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Time-Domain Fatigue Analysis of Multi-planar Tubular Joints for a Jacket-Type Substructure of Offshore Wind Turbines

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In this study, time-domain fatigue analyses of multi-planar tubular joints for a jacket-type substructure of offshore wind turbines designed for Taiwan's local environmental conditions are performed. The potential design load cases could affect the overall calculation procedure. A series of fatigue loads from the IEC 61400-3 standard were calculated to investigate the dominant design load cases and to improve the load calculation efficiency. The stress distributions of tubular joints are computed by finite element analysis to determine the stress concentration factors. The results show that the fatigue damage caused by the power production design scenario accounts for the total cumulative fatigue damage up to 90%. This work, in addition to more efficient load calculation procedure, will be helpful for cost assessment and could accelerate the development of offshore wind farms in Taiwan.

INTRODUCTION

Because of global warming and climate change, using renewable energy has become an inevitable substitute for fossil fuel and coal power. Wind power is one of the most promising renewable energy utilizations, providing an essential contribution to a clean, robust, and diversified energy portfolio. In Taiwan, the government's reiteration of the target is that 20% of the country's electricity will come from renewable energy by 2025, with wind power generation accounting for 15% of the renewable energy. In 2017, the first two offshore wind turbines of the 128 MW Formosa 1 Project, each a 4 MW machine, were installed, and the total installed capacity for offshore wind is predicted to reach 5.5 GW by 2025.

Taiwan is located in the western Pacific Ocean region where it has good offshore wind resources but a high risk of seismic and typhoon threats. The problems of the regional environmental conditions include earthquakes, typhoons, and weak seabed conditions. Previously, Lai et al. (2016) mentioned that earthquake conditions are a crucial design problem, especially for the ultimate strength design. Although the fatigue damage is not the main cause of resulting catastrophic failure, its effect on the cost of the maintenance of offshore wind turbine support structures cannot be overlooked. The general reason for large-scale tubular structure failures after a long period of operation is fatigue failure. Besides this, the fatigue damage at some regions near the top of the substructure is significantly affected by wind load (Fan et al., 2017), and the welded tubular joints of the support structure have high stress concentrations because of their complex geometry.

In recent years, there has been a dramatic proliferation of research concerned with the fatigue analysis of jacket substructures of offshore wind turbines (OWTs), which is increasingly important with mature and viable technology. However, the lack of experience with offshore wind technology may contribute considerable uncertainties in estimating the potential cost of domestic offshore wind energy. The substructure is the primary component of an offshore wind turbine system and occupies a significant share of the total cost. Furthermore, the jacket-type substructure is considered to be a more cost-effective solution than other types of structures, especially in water depths between 30 m and 60 m (Seidel, 2007; Musial and Ram, 2010). Jacket-type substructures have been widely used in the oil and gas sector. Many design analyses and assessment procedures can be transferred to the design of jackets for OWTs. Some areas still require new constructions or significant considerations in the design process, especially for the fatigue analysis. The previously mentioned codes contain several methods for fatigue analysis, among which the frequency domain approach (or spectral fatigue) is the most common for jacket structural dynamic design. Several studies suggested that the frequency domain analysis was more efficient in computation, but its accuracy has been shown to be poor in comparison with the time domain approach (Naess and Moan, 2013; Mohammadi et al., 2016). However, the time domain simulations would be very time consuming. In this paper, the authors present more efficient load calculation procedures (LCPs). These LCPs will be helpful for the cost assessment and selection of appropriate types of substructures in the preliminary design stage of future offshore wind farm planning under Taiwan's environmental conditions.

The objective of this study is to perform fatigue analyses for jacket-type OWTs under Taiwan's environmental conditions. The potential design load cases (DLCs) could affect the overall calculation procedures. Thus, a series of fatigue DLCs from the IEC International Standard 61400-3 (International Electromechanical Commission (IEC), 2009) were carried out to investigate the dominant DLC under local environmental conditions and more efficient LCPs. Based on sequentially coupled approaches, NREL FAST (Jonkman and Buhl, 2005) and ANSYS software (ANSYS, 2015) are employed to analyze the dynamic responses of offshore wind turbine systems and jacket-type substructures under various DLCs defined in IEC International Standard 61400-3 (Lai et al., 2016). The computed results of shear forces, axial forces, bending moments, and torques at the top of the tower are then used to perform local analyses in the time domain by ANSYS software. Using the finite element analysis (FEA), the stress concentration factors (SCFs) and hot spot stresses are used to assess the structural fatigue life. The cumulative fatigue damage factors can thus be calculated by S-N curves and Palmgren-Miner's rule.

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KEY WORDS: Fatigue analysis, offshore wind turbine, jacket-type substructure, load calculation procedure.