Mitigation of jacket offshore wind turbines under misaligned wind and ice loading using a 3D pendulum tuned mass damper

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ABSTRACT

Offshore wind turbines located in sea ice zones are subjected to severe ice-induced vibration. The present study uses a three-dimensional pendulum tuned mass damper (3D-PTMD) to mitigate the nacelle/tower and foundation dynamic response under the combined action of wind and ice loading. The results show that the 3D-PTMD is effective in mitigating RMS and peak response of the nacelle/tower and foundation, as well as the stress of the TP and leg. It is also shown that the 3D-PTMD can dramatically reduce the dynamic response of the nacelle/tower and foundation in both fore-aft and side-side directions under misaligned wind and ice loading.

KEY WORDS: Offshore wind turbine; ice-induced vibration; vibration mitigation; 3d-PTMD

INTRODUCTION

Offshore wind energy is an important renewable energy source, especially in cold climate regions. In the past 10 years, with the development of offshore wind industry and due to some advantages such as higher and steadier wind speed which leads to more efficient power generation, more and more offshore wind turbines (OWTs) are being installed in high-latitude cold sea areas by many countries around the world. In China, the Bohai Sea is becoming increasingly popular for the development of offshore wind farms due to the rich wind resources, shallow water, and low penetration of wind energy sector. However, the sea freezes annually in this area which poses a huge hazard to the structural safety severely affecting the power generation efficiency of the OWTs (Tian, 2019). One of the main concerns for engineering activities in cold areas with ice-infested water is the ice-induced vibration (IIV). Several solutions have been proposed for the mitigation of ice-induced vibrations. The most common approach is to install ice-breaking cones (ICBs) at the ice-structure interface, which is widely used in offshore oil platforms (Huang, 2013). However, the IBC only reduces the ice load acting on the structure, it does not fundamentally cure the IIV. The ice force frequency lock-in (FLI) occurs when the ice loading frequency resonates with the structural natural frequency. Furthermore, the tower diameters are between 3m to 8m for monopile type OWT, which are much larger than the diameters of offshore platform legs. Therefore, the maximum diameter of the cones mounted on the monopile can be up to 10m, which would cause the ice accumulation more easily. The ice accumulation will increase the ice loading dramatically and is severely harmful to the safety of the OWT. Also, designing IBCs for jacket-type OWTs is challenging as the distance between the legs at the mean sea level (MSL) is much smaller than that of the offshore oil platforms. There is not enough clear distance for crushed ice drifting through the jacket successfully if each leg is equipped with ice cone. More importantly, the cones increase the cost for the construction and installation of the OWTs dramatically, which are unacceptable for most OWT manufactures. Besides, the cone amplifies the wave load acting on the OWT during the non-icing season.

In this situation, tuned mass dampers (TMDs), which have been widely used in traditional civil structures, provide an alternative solution for IIV control of the OWT. Sun (2017, 2018) studied the mitigation of fixed-bottom offshore wind turbines subjected to wind-wave loadings using semi-active TMD. Buckley (2018) proposed a tuned liquid column damper to control the structural vibrations of wind turbines. Ghasempour (2019) investigated the load mitigation effectiveness for the National Renewable Energy Laboratory (NREL) 5MW monopile OWT via an omnidirectional TMD both in operational and parked rotor conditions. However, these studies did not consider the floating ice load. Heinonen (2017) developed two submodules IceFloe and IceDyn, and coupled them into the FAST program to study the floating ice against the narrow vertical tower for the NREL 5MW OWT. Kärnä, T (2004) using the TMD method studied the further reduction for the remaining vibration of slender OWT mounted with a cone on the waterline. Heinonen (2011) analyzed the FLI vibration of two OWTs with different structural stiffnesses using the self-excited IIV model. Nevertheless, their study did not consider the effectiveness of the aerodynamic load. Ye Kehua (2018) implemented and compared the effectiveness of the IBC and the TMD for reducing the aerodynamic load and the floating ice load on the monopile OWT. Their results indicated that TMD could mitigate the side-side vibration, while it is ineffective in reducing the responses in the fore-aft direction when the IBC is not mounted on the OWT. Perhaps the dual TMDs studied by Lackner (2011) could mitigate the vibration in the fore-aft and side-side directions, however, there are still several limitations existing in this approach. For instance, the optimal design is extremely challenging as the mass allocation and arrangement of the two TMDs are correlated with the probabilistic distribution of the directionality of external