Ref. Ares(2023)6618382 - 29/09/2023

D1.4 Recommendations for model-scale testing of FOWTs under large motions

[Version 1.0]

STEP4WIND

Training network in floating wind energy

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 860737.

Document History

Revision Nr	Description	Author	Review	Date
1	First draft	Ricardo Amaral		September 20th 2023
2			Kasper Laugesen	September 21st 2023
3			Axelle Viré	September 21st 2023

Index

1. Overview

The subject of this deliverable diverges from its name because we already had access to the experimental data of the model-scale tests and therefore, it was not necessary to conduct research into how to best perform the experiment and provide recommendations. Hence, this deliverable addresses the next step following the recommendations for model-scale testing which is comparing the results of our simulations with the experimental data. Consequently, this report discusses an experimental and code-to-code comparison of our floating wind turbine simulations under prescribed motion which led to a scientific paper. Many participants including us, simulated a small-scale model of the DTU 10 MW wind turbine in a wind tunnel setup where the turbine was either fixed or moving. Data regarding the wake and the loads experienced by the turbine were later compared to experimental data of the same turbine under the same setups with the ultimate goal being the validation of our simulation tool for floating cases. This paper will shortly be published as an open access journal publication in the "Wind Energy Science" journal under the name "On the characteristics of the wake of a wind turbine undergoing large motions caused by a floating structure: an insight based on experiments and multi-fidelity simulations from the OC6 Phase III Project" [1] with a link: https://wes.copernicus.org/preprints/wes-2023-21/wes-2023-21.pdf. This deliverable provides a general overview of the publication and its conclusions. The reader is directed to the journal publication for further details.

2. Abstract

This study reports the results of the second round of analyses of the OC6 project Phase III. While the first round investigated rotor aerodynamic loading, here focus is given to the wake behavior of a floating wind turbine under large motion. Wind tunnel experimental data from the UNsteady Aerodynamics for FLOating Wind (UNAFLOW) project are compared with the results of simulations provided by participants with methods and codes of different levels of fidelity. The effect of platform motion both on the near and the far wake is investigated. More specifically, the behavior of tip vortices in the near wake is evaluated through multiple metrics, such as streamwise position, core radius, convection velocity, and circulation. Additionally, the onset of velocity oscillations in the far wake is analyzed because this can have a negative effect on stability and loading of downstream rotors. Results in the near wake for unsteady cases confirm that simulations and experiments tend to diverge from the expected linearized quasi-steady behavior when the rotor reduced frequency increases over 0.5. Additionally, differences across the simulations become significant, suggesting that further efforts are required to tune the currently available methodologies in order to correctly evaluate the aerodynamic response of a floating wind turbine in unsteady conditions. Regarding the far wake, it is seen that, in some conditions, numerical methods over-predict the impact of platform motion on the velocity fluctuations. Moreover, results suggest that, different from original expectations about a faster wake recovery in a floating wind turbine, the effect of platform motion on the far wake seems to be limited or even oriented to the generation of a wake less prone to dissipation.

3. Objectives

Focus is given in this study to the turbine wake, whose proper modeling is of paramount importance for future design of floating wind farms. Another aspect of interest is the prediction of the distance at which the wind velocity starts to recover and the understanding of the mechanisms governing the tip vortices behavior which can lead to a better comprehension of the wake dynamics. More specifically, the aim of the study is to provide further insight into the modifications taking place in the near and far wake of a small-scale floating wind turbine under imposed surge and pitch motions by comparing experimental data with simulation results obtained with a range of methodologies by the participants. In the near wake, the objective is to evaluate and quantify the effect of platform motion on the tip vortices by analyzing multiple tip vortex metrics, namely position, core radius and strength. The goal is to evaluate from these results the aerodynamic response of a FOWT under imposed motion. In the far wake, the objective is instead to highlight the effect of platform motion on the wake recovery, as this represents a crucial parameter for wind farm planning. Additionally, the onset of velocity oscillations in the wake can be evaluated and quantified, providing valuable information that could be used to verify the stability and loading of downstream turbines.

