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Strength Analysis for a Jacket-type Substructure of an Offshore Wind Turbine Under Extreme Environment Conditions

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This study investigates the extreme environment conditions behaviors of a reference offshore wind turbine with jacket substructure for transitional water depths. Fully coupled, nonlinear time-domain simulations on full system models are carried out under earthquake and typhoon loads. For a further insight into the importance of seismic and typhoon assessment, a comparison with demands from some typical design load cases prescribed by International Electromechanical Commission standard IEC 61400-3 is also provided. It is shown that earthquake loading may cause a significant increase of stress resultant demands, especially for seismically active areas. In addition, the results also showed the vertical accelerations at the ground surface were amplified by a factor of 8 at the location of the tower top. Larger structures with lower natural frequencies may be prone to significant responses of excitation in the vertical direction. This acceleration can have significant bearing on the design of the tower and its connection to the nacelle and performance of the turbine after the earthquake.

INTRODUCTION

Severe environmental issues have increasingly impacted our population in recent years. Using renewable energy has become an inevitable substitute for traditional fossil fuel or coal power to reduce the carbon emission. Wind power is one of the most promising renewable energy utilizations. It provides an essential contribution to clean, robust, and diversified energy portfolio. Technological advances and maturing supply chains are making offshore wind power an increasingly viable option for renewable-based electricity power.

According to the IEC 61400-3 standard (International Electromechanical Commission (IEC), 2009) and the API RP 2A-WSD code (American Petroleum Institute (API), 2014) associated with the extended American Bureau of Shipping (ABS) guidance for building and offshore wind turbine (OWT) installations (ABS, 2010), ABS completed a design standard for offshore wind farms in 2011 (ABS, 2011). Because of the global demand for an offshore wind turbine system (OWTs), the Offshore Code Comparison Collaboration (OC3) and Offshore Code Comparison Collaboration Continuation (OC4) have been conducted by the International Energy Agency (IEA) since 2005 (Jonkman and Buhl, 2005; Jonkman et al., 2009, 2012; Jonkman and Musial, 2010) and implemented a series of code comparisons based on a 5 MW reference OWT published by NREL (Jonkman et al., 2009). The specifications of the widely used reference OWT are listed in Table 1.

The substructure is the primary component of an OWT system and occupies a significant share of the total cost. A few common types of support structures for OWTs include monopile, gravity, tripod, jacket (as shown in Fig. 1), and floating types. Jacket-type substructures are one of candidate types in Taiwan's offshore wind farm because they can be properly used in water regions of depths between 30 and 50 m and can dissolve the global moments to pairs of forces and transfer them as axial loads to the soil, and they therefore are advantageous especially in weak soil conditions. A jacket is considered to be a relatively lightweight concept and possesses stability and high structural stiffness (Zaaijer, 2003). Compared with the tripod, the jacket substructure is more preferable in terms of scour, ship collision, complexity of joints, and deflection at the tower top and overall weight (Schaumann and Böker, 2005).

Since the Fukushima nuclear accident that happened in Japan in 2011, the countries in East Asia have been tremendously concerned for the development of offshore wind energy. In Taiwan, the first two offshore wind turbines of the 128 MW Formosa 1 Project in 2017, each a 4 MW machine, were installed, and the total installed capacity for offshore wind is predicted to reach 5.5 GW by 2025. However, Taiwan is located in the western Pacific Ocean region, where it has good offshore wind resources but some high-risk threats. Regional environmental problems

Rating	5 MW
Rotor orientation, configuration	Upwind, three blades
Control	Variable-speed, collective pitch
Drivetrain	High-speed, multiple-stage gearbox
Rotor, hub diameter	126 m, 3 m
Hub height	90 m
Cut-in, rated, cutout wind speed	3 m/s, 11.4 m/s, 25 m/s
Cut-in, rated rotor speed	6.9 rpm, 12.1 rpm
Rated tip speed	80 m/s
Overhang, shaft tilt, precone	5 m, 5°, 2.5°
Rotor mass	110,000 kg
Nacelle mass	240,000 kg
Tower mass	347,460 kg
Coordinate location at overall center of mass	(−0.2 m, 0.0 m, 64.0 m)

Table 1 Gross property of the NREL 5 MW reference wind turbine

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KEY WORDS: Extreme environment, strength analysis, offshore wind turbine, jacket substructure, load calculation procedure.