Two-bladed VS Three-bladed Floating Offshore Wind Turbine Design

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Abstract

The design of floating offshore wind turbine (FOWT) is challenging due to the complex environment they operate, which includes wind, waves and currents. An integrated design ensures that all components of the turbine, such as the rotor, tower, and floating substructure, are harmonized with these environmental factors and the optimal combination is found with the aim of reducing the levelized cost of energy (LCOE).

In this paper, a holistic approach, which considers from the very beginning of the design phase all the main components of the floating wind turbine, is developed and tested on a classical multi-megawatt wind turbine.
This approach includes the rotor and tower sizing together with the floating platform, the catenary mooring lines and the anchors design. Several nested optimization problems include steps involving i) an aerodynamic co-design (i.e. the aerodynamic rotor shape together with the floating sub-substructure), ii) a model-based controller design and iii) a structural sizing of the blade and tower elements, guided by certification-standard load cases together with a re-design of the floating support structure.

The results include a classical multi-megawatt three-bladed rotor wind turbine and an upwind teeter-hinge upwind two-bladed one. This also allows us to consider the effects of the tower frequencies (which may be placed differently with respect to the blade pass frequency) on the floater design.

Introduction

The design of floating offshore wind turbine (FOWT) is challenging due to the complex environment they operate, which includes wind, waves and currents. An integrated design ensures that all components of the turbine, such as the rotor, tower, and floating substructure, are harmonized with these environmental factors and the optimal combination is found with the aim of reducing the levelized cost of energy (LCOE).

In recent years, the offshore wind industry has shifted from conventional design methods—where individual components were developed in isolation—towards an integrated design approach. This state-of-the-art methodology considers the turbine as a complete system, optimizing each component in relation to the others to maximize overall performance, reliability, and cost-efficiency. This integrated approach is crucial for ensuring the long-term viability of offshore wind farms, reducing operational and maintenance costs, and driving the industry towards large-scale deployment.

Moreover, the integration of advanced control systems, such as real-time monitoring and predictive maintenance technologies, enhances turbine performance and reduces downtime. By considering the entire lifecycle of the turbine—from manufacturing to end-of-life—integrated design also plays a vital role in lowering the LCOE and promoting sustainability through better use of materials and resources.

In this paper, a holistic approach, which considers from the very beginning of the design phase all the main components of the floating wind turbine, is developed and tested on a classical multi-megawatt wind turbine. The approach is also applied to an upwind two-bladed rotor, to consider the effects of the tower frequencies (which may be placed differently with respect to the blade pass frequency) on the floater design.

Methods

This work builds on a decade of advancements in multidisciplinary design technologies for land-based wind turbines (see [1], [2], and references therein). The holistic design framework utilizes nested optimization problems to integrate aerodynamic and structural design of both rotor and tower, with the main objective of minimizing the Levelized Cost of Energy (LCOE).

In this study, this approach has been extended to include the floating platform, catenary mooring lines and anchors in the design loop. Several nested optimization problems as shown in Fig.1 include steps involving i) an aerodynamic co-design (i.e. the aerodynamic rotor shape together with the floating sub-substructure), ii) a model-based controller design and iii) a structural sizing of the blade and tower elements, guided by certification-standard load cases together with a re-design of the floating support structure. In fact, during the final structural optimization, floating substructures are resized in response to system mass adjustments while meeting ultimate limit state constraints. To address varying levels of design detail, turbine models of different fidelity are used, from a reduced-order model for static aero-hydro-structural assessments to a fully coupled multi-body model for time-domain load calculations.

