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Impact of different turbulent models on floating offshore wind turbine loads and motions

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1 Introduction

In the fast-growing interest of floating offshore wind turbines (FOWTs), design standards related to the met-ocean conditions have become a critical aspect to minimize uncertainties in the design of FOWTs. Although up to date, several full-scale offshore wind turbine demo are available for research and product development, software simulations is still considered as a reliable method during the offshore wind turbines design phase. Many rely on software simulations to predict and check the reliability of the operating wind turbine structures, especially those located at offshore. In the absence of wind measurement data, standards are referred to as the simulations input. The widely used standards for offshore wind turbines are the IEC 61400-1 [1] (and 61400-3) as well as DNV-OS-J101. The current available standards do not elaborate a thorough prescription on turbulent wind model suitable for offshore environments, although some recommended turbulent wind models are provided. However, despite the standard recommended wind models were prescribed to have equivalent characteristics, previous studies have suggested that the implementation of standard wind models give a considerable uncertainty in the loads and motions response prediction for a spar FOWT. For this reason, one must select a justifiable wind model for FOWT simulations thoroughly. Our main study focus is to further investigate the distinct characteristics of different wind models and its relation to wind turbine rotor behavior to finally able to recommend suitable wind models for FOWT simulations.

2 Main Finding

In the IEC 61400-1 [1], two turbulent wind models are given: Mann uniform shear model and Kaimal spectra and exponential coherence model. Both models were derived to fit neutral atmospheric stability conditions and have equal spectral energy content of the along wind velocity component (S_u). The distinct characteristic between the two model is that how the spatial coherence of the wind components are defined. Spatial coherence relates the characteristics of turbulent wind at two points separated by a particular distance. Our previous study [2] found that the two models given in the IEC standards resulted in significant difference of yaw-mode loads on a spar wind turbine (up to 70%), which leads to the hypothesis that the wind coherences were the main cause for this difference.

Aside from these standard models, wind models developed from site-specific measurement taking into account various atmospheric stability conditions are also available, namely Højstrup Model [3] and Pointed Blunt [4]. What characterises a specific wind model is the wind spectra and the wind spatial coherence. Both wind spectra and wind spatial coherence are highly influenced by atmospheric stability conditions. Under unstable atmospheric conditions, the eddy size is the largest and therefore have the highest spatial coherence compared to neutral and stable atmospheric stability conditions. Moreover, under unstable atmospheric stability conditions there is an addition of low-frequency energy content in S_u which causes a two-peak wind spectral energy content [3]. The two-peak wind spectra is not applicable for neutral and stable atmospheric conditions, which suggests that unstable conditions have the highest S_u compared to neutral and stable conditions. The question then will be what significance do unstable conditions have on FOWT loads and motions responses. By using Højstrup Wind Model to simulate wind fields under different degree of unstable conditions with constant coherence, it was found that the S_u was proven to increase progressively as the stability conditions move toward more unstable [5]. Secondly, there is an increasing trend in loads and motions of the same spar wind turbine from neutral to very unstable stability conditions, given that a constant wind coherence input was applied [5]. A 60% difference in yaw-mode loads were observed when comparing neutral and very unstable atmospheric stability conditions. In another study [6], a similar simulation setup with this case was set for different degree of unstable conditions using Højstrup Model but paired with stability-adjusted coherences. It was found that the loads and motions response of the spar wind turbine was only slightly affected, where the highest difference is less than 10%. This ratio is relatively small compared to the 70% difference when we compare the two standard models having different wind coherence prescription.

The findings above suggest that both wind spectral energy and wind spatial coherence are equally important in contributing significant difference in loads and motions response of a FOWT. This being said, a gap exist in the conclusion of wind spatial coherence influence on FOWT loads and motions responses. When comparing the two standard models, a significant influence of spatial coherence on the FOWT loads and motions responses is observed, but when comparing a site-specific derived model with stability-adjusted coherences, the influence is less significant.

3 Discussion and Conclusion

Based on our previous finding and current research, we recommend a reliable and representative wind measurement data should be used in the wind turbine design whenever available. One must carefully select proper wind input for FOWT simulations. In the absence of reliable measurement data, the IEC 61400-1 is often used as wind turbine design guideline. The standard models do not account for various atmospheric stability conditions, while wind models developed from a site-specific measurement has the possibility to include atmospheric stability conditions. In the IEC 61400-1 standard, two wind models are recommended for wind turbines design: Kaimal Spectra & Exponential Coherence and Mann Spectral Tensor Model. We observed that the later model in the IEC 61400-1 would give a considerably conservative results than the first model and several site-specific derived wind models. Nonetheless, over-conservatism might also lead to over-design and thus the wind turbine design would not be cost-effective and realistic. We suggest the use of standard models paired with reliable site-specific wind measurement input would give proper prediction of FOWT loads and motions response. Alternatively, site-specific derived wind models with design input from the standards could be also considered for FOWT simulations.

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