On the Verification of a new Mid-fidelity Simulation Tool for Large Offshore Wind Turbines

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ABSTRACT

Offshore wind energy is expected to play a major role in the future energy supply given the recognized need to reduce the carbon emissions [1]. To be able to fulfil this potential, wind turbines have steadily grown in size over the past years and will continue to do so: future wind turbines will likely have diameters of up to 400 m and a rated power of more than 20 MW [2]. These new wind turbines will consist of large, slender structures which are more prone to large deformations than current generations of wind turbines [3]. Additionally, they will be subject to yet unknown loads, as they will reach further into the atmospheric boundary layer [4]. Nonlinear dynamic phenomena become more dominant and the interactions between the different components of the wind turbine as well as with their environment have to be considered in more detail.

Due to these factors, currently used simulation methods relying on low-fidelity methods such as Blade Element Momentum Theory and linear beam theories might not be sufficient to realistically approximate the behaviour of such large wind turbines [5]. High-fidelity methods like computational fluid dynamics or full three-dimensional finite element analysis are however too computationally expensive to be employed during the design process [3]. Instead, mid-fidelity methods seem to present an attractive compromise between computational effort and accuracy.

Therefore, we are developing a mid-fidelity nonlinear aeroelastic approach, which combines the unsteady vortex-lattice method (UVLM) and a flexible multi-body system/finite elements approach. The structural model consists of rigid bodies, geometrically exact beams and holonomic and non-holonomic constraints [6], [7]. The aerodynamic forces are computed using the UVLM, which is a well-established tool to compute the three-dimensional vortex dominated flow of an ideal fluid around lifting as well as non-lifting surfaces [8]. The nonlinear structural and aerodynamic equations are coupled strongly using an approach based on the principle of virtual work. The hydrodynamic forces acting on the sub-structure are computed using the well-known approach based on the Morison equation [9]. As controller serves the publicly available ROSCO controller [10].

In this work, we verify our tool by comparing the results of aero-hydro-servo-elastic simulations using our tool with results obtained by OpenFAST [11], one of the current standard tools. We compare the displacements and stress resultants at different locations in the wind turbine for different load cases, both regarding the aero- and hydrodynamic loads. By investigating wind turbines of different sizes, e.g., the NREL 5 MW reference wind turbine [12] with rotor blades of length 61.5 m as well as the NREL 15 MW turbine [5] with large slender blades of length 117 m, it can be shown that for larger wind turbines geometrical nonlinearities become more relevant for the dynamic behaviour of the complete wind turbine and thus a nonlinear model is required.

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