Modelling of the soil-structure interaction for large offshore wind turbines in a new finite element simulation framework

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ABSTRACT

The increasing demand for clean energy has led to the development of very large wind turbines. Consequently, the dimensions of the whole structure increase and thus its sensitivity to large structural deformations becomes more relevant. The demand for a simulation tool analysing and designing those wind turbines requires a robust nonlinear structural model which allows to consider large displacements and large rotations in long-time simulations without suffering from numerical errors due to an inaccurate representation of physical quantities like objectivity and path independence as well as conservation of invariants.

Existing simulation tools, e.g., FAST [1]. Bladed [2] or HAWC2 [3] use multi-body approaches with finite elements and rigid bodies based on geometrically linear or slightly nonlinear theories. However, these theories are not suitable for analysing higher-order geometrically nonlinear effects that occur in large and slender wind turbines. Maintaining objectivity, path independence and preserving invariants is crucial to avoid cumulative errors in robust nonlinear dynamic calculations, especially simulating long-term periods, as it is necessary for offshore wind turbine design.

The newly developed aero-hydro-servo-elastic simulation framework, DeSiO, consists of a robust nonlinear multibody system finite element scheme in the total Lagrangian description, considering director-based kinematics [4] to present geometrically exact kinematics. In order to ensure the conservation of energy and to preserve linear and angular momentum, we apply a conservative and dissipative time integration scheme developed by Gebhardt et al. [5]. The geometrically exact beam elements are used to model the tower and the slender blades. Rigid components, like hub and nacelle, are idealized by rigid bodies.

In the present work, the soil-structure interaction is presented, which is modelled by means of consistent objective spring-, mass- and damping elements. Considering two finite element nodes, a relative displacement generates elastic forces. Accordingly, relative velocity causes damping forces and relative accelerations cause inertia forces. To match realistic damping properties, we parameterise the dissipation function given in [6]. The main innovation is consistently maintaining objectivity, following the philosophy of our structural model. On the example of the NREL 15 MW reference offshore wind turbine with a monopile foundation, we show a significant impact on the dynamic behaviour caused by the soil-stiffness, -mass and –damping properties.

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