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Time domain analysis procedures for fatigue assessment of a semi-submersible wind turbine☆

Marit I. Kvittem [a, b, *], Torgeir Moan [b]

[a] NOWITECH, Norwegian University of Science and Technology, Trondheim, Norway
[b] CeSOS, Norwegian University of Science and Technology, Trondheim, Norway

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ABSTRACT

Long term time domain analysis of the nominal stress for fatigue assessment of the tower and platform members of a three-column semi-submersible was performed by fully coupled time domain analyses in Simo-Riflex-AeroDyn. By combining the nominal stress ranges with stress concentration factors, hot spot stresses for fatigue damage calculation can be obtained. The aim of the study was to investigate the necessary simulation duration, number of random realisations and bin sizes for the discretisation of the joint wind and wave distribution. A total of 2316 3-h time domain simulations, were performed.

In mild sea states with wind speeds between 7 and 9 m/s, the tower and pontoon experienced high fatigue damage due to resonance in the first bending frequency of the tower from the tower wake blade passing frequency (3P).

Important fatigue effects seemed to be captured by 1 h simulations, and the sensitivity to number of random realisations was low when running simulations of more than 1 h. Fatigue damage for the tower base converged faster with simulation duration and number of random realisations than it did for the platform members.

Bin sizes of 2 m/s for wind, 1 s for wave periods and 1 m for wave heights seemed to give acceptable estimates of total fatigue damage. It is, however, important that wind speeds that give coinciding 3P and tower resonance are included and that wave periods that give the largest pitch motion are included in the analysis.

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* Corresponding author. NOWITECH, Norwegian University of Science and Technology, Trondheim, Norway.
E-mail address: marit.irene.kvittem@ntnu.no (M.I. Kvittem).

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1. Introduction

Fatigue damage is known to be a problem for bottom fixed offshore wind turbine substructures, and is also expected to be significant to floating wind turbines (FWTs). Adequate fatigue strength should be ensured by design. Wind parks consist of units with similar designs, and are thus vulnerable to "common cause" failures, which means that the economic consequences of poor fatigue design are serious. It is important, therefore, to make good fatigue estimates early in the design process.

Whereas for a wave only case, environmental conditions are taken from a scatter *table* (two variables: wave height and period), environmental conditions for a combined wind and wave case have to be taken from a scatter *block* (three variables: wind speed, wave height and period). This increases the number of combinations of wind and sea states that needs to be included in the fatigue damage assessment significantly compared to an onshore turbine or a traditional offshore structure. Wind- and wave directions and current are additional parameters that further increase the number of load cases.

The equations of motion for a wind turbine on a compliant sub-structure has many non-linear contributions: Catenary mooring line forces, viscous and aerodynamic forces and large displacements that require the loads to be calculated at the updated position. Due to these non-linearities the wind and wave loads on the structure can not be treated separately, which means that all combinations of wind and wave loads must be analysed individually. Analysis of a non-linear system must also be performed in the time-domain, which is much more computationally time consuming than in the frequency domain.

Another issue is the discrepancy between guidelines for onshore wind turbines and for floating platforms when it comes to simulation length requirements. Due to the long natural periods of a compliant floating platform, it is often necessary to simulate from 3 to 6 h to capture slowly varying response to wave and wind loads. This is emphasized in the new offshore standard for floating wind turbines from DNV [1]. Fixed wind turbines have higher natural frequencies, and the slowly varying response will be static, thus the normal simulation time for wind turbines is 10 min. It is also common practice to assume 10 min stationary wind in wind statistics, whereas it is 1–6 h for waves. Karimirad and Moan [2] found that a minimum of 3 h simulations were needed to capture extreme bending moments for a 5 MW spar turbine, unless proper extrapolation was used. However, extreme values relate to the ultimate limit state, and do not normally contribute to fatigue due to the high return period.

In summary, all of these factors lead to a large number of environmental conditions that need to be simulated in the time domain for one to 6 h. Also, to account for statistical uncertainty, a number of different realisations of the wind and wave histories must be included in the fatigue assessment. This requires unrealistic amounts of computing capacity and time in the design phase, and is the motivation for studying the parameters that make the execution time so long.

A recent paper by Haid et al. [3] studied the effect of simulation length on fatigue and ultimate loads for the OC3 spar buoy wind turbine, and concluded that the fatigue damage in the tower, blades and mooring system was more sensitive to the treatment of residuals in rainflow cycle counting than to simulation length. This work was done using the non-linear aero-hydro-servo-elastic tool FAST.

Earlier work by the authors [4], analyses applying the simplified aerodynamics model TDHmill in combination with Simo-Riflex indicated that 6–7 realisations of 1-h wind and wave histories will give a fatigue estimate close to the damage based on the average of 10 3-h realisations. This was, however, based on a limited number of environmental conditions.

The current study aims at assessing simulation requirements for fatigue damage estimation, and the key questions are:

- How many realisations are needed to capture the effect of statistical uncertainty?
- What simulation duration is necessary to capture the important effects of slowly varying loads?
- What is the maximum bin size for the discretisation of the joint wind and wave distribution?

Fatigue for a three column, catenary moored semi-submersible with the NREL 5 MW [5] supported by the OC3 tower [6] (see Fig. 1) was examined. The single semi-submersible wind turbine (SSWT) was