Abstract No.

Wind turbine response characteristics in the wind speed – significant wave height variable space

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Analyzing a wind turbine's structural design involves analyzing fatigue and extreme loads. The design philosophy for extreme loads is based on statistical methods and the concept of reliability: its goal is not to design a structure, which can survive all conceivable environmental extreme conditions, but to design a turbine that has a very low, but non-zero, probability of failure. The design standard IEC 61400-3-1 states that the extreme environmental conditions that are considered for the design load cases (DLCs) during the design process "are intended to produce N-year (N = 1 or 50) return period load effects" (International Electrotechnical Commission, 2019, p. 24).

The standard's DLCs combine extreme values of variables such as wind speed, wave height and ocean current with return periods of 1 and 50 years. There is no fixed connection between the environment and the structural response such that for a given set of environmental conditions one structure might respond with a, say, 40-year response and another structure with a, say, 90-year response. In principal, the true long-term response function could be evaluated using a full probabilistic analysis. However, in such an analysis the response must be evaluated in the complete environmental variable space (wind speed, wind direction, wave height, wave period, wave direction, …) such that, due to the high computational costs, typically, this is considered infeasible in wind turbine design.

Although theory exists that describes when an N-year joint extreme should lead to an N-year response (see, for example, Mackay and Haselsteiner, 2021), currently the standardized combinations of N-year environmental extremes are not related to typical response characteristics of modern wind turbines. Here, we explore the response of an offshore wind turbine in the wind speed – wave height space. For this study, we used the NREL 5 MW reference wind turbine (Jonkman et al., 2009) with a monopile foundation in a water depth of 30 m. Simulations were performed with openFAST. As an example, we analyzed the mudline overturning moment (Figure 1). When the sea is calm and consequently the variable significant wave height is zero, the overturning moment peaks at ca. 17 m/s. At 25 m/s, the turbine switches into parking mode, pitching its blades to reduce loads. Nevertheless, starting at ca. 50 m/s the overturning moment exceeds the peak value that occurred during power production.

Thus, due to the turbine's pitch control, lines of constant overturning moment follow rather complex paths in the wind speed– significant wave height variable space. One of these lines of constant overturning moment equals the turbine's capacity such that possible failure regions do not have linear boundaries and are not convex. Consequently, the assumption of an IFORM environmental contour – the method that is currently recommended in IEC's design standard to define joint extremes – is not met, suggesting that performing simulations with environmental conditions along such a 50-year IFORM contour could cause a response with a return period of less than 50 years. Two other important effects that influence the relationship between the environment's return period and the response's return period are the serial correlation between environmental states and the response's short-term variability.

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Images:
Link: https://s3-eu-west-1.amazonaws.com/static.vcongress.de/cms/forwind/paper/48d25310-6026-4378-98cc-66aacfc33e0e.png
Description: Mudline overturning moment at various wind speeds during calm sea (significant wave height is zero)

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