Integrated structural optimisation of offshore wind turbine support structures based on finite element analysis and genetic algorithm

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HIGHLIGHTS
- Combination of FEA and GA provides effective design optimisation of RES components.
- The proposed model achieves mass reduction of the support structure by 19.8%.
- The optimised geometry is more sophisticated than the initial one.
- Fatigue and natural frequency are the main design drivers.

ABSTRACT
By accounting for almost 25% of the capital cost of an OWT (offshore wind turbine), optimisation of support structures provides an efficient way to reduce the currently high cost of offshore wind energy. In this paper, a structural optimisation model for OWT support structures has been developed based on a coupled parametric FEA (Finite Element Analysis) and GA (Genetic Algorithm), minimising the mass of the support structure under multi-criteria constraints. Contrary to existing optimisation models for OWT support structures, the proposed model is an integrated structural optimisation model, which optimises the components of the support structure (i.e. tower, transition piece, grout and monopile) simultaneously. The outer diameters and section thicknesses along the support structure are chosen as design variables. A set of constraints based on multi-criteria design assessment is applied according to standard requirements, which includes vibration, stress, deformation, buckling, fatigue and design variable constraints. The model has been applied to the NREL (National Renewable Energy Laboratory) 5 MW OWT on an OC3 (Offshore Code Comparison Collaboration) monopile. The results of the application of the integrated optimisation methodology show a 19.8% reduction in the global mass of the support structure while satisfying all the design constraints. It is demonstrated that the proposed structural optimisation model is capable of effectively and accurately determining the optimal design of OWT support structures, which significantly improves their design efficiency.

1. Introduction
Since its early development in the 1980s, wind energy has experienced an unprecedented development with more than 1500% increase in global wind power installation over the last 15 years, reaching a total installed capacity of 432 GW at the end of 2015 [1]. It is considered to be one of the key contributors to satisfying continuous, increasing energy demand and targets for reduced environmental emissions. Given the increasing trend of rotor sizes [2], and since OWTs (offshore wind turbines) benefit from the larger available space, higher wind shear and less variability on market price [3], considerable investments are being deployed in deeper sites located further from shore [4], sharing experience from onshore wind turbines and offshore technologies [5]. Studies have shown that offshore wind could contribute to around 5.5% of the world’s electricity by 2050 [6].

Different types of support structures for OWTs exist, as illustrated in Fig. 1. The choice of types of support structure depends on multiple criteria, such as water depth, seabed conditions and financial constraints [7–11]. Monopiles (see Fig. 1b) are currently the most common foundation concept, representing 80.1% of total EU’s installations in 2015 [12]. Preferred by industry for their simple and robust design, monopiles have been installed in water depths ranging from 5 m to 30 m. For deeper site locations, monopiles tend to become practically constrained and economically
A structural optimisation model of OWT support structures requires two main components, i.e. (1) a structural model which describes the structural behaviour of support structures; and (2) an optimisation algorithm which finds the optimal set of design variable(s), with regard to the objective function(s) and constraint(s).

Structural models used for OWT support structures can be roughly categorised into two groups, i.e. 1D (one-dimensional) beam models and 3D (three-dimensional) FEA (finite element analysis) models. A 1D beam model discretises the support structure into a series of elastic Euler or Timoshenko beam elements. Due to its computational efficiency and acceptable accuracy to model global structural dynamics behaviour, the beam model has been widely used in commercial codes (e.g. GH-Bladed [16]) to model OWT support structures. Although efficient, the beam model fails to represent accurately structural responses, such as stress concen-
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