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Assessment of the dynamic responses and allowable sea states for a novel offshore wind turbine installation concept based on the inverted pendulum principle

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Abstract

This paper presents a numerical study for preliminary assessment of the dynamic responses and allowable sea states for the installation of an offshore wind turbine (OWT) tower and rotor nacelle assembly (RNA) based on a novel method. This method is based on the inverted pendulum principle and consists of various sequential activities for which the allowable limits of sea states need to be established. For critical installation activities, numerical analyses methodologies have been applied to model the actual operations. For the parameters limiting the execution of the operations, response statistics are provided. It is found that at least 45 seeds are required to achieve convergence of snap force statistics during the OWT lift-off. The response statistics are used to calculate a characteristic value corresponding to a target probability of non-exceedance. For the lift-off and mating operations, these characteristic values are compared with the allowable limits of the response parameters to establish the allowable limits of sea states. In addition, sensitivity study on key modeling parameters are conducted. Spring coefficients of contact elements and hinged connections, winch speed, and hoist wire stiffness are shown to be important modeling parameters. The results provided in this paper are important for future finite element modeling (FEM) and cost-effective design of the structural components.

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1. Introduction

Installation is an important phase of the offshore wind turbine life cycle, where several activities are executed in sequence by following installation procedures. Each activity may have several critical events that may jeopardize or restrict the complete operation. These critical events have their own limiting (response) parameters, e.g., a sling breakage event has the tension as a limiting parameter. However, it is desired that the allowable limit of the tension is

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expressed in terms of allowable sea state parameters. The limits of allowable sea states can be derived for each installation activity, and by taking the lower envelope, the “operational limits” of the whole installation can be established. These operational limits need to be derived in a systematic manner.

In [3], a novel OWT tower and RNA installation concept was introduced and shown to be feasible. It allows the installation of a fully assembled superstructure using a medium size HLV, a cargo barge and an especially designed upending frame. The method is based on the inverted pendulum principle and takes advantage of the shielding effects of the HLV on the motions of the cargo barge. The foundations can be monopile, tripod and jacket structures. In addition, no major modifications of current designs are required for monopiles and tripods. In this paper, the tripod structure is selected arbitrarily. The installation procedure is summarized as follows: First, the stern of the cargo barge transporting the OWT in horizontal position is moored to the foundation, see Fig. 1 (a). Second, the HLV is positioned parallel to the cargo barge using mooring lines or a dynamic positioning (DP) system. The motions are monitored prior to the lifting operation. Third, the crane winch starts lifting the OWT tower until clearance of the saddle support on the bow of the cargo barge is achieved, see Fig. 1 (c). Fourth, mating between the upending frame bottom pin and the foundation support occurs, see Fig. 1, detail X. Fifth, the OWT is further upended to the vertical position, lowered to the foundation using hydraulic jacks, bolted to the foundation flanges, and the upending frame is removed, see Fig. 1 (d,e). During all installation activities except in the final OWT upending phase, it is required that the crane tip and the lifting point on the OWT tower are vertically aligned.

Based on the installation procedure, time domain (TD) simulations of the critical operations were conducted. It was identified by [3] that the critical events and corresponding limiting (response) parameters are: the wire rope or crane structure failure during the lift-off phase and the limiting parameter is the snap force in the hoist wire rope. For the mating operation between the upending frame bottom pins and the foundation support, the failed mating attempt is a critical event, and the limiting parameters is the horizontal motion of the pin. During the mating operation, another critical event is the structural damage of the foundation supports (docking cones) due to large impact forces or corresponding velocities. Finally, during the final upending stage of the OWT tower, the structural damage of the foundation supports and docking pins are critical events. The limiting parameters are the reaction forces in the structural connections.

To establish the allowable sea states of each installation activity, characteristic values S_c and allowable limits S_{allow} of limiting (response) parameters are needed. The allowable limits of sea states can be established in a straightforward manner for the condition satisfying the equality $S_{allow} = S_c$.

The allowable limits of sea states for the lift-off and initial phase of the mating activities can be assessed at this stage of the design because the allowable limits of the limiting (response) parameters can be reasonably estimated from manufacturer specifications and geometrical constrains. These limiting parameters were identified by [3], and they are the snap loads on the wire ropes and horizontal motions of the upending frame’s locking pin.

In this paper, the allowable limits of sea states for the lift-off and initial phase of the mating activity are established. In addition, the lower envelopes of these allowable limits of sea states are used to assess response statistics of impact velocities during the mating operation and reaction forces during the upending phase. Moreover, sensitivity study on key modeling parameters such as lifting winch speed, hoist wire stiffness and contact stiffness is conducted. The results provide “representative” values of dynamic responses for future cost-effective design of the structural components.

Furthermore, allowable limits of structural components subjected to impact velocities during the upending frame mating operation and reaction forces during the OWT upending phase, require structural damage criteria based on FEM of the structural components. The detailed designs of these components are not available at this stage of the study, and thus, are not considered in this paper.

This installation method assumes that the horizontal transportation of the OWT tower and RNA is feasible. In practice, local permanent deformations and damage of the bearings and supports of the drive train can occur, and thus, affect their fatigue life. This is due to gravity and acceleration loads for which the allowable limits need to be established. These limits can be set based on structural damage criteria obtained from FEM of the complete nacelle structure. In addition, possible leakage of hydraulic fluids have to be considered. The issues discussed above need to be addressed for a complete assessment of the operational limits; however, these topics are out of the scope of this paper.