Structural Optimization of an Innovative 10 MW Wind Turbine Nacelle

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Abstract

For large wind turbine configurations of 10 MW and higher capacities, direct-drives present a more compact solution over conventional geared drivetrains. Further, if the generator is placed in front of the wind turbine rotor, a compact “king-pin” drive is designed, that allows the generator to be directly coupled to the hub. In presented study, the structural re-design of the 10 MW king-pin drive and nacelle was made using extreme loads obtained from a 10 MW reference wind turbine. On the basis of extreme loads the ultimate stresses of critical components were determined to ensure integrity of the structure. Farther, the tower top mass was reduced on the basis of the topology optimization results with compliance limits applied for the mainframe. Presented analysis shows that a structural mass of the nacelle components can be reduced without significant influence on the mechanical properties of the structure. The total weight of the nacelle after mass reduction is 24 % lower than for the initial design.

Objective and Methodology

In the study the design concept of direct-drive 10 MW offshore wind turbine with a 178 m rotor diameter and three blades was analyzed [1 - 3].

- **Objective** - to reduce tower top mass for floating offshore wind turbines
- **Methodology** - application of topology optimization algorithms on a predefined design domain for the chosen nacelle component
- **Assumptions** - the parameters of bolted connections and yaw mechanism in topology optimization study were neglected. Nacelle components made from ductile cast iron EN-GJS-400 with design strength of 246 MPa.

Organization of the study:

- The initial design of 10 MW offshore wind turbine
- FE model, extreme loads
- Verification of the integrity of a structure (king-pin connected to mainframe) means for a mass reduction
  - Topology optimization
  - The optimal topology of the mainframe under ultimate loads
  - Correction of geometry to avoid local stiffness in flanges and yaw bearing
  - The final geometry meeting the design constraints
  - FE model, extreme loads
- Verified design

structural optimization

- Finite Element model:
- • the king-pin connected to the mainframe constrained on the bottom part
- Topology optimization:
- • design area – the mainframe between the flange and yaw bearing,
- • design variable - density of the finite elements,
- • objective - to minimize material volume of the design area,
- • constraint – compliance of the structure.

In the study analyzed topology optimization cases with different compliance limits and load sets. Compliance limits set on the nodes located on the surface connecting the king-pin with generator.

Results

To increase stiffness in the bolted connection between the king-pin and mainframe and to provide an uniform load distribution on the yaw bearing, additional material was added to the optimal design presented in figure 3 and 4. Beside of the structural modifications of the mainframe, additionally mass from the king-pin was reduced by decreasing thickness of the cylinder wall about 20 %, that connects the upwind and downwind bearings.

Table 2 Mass reduction summary

<table>
<thead>
<tr>
<th>Component</th>
<th>Initial design</th>
<th>Final design</th>
</tr>
</thead>
<tbody>
<tr>
<td>King-pin mass</td>
<td>57,043 kg</td>
<td>49,927 kg</td>
</tr>
<tr>
<td>Mainframe mass</td>
<td>65,176 kg</td>
<td>43,084 kg</td>
</tr>
<tr>
<td>Total mass</td>
<td>122,219 kg</td>
<td>93,011 kg</td>
</tr>
<tr>
<td>King-pin mass reduction</td>
<td>-</td>
<td>12.5 %</td>
</tr>
<tr>
<td>Mainframe mass reduction</td>
<td>-</td>
<td>33.9 %</td>
</tr>
<tr>
<td>Total mass reduction</td>
<td>-</td>
<td>23.9 %</td>
</tr>
</tbody>
</table>

Conclusions

The total mass reduction of the nacelle for the concept design of 10 MW offshore wind turbine was obtained as 24 % lower than the initial concept. The topology modifications do not affect the integrity of the structure as verified on the basis of ultimate stresses. The negative influence of geometry modifications on the bolted connections and yaw bearing was corrected by increasing the material density around these areas. Proposed design of the mainframe can be improved in terms of its stiffness by including stiffeners and ribs.

References