Coupled analysis of an offshore monopile wind turbine subjected to wind and waves

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ABSTRACT

In this paper, an offshore wind turbine installed on a monopile foundation is studied while taking into consideration the flexibility of the supporting structure. Both wind and waves are simulated in OpenFOAM to obtain the environmental loadings applied to the offshore structure. The response of the offshore wind turbine is solved in MBDyn by modelling the flexible supporting structure using beam elements. Research shows that the wave height has great influence on the hydrodynamic force of the offshore wind turbine, and the flexible foundation motion can also greatly affect wind turbine aerodynamics.

KEY WORDS: Offshore wind turbine; flexible foundation; coupled analysis; CFD.

INTRODUCTION

The offshore wind industry is moving towards larger turbines in order to save costs on installation and maintenance. The increase in rotor size and aerodynamic loads requires increasingly large support structures. For monopile wind turbine foundations (which support roughly 80% of the offshore wind turbines in Europe), this corresponds to an increase in diameter and more significant wave loads.

Some researchers have applied coupled CFD and beam codes to investigate wind turbine FSI. As a wind turbine consists of both rigid components, like hub and nacelle, and flexible parts, such as blades and tower, one common approach is to construct a multibody dynamics (MBD) system where a number of bodies, either rigid or flexible, are interconnected via kinematic constraints, while modelling flexible bodies as beams (Li et al., 2015). Currently, these studies are limited to fixed-bottom wind turbines without considering supporting structure motions. On the other hand, impacts of supporting structure motions induced by waves and current on wind turbine aerodynamics have been investigated extensively using CFD methods either by imposing prescribed periodic motions to wind turbines or via performing fully coupled aero-hydrodynamic analysis (Leble et al., 2016). These CFD studies demonstrated that supporting structure motions greatly affected wind turbine aerodynamics as well as its wake.

In recent years, numerical investigations of coupled analysis of the offshore monopile wind turbine have also been carried out by some researchers using Computational Fluid Dynamics (CFD) methods, which are able to provide detailed visualisation of flow field and thus help improve the understanding of the interaction between fluid flow and supporting structures. Ma (2017) presents a three-dimensional finite element model for analyzing the long-term performance of offshore wind turbines on large-diameter monopiles in sand in a simple way. Nikolaos (2019) conducted a nonlinear Finite Element (FE) analysis, and showed that increased number of shear keys are advantageous for stiffness and reduce the gap at the interfaces, whereas the grout failure depends on the spacing between neighbouring shear keys. Erin (2019) compared the experimental results with a numerical model using beam elements and Morison-type wave loads with second order wave kinematics. Simone (2017) applied the 3D finite element (FE) modelling to the dynamic analysis of OWTs (offshore wind turbines). Ramtin (2018) investigated the effects of the wind turbine operation, environmental loads, and variable damping levels on the fatigue life. The fatigue life increased significantly as a result of reductions in the bending stress caused by increased damping.

In the present study, the NREL 5-MW turbine (Jonkman et al., 2011) is investigated, which is supported by a monopile. The monopile and the turbine tower are modelled as elastic bodies, and the blades are assumed to be rigid. A coupled fluid-structure interaction (FSI) analysis tool (Liu et al., 2019a; Liu et al., 2019b) previously developed for offshore wind turbines is adopted, which integrates an open source computational fluid dynamics (CFD) toolbox OpenFOAM with an open source multibody dynamics (MBD) code MBDyn. Both wind and waves are simulated in OpenFOAM to obtain the environmental loadings applied to the offshore structure.

NUMERICAL METHODS

Fluid Solver

The interaction between supporting structures and wave could be seen as