Geophysical Research Abstracts
Vol. 21, EGU2019-14419, 2019
EGU General Assembly 2019

Assessing offshore wind turbine risk using advanced simulation and machine learning

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Offshore wind turbines (OWTs) are unique engineering structures which are exposed to highly stochastic wind and wave loading conditions. These include extreme events, such as severe typhoons in Asia, hurricanes in the USA, and extra-tropical cyclones (windstorms) in Europe. OWT structures must withstand these loading conditions and protect the electrical/mechanical equipment (including an expensive gearbox and transformer) upon which the production of electricity depends. Failure of any of the primary structural components implies both complete loss of the OWT and loss of earnings associated with production stoppage (i.e. business interruption).

In this study, we first propose the use of a catastrophe (CAT) risk modelling approach to evaluate the structural risk posed by various metocean conditions to OWTs. Specifically, we investigate two commonly used performance objectives (or limit states) for OWT structures using a CAT modelling risk framework: 1) the ultimate limit state (ULS), assessing the collapse of the OWT in the case of extreme metocean conditions, such as a hurricane; and 2) the fatigue limit state (FLS), addressing the cumulative effects of cyclic loading, i.e. cracks that grow over the life of the structure until they threaten its integrity.

In particular, evaluation of the FLS is computationally demanding as it requires the assessment of a large number of loading conditions. Within this calculation, estimation of hazard is complex – requiring definition of multivariate distributions fit to large datasets of historical site-specific measurements. Furthermore, it is essential to account for uncertainties in the OWT structural capacity (e.g., material properties, geometry) as these have a large influence on the estimated fatigue life.

In this study a novel machine learning technique based on Gaussian Process Regression is used to evaluate the FLS in a computationally efficient manner. The proposed framework allows a comparison between the annual loss evaluated for both the ULS and FLS. It also enables these loss estimates to be compared (and combined) with the annual losses expected due to routine repair of equipment within an OWT.

The results from applying the proposed framework to a case-study European offshore wind farm indicate, that, for the relatively calm environmental conditions in the North Sea, the FLS dominates the structural annual loss and FLS is especially relevant when considering the structural and equipment components.