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Damage Assessment of Floating Offshore Wind Turbines Using Response Surface Modeling

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Abstract

Fatigue assessment for floating wind turbines is commonly done through comprehensive simulation studies of integrated time-domain simulations. Procedures which incorporate simplifications of the environmental conditions in order to limit the number of simulations typically lead to more conservative designs. An alternative approach is proposed here based on response surface modeling using Latin Hypercube Sampling and artificial neural networks. The presented method takes into account the statistical characteristics of environmental parameters during the system's life time (resulting in more realistic and accurate damage calculations) while keeping the numerical effort to a minimum. The procedure is exemplified using a hypothetical site presented linked to the H2020 project LIFES50+ site A. The considered system is a concrete semi-submersible on which a 10 MW turbine is mounted. The system is implemented in the simulation tool FAST. The effect of different numbers of samples is analyzed and a final comparison to a conventional procedure is performed. Results indicate a reduction in the predicted value of expected lifetime damage compared to conservative estimates. More research is necessary in determining the quality of the response surface, in order to be able to fully evaluate the performance of the method.

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Keywords: floating offshore wind turbine design; fatigue design; probabilistic design; response surface modeling; latin hypercube sampling

1. Introduction

The site specific design of floating offshore wind turbines (FOWT) requires the target system to endure both ultimate and fatigue limit states (ULS, FLS). While ULS loads represent worst case scenarios that can be described by discrete

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combinations of extreme environmental conditions, the site specific fatigue evaluation is more complex. As part of the work in the H2020 project LIFES50+ efficient procedures are developed in order to understand system behaviour. Because the evaluation of fatigue requires the consideration of all possible events during the system lifetime that contribute to load cycles, an accurate fatigue evaluation is difficult, as there is a large number of environmental loads that act on the highly dynamic system. Environmental conditions that affect fatigue loads of FOWT components (i.e. RNA, tower, substructure and station keeping) are:

- Wind direction, wind speed, turbulence intensity, wind shear
- Wave direction, wave height, wave period
- Wind-wave misalignment, yawed inflow
- Current direction, current speed
- Ice, marine growth, etc.

In addition to the large number of events to be considered, fully coupled, time domain simulations are commonly done for fatigue evaluation in the certification process. This is due to the complex interaction of the environment and the different structural components (including also the controller). Even though existing tools, based on engineering models, are capable of calculating the structural loads on FOWT in an integrated way with feasible simulation time, the sheer number of simulations that would have to be carried out in order to consider all possible events has generally led to application of conservative estimates of the environment.

The similar problem formulation for fixed bottom offshore wind turbines has already produced some simplification procedures for the offshore environment [1], [2]. A conservative approach that was also used in the Design Basis of LIFES50+ is the definition of wave heights in analogy to damage equivalent loads. The detailed approach is described in [3] and applied in this study as reference. Stewart [4] has also looked into simplification methods for two different floating wind concepts, investigating bin reduction methods, probability-based sampling, response surface methods, and genetic programming. The response surface method applied there is based on a linear regression which did not lead to satisfying results. The potential for load case reduction by application of response surface approaches was also shown in [29].

The structural design can also take into account the stochastic nature of the posed design problem, and hence design of experiment approaches (DoE) in combination with response surface modeling techniques for efficient numerical analysis have found their way into the literature of stochastic mechanics [5], [6]. Design of Experiment models were originally developed by Box [7] for efficient performance of physical experiments and aim at the reduction of the necessary evaluations. Hence, they also optimize the information output per evaluation in simulation experiments [8], [9], [10]. More recent developments in response surface modeling also consider more stochastic techniques for efficient space filling such as Latin Hypercube Sampling (LHS), which is applied in this study, see [5], [6].

DoE approaches have been applied for numeric design optimization [6], [11] and have also been proposed in stochastic reliability design (e.g. in combination with first- and second-order reliability methods or FORM/SORM, [5]) and they can also support the identification of the considered systems' response exposed to a stochastic environment, as will be presented in this study. An application of DoE to the full scale validation of state-of-the-art simulation modeling of fatigue loads at the offshore demonstration wind farm Alpha Ventus has been shown in [12].

In the presented study, we will apply DoE and response surface modeling techniques to the fatigue evaluation of FOWT in order to arrive at a more accurate analysis of the fatigue behavior with a feasible number of simulations. The variation of the four environmental conditions wind speed, turbulence intensity, wave height and wave period is taken into account. We focus on the fatigue loads occurring during power production as described in design load case (DLC) 1.2 in [13] or [3].

Nomenclature

ANN	Artificial Neural Network
DEL	Damage equivalent load
DLC	Design load case
FLR	Full load range
FLS	fatigue limit state
FOWT	Floating offshore wind turbine