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Improved Simulation of Wave Loads on Offshore Structures in Integral Design Load Case Simulations

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Abstract

Several wind turbine simulation packages use reduced models for computationally efficient load case simulations of offshore wind turbines. These models capture the global wind turbine behaviour, where the support structure behaviour is expressed using a limited number of eigenmode amplitudes involving the lower frequencies. However, the disregarded higher eigenmodes are significant for the detailed behaviour of support structure members and contribute significantly to the fatigue damage and maximum stresses under extreme loads.

To get detailed member load information, fully integrated simulations can be performed at the expense of the computational efficiency gained by using reduced models. Alternatively, load case simulations may be performed sequentially. This involves water flow load evaluation at a stage where the tower motion is not yet known.

This paper presents a new sequential approach in which the sensitivities of the water flow loads with respect to support structure motion are conveyed to the dynamic simulation stage, and in which the parts of the water flow loads that are disregarded in the reduced model space are recovered in the retrieval run, allowing evaluation of the contribution of these forces to the fatigue damage and maximum stresses.

Application of the new approach confirms that these contributions are significant. Furthermore, the new method is reasonably efficient, requiring about 80% extra calculation time compared to the traditional method.

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Keywords: offshore wind turbine; jacket support structure; integrated wind turbine design; hydro-elastic simulation; Morison equation; Craig Bampton method

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1. Introduction

Finite Element (FE) modelling is commonly used to obtain accurate models of support structures. Typically, these models involve large computational efforts for simulation. This is an issue, considering the increasingly large number of required design load case simulations, as for instance prescribed by the IEC standard for offshore wind turbines [1]. To mitigate this, state-of-the-art integrated wind turbine design software currently makes use of model reduction methods. With these methods, a small, effective support structure model is obtained, which is suitable for the time-dependent aero- and hydro-elastic analysis of a wind turbine and support structure system in an efficient manner. Verification of simulation results in previous benchmark projects (e.g. [2]) has shown that global turbine response is simulated satisfactorily.

However, analysis of data from research projects showed that higher-order modes which involve significant local deflection can be observed, e.g. in out-of-plane moments in the bracing system (see e.g. [3], [4], [5]). This indicates that the wave and current loading on the individual members of a jacket tower is important, which is not covered by using reduced-system solutions. For an optimal integrated design solution, the modelling of the local effects of wave and current loading in integrated design tools needs to improved.

There are several methods to achieve this improvement [5]. Load case simulations may be performed coupling the wind turbine simulation software and the support structure simulation software to obtain fully integrated solutions. This partly eliminates the computational efficiency gained by using reduced models. Alternatively, load case simulations may be performed sequentially: First, a reduced support structure model and corresponding wave loads are generated, then this data is used to perform the wind turbine simulation and obtain the wind turbine loads on the support structure, and finally, a “retrieval run” is performed to obtain member forces. The wave loads are evaluated beforehand, neglecting the contribution of the tower motion to the relative flow velocities. Furthermore, the wind turbine behaviour is characterized by the time histories of the displacements or the loads at the interface node.

The method discussed in the present paper achieves to include most of the relative part of the flow velocities, and expresses the behaviour of the support structure in the time histories of the interface node displacement as well as the involved amplitudes of the internal modes of the support structure. Furthermore, the “retrieval run” then also corrects for the flow loads omitted in the reduced–system simulation.

The method has been applied to a model of the XEMC Darwind XD115 wind turbine, and significantly larger loads are obtained as expected, at limited computational cost.

2. Method

For the simulation of the wind turbine behaviour, WMC’s aeroelastic code ‘PHATAS’ is used. It uses a Craig Bampton [6] model for the support structure, and consequently operates in the reduced modal space. For monopiles, PHATAS can calculate the Craig Bampton model. For more complex structures WMC’s finite element code ‘wmc_fem‘ is used to generate the Craig Bampton model. The support structure loads are also evaluated in modal coordinates by the FE code, as it knows the 3D geometry of the support structure. After the Craig Bampton model and the loads are generated, PHATAS performs the simulation.

This leads to two issues that are addressed in this paper. First, the water flow load evaluation cannot be done completely by the FE code since it involves the structural geometry, water flow and tower motion, and the tower motion is not known to the FE code. In section 2.1, sensitivities of the modal loads to the tower motion are derived to infer the tower motion in the simulation.

The second issue is that the simulation program operates in a reduced modal space, involving only the first few modes that are considered significant for the global behaviour. Load components corresponding to the remaining modes are ignored in the simulation. In section 2.2, these so-called surplus loads are discussed.

Section 2.3 briefly touches post processing, where wmc_fem combines the time series of the modal amplitudes generated by PHATAS with the time series of the surplus loads to evaluate the desired response quantities.