Concept design verification of a semi-submersible floating wind turbine using coupled simulations

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Presentation outline

- Tri-Floater design
- Simulation approach
- Software and numerical model
- Simulation results
- Conclusions
Tri-Floater design

- Wind turbine: NREL 5MW
- Hub height above SWL: 90 m
- Control system: ECN
- Radius to column centre: 36.0 m
- Column width: 8.0 m
- Design draft: 13.2 m
- Air gap to deck structure: 12.0 m
- Displacement: 3627 t
- Catenary mooring lines: 3 x 750 m
- Chain diameter: 100 mm
### Tri-Floater design

<table>
<thead>
<tr>
<th></th>
<th>rated</th>
<th>operational</th>
<th>cut-out</th>
<th>survival</th>
<th>parked</th>
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</thead>
<tbody>
<tr>
<td>significant wave height</td>
<td>[m]</td>
<td>[m]</td>
<td>[m]</td>
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<tr>
<td>wave peak period</td>
<td>[s]</td>
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<td>[s]</td>
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<tr>
<td>wind velocity at hub</td>
<td>[m/s]</td>
<td>[m/s]</td>
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<tr>
<td>current velocity</td>
<td>[m/s]</td>
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<td>[m/s]</td>
<td>[m/s]</td>
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</tbody>
</table>

- Operational inclination ≤ 10 deg
- Operational nacelle acceleration ≤ 3 m/s²
- Safety factor mooring line ≥ 1.7
Simulation approach

- Verify design requirements motions and mooring loads
- Concept design stage, so minimized computational effort

- Simulation duration: 1 hour
- Weibull distribution fitted to 50 % highest extremes
- Expected maxima determined for 3 hours by extrapolation

- Time step and seed dependency studied
Software and numerical model

- AQWA (Ansys)
  - Hydrodynamics (1\textsuperscript{st} and 2\textsuperscript{nd} order)
  - Mooring
- PHATAS (ECN)
  - Rotor aerodynamics
  - Rotor and tower structural dynamics
  - Drive-train and control systems

- Benchmarked with OC3 spar
- Hydrodynamic model validated with model tests
Software and numerical model

- Frequency domain motion analysis
- Coupled simulations in regular waves
- Model test in white noise
Simulation results

Floater surge

Floater heave

Floater pitch

Nacelle heave acc. spectra for Vhub 11.4 m/s & Hs 4.5 m

TD sim.  Tp 7.5 s
TD sim.  Tp 10 s
FD calc. Tp 7.5 s
FD calc. Tp 10 s
Simulation results

Nacelle surge acceleration

Nacelle heave acceleration

TD sim.  Tp 7.5 s
TD sim.  Tp 10 s
FD calc. Tp 7.5 s
FD calc. Tp 10 s
## Simulation results

<table>
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<tr>
<th></th>
<th>operational</th>
<th>survival</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>rated</td>
<td>above rated</td>
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<tr>
<td>floater inclination [deg]</td>
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<tr>
<td>mean</td>
<td>3.5</td>
<td>2.9</td>
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<tr>
<td>3-hour extreme (90%)</td>
<td>7.4</td>
<td>8.5</td>
</tr>
<tr>
<td>nacelle hor. accel. [m/s^2]</td>
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<td></td>
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<tr>
<td>mean</td>
<td>0.7</td>
<td>0.6</td>
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<tr>
<td>3-hour extreme (90%)</td>
<td>2.4</td>
<td>2.5</td>
</tr>
</tbody>
</table>
Conclusions

- Tri-Floater fulfills design criteria
- Low frequency motions are dominant
- Wave frequency motions are well predicted by uncoupled frequency domain motion analysis
- Such analysis is useful to assess global floater motions in early design stages and optimize the floater design
- Coupled simulations are however indispensable in later design stages
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