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Fully integrated load analysis included in the structural reliability assessment of a monopile supported offshore wind turbine

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Abstract

The present work investigates where cost reductions in the support structure are possible while keeping a sound and safe design. A probabilistic design tool is presented, which involves a coupling between reliability analysis and wind turbine simulation tools. A proof of principle of the proposed tool is given in a case study considering a 4 MW reference wind turbine and a limited lumped load set. The assumptions made in this case study are presented and the results show the reliability index is higher than recommended by DNV. The main contributors to the variance of the fatigue limit state function are the Miner's rule uncertainty and *log(C2)* parameter in the SN-curve.

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Keywords: Structural Reliability; Linear-Hydro-Aero-Elastic Load Analysis; Monopile; Offshore Wind Turbine.

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Nomenclature

c Weibull scale parameter
C_D Drag coefficient
C_D Moment coefficient
C1 First slope parameter of the SN-curve
C2 Second slope parameter of the SN-curve
D Cumulative damage
E Young's modulus
g Limit state function
H_S Significant wave height
k Weibull shape parameter
p_F Failure probability
T_P Wave peak period
u Wind speed
β Reliability index
γ Peak shape parameter of Jonswap wave spectrum
Δ Uncertainty on Miner's rule
μ Mean value
σ Standard deviation

1. Introduction

Reduction of the levelized cost of energy will push a wide deployment of offshore wind energy. Probabilistic design methods can be used to determine the optimal support structure design and minimize the costs. The use of reliability analysis for wind turbine design is widely applied in literature [1] and the international certification body DNV GL provides reference values specific to offshore applications [2]. The reliability analysis can be done for both known and new designs.

Monopile designs are governed by fatigue loads with main contributions from wind and wave excitation [3]. Hence fatigue load estimates are of high interest for a design optimization of offshore support structures. Several authors provided literature studies considering different approaches to the probabilistic design. Márquez-Domnguez and Sørensen [4] provided reliability-based probabilistic models developed partially based on experience from offshore oil & gas structures. Their results show that the Fatigue design factors (FDF) highly depend on the level of uncertainty of the assessment of the loads and the stress concentration factors and in general should be increased compared to the values currently recommended in standards. Sørensen [5] describes statistics and methods for reliability assessment of electrical and mechanical components. In his paper, two examples with uncertainty modeling, reliability assessment and calibration of partial safety factors for structural components exposed to fatigue and extreme loads are presented. It is seen that the required partial safety factor highly depends on the coefficient of variation for the fatigue load. Finally, Ziegler [6] in her M.Sc. thesis developed and verified a probabilistic fatigue load estimation method based on frequency domain analysis to calculate wave-induced fatigue loads while the wind loads are added separately using a scaling approach from a reference case. The developed method is applied for an exemplary wind farm of 150 turbines in 30-40 m water depth. Results for the exemplary wind farm show a design load reduction of up to 13% compared to standardized design.

For a generic reliability analysis, the aeroelastic load calculations should be incorporated in the analysis. In the present work, the reliability analysis is performed by coupling an aeroelastic simulation tool with a reliability tool. The adopted simulation tool is TURBU [7,8], a fast fully integrated wind turbine design and analysis tool in the frequency domain. TURBU is coupled with the reliability analysis tool FERUM [9]. FERUM capabilities exploited in the present work are the First Order Reliability Method (FORM) and Second Order Reliability Method (SORM) analyses. The coupled tool is adopted to perform the reliability analysis of a 4 MW reference wind turbine based on