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Dynamic response analysis of a catamaran installation vessel during the positioning of a wind turbine assembly onto a spar foundation

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A B S T R A C T

Installation of floating wind turbines is a challenging task. The time and costs are closely related to the installation method chosen. This paper investigates the performance of an efficient installation concept – a catamaran wind turbine installation vessel. The vessel carries pre-assembled wind turbine units including towers and rotor nacelle assemblies. Each unit is placed onto a pre-installed offshore support structure (in this paper a spar floater) during installation. The challenge is to analyse the responses of the multibody system (catamaran-spar-wind turbine) under simultaneous wind and wave loads. Time-domain simulations were conducted for the coupled catamaran-spar system with mechanical coupling, passive mooring system for the spar, and dynamic positioning control for the catamaran. We focus on the steady-state stage prior to the mating process between one turbine unit and the spar, and discuss the effects of wind loads and wave conditions on motion responses of the catamaran and the spar, relative motions at the mating point, gripper forces and mooring forces. The relative motion at the mating point is less sensitive to the blade orientation, but influenced by the wave conditions. Under the investigated sea states, the present installation method shows decent performance.

1. Introduction

Renewable energy resources have attracted broad interests worldwide, because of the increasing demand for energy and concerns about global warming. Among the various sources of renewable energy, wind energy is among the most rapidly developing one, with energy production at an annual growth rate of 25–30% [1]. At the end of 2016, Europe's cumulative installed offshore wind capacity reached 12631 MW (MW). 81 offshore wind farms across 10 European countries had been constructed, with an average capacity rating of 4.8 MW per turbine and an average water depth of 29.2 m (m) [2].

Because of the high-quality wind resources and geographical limitations, several countries are considering deep water offshore

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areas for future development of wind power facilities. In deep water of more than 150 m, floating foundations are more cost effective than bottom-fixed ones. Different forms of floating foundations have been proposed. Spar, tension leg platform, and semi-submersible types are most promising. Although the technologies are proven and have been applied to the oil and gas industry, commercial deployment is still at an early stage because of costs. The Hywind pilot park, the world's first floating wind farm, has started power production since October 2017 [3].

Research of offshore wind technologies has been gaining momentum since 2000. With the development and maturity of the state-of-the-art numerical simulation tools [4–6], coupled dynamic analysis of offshore wind turbines (OWTs) becomes possible. Still, most of the related literature is focused on design and analysis of OWTs in various operational or parked conditions [7–11]. In contrast, there is limited research work on installation of OWTs. Sarkar et al. [12] presented the technical feasiblity of an installation concept using a floating vessel along with a floatable subsea structure for installing monopile-type OWTs. Guachamin-Acero et al. [13] developed an installation concept for small crane vessels using the inverted pendulum principle in which the pre-assembled rotor, nacelle and tower can be installed via rotation through a rotating frame at the tower base. Ahn et al. [14] evaluated various methods of wind turbine installation in the Korean west-south wind farm and analysed the instalaltion cost of OWTs. Paterso et al. [15] considered the installation modelling for UK offshore wind Rounds 1 and 2 using a probabilistic simulation tool and provided a quantification of installation vessel performance to support developers and project planners. Esteban et al. [16] reviewed the processes and methods employed in the offshore installation of the most relevant types of gravity-based structures in offshore wind facilities operating in Europe.

To reduce the cost of offshore installations, one primary challenge is to increase the weather window and to avoid unexpected delays. To achieve this, accurate assessment is desired of the performance of the installation vessels and installation methods, and numerical methods and models have been developed to estimate systems' dynamic responses during installation. Most of the studies focused on static [17] or steady-state dynamic responses [18], whereas in a few studies, the nonstationary features of the installation process were also considered [19,20]. Based on numerical simulations and response-based criteria, methodologies for assessment of allowable sea states for installing OWTs can be established. So far, these methodologies have been applied to monopile foundation installation [21] and transition piece installation [22] of bottom-fixed OWTs.

Compared to bottom-fixed OWTs with monopile, gravity-based, or jacket foundations [23], floating wind turbines are born with even more challenges with regard to transportation, assembly, and installation. Consider the installation of Hywind, which is a spar-type floating wind turbine. In order to increase the operability, the upending and assembly was done at a well-sheltered location. Then the unit was towed to the site and hooked up to the mooring system [24]. For OWT installations, the tower, nacelle, and blades can be either pre-assembled and installed by a single lift [25], or separated and installed piece by piece in a split way [26,27]. In the Hywind installation challenge campaign [28], and among the proposed innovative installation concepts, there is a tendency to favour novel installation vessels and facilities to reduce offshore lifts and operation time. A novel wind turbine installation concept has been recently proposed by the SFI MOVE project [29,30]. Fig. 1 gives an overview of the concept, which uses a catamaran installation vessel for installations of OWTs, and can be used for offshore bottom-fixed or floating foundations. The aim of this concept is to avoid extremely weather-sensitive high lifts from a floating vessel.

The concept is in its infancy, and to demonstrate the feasibility of the concept, numerical simulations and model tests should be performed. Compared to single floating bodies, behaviour of the coupled catamaran-spar system will be more complex, because of mechanical and hydrodynamic couplings between the floating bodies. It is necessary to identify the motion characteristics of the system, under various environmental conditions. For a proper design of the mechanical grippers, the coupling forces acting on them should be accurately estimated. Additionally, the relative motions between the pre-assembled wind turbine and the spar foundation should be limited in order to connect them.

This study presents the numerical modelling and results of the catamaran-spar system with a focus on the dynamic behaviour of

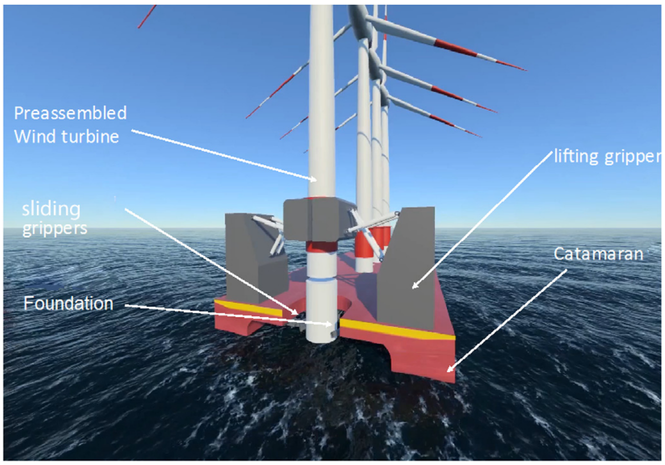

Fig. 1. Overview of the catamaran concept during installation of a floating wind turbine.