Control for Avoiding Negative Damping on Floating Offshore Wind Turbine

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Introduction

- Demand for renewable energy is increasing
  - Securing laying area for wind farm
  - Wind is consistent and strong over the sea
  - Establish offshore wind turbine technology
    - Floating Wind Turbine
      - Able to use on Deep Water
      - Unstable foundation

Verification test cases
- Hywind (statoil, Norway)
- Small test turbine (Nagasaki Japan)

Negative damping of Floating Wind Turbine

• Pitch Control
  Change blade pitch depend on the wind speed variation.
  – Torque : Constant ↔ Thrust : Vary

• Relative wind speed vary due to the motion of tower.
  – Lean to the front (back) → Relative wind speed increase (decrease),
    Thrust decrease (increase)

  **Negative damping**
Purpose of research

- Applying conventional pitch control
  - Motion of float is negative damped
  - Reducing rated power (Power decrease)
  - Increasing fatigue load

- We need to develop a new pitch control corresponding to floating wind turbine

We propose a new control method for floating turbine to suppress the negative damping with power kept to rate.

Control method

Combining two control (Mixed control)

- Pitch Control (Make rotational speed constant)
- Motion Control (Suppress tower motion $\theta_{\text{tower}}$)
Experiment and Simulation

• Set floating wind turbine model on test tank with fan.  
  (Cooperated with NMRI : National Maritime Research Institute)

• Software for numerical simulation : FAST  
  - Developed by NREL (National Renewable Energy Laboratory)  
  - Able to compute floating wind turbine  
  (NREL 5MW)

### Turbine and condition

#### Wind speed

<table>
<thead>
<tr>
<th>Wind speed [m/s]</th>
<th>3.9</th>
</tr>
</thead>
</table>

#### Wave (regular)

<table>
<thead>
<tr>
<th>Height [cm]</th>
<th>4.22</th>
<th>6.3</th>
<th>8</th>
<th>8.7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Period [s]</td>
<td>3.0</td>
<td>2.5</td>
<td>1.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>

#### Wind turbine

<table>
<thead>
<tr>
<th>Wind turbine</th>
<th>Blade</th>
<th>Length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>600mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Number</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Rotor diameter</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1300mm</td>
</tr>
<tr>
<td>Nacelle</td>
<td>Weight</td>
<td></td>
</tr>
<tr>
<td></td>
<td>1150g</td>
<td></td>
</tr>
<tr>
<td>Tower</td>
<td>Hub height</td>
<td></td>
</tr>
<tr>
<td></td>
<td>900mm</td>
<td></td>
</tr>
</tbody>
</table>

#### Float

<table>
<thead>
<tr>
<th>Float</th>
<th>Diameter</th>
<th>160mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Draft</td>
<td>1270mm</td>
</tr>
<tr>
<td></td>
<td>Displaced volume of water</td>
<td>23kg</td>
</tr>
<tr>
<td>Mooring line</td>
<td>Number</td>
<td>6</td>
</tr>
</tbody>
</table>

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Validation of simulation

Blade load (Thrust)

Float response to the wave

- Aero dynamic force of blade and float response to the wave are generally consistent

Thrust coefficient of test turbine in onshore.
(Change blade pitch on wind speed 3.9 m/s)

Tower amplitude of floating test turbine with wave and no wind.
(Tower amplitude is non-dimensionalized by wave height and wave number)

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Negative damping on experiment
(Wind speed: 3.9m/s, Wave period: 2.5s, Wave height: 6cm)

• Tower pitch amplitude: increase \leftrightarrow\text{ rotor speed vibration: decrease}
• Negative damping has occurred on experiment
Negative damping on simulation

(Wind speed: 3.9m/s, Wave period: 2.5s, Wave height: 6cm)

- Tower motion and rotor speed vibration are smaller than experiment.
- Trends of parameter are matched with experiment.
Mixed control on simulation
(Wind speed: 3.9m/s, Wave period: 2.5s, Wave height: 6cm)

- **K_p**: Control parameter of motion controller on mixed control.
- **Basis of rate on right side is parameter on conventional control. (when K_p=0)**

<table>
<thead>
<tr>
<th>Control parameter K_p</th>
<th>θ_tower Amplitude (deg)</th>
<th>Rotor speed average (rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>5.51 (100%)</td>
<td>336 (100%)</td>
</tr>
<tr>
<td>0.0001</td>
<td>5.38 (97.6%)</td>
<td>336 (99.97%)</td>
</tr>
<tr>
<td>0.001</td>
<td>5.24 (95.1%)</td>
<td>335 (99.7%)</td>
</tr>
<tr>
<td>0.01</td>
<td>3.70 (67.2%)</td>
<td>326 (97.1%)</td>
</tr>
<tr>
<td>0.1</td>
<td>5.01 (91.0%)</td>
<td>239 (71.3%)</td>
</tr>
<tr>
<td>1</td>
<td>5.32 (96.6%)</td>
<td>74.7 (22.2%)</td>
</tr>
</tbody>
</table>

- As K_p=0.01, Tower motion is much suppressed though rotor speed is not so much changed.
  
  Mixed control can suppress the negative damping with little affect to the rotor speed.
Conclusion

• On simulation aero dynamic force of blade and float response to the wave are generally match to experiment.
• We confirmed that tower motion is amplified by onshore pitch control on experiment and simulation.
• We proposed the new control, mixed control, and shows that mixed control can reduce the tower motion with maintaining rotor speed.

Further study

• Improving simulation model, we will apply this control to practical turbine, verification test turbine or full scale turbine and investigate the applicability and effectiveness of this control in actual seas.

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