Hydrodynamics meet wind turbines: specification and development of a simulation tool for floating wind turbines with Modelica

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ABSTRACT

The research presented in this paper aims at improving hydrodynamics modelling for floating offshore wind turbines, as part of a broader effort to develop a fast, modern, more flexible aero-hydro-servo-elastic simulation tool utilizing state-of-the-art modelling software.

A review of floater concepts proposed in recent years leads to the definition of a set of requirements and specifications for a novel hydrodynamics simulation module within the aforementioned tool, including wave and load models and validation.

An outline of the entire dynamic simulation tool is presented, which takes advantage of prospects offered by the modelling language Modelica, developed specifically to model large, heterogeneous, complex physical systems.

As a first implementation step, the development and validation of the wave kinematics module are detailed together with a benchmark against existing tools.

Further optimisation and integration steps are discussed, followed by an outlook on future developments.

KEYWORDS

floating wind turbine; hydrodynamics; simulation; modeling; Modelica

INTRODUCTION

Floating offshore wind turbines represent both a great hope for renewable energies due to the great wind energy potential available offshore in deep water areas, and a significant challenge for engineers and scientists. Compared to their oil and gas siblings, those offshore structures are subjected to a remarkably high wind thrust on the rotor, itself located together with the 400+ tons nacelle some 90 m above the still water level, resulting in a comparatively high overturning moment as well as aeroelastic and gyroscopic effects. Due to the stochastic nature of wind and wave loads, combined with turbine dynamics inducing high numbers of variable amplitude load cycles (10⁹), fatigue is an important design driver. The 60+ m long flexible rotor blades and complex controls lead to non-linear dynamic behaviour in the electro-mechanical system. Furthermore, the lower profitability of offshore wind energy projects compared to oil and gas projects puts more pressure on engineers to design light, less-conservative structures subject to high dynamic loads and ensure easy maintenance.

Modelling of the dynamic behaviour of wind turbines together with their support structures plays a key role by allowing resonance prediction in the general design phase and by providing load levels and patterns for the detailed design of single components. The challenge of simulating simultaneously aerodynamic and wave loads, drive-train dynamics, generator and grid response, soil-pile interaction and control systems has already been tackled for offshore wind turbines on bottom-mounted support structures by means of software systems combining physical models with numerical analysis methods. For the design of floating wind turbines, those simulation tools must be extended to account for wave-structure interaction in more detail.

Typical hydrodynamic and structural models developed and validated over the years for offshore oil and gas need fail to account for critical issues related to the particular nature of wind turbines and notably to non-linearities which require time-domain analysis methods, while the aforementioned models usually apply in the frequency domain.

Moving away from the typical approach consisting in stitching together available offshore hydrodynamics and wind turbine dynamics simulation tools, a new take on applied hydrodynamics for offshore wind turbines is proposed with the development of an in-house simulation code taking advantage of state-of-the-art software development tools.