Digital Twin Model Development for Mitigating Floating Offshore Wind Turbine Motions Due to Wave Actions

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ABSTRACT

The coupled action of wind and wave on the stability of floating offshore wind turbines (FOWT) tremendously affects the lifespan of these energy systems and their energy output. Passive control systems reduce such loads but can only mitigate the loading over a small range of excitation frequencies. To improve this, an active control system (ACS) is needed. The aim of this research is a digital twin proof of concept allowing the diagnosis of current and upcoming environmental events and re-tuning the ACS based on a tuned mass dampers system (TMD) to minimize wave-induced response at the frequency range of interest. This is accomplished through a series of numerical investigations supported by laboratory measurements in a wave basin made on a scale model of a 15MW FOWT. The numerical models are implemented via the multi-physics, multi-fidelity code: OpenFAST, that enables coupled nonlinear aero-hydro-servo-elastic simulation in time domain. The code is modified to enable ACS implementation and ease of communication between the controller and OpenFAST. After validating the model, an open-loop controller is designed to allow multiple stiffness and damping entries targeting first-order wave-frequency region. Two methods of data acquisition are investigated: the Current Sea-State Controller (CSSC) where sea-state prediction is governed by past wave elevation data points using a polynomial weighted buffer that leverages more recent data, and the Future Sea-State Controller (FSSC) that, additionally utilizes reconstruction/prediction model of the upcoming wave to investigate the effect of reduced latency in the controller response. Both controllers are optimized through a genetic algorithm scheme. Results show reduction in wave excitations ranging between 10s to 20s under varying sea-state when future wave elevation data is fed to the controller.

KEYWORDS: Floating offshore wind; Physical model; Hydrodynamics modeling; Control optimization; Digital twin; Tuned mass dampers.

INTRODUCTION

Wind energy is being recognized as a central factor in attaining Paris agreement (COP21) goals of 1.5°C global warming by the year 2100. Specifically, offshore wind energy is the most commercially well-established marine renewable form with a relatively mature technology (Astariz and Iglesias, 2016). This motivates more industry to be included in the picture and is the reason behind a year-over-year (YoY) growth of 12% in the year 2021 which was the wind industry’s second-best year after 2020. Onshore wind market added 72.5 GW worldwide whereas offshore installations represented 22.5% of all new installations in the year 2021, bringing the world’s total offshore capacity to 57GW (Council, 2022).

As offshore wind is transitioning towards floating technologies, the platform rigid-body motion becomes an urgent issue in the design and analysis stage (Alkarem, 2020). Hence, numerical and experimental applications are necessary to understand this multi-faceted problem (Martin et al., 2014; Viselli et al., 2015). For instance, the sea-to-land ratio of fore-aft tower base bending moment fatigue loads is 2.5 for spar-type and 7.0 for barge-type platform (Jonkman, 2009). Therefore, innovation that leads to response reduction is critical in the design of floating offshore wind turbines (FOWT) and active control system becomes a necessity. While active control systems have been extensively researched for the turbine control (Raach et al., 2014), strategies for minimizing wave-induced rigid body motion of the platform are usually based on passive techniques such as tuned mass dampers (TMDs) that can be optimized to mitigate vibrations/motions of certain frequencies (Villoslada et al., 2020; Stewart and Lackner, 2014). These dampers can be either situated in the nacelle (Ding et al., 2019; Lackner and Rotea, 2011b), in the platform (Kimball et al., 2022), or both (Yang and He, 2020) and can be either passive (Lackner and Rotea, 2011a) or active (Namik et al., 2013). In general, active retuning of TMDs show better reduction in motion at the expense of active power and mass stroke distance which can be unrealistic for practical applications.

As digital technology related solutions are invading every industry, research in its early stages is taking place worldwide to enhance the efficiency and productivity of offshore operations such as in oil and gas (OG) industry (LaGrange, 2019) and in fault diagnosis and operation optimization of offshore wind turbines (Meandal et al., 2022). In this research, digital twin is a loose term that translates to the active feed of the short-term predicted wave elevation to the controller, how the platform would respond to that input, and the active retuning of the TMD to minimize