Aero-elastic-control coupled simulation of a vertical axis wind turbine-generator system
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Abstract
An aero-elastic-control coupled simulation model of large-scale vertical axis wind turbine-generator systems was developed as the first phase of the development of floating offshore vertical axis wind turbine-generator systems. This coupled simulation model consists of an aerodynamic submodel of a vertical axis wind turbine, an elastic vibration submodel, and a control submodel. A weak-coupled approach between the aerodynamic submodel and the vibration and control submodels was employed from the perspective of computational loads for nonlinear aerodynamic characteristics of vertical axis wind turbines. The developed simulation model was applied to a virtual 86-m straight-wing vertical axis wind turbine-generator system. The numerical analysis under turbulent wind fields revealed the impact of the aero-elastic-control coupled behaviors on the dynamic system performances including damage equivalent fatigue loads.

Objectives

- Large-scale vertical axis wind turbine for floating application
  - Background
    - Independence of wind direction and low center of gravity
    - Cyclic variation in aerodynamic torque and loads
  - Objectives
    - Aero-elastic-control coupled analysis
    - Dynamic behavior and load variation under turbulent winds
    - Impact analysis of elastic vibration on system performances

Target system

- Straight-wing vertical axis wind turbine-generator system
  - Rated power output kW
  - 3400
  - Rated wind speed m/s
  - 13.4
  - Rated rotor speed rpm
  - 7.65
  - Rotor diameter / blade length m
  - 86/103
  - Number of blade
  - 3
  - Solderity
  - 0.3
  - Rotor shaft length m
  - 107
  - Blade airfoil
  - NACA0015

Vertical axis wind turbine-generator system

- System configuration
  - Vertical axis wind turbine
  - Gearbox
  - Induction generator
  - Power converter
  - Speed/power controller

- Operating method
  - Variable speed operation at low wind speeds
  - Constant speed operation at high wind speeds
  - Stall control for power output

Coupled behavior analysis

- Model-C: Average aerodynamic and rigid model (Conventional)
- Model-R: Distributed aerodynamic and rigid model (Coupled)
- Model-E: Distributed aerodynamic and elastic model (Coupled)

Aero-elastic-control coupled simulation

- Aerodynamic submodel
  - Aerodynamic torque and loads to turbulent wind and elastic displacement
  - Dynamic stall and tip loss effects
  - Reynolds number effect on airfoil characteristics

- Elastic vibration submodel
  - Bending vibration of rotational shaft and turbine blades to aerodynamic loads
  - Torsional vibration of drivetrain to turbine and generator torques
  - Bending and torsional moments based on elastic vibration
  - Generator power to turbulent wind

- Control submodel
  - Generator torque manipulation to variable speed operation

Normalized system performances under turbulent winds

<table>
<thead>
<tr>
<th>Performances</th>
<th>Model-C</th>
<th>Model-R</th>
<th>Model-E</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS of rotor speed</td>
<td>1.0</td>
<td>0.984</td>
<td>0.984</td>
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<tr>
<td>RMS of turbine torque</td>
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<td>1.007</td>
<td>1.007</td>
</tr>
<tr>
<td>RMS of generator torque</td>
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<td>0.974</td>
<td>0.974</td>
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<tr>
<td>RMS of generator power</td>
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<td>0.966</td>
<td>0.967</td>
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<tr>
<td>DEL of FA bending moment at tower base</td>
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<td>2.231</td>
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<tr>
<td>DEL of SS bending moment at tower base</td>
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<td>1.993</td>
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<td>DEL of flapwise bending moment at blade joint</td>
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<td>1.114</td>
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<tr>
<td>DEL of edgewise bending moment at blade joint</td>
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<td>1.003</td>
</tr>
</tbody>
</table>

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