Multi-objective Active Structural Control of the OC3-Hywind Floating Wind Turbine

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ABSTRACT

In this paper, active structural control design of the OC3-Hywind floating wind turbine is investigated to reduce platform oscillation and fatigue load. Firstly, a non-linear dynamic model for system surge-heave-pitch motion is established based on the first principle. Secondly, system identification is performed in order to verify the effectiveness of the proposed model, and it is then simplified into a linear form to facilitate control design. Thirdly, multi-objective controller with guaranteed cost and poles assignment is designed. Finally, we analyze the simulation results and give conclusions.

KEY WORDS: OC3-Hywind; active structural control; multi-objective design; tuned mass damper; linear matrix inequality

INTRODUCTION

Currently, most of the large wind turbines around the world are installed on land with sparse population. However, in many countries, large populations are usually concentrated in places along coastlines where land is scarce. Therefore, utilizing offshore wind resources is more beneficial which will both reduce electricity transmission loss and reserve land space for people. Global wind energy development is gradually moving to offshore (Kaldellis and Kapsali, 2013).

In fact, near offshore wind farms in shallow water are often blamed for visual and noise annoyance, while offshore deep water wind energy with less space constraints and more consistent wind has attracted more attention in recent years. Deep water wind turbines are usually installed at places where sea depth is between 60m and 900m, so floating foundations are generally considered to be an economical and feasible way of deployment. Based on decades of experience from offshore oil and gas industry, several different traditional floating platforms have been proposed to support large wind turbines in deep sea regions (Jonkman and Matha, 2009), including spar-buoy, tension leg, barge, and semi-submersible. In detailed design, they each correspond to OC3-Hywind, MIT/NREL TLP, ITI Barge, and WindFloat.

Different from fixed bottom wind turbines, the very first challenge (Butterfield, Musial, Jonkman, Sclavounos, Wayman, 2005) for floating wind turbines is the wave and wind induced platform motion, which will heavily increase the load on nacelle and tower due to the high inertial and gravitational forces. Large platform motion will bring severe fatigue and ultimate loads on tower base, tower top and blades root, bring more bending moment (including fore-aft and side-side) on the elastic tower, even cause the failure of blade pitch control system. According to Jonkman (2009), the sea-to-land ratio of fatigue loads has reached 7 for certain design. What is worse, floating platform rotation is usually in low frequency (Larsen and Hanson, 2007), which brings difficulty in effective damping. These problems have attracted a lot of attention on design and control for load reduction of floating wind turbines.

In order to reduce the extra load on supported wind turbine structure, different methods have been proposed in literature, which can mainly be classified into two categories. One type is to improve the blade pitch control system for load reduction. In order to effectively damp the platform fore-aft motion, Larsen and Hanson (2007) designed a new collective pitch control strategy to ensure the desired control structure natural frequency lower than the lowest critical tower frequency. Namik and Stol (2010) proposed to introduce advanced individual blade pitch control for floating wind turbines to reduce both the tower fore-aft and side-side bending moments. Another novel approach is to use structural vibration control device for direct load reduction, which has been successfully applied in civil engineering structures, such as buildings and bridges (Korkmaz 2011). In literature (Murtagh, Ghosh, Basu, Broderick, 2008; Colwell and Basu, 2009; Luo, Bottasso, Karimi, Zapateiro, 2011), several passive and semi-active structural control methods were proposed for onshore and offshore wind turbines. However, their works were not based on the cutting-edge codes for wind turbine analysis, which did not capture the comprehensive coupled dynamics of wind turbines. Based on the powerful aero-hydro-servo-elastic wind turbine simulator FAST (fatigue, aerodynamics, structures, and turbulence) (Jonkman, 2005), Lackner and Rotea (2011) developed a new simulation tool FAST-SC for passive, semi-active, and active structural control design of wind turbines. Utilizing this tool, they proposed to install a passive tuned mass damper (TMD) in the