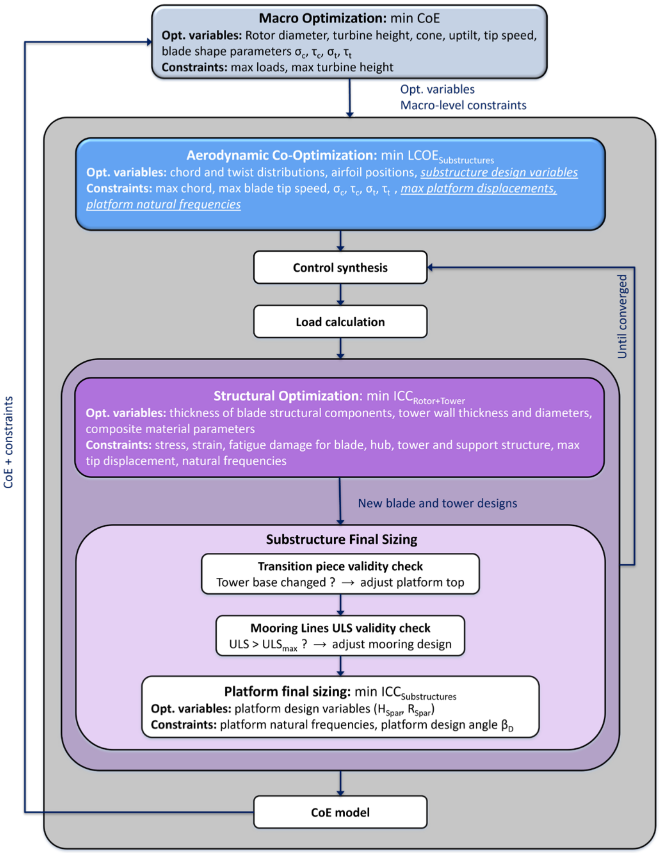

Figure 1: Figure 1. Holistic design framework with nested optimization problem inside.

Results

To demonstrate this multi-disciplinary and multi-nested design methodology, a classic 10-MW turbine on a spar platform has been re-designed for floating conditions. The results reveal substantial design modifications, especially in the rotor aerodynamic shape and, consequently, in the structural components of the blade and tower, compared to the baseline turbine. For instance, Fig. 2 shows, on the left, the chord distribution for the original land-based optimized blade (red solid line) compared with the one optimized together with the substructures (dashed blue line). The same Fig. 2, on the right, shows the floating spar design for the baseline case, the optimal co-design and the final one (respectively, magenta, blue and green). The final low-solidity (hence high-Tip Speed Ratio) rotor shape is found by the optimizer because, in presence of a design tip speed, this solution allows to reduce the aerodynamic thrust hence the maximum platform pitch angle. This example highlights the significant interdependence between system components in floating wind turbines, emphasizing that their design should adopt similar holistic techniques to achieve optimal performance.

The final presentation will provide an extensive description of the design methodology, with a comparison between a classical three-bladed rotor and a two-bladed teeter-hinged upwind rotor. The latter has a different positioning of the natural frequencies of the tower relative to the rotor, conditioning the sizing of, not only the tower itself, but also the floating support.

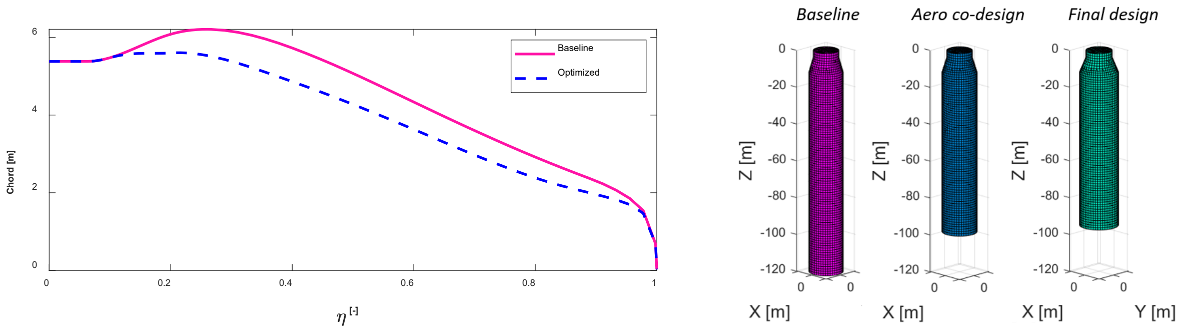

Figure 1: chord distribution (left) and spar design (right) comparison during the design phases.

Conclusions

This paper presents a novel approach for the integrated design of offshore wind turbines with the goal of reducing LCOE. This methodology couples the aerodynamic and structural design of the rotor together with the design of its support structure (tower, floater and mooring lines).

The technology developed for the integrated design, based on solving nested optimization problems, allows different coupling solutions between the turbine and substructures to be studied. Initial results, on a 10MW wind turbine, show interesting compromise solutions that can be further developed and investigated in the future.

Moreover, the comparison with a two-bladed floating offshore wind turbine design allows considerations to be made about the tower sizing and its frequencies.

References

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