Effect of pitch and safety system design on dimensioning loads for offshore wind turbines during grid fault

Lars Frøyd*, Ole G. Dahlhaug*

* Department of Energy and Process Engineering
Norwegian University of Science and Technology
NO-7491 Trondheim, Norway
Objective of study

- Investigate the potential to reduce the ultimate loads on WT substructures by optimizing the pitch system design (hardware)
  - Detailed dynamic modelling of the pitch system
  - Design of a basic (but sufficient) control system
  - Aero-servo-hydro-elastic simulation of WT with pitch model

- Goal: To reduce the ultimate loads on the WT from extreme load cases (EOG with grid fault) => reduce the cost
  - Without increasing complexity / reducing safety redundancy
# Wind turbine characteristics

<table>
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<tr>
<th>Design basis</th>
<th>Turbine key figures</th>
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</thead>
<tbody>
<tr>
<td>Location</td>
<td>North Sea</td>
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<tr>
<td>Air density ( \rho = 1.225 \text{ kg/m}^3 )</td>
<td>Rated power ( 10 \text{ MW} )</td>
</tr>
<tr>
<td>Design class IEC I_B</td>
<td>Design wind speed ( 13 \text{ m/s} )</td>
</tr>
<tr>
<td>Average wind speed 10 m/s</td>
<td>Optimum TSR ( 7.8 )</td>
</tr>
<tr>
<td>Weibull parameters</td>
<td>Max. tip velocity ( 100 \text{ m/s} )</td>
</tr>
<tr>
<td>scaling: 11.23</td>
<td>Shaft tilt angle ( 5^\circ )</td>
</tr>
<tr>
<td>shape: 2.17</td>
<td>Hub coning angle ( 0^\circ )</td>
</tr>
<tr>
<td>Extreme wind speed 1 year: 56 m/s</td>
<td>Rotor speed range ( 5.5 -13.5 \text{ rpm} )</td>
</tr>
<tr>
<td>50 year: 70 m/s</td>
<td>Tower frequency ( 0.25 \text{ Hz} )</td>
</tr>
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<tr>
<th>Blade key figures</th>
<th>Blade frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length ( 68 \text{ m} )</td>
<td>1\textsuperscript{st} flapwise freq. ( 0.79 \text{ Hz} )</td>
</tr>
<tr>
<td>Mass ( 26.5 \text{ t} )</td>
<td>1\textsuperscript{st} edgewise freq. ( 1.06 \text{ Hz} )</td>
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<tr>
<td>Pitch inertia ( 68 \text{ 500 kg/m}^2 )</td>
<td>2\textsuperscript{nd} flapwise freq. ( 2.08 \text{ Hz} )</td>
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<tr>
<td>Aspect ratio ( 17.7 )</td>
<td>2\textsuperscript{nd} edgewise freq. ( 3.63 \text{ Hz} )</td>
</tr>
<tr>
<td>Root diameter ( 3.46 \text{ m} )</td>
<td>3\textsuperscript{rd} flapwise freq. ( 4.27 \text{ Hz} )</td>
</tr>
<tr>
<td>Pre-curve 4.3 % of radius</td>
<td>1\textsuperscript{st} torsional freq. ( 7.47 \text{ Hz} )</td>
</tr>
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Load case

- In design standards for offshore wind (IEC/DNV/GL):
  DLC 2.3 - *EOG with external or internal electrical fault including loss of electrical network*

- Very unlikely, but also very severe load combination that could be dimensioning for overturning moment
The pitch system

1318 kg

7.2 m
The pitch system
Pitch system performance

![Pitch angle vs time graphs]

![Tower bending moment vs wind speed graph]

![Tower bending moment vs time graph with max bending moment and 50y H_s]

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Pitch system performance 2

Power curve

Pitch curve
Results 1
Results 2

![Graphs showing results for different scenarios.](image-url)
Results 3
Conclusion

► The loads during an emergency shutdown depend heavily on the pitch velocity, and both too high or too low velocities will increase the bending moments in the tower and foundation.

► The maximum tower bending moment was, however, not dominated by the loads during grid fault, but rather by the loads during an EOG *without* fault.

► It is possible to reduce these loads (somewhat) by increasing the dimensions of the pitch system (considerably).

► The only thing that appears to be dominated by the grid fault is the negative flapwise blade deflection, which is most relevant for a downwind turbine.

► It is possible to reduce this deflection using UPS and dump load.
Acknowledgement

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www.nowitech.no

www.ntnu.edu/research/offshore-energy

www.statkraft.com