating

Dynamic Bayesian Networks

- inspection at time $t$
- update of uncertain parameters in damage model

Distribution of crack size before/after inspection

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Risk-based maintenance – Model updating

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Risk-based maintenance – Model updating

Dynamic Bayesian Networks

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Distribution of crack size before/after inspection
Risk-based maintenance – Decision rule

Inspection plan

<table>
<thead>
<tr>
<th>Thr 0.1</th>
<th>1.7</th>
<th>7</th>
<th>12.3</th>
<th>14.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thr 0.2</td>
<td>3.8</td>
<td>8.9</td>
<td>13.3</td>
<td>14.6</td>
</tr>
</tbody>
</table>
Case study

NORCOWE Reference Wind Farm

• Reference site: FINO3
• Installed capacity: 800 MW
• Number of turbines: 80
• Turbine: DTU 10 MW turbine, rotor 178m, hub height 119m
• Water depth / foundations
  • 22 meter, monopiles
Case study

Vessels

<table>
<thead>
<tr>
<th></th>
<th>CTV</th>
<th>HLV</th>
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<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>10000</td>
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</table>

Cost model

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

Preventive strategy

- Time/condition based
- Risk/reliability based
Case study

Time/condition based model
- Interval of inspection
- Repair threshold

Risk/reliability based model
- Failure threshold

Optimal decision
- 2 year interval
- 0.4 [m] crack size

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

11 inspection & 2.3 repairs/turbine

Optimal decision
- 1% failure probability

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

7.2 inspection & 1.9 repairs/turbine
14% cost reduction

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Future work

• Include system effects
• Risk-based O&M planning for other components such as bearings and welded details in towers
• More detailed comparison between traditional and risk based maintenance
Thank you for your attention!

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