Design Optimization of Multi-Use Components for Floating Offshore Wind Turbine Substructures

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Summary:

In today's world, climate change poses a major threat to the environment, raising ecological, economic, and social concerns. Scientific reports warn that both climatic and non-climatic risks are expected to escalate, creating even more complex challenges for future generations. To address these interconnected problems, an urgent transition away from conventional energy sources, such as fossil fuels, is essential. In recent years, offshore wind energy has garnered significant attention, driving the rapid development of the sector through growing interest and efforts from academia, industry, and policy-makers. In this context, offshore wind turbines have become a key part of the global energy transition, offering a scalable and effective solution. However, traditional bottom-fixed offshore wind turbines are constrained in deep waters, where installation becomes overly complex and costly. To overcome these limitations, floating offshore wind turbines have emerged as a promising alternative, enabling wind energy to be harnessed in areas where fixed-bottom foundations are not feasible. Despite their potential, floating offshore wind turbines face significant challenges, primarily due to the high costs of manufacturing, installation, and maintenance. Additional complexities arise as turbines increase in size and systems become more intricate to enhance efficiency, leading to new multidisciplinary research areas and design challenges.

The main objective of this thesis is to address design optimization for floating offshore wind turbine substructures and extend the research work on the innovative design of the GICON®-TLP. Currently, floating foundations are optimized not only for performance but also for cost-efficiency and critical factors such as manufacturing, transportation, and installation at both system and farm levels. Many design concepts incorporate structural components that can be adapted for use across various types of floating substructures as multi-use components. This particular platform features a cylindrical buoyancy body adaptable to other floating foundations, which serves as a case study to develop and evaluate an efficient design optimization framework. This thesis is structured around three main objectives:

- Provide a state-of-the-art review relevant to floating offshore wind turbine modeling and substructure design optimization.

- Develop an efficient design optimization tool tailored for multi-use components and floating substructures.

- Reduce the cost of floating offshore wind energy through efficient and optimized substructure design.

The first part of this thesis introduces the broad topic of floating offshore wind energy, highlighting its potential as a renewable energy source and addressing the key challenge of high costs that must be reduced. It provides a detailed review of the current state of the art in modeling the complex floating offshore wind energy system and the design optimization of floating substructures and their components. This includes an evaluation of the different types of floating platforms, identification of design trends, and exploration of strategies to lower the cost of floating offshore wind energy. Main theories and engineering models for floating offshore wind turbine dynamics are presented, along with relevant design methodologies and widely used numerical tools. Additionally, the thesis reviews literature on substructure design optimization, offering a concise yet comprehensive overview of the challenges associated with modeling these systems and evaluating design solutions within an optimization process.

Building on this foundation, the thesis applies insights from the state-of-the-art review to develop an efficient optimization framework for designing floating offshore wind turbine substructures and multi-use components. This design optimization tool extends prior work on the GICON®-TLP, which has been extensively studied through detailed numerical and experimental analyses. The primary objective is to minimize the manufacturing costs of the floating platform while maintaining its performance and structural integrity. The framework incorporates a structural model of the cylindrical buoyancy body, a key multi-use component of the GICON®-TLP, to assess its structural integrity and integration into the overall floating foundation. To evaluate the behavior of the substructure and other dynamic properties of the complete system, a frequency-domain dynamic model of the floating offshore wind turbine is also implemented. Additionally, an efficient genetic algorithm is specifically developed and coupled with these numerical models. This approach addresses key limitations of evolutionary algorithms in floating offshore wind turbine design optimization by incorporating fitness scaling, optimized genetic operations, and mechanisms to reduce unnecessary design evaluations.

The final chapters of this thesis present the application of the developed optimization framework. The case study demonstrates an optimized design for the GICON®-TLP and its multi-use components, which play a key role in its design. This analysis also evaluates the efficiency of the framework and the potential cost reductions achievable through its application and the use of modular, multi-use components. The results validate the framework's ability to address early-phase design challenges effectively, while also highlighting its potential for more detailed applications in later design stages. In conclusion, this thesis emphasizes the critical role of floating offshore wind turbines in the global transition to renewable energy. By introducing an efficient design optimization framework and showcasing the benefits of modular, multi-use components, the research provides a practical approach to reducing costs and enhancing scalability. Future work could build on these findings by integrating more detailed dynamic analyses and exploring additional substructure configurations to further expand the framework's capabilities.