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Design optimization and upscaling of a semi-submersible floating platform

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Topic: Turbine technology

Introduction

As offshore wind turbines increase in size and move farther offshore into deeper water, there is increased focus on floating systems. The increase in turbine size can reduce the costs of offshore wind energy, but requires larger support structures capable of carrying those bigger turbines. Rather than redesigning the structure completely, a rational methodology for upscaling an existing floating substructure can improve the efficiency of the design process. Special challenges related to the design criteria for floating platforms and to technical changes in turbine design must be addressed (Gasch & Twele, 2012; Jamieson, 2011; Sieros, et al., 2012). This work presents a guideline for the optimization and upscaling of a semi-submersible floating platform in order to support a predefined larger wind turbine.

Approach

As starting point of this study, the OC4 semi-submersible platform (Robertson, et al., 2014) is used. The main criteria when dealing with a semi-submersible floating platform are specified and used for optimizing the original OC4 semi-submersible floater. On this basis, an upscaled platform is designed for Fraunhofer's offshore wind turbine IWT-7.5-164 (Sevinc, et al., 2016). Simplified spreadsheet methods are developed, linear frequency-domain methods (in DNV's software HydroD), and detailed equation-based models (in Fraunhofer's software Modelica) are developed and employed. Following the same upscaling procedure, reasonable floater designs for any existing wind turbine can be obtained: in the present work, the DTU 10MW reference wind turbine (Bak, et al., 2013) is also examined.

Main body of abstract

The main focus in the optimization and upscaling process lies on system stability and eigenfrequencies. Aiming for longer natural periods in heave and pitch, a lighter and cheaper platform, and a less over-conservative but still safe system, the original OC4 semi-submersible platform is optimized by reducing the upper column diameter and changing the ballast position within the columns. The dimensions of the optimized design are determined based on an aimed heave natural period of at least 20s, and a nominal pitch at rated wind speed of 5°, accounting for a potential doubling of the loads due to fault situations without exceeding the typical maximum allowable pitch of 10°. Fig. 1 shows schematically the original and optimized designs, as well as their performances in a comparative form.

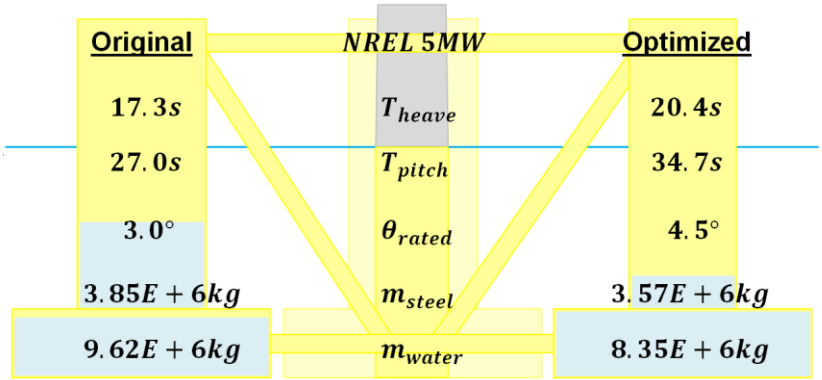

Fig. 1. Original and optimized design in comparison

Based on this optimized design, a guideline for an upscaling procedure for any other turbine is given. The main scaling factor is based on the mass ratio of the top structures rather than the turbine rating. The main column is scaled, so that it fits the new tower base diameter. The scaling factor for the upper columns is computed based on the ratio of the overturning moments, and considers the contribution of the different columns to the stiffness component in pitch. The mooring line length is scaled such that it can yield a predefined stiffness. Finally, the controller gains are recalculated based on the expected natural frequency in pitch.

The optimization and upscaling process is carried out for the IWT-7.5-164 and DTU 10MW reference wind turbines. The floating wind turbines are modelled and simulated by means of HydroD and Modelica. The systems are analyzed regarding their eigenfrequencies, nominal pitch and stability, taking into account that the buoyancy and centre of buoyancy vary with the motion of the platform, and adjusting the blade-pitch controller gains based on the natural period in pitch. The results obtained from both computer programs and the initial hand calculations are comparable and satisfying. The structural integrity is proved by a simplified approach, using tank pressure and sea pressure for computing the equivalent stress based on the shape modification hypothesis. More detailed strength checks for fatigue and ultimate limit states, as well as optimization of the mooring system, are left for future work.

Conclusion

The present work provides a guideline for the optimization and upscaling of a semi-submersible floating platform in order to support a predefined larger wind turbine. Support structures for 7.5 MW and 10 MW wind turbines are developed based on a 5MW design. The procedure allows for improved stability and dynamic performance compared to the baseline design, while also increasing the design efficiency.

Learning objectives

The present work provides insight into the particular challenges related to upscaling of floating platforms which support wind turbines which differ not only in rating, but also in technology. A method is proposed in order to obtain an improved initial design compared to traditional rating-based upscaling laws. Case studies and numerical tools are presented such that the method can be applied in practice.

References

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