4. Conclusions

During the OC6 project, the participants modeled a scaled model of the DTU 10 MW rotor under fixed-bottom, surge, and pitching motion conditions using several numerical approaches with varying levels of fidelity. Simulations were also benchmarked against experimental data obtained during wind tunnel tests by Politecnico di Milano. The present study analyzes in particular the characteristics of the near (i.e., from 0.25D to 0.5D) and mid wake (i.e., from 0.9D to 2.3D) of the rotor, with special focus on the propagation of tip vortices in the near wake. In the fixed-bottom case, all simulation approaches are in good agreement with each other, and results are consistent with experimental data in terms of tip vortex position, convection velocity and vortex strength. Larger differences were observed in terms of core radius for both free-vortex wake (FVW) and computational fluid dynamics (CFD) approaches, which indicates some improvements can still be made in predicting parameters such as the initial core radius. Careful consideration of these parameters should be carried out when analyzing the tip vortices behavior. In CFD actuator-line models (ALM) results, the core radius is overpredicted by all the participants, which underlines a limitation of this approach that could also affect its reliability in wake modeling. For unsteady cases, the effect of platform motion on the tip vortex position and strength was evaluated. In surge cases, simulations showed good agreement when the reduced frequency is less than 0.5, with the results oscillating around the steady-state fixed-bottom value as predicted by the linearized quasi-steady theory. However, results diverge from the expected quasi- steady behavior when the reduced frequency increases. Additionally, the differences across both FVW and CFD approaches increase in those cases, underlining how efforts are probably required to tune the currently available methodologies in order to correctly predict the position and strength of the tip vortices shed from a floating wind turbine under surge motion. Similar conclusions can be drawn when a pitch motion is imposed. Under this condition, however, additional discrepancies between the participants were observed at low frequencies of motion, when the largest tilt angles of the rotor are reached. Additional PIV campaigns are recommended to better understand the evolution of tip vortex strength and position in these conditions. Such a campaign should focus on obtaining measurements at higher reduced frequencies, where wake behavior is yet to be properly characterized. Additionally, the measurements could be performed over multiple cycles of platform motion in order to provide a more reliable description of the wake response. Upon examination of hotwire data, the effect of platform motion on the far wake was further analyzed. Surge and pitch motions induce streamwise velocity oscillations in the wake, which could be problematic for downstream machines, as they could increase rotor loading or affect platform stability. At low frequencies of motion, as is the case for LC 2.1, all simulation methodologies showed good agreement with experimental data and the velocity perturbations in the wake oscillate around the fixed-bottom value. However, in LCs 2.7 and 3.7, where the reduced frequency increases up to 1.2, major differences arise between simulation results and experiments. More in detail, most simulations predict a significant increase in the amplitude of velocity oscillations as distance from the rotor increases, even though this trend is not present in the experimental data. Moreover, the codes do not agree on the predicted magnitude of the velocity oscillations. This result suggests that numerical methods might over-predict the effect of platform motion on the wake. This issue affects all simulation methodologies with varying degrees of severity (up to a factor of three); hence, it does not seem to be connected with a specific approach. A possible cause of the discrepancy between the experimental data and simulations might be unsteadiness (background turbulence and wall effects) in the wind tunnel inflow, which does not allow these instabilities to grow as they do in the simulations. Higher fidelity CFD models, able to comprehensively model inflow turbulence, are one of the key topics for future aerodynamics studies on FOWTs, although their computational cost is still very high. Concerning the wake recovery, both simulations and experiment predict a limited effect of surge motion on the velocity recovery at the analyzed frequencies and amplitudes. Additionally, for a pitch motion of the platform, some simulation methodologies showed a slower recovery of the streamwise velocity, even though no experimental data are available to validate this aspect. Overall, current results suggested that, differently from original expectations about a faster wake recovery, the effect of platform motion on the far wake seems to be very limited or even oriented to the generation of a wake less prone to dissipation.

References:

[1] Cioni, S., Papi, F., Pagamonci, L., Bianchini, A., Ramos-García, N., Pirrung, G., Corniglion, R., Lovera, A., Galván, J., Boisard, R., Fontanella, A., Schito, P., Zasso, A., Belloli, M., Sanvito, A., Persico, G., Zhang, L., Li, Y., Zhou, Y., Mancini, S., Boorsma, K., Amaral, R., Viré, A., Schulz, C. W., Netzband, S., Soto Valle, R., Marten, D., Martín-San-Román, R., Trubat, P., Molins, C., Bergua, R., Branlard, E., Jonkman, J., and Robertson, A.: On the characteristics of the wake of a wind turbine undergoing large motions caused by a floating structure: an insight based on experiments and multi-fidelity simulations from the OC6 Phase III Project, Wind Energ. Sci. Discuss. [preprint], https://doi.org/10.5194/wes-2023-21, in review, 2023.