Consequences of Load Mitigation Control Strategies for a Floating Wind Turbine

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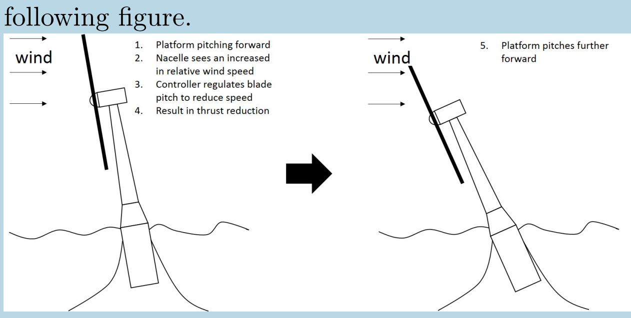
Problem

The use of conventional fixed wind turbine controller on floating offshore wind turbines (FOWT) exposed a set of issues due to the non-fixed nature of a FWT. On top of the wave induced motions due to a large displacement hull, the coupling between blade pitch control system and platform dynamics further exacerbates the response in the surge and pitch directions. As wind speed increases above the rated value, blades are feathered to maintain a constant speed. The corresponding aerodynamic thrust reduction shows that conventional blade pitch algorithm leads to negative damping above rated wind speed. The phenomenon is identified by Nielsen et al as particularly destructive for FOWTs as the low frequency wind energy usually concentrates around the pitch natural frequencies of FOWTs [5]. The problem can be better elaborated using a platform pitching scenario described in the following figure.



Basic Concepts

A baseline Proportional-Integral-Differential (PID) controller to output the blade pitch perturbation $\Delta\theta$ about an instantaneous operating point based on the rotor-speed perturbations $\Delta\Omega$ about a constant setting can be defined as follows

$$\Delta\theta = K_P N_{Gear}\Delta\Omega + K_I \int_0^t N_{Gear}\Delta\Omega dt + K_D N_{Gear}\Delta\dot{\Omega}$$

where K_P, K_I and K_D are the proportional, integral and differential gains respectively and N_{Gear} is the gear ratio. Throughout this work, different methods of augmenting rotor reference speed are explored and performance comparisons are made with the initial baseline controller. Individual pitch controller (IPC) is also implemented to study its performance in terms of blade root fatigue reduction.

Controller Models

Baseline uses a PID controller with constant reference speed and is driven by the errors deviating from the reference speed. [1]

Baseline-AD is a baseline controller with an active damping (AD) injection term to augment the speed reference. [3]

ES is the energy shaping controller based on the conservation of energy within the rotor system. [6]

IPC is a PID controller that uses the blade root moment measurements as inputs and aims at reducing them. IPC can be used in addition to any of the previously mentioned controller. [4]

References

[1] J. M. Jonkman, S. Butterfield, W. Musial, and G. Scott, *Definition of a 5-mw wind turbine for offshore system development*, National Renewable Energy Laboratory, Technical Report NREL/TP 500 38060, February 2009

[2] J. M. Jonkman, *Definition of the Floating System for Phase IV of OC3*, National Renewable Energy Laboratory, Technical Report NREL/TP 500 47535, February 2009

[3] M. A. Lackner, "Controlling Platform Motions and Reducing Blade Loads for Floating Wind Turbines", Wind Engineering Volume 33, No. 6, 2007

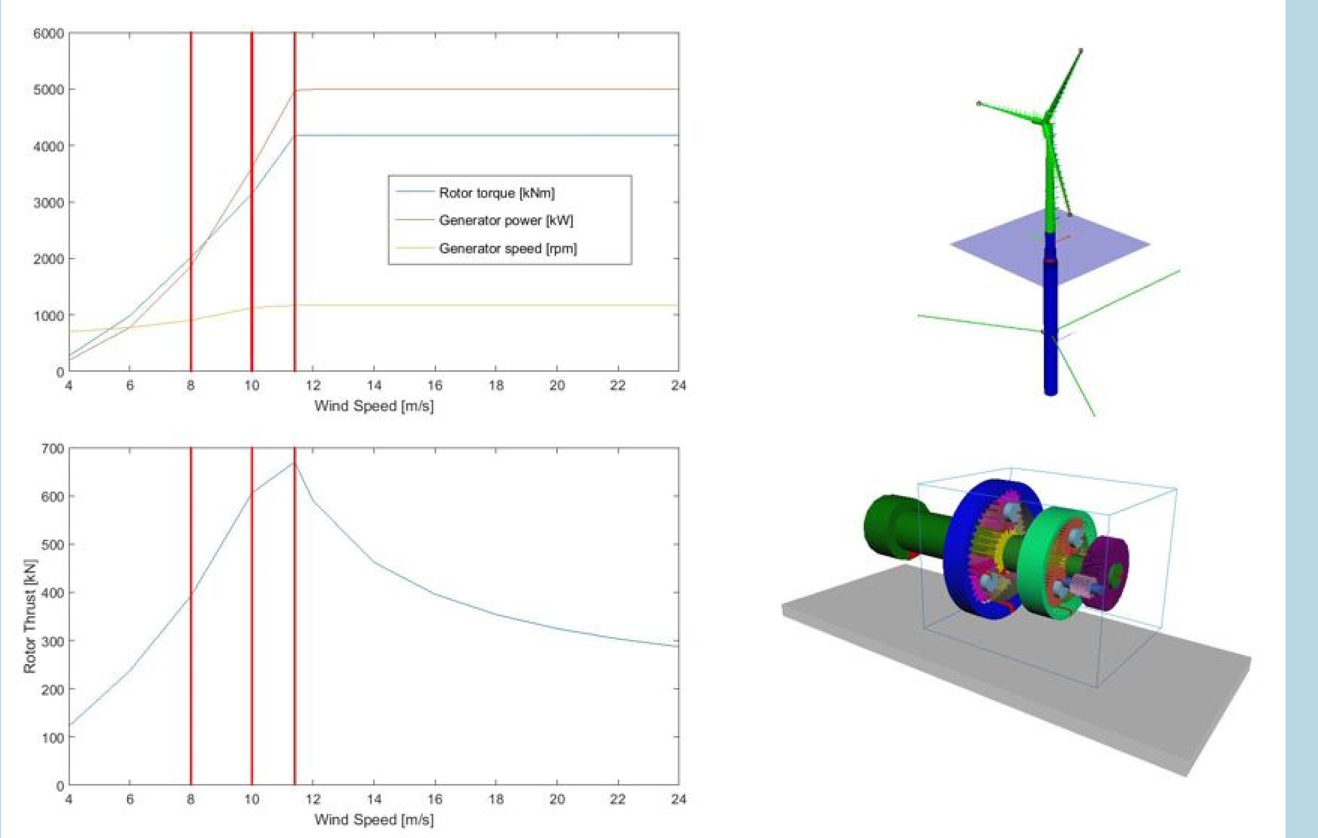
[4] M. A. Lackner, G. van Kuik, "A Comparison of Smart Rotor Control Approaches using Trailing Edge Flaps and Individual Pitch Control", 47th AIAA Aerospace Sciences Meeting Including The New Horizons Forum and Aerospace Exposition, AIAA 2009-685, January 2009

