A Coupled RANS-VOF and Actuator Disk Model for Floating Offshore Wind Turbines
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ABSTRACT

Floating offshore wind turbines (FOWTs) may offer a solution to exploit resources at deep-water sites, but there are still many design challenges to overcome. Numerical modelling enables developers to explore these challenges with reduced risk. However, available tools typically simplify critical hydrodynamic interactions and so, here, a model, including high-fidelity hydrodynamic simulation, is presented and compared against existing solutions to two IEA OC4 load cases, which use lower-fidelity approaches. Two mooring models are investigated: a quasi-static approach that predicts a near-sinusoidal response in phase with the surge motion; and a dynamic approach which predicts considerable nonlinearity and a phase shift.

KEY WORDS: FOWT; CFD; OpenFOAM; Moody; IEA Wind OC4; numerical wave tank (NWT); dynamic mooring model.

INTRODUCTION

In many places around the world, offshore wind has been proven to be a successful option in the transition towards renewable energy sources. As the move towards net zero greenhouse gas emissions intensifies, there is considerable focus on the exploitation of offshore wind resources in locations where the water depth exceeds that in which traditional monopile foundations are appropriate. Floating offshore wind turbines (FOWTs) represent one solution, to the realisation of deep-water offshore wind, and have received significant attention from developers over the last ten years or so. Despite this, technology convergence of FOWT design concepts has not yet been achieved and considerable uncertainties and design challenges remain.

As is commonplace in offshore engineering, numerical modelling represents an invaluable part of the research, design and development (RD&D) process; however, the system complexity of a FOWT concept represents a significant challenge for numerical modelling tools, particularly those high-fidelity methods attempting to predict the highly nonlinear phenomena associated with extreme wind, wave and current interaction with the structure. Furthermore, in the case of FOWTs, high-fidelity numerical models that resolve both the aerodynamic flow around the wind turbine blades and the hydrodynamic flow around the floating platform require excessive computational resources to produce a solution; this limits the practical use of these methods by industry, who tend to favour lower-fidelity design tools that have shorter execution times (at the expense of potential improvements in accuracy). Recent work, looking at the effective numerical modelling of FOWTs, found that there was notable uncertainty in the nonlinear wave forces and viscous loading on FOWT platforms, when predicted by mid-to-low fidelity ‘engineering tools’, and that these loads are important in accurately predicting the excitation of natural frequencies outside the wave-excitation region (Robertson et al. 2017). Furthermore, the mooring load, in catenary-moored FOWT systems, is shown to differ greatly depending on the use of quasi-static or dynamic mooring models (Robertson et al. 2014b) and the latter is required to capture the ultimate and fatigue loads in the lines (Robertson et al. 2017).

Therefore, in this work, a two-phase Reynolds-averaged Navier-Stokes (RANS), and volume of fluid (VOF), solver is coupled with an actuator-theory-based wind turbine emulator and dynamic mooring model. This offers a more efficient (compared to ‘blade-resolved’ models), model capable of predicting the fully nonlinear, viscous, hydrodynamic loads and aero-hydro response of FOWT and mooring coupled systems but with simplified rotor aerodynamics, i.e. steady momentum theory (no unsteady/dynamic behaviour or 3D effects are included and the force distribution is considered to be uniform and axisymmetric).

The model is used to simulate a pair of load cases from Phase II of the Offshore Code Comparison Collaboration, Continuation (OC4) project developed under the International Energy Agency (IEA) Wind Task 30 (Robertson et al. 2014b). Each case is simulated using both a quasi-static mooring model (Bruinsma et al. 2018) and the dynamic mooring library, Moody (Palm 2017; Palm et al. 2017). The results are compared with each other and with published results, for the same cases, generated using simulation tools with lower-fidelity hydrodynamic solvers, e.g. codes based on linear (or weakly nonlinear) potential flow theory.