OpenFOAM Modelling the Equilibrium and Free-decay Tests of a Semi-submersible FOWT Model

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ABSTRACT

This work forms a part of the contribution to the ”1st FOWT comparative study” for modelling floating offshore wind turbine (FOWT) hydrodynamics based on the wave tank tests of a 1:70 scaled moored VolturnUS semi-submersible floater model. Two tests of test cases have been simulated - one is a static equilibrium test and the other is the heave decay test to determine the natural frequencies of the coupled floater-mooring system. The numerical modelling is carried out in a numerical wave tank using high-fidelity computational fluid dynamics based on the OpenFOAM toolbox and the results are generally in good agreement with the experimental measurements. In addition, it was found that the mooring lines have a significant influence on the pitch natural frequencies of the coupled system but their impact on the heave natural frequencies was minimal.

KEY WORDS: OpenFOAM; Finite volume method; Floating offshore wind turbines; VolturnUS semi-submersible floater; 1st FOWT comparative study.

INTRODUCTION

Numerical tools have been widely adopted for predicting the hydrodynamic responses of floating offshore wind turbines (FOWTs) (Cheng et al. (2019); Otter et al. (2022)). Generally, the mid-fidelity potential flow method and high-fidelity Computational Fluid Dynamics (CFD) method are the most commonly used approaches for FOWTs analysis (Zhou et al. (2021); Wang et al. (2020)). However, the potential flow models would underestimate the responses of semi-submersible FOWTs under certain wave conditions (Wang et al. (2021)). On the other hand, the CFD models would allow us to solve the fluid flow governing equations directly, i.e., Navier-Stokes equations, and produce the required flow quantities in both the time and spatial domains so that the transient hydrodynamic loading on the FOWTs, can all be well resolved, including the effects from the extreme waves, fluid viscosity and wave-current interactions.

The Offshore Code Comparison, Collaboration, Continued, with Correlation (OC5) project led by National Renewable Energy Laboratory (NREL) validated and verified a wide range of mid-fidelity engineering-level models by using experimental data (AN Robertson et al. (2017)). However, it was shown that those mid-fidelity tools significantly underestimated the second-order difference-frequency hydrodynamic loads. This deficiency was mainly due to their limitations in capturing all the nonlinearities and viscous damping effects as demonstrated in the Offshore Code Comparison Collaboration, Continued, with Correlation, and Uncertainty (OC6) project (Wang et al. (2021)). In the OC6 project, work has also been conducted through a series of validation studies by using high-fidelity CFD models with tank test results. The outcome of the project showed that CFD models are able to provide more accurate results at low-frequency nonlinear excitation.

Considering all three types (spar, TLP, and semi-submersible) of FOWTs substructures, the semi-submersible platforms have recently received significant attention for its relatively shallow draft that improves site flexibility and installation cost-effectiveness. In 2020, a new semi-submersible platform named VolturnUS was designed and developed by the University of Maine (Allen et al. (2020)). The platform can accommodate an Energy Agency (IEA) 15 MW wind turbine and has been designed with sustainability and cost-effectiveness in mind. As shown in Figure 1, compared with the widely used and well studied OC4 DeepCWind semi-submersible platform (A Robertson et al. (2014)), which is made up of three offset columns with large heave plate bases, with one centre column used to support the wind turbine and several connecting braces which act together to stabilise the floater, the VolturnUS platform has a simpler structure, with a floating hull that is partially submerged and a wind turbine tower and blades positioned at its centre above the water surface. This design would reduce the effects of wave motion on the support structure and wind loads on the turbine, making it possible to install large turbines in deeper waters.

In the present work, which forms a contribution to the ”1st FOWT comparative study” (Ransley et al. (2022)) at ISOPE 23 organised by the Engineering and Physical Science Research Council (EPSRC, UK) funded project titled 'Extreme Loading on FOWT under Complex