Effect of Forced Excitation on Wind Turbine with Dynamic Analysis in Deep Offshore Wind

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Introduction

One of the unique problems of floating offshore wind turbines is negative damping of tower pitching motion. The reason is that the increase of wind speed causes the decrease of thrust force of the rotor.

The equation of motion for single degree of freedom of nacelle (Jonkman \textsuperscript{1}):

\[ \left( \frac{I_{\text{mass}} + A_{\text{radation}}}{L^2} \right) \ddot{x} + \left( \frac{B_{\text{radiation}} + B_{\text{viscous}}}{L^2} \right) \dot{x} + \left( \frac{C_{\text{hydrostatic}} + C_{\text{lines}}}{L} \right) x = \tau_0 \]

\( L \) : Hub height
\( x \) : Nacelle fore- aft displacement
\( \tau_0 \) : Thrust force in equilibrium

\[ \frac{\partial \tau}{\partial V} \Rightarrow \text{Negative Damping} \]

As nacelle oscillates backward, relative inflow wind speed decreases. This decrease causes the change of thrust force. With blade pitch control, thrust force increases with this decrease of wind speed. Then, nacelle moves more backward.(Fig.1)

![Figure 1 Change of Thrust Force with Tower Pitching Motion](image)

Simulation Methods

We simulated change of thrust force by analysis of the turbine for wind tunnel testing\textsuperscript{2}. To simulate the relative wind speed change, oscillating inflow speed and rigid turbine model are used(Fig.3). Two controls are tested: Blade pitch control and variable speed control. Pitch control observes generator speed.

<table>
<thead>
<tr>
<th>Turbine Type</th>
<th>Horizontal Axis</th>
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</thead>
<tbody>
<tr>
<td>Rotor Diameter</td>
<td>5.5m</td>
</tr>
<tr>
<td>Number of Blades</td>
<td>3 blades</td>
</tr>
<tr>
<td>Tower Height</td>
<td>0.8m</td>
</tr>
<tr>
<td>Hub Height</td>
<td>0.95m</td>
</tr>
<tr>
<td>Generator</td>
<td>Coreless DC motor</td>
</tr>
</tbody>
</table>

![Figure 2 Modeled Wind Turbine\textsuperscript{2}](image)

Variable speed control maintains optimal tip speed ratio. GH bladed is used for this simulation.

Results

Fig4. shows time-series of thrust force and wind speed with variable speed control. The fluctuation of thrust force and wind speed shows the same sign. This means \( \frac{\partial \tau}{\partial V} \geq 0 \) and negative damping is not caused.

![Figure 3 Simulation Condition](image)

Fig5. shows time-series of thrust force and wind speed with variable speed control. The fluctuation of thrust force and wind speed shows the same sign. This means \( \frac{\partial \tau}{\partial V} \leq 0 \) and negative damping can be caused.

Conclusion

Traditional blade pitch control above rated wind speed can cause the negative damping of the wind turbine. In addition, this phenomenon can be observed by small scale turbine for wind tunnel testing.

Future work

We are planning to introduce the new control variables such as nacelle speed or thrust force. By observing nacelle speed, pitch control is not disturbed with relative wind speed change caused by nacelle motion. Furthermore, by observing thrust force, we think thrust force decreasing can be prevented with both pitch and variable speed control.

References