[5] F. G. Nielsen, T. D. Hanson, and B. Skaare, *Integrated dynamic analysis of floating offshore wind turbines*, 25th International Conference on Offshore Mechanics and Arctic Engineering. American Society of Mechanical Engineers, 2006, pp. 671 to 679.

[6] M. D. Pedersen, "Stabilization of Floating Wind Turbines", Norwegian University of Science and Technology, Department of Engineering Cybernetics, May 18, 2017

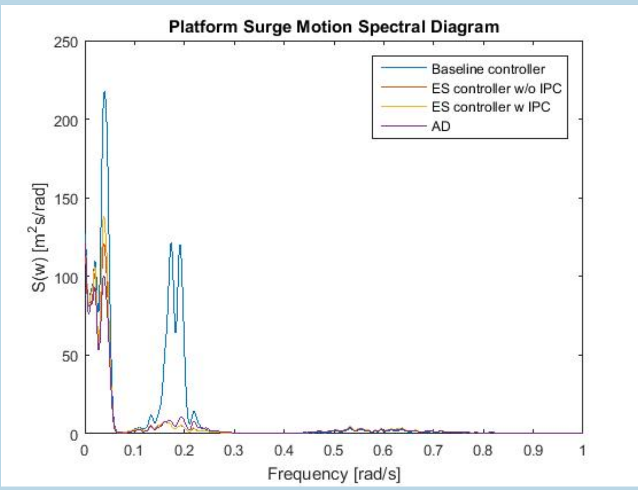
Model and Methodology

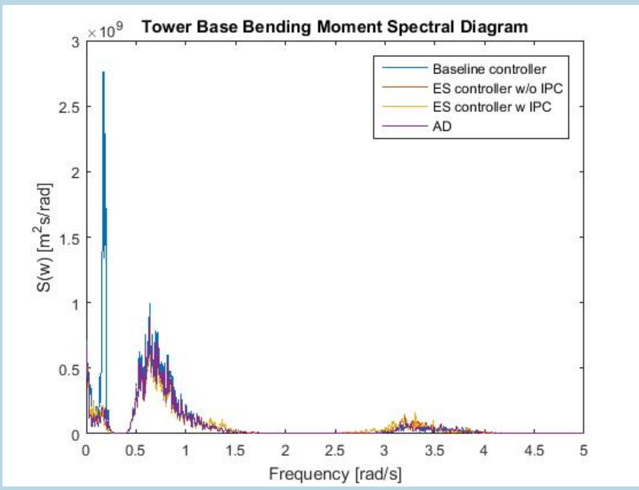
The model that is being used is the NREL 5MW reference wind turbine supported by the OC3-Hywind spar model. The analysis method used in this work can be divided into three stages - model verification, global load analysis and drivetrain dynamic analysis. In order to identify some preliminary characteristics of the OC3-Hywind model as a basis for further analysis, constant wind and free decay tests are performed in SIMA and comparison is made with the system steady state behavior as documented by Jonkman et. al. [1] and the floating platform hydrodynamic properties as described by Jonkman [2]. In general, the loads acting on an offshore wind turbine is time varying and thus time domain analysis should be carried out to fully capture the responses. The model verification global analysis of FOWT model is carried out in SIMA simulation environment which consists of four main modules - SIMO, RIFLEX, Aerodynamic Module and Control Module. Finally, drivetrain dynamic analysis is carried out in SIMPACK simulation environment to study the effect of environmental loads on drivetrain fatigue performance. The model in SIMA and SIMPACK together with some constant wind characteristics are shown below.



Global Analysis Response Comparison

Results from one of the global analyses under the environmental condition with significant wave height, $H_S = 4m$, peak period $T_P = 10s$ and mean wind speed $U = 14m/s$ are shown. All proposed controllers achieved significant amount of surge reduction primarily at wave frequency which leads to tower bending moment reduction at the same frequency.





The effect of IPC can be seen from the spectral diagram of flapwise root bending moment of one of the blades with significant reduction achievable at rotor frequency (1P). For the main shaft yaw aerodynamic moment, other than the 1P frequency region, great reduction of excitation can be observed at frequencies closed to wind frequency.