Alleviation of the Vortex-ring State for Floating Offshore Wind Turbines using a Modified Blade-tip Shape

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Project background

- Floating offshore wind has potential for higher wind resource at deeper sites.
  - World’s first commercial 6-turbine site off Aberdeen [1].

Project background

Floating offshore wind has potential for higher wind resource at deeper sites.

- World’s first commercial 6-turbine site off Aberdeen [1].

- These turbines experience additional motion depending on sea state and platform:

<table>
<thead>
<tr>
<th>Translational</th>
<th>Rotational</th>
</tr>
</thead>
<tbody>
<tr>
<td>x: Surge</td>
<td>Roll</td>
</tr>
<tr>
<td>y: Sway</td>
<td>Pitch</td>
</tr>
<tr>
<td>z: Heave</td>
<td>Yaw</td>
</tr>
</tbody>
</table>

Project background

- Even small changes in relative velocity (motion) can impact performance.

Power output with surge for NREL 5 MW turbine on a tension-leg platform at 11 m/s, surge amplitude of 1.348 m and surge frequency of 0.075 Hz [3].

Project background

• Even small changes in relative velocity (motion) can impact performance.

• In the most extreme cases, flow can recirculate around the rotor as surging/pitching pushes the rotor through its own wake.

This is called the **Vortex-ring state (VRS)**. It can be identified with a negative induction factor.

A pitching floating turbine experiencing VRS [2].
Project background

• Tip vortices are a major contributor to the wake.

• The tip vortex can be manipulated using passive tip flow control, such as winglets.
  • Move tip vortices downstream from rotor.
  • Delay rotor’s contact with wake during a leeward cycle.

Winglets might not be the ideal solution...

Moving HAWT tip vortices downstream using winglets [4].

Aims & objectives

Aim:

• Determine the impact of a modified tip shape on VRS occurrence.

Objectives:

• Quantify axial induction factor during pitch/surge using CFD.

• Quantify VRS occurrence (negative induction).

• Assess near-wake and tip vortex characteristics to then design new tip.

• Re-run and compare VRS occurrence/induction factor.
Model formulation

• Test the NREL 5 MW rotor under pitch and/or surge, the most dominant motions.

• Choose a single wind speed and two sea states (surge/pitch amplitudes/frequencies).
  • Lower $U_\infty \rightarrow$ wake advected slower $\rightarrow$ higher chance of VRS.
  • Use Detached Eddy Simulation (DES) as my turbulence model.

• Test the turbine with and without a modified tip.

<table>
<thead>
<tr>
<th>Motion case</th>
<th>Tip case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-base</td>
<td>Without tip modification</td>
</tr>
<tr>
<td>With pitch</td>
<td>With \textit{and} without tip modification</td>
</tr>
<tr>
<td>With surge</td>
<td>With \textit{and} without tip modification</td>
</tr>
<tr>
<td>With both</td>
<td></td>
</tr>
</tbody>
</table>
Computational methodology

• The NREL 5 MW rotor will be drawn using Autodesk Inventor.

• Rotor .stl file can then be exported to OpenFOAM, a free CFD package.

• A dynamic mesh solver can then be used to rotate, surge and pitch rotor.
  • OpenFOAM will calculate thrust coefficient for rotor:
    $$C_T = 4a(1 - a)$$
  • Can then get axial induction factor, $a$, from $C_T$.

• Use in-house computing cluster of 64 cores, and/or ARCHER (epcc).
Initial results

Run low-res simulations (~1m cells) using pimpleDyMFoam (dynamic mesh solver) in 3.3D cube domain:

- 6s of fixed-based; $U_\infty$ of 11.4 m/s.
- 6s of surge-only; $U_\infty$ of 11.4 m/s, surge amplitude of 14 m, surge frequency of 0.77 rad/s [5].

Initial results

Plotted thrust coefficient over surge cycle:

• Clearly see thrust dropping to negative temporarily during cycle.
• This shows VRS occurring.
Future work

1. Applying pitching motion to turbine.
   • Learning how to tweak source code (C++).
2. Validate model/mesh against literature.
3. Run my base simulations (no tip change).
4. Assess tip vortices to design suitable tip.
5. Re-run simulations with new tip to determine impact.
Thanks for listening

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## Platform types

<table>
<thead>
<tr>
<th></th>
<th>Spar</th>
<th>TLP</th>
<th>Semi-Sub</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stability</td>
<td>Ballast</td>
<td>Moorings</td>
<td>Hydrostatics</td>
</tr>
<tr>
<td>Min depth *</td>
<td>Deeper</td>
<td>Shallower</td>
<td>Shallower</td>
</tr>
<tr>
<td>Periods</td>
<td>Good</td>
<td>Good</td>
<td>Acceptable</td>
</tr>
<tr>
<td>Cost</td>
<td>Uncertain</td>
<td>Uncertain</td>
<td>Uncertain</td>
</tr>
<tr>
<td>Yaw and torque</td>
<td>Acceptable</td>
<td>Probably good</td>
<td>Good</td>
</tr>
<tr>
<td>Fabrication</td>
<td>Potentially simple structure</td>
<td>More complex structure</td>
<td>More complex structure</td>
</tr>
<tr>
<td>Installation</td>
<td>More complex operation</td>
<td>More complex operation</td>
<td>Good</td>
</tr>
</tbody>
</table>

*However greater depths will typically allow a better performing and lower cost design to be deployed*

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Platform motions

ITI Energy barge  
Hywind spar-buoy  
Tension-leg platform

All at rated wind speed of 11.4m/s, wave heights of 3m and periods of 12s

CFD domain
Mesh refinement

- 1,196,774 total
- 53,964 in rotor