Influence of Control Strategy to FOWT Hull Motions
by Aero-Elastic-Control-Floater-Mooring Coupled Dynamic Analysis

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ABSTRACT

More FOWTs (floating offshore wind turbines) will be installed as relevant regulations and technological hurdles are removed in the coming years. In the present study, a numerical prediction tool has been developed for the fully coupled dynamic analysis of FOWTs in time domain including aero-loading, tower elasticity, blade-rotor dynamics and control, mooring dynamics, and platform motions so that the influence of rotor-control dynamics on the hull-mooring performance and vice versa can be assessed. The developed coupled analysis program is applied to Hywind spar design with 5MW turbine. In case of spar-type floaters, the control strategy significantly influences the hull and mooring dynamics due to the possibility of control-induced instability causing resonant hull motions. Therefore, it is important to use a control strategy without such problems at the penalty of possibly less uniform power outputs. In this regard, the results of two different control strategies - conventional and modified control strategies - are systematically compared to better understand the subtle coupling effects between the blade-pitch-angle-control and hull motions. The developed technology and numerical tool are readily applicable to any types of floating wind farms in any combinations of irregular waves, dynamic winds, and steady currents.

KEY WORDS: Renewable Wind Energy, FOWT (floating offshore wind turbine), aero-elastic-control-floater-mooring coupled dynamics, spar hull, control-induced excitation/resonance, conventional/modified control strategies, generated power quality, wind farm.

INTRODUCTION

Wind is the fastest-growing clean and renewable energy source. Until recently, most of the wind-farm development has been limited to the land space or shallow-water areas. However, there exist negative features of on-land wind farms that include lack of available space, noise restriction, shade, visual pollution, limited accessibility in mountainous areas, community opposition, and regulatory problems.

In this regard, several countries started to plan floating offshore wind farms. Although they are considered to be more difficult to design, wind farms in deeper waters are in general less sensitive to space availability, noise restriction, visual pollution, and regulatory problems. They are also exposed to much stronger and steadier wind field to be more effective. Furthermore, in designing those floating wind farms, the existing technology and experience of offshore industry used for petroleum production is directly applicable. If the relevant technology and infrastructure are fully developed, offshore floating wind farms are expected to produce huge amount of clean electricity at a competitive price compared to other energy sources.

For floating wind turbines, their natural frequencies of 6DOF motions are typically much lower than those rotor-induced or tower-flexibility-induced excitations, so the possibility of such dynamic resonance is small (e.g. Withee 2004, Jonkman et al 2006). One exception is the TLP-type OWT (Bae et al., 2010; Jagdale & Ma, 2010), which is much stiffer in the vertical-plane modes compared to other floating wind turbines, and thus the effects of such high-frequency excitations from the tower and blades need to be checked. For spar or semi-submersible floaters (Roddier et al., 2009), the low-frequency excitations related to blade pitch-angle control may cause large-amplitude slowly-varying resonant floater motions (Nielsen et al., 2006). Therefore, the accurate estimation of the coupling effects between the floater dynamics and control-induced actuation forces is very important in the optimal design of such floating OWTs.

In this regard, a rotor (aero-elastic-control)-floater-mooring coupled dynamic analysis computer program is developed by combining several modules. For the dynamic analysis and control of wind turbine system, the primary design code of wind turbines FAST promoted by National Renewable Energy Laboratory (NREL) is employed (Jonkman, 2003, 2007, 2008; Jonkman et al., 2004). The FAST is implemented into the floater-mooring coupled dynamic analysis program, CHARM3D, which has been developed by authors’ group during the past decade (e.g. Kim et al., 2001ab; Arcandra & Kim, 2003; Yang & Kim 2010). They are combined and modified so that the whole system can be solved in time domain by a big combined matrix including all the relevant coupling forces and degrees of freedom. As a result, the dynamic time histories of the whole system including full couplings among tower, floater, and mooring can be obtained simultaneously by a single run. The developed computer program is applied here to study the effects of respective blade-control strategies on the global responses and generated power outputs of a 5MW spar-type FOWT.