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Structural control of floating wind turbines

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ABSTRACT

The application of control techniques to offshore wind turbines has the potential to significantly improve the structural response, and thus reliability, of these systems. Passive and active control is investigated for a floating barge-type wind turbine. Optimal passive parameters are determined using a parametric investigation for a tuned mass damper system. A limited degree of freedom model is identified with synthetic data and used to design a family of controllers using H_∞ multivariable loop shaping. The controllers in this family are then implemented in full degree of freedom time domain simulations. The performance of the passive and active control is quantified using the reduction in fatigue loads of the tower base bending moment. The performance is calculated as a function of active power consumption and the stroke of the actuator. The results are compared to the baseline and optimal passive system, and the additional achievable load reduction using active control is quantified. It is shown that the optimized passive system results in tower fore-aft fatigue load reductions of approximately 10% compared to a baseline turbine. For the active control, load reductions of 30% or more are achievable, at the expense of active power and large strokes. Active control is shown to be an effective means of reducing structural loads, and the costs in power and stroke to achieve these reductions are demonstrated.

1. Introduction

As wind power continues its rapid growth worldwide, offshore wind farms are likely to comprise a significant portion of the total production of wind energy, and may even become a sizable contributor to the total electricity production in some countries. The high quality offshore wind resource and the proximity to load centers make offshore wind energy a compelling proposition [1].

To date, offshore installations have been predominantly limited to fixed-bottom structures, such as monopiles and gravity foundations [1]. While these support structures are viable options in shallow water installations, they are no longer economically feasible in deeper waters greater than approximately 50 m [1,2]. For deeper water sites, floating support structures may be needed, such as spar buoys, tension leg platforms, and barges [2–8]. Three types of floating structures are shown in Fig. 1. In 2009, a 2.3 MW spar buoy floating turbine was installed near Norway as part of the Hywind project.

For an offshore support structure to be viable for wind turbines, it must safely withstand the offshore environment, which includes the combined effects of wind and wave loads [9]. Wind and waves generate significant structural vibrations, fatigue loads, and extreme loads in the blades, support structure, and other components. Fatigue loads can lead to increased maintenance, reduced availability, more expensive components, and failures [10,11].

This research investigates the use of an additional control degree of freedom for passive and active structural control of a floating barge-type offshore wind turbine. We present the development of an advanced modeling tool for structural control of wind turbines. Both passive and active control are then investigated. For the passive case, optimal parameters of a passive tuned mass damper system are determined. For the active investigation, a reduced-order model of the floating wind turbine is extracted from input/output simulations, and utilized to design a family of controllers with varying degree of control authority. Full degree of freedom simulations of the system equipped with the optimized passive system and the active hybrid mass damper are performed in above and below rated conditions, and the tradeoffs associated with the use of passive and active structural control are highlighted.

1.1. Previous work

1.1.1. Control of structures

The control of civil engineering structures has been an active research area for over two decades [12–17]. The goal of this body of work has been to protect structures from dynamic loading due to earthquakes, wind, waves, and other sources [18].

There are three major categories of control methods for structures: passive, semi-active, and active [13]. Passive structural control systems have constant parameters and no energy input to the

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