University of Victoria | Graduate Studies

Notice of the Final Oral Examination for the Degree of Doctor of Philosophy

of

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"Frequency Domain Modeling and Multidisciplinary Design Optimization of Floating Offshore Wind Turbines"

Department of Mechanical Engineering

Friday, September 21, 2018
10:30 A.M.
Engineering Office Wing
Room 106

Supervisory Committee:
Dr. Curran Crawford, Department of Mechanical Engineering, University of Victoria (Co-Supervisor)
Dr. Brad Buckham, Department of Mechanical Engineering, UVic (Co-Supervisor)
Dr. Richard Dewey, School of Earth and Ocean Sciences, UVic (Outside Member)

External Examiner:
Dr. Wei Qiu, Department of Ocean and Naval Architectural Engineering, Memorial University

Chair of Oral Examination:
Dr. Charles Curry, School of Earth and Ocean Sciences, UVic

Dr. David Capson, Dean, Faculty of Graduate Studies

Abstract

Offshore floating wind turbine technology is growing rapidly and has the potential to become one of the main sources of affordable renewable energy. However, this technology is still immature owing in part to complications from the integrated design of wind turbines and floating platforms, aero-hydro-servo-elastic responses, grid integrations, and offshore wind resource assessments. This research focuses on developing methodologies to investigate the technical and economic feasibility of a wide range of floating offshore wind turbine support structures. To achieve this goal, interdisciplinary interactions among hydrodynamics, aerodynamics, structure and control subject to constraints on stresses/loads, displacements/rotations, and costs need to be considered. Therefore, a multidisciplinary design optimization approach for minimum levelized cost of energy executed using parameterization schemes for floating support structures as well as a frequency domain dynamic model for the entire coupled system. This approach was based on a tractable framework and models (i.e. not too computationally expensive) to explore the design space, but retaining required fidelity/accuracy.

In this dissertation, a new frequency domain approach for a coupled wind turbine, floating platform, and mooring system was developed using a unique combination of the validated numerical tools FAST and WAMIT. Irregular wave and turbulent wind loads were incorporated using wave and wind power spectral densities, JONSWAP and Kaimal. The system submodels are coupled to yield a simple frequency domain model of the system with a flexible moored support structure. Although the model framework has the capability of incorporating tower and blade structural DOF, these components were considered as rigid bodies for further simplicity here. A collective blade pitch controller was also designed for the frequency domain dynamic model to increase the platform restoring moments. To validate the proposed framework, predicted wind turbine, floating platform and mooring system responses to the turbulent wind and irregular wave loads were compared with the FAST time domain model.

By incorporating the design parameterization scheme and the frequency domain modeling the overall system responses of tension leg platforms, spar buoy platforms, and semisubmersibles to combined turbulent wind and irregular wave loads were determined. To calculate the system costs, a set of cost scaling tools for an offshore wind turbine was used to

estimate the levelized cost of energy. Evaluation and comparison of different classes of floating platforms was performed using a Kriging-Bat optimization method to find the minimum levelized cost of energy of a 5 MW NREL offshore wind turbine across standard operational environmental conditions. To show the potential of the method, three baseline platforms including the OC3-Hywind spar buoy, the MIT/NREL TLP, and the OC4-DeepCwind semisubmersible were compared with the results of design optimization. Results for the tension leg and spar buoy case studies showed 5:2% and 3:1% decrease in the levelized cost of energy of the optimal design candidates in comparison to the MIT/NREL TLP and the OC3-Hywind respectively. Optimization results for the semisubmersible case study indicated that the levelized cost of energy decreased by 1:5% for the optimal design in comparison to the OC4-DeepCwind.