A High-order Spectral Element based Time-Domain Simulation of a Model-Scale Floating Offshore Wind Turbine

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ABSTRACT

This paper describes a new high-order composite numerical model designed for the efficient arbitrary-scale simulation of moored floating offshore bodies. The study focuses on static equilibrium and free decay of such structures, particularly a floating offshore wind turbine. The composite scheme models the linear or weakly-nonlinear motion in the time domain by solving the Cummins equations derived from Newton’s 2nd law of motion. The mooring forces are acquired from a discontinuous Galerkin spectral element solver. The linear pseudo-impulsive radiation problems are modeled via a three-dimensional spectral element-based solver on an unstructured hybrid-configured mesh, ultimately providing accurate frequency-dependent added mass and damping coefficients. In this work, a numerical simulation of a moored model-scale floating offshore wind turbine is performed and compared with experimental measurements. The numerical experiments agree with the measurements and demonstrate that the model can be used for full-scale computations relevant to offshore engineering applications.

KEY WORDS: Spectral element method; high-order numerical scheme; wave-body interactions; 1st FOWT Comparative Study; water waves; marine hydrodynamics.

INTRODUCTION

Over the past decades, the importance and need for sustainable, renewable, and reliable energy resources has increased rapidly to cope with the climate crisis, and also – as seen recently – in response to political interest. Year by year, more ambitious targets are set to reduce net greenhouse gas emissions, where the current goal of the European Union is to cut the emissions by at least 55% (compared with 1990 levels) by 2030 and be completely neutral by 2050, European Commission (2022). The energy sector is indisputably the major contributor to this carbonation of the atmosphere and hereby, a key component towards a green energy transition.

In the quest to keep up with this desire, the offshore industry can be seen to play a principal role by having e.g., wind turbines, wave energy converters, dams, and so on, produce green non-fossil energy for society. Regarding wind turbines, a bottom-fixed installation technique is the most well-known approach, yielding requirements on the water depth, soil mechanics, scour protection, and much more. Another promising installation approach is to mount the wind turbines on floating offshore structures, which will allow for the establishment of floating offshore wind turbines (FOWT) farms in much greater depths and expand the energy potential of offshore wind.

Developing and maturing such floating offshore structures relies heavily on testing, traditionally done by considering full-scale prototypes in real-life environments or scaled models in large wave flumes. These types of experiments can often be cumbersome, i.e., time-consuming and expensive to carry out. With the rapidly increasing power of computational resources, numerical modeling is becoming increasingly attractive as a cost-efficient rational means to evaluate and refine practical design features quickly.

The choice of a mathematical model ranges in complexity and computational demand, with the Navier-Stokes equations as the most precise – yet most expensive – one. At the other end of the spectrum, potential flow (PF) models – both nonlinear and linear – rely on the assumptions of an irrotational, inviscid, and incompressible fluid flow. For a recent review of the modeling of floating wave energy converters, consult Davidson and Costello (2020), which highlights promising numerical approaches. Narrowing the scope to numerical methods for solving wave-structure interaction in the linear PF setting. This has been done using various numerical methods. To highlight a few: The boundary element method (BEM), see Korsmeyer (1988) for a zero-speed impulsive problem and consider Lee and Newman (2006) for the state-of-the-art frequency-domain-based commercial software WAMIT.