20th EAWE PhD Seminar on Wind Energy
24 - 26 September 2024
Visby, Sweden

Inspection and Maintenance Planning for Offshore Wind Turbine Support Structures: New Insights

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Keywords: Offshore wind turbine, fatigue deterioration, inspection, predictive maintenance.

1 Introduction

Offshore wind energy is gaining importance in the shift towards renewable energy. As wind turbines become progressively larger and wind farms are installed in deeper waters, the support structures of offshore wind turbines (OWTs) must withstand larger loads, ultimately increasing the costs associated with these structures. Maintaining the structural integrity of OWTs remains a significant challenge due to their due to their susceptibility to environmental factors like wind, waves, and corrosion, which can lead to structural degradation and ultimately structural failure.

Typical maintenance strategies often rely on reactive approaches can be explained in Figure 1, commonly referred as corrective maintenance, which can lead to increased downtime, maintenance costs, and operational risks. Industrial standards and guidelines for determining design loads for maintenance strategies, such as those from DNV [1], are conservative and subject to high levels of uncertainty. DNV acknowledges these uncertainties and recommends conservative evaluations to mitigate risks, ensuring that structures are over-designed to handle worst-case scenarios, thereby prioritizing safety and reliability.

Inspection and maintenance planning relies on conservative assumptions at design stage without exposing the structure to unnecessary risks. Inspection identifies defects in the structural components, while maintenance improves their condition. In practice, I&M planning can, for instance, decrease some design safety factors, possible resulting in lighter and therefore cheaper structures. Traditionally, heuristic-based plannings are often employed to establish the I&M strategy. Although fast and satisfactory, heuristic-based solutions are likely suboptimal. A fully optimized solution depends on complex models that might demand significant computational resources [2].

This article discusses three perspectives to enhance I&M planning for OWT support structures. They approach deterioration modelling of fatigue cracks and techniques to incorporate diverse sources of information to increase the accuracy of the reliability models necessary for I&M planning. These perspectives provide different insights to reduce the uncertainties related to the deterioration modelling with feasible computational efforts.

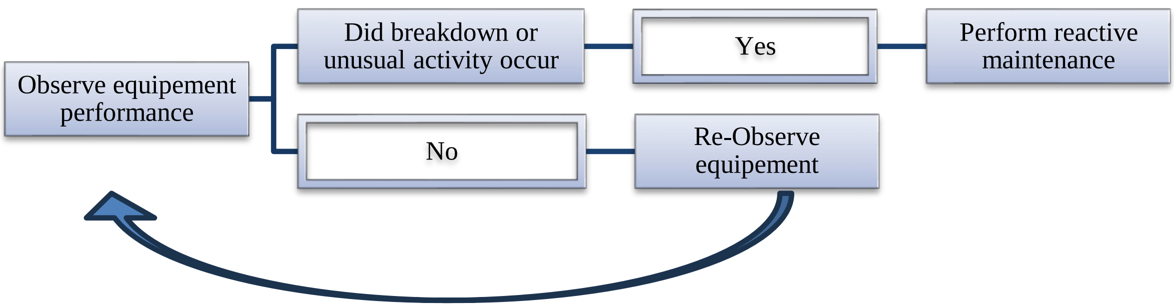

Figure 1: What is Reactive Maintenance used for?

2 Insights for I&M planning

This study presents a synthesis of research conducted by various researchers at University of Liège (ULiège), aimed at tackling challenges in I&M from diverse perspectives. Specifically, the study aims to support I&M planning by integrating multiple sources of information. By doing so, this enhances predictive maintenance capabilities, optimize resource allocation, and mitigate operational risks effectively. This approach not only refines maintenance strategies but also adapts these strategies to changing environmental conditions and operational requirements, ensuring the long-term structural integrity and performance of OWT foundations.

2.1 Fatigue Crack Interaction in Monopile Substructures

The challenges faced by OWT support structures due to combined cyclic loading from wind, waves, and currents, which lead to fatigue and corrosion have been investigated. Notably, research has delved into the interaction between fatigue cracks in monopile substructures has been investigated [3]. This advanced model aims to improve the accuracy and reliability of structural integrity assessments, thereby enhancing the overall reliability of OWT support structures.

2.2 Inter-dependencies among deteriorating components

The support structure can be considered as system composed by different structural components. Groups of these components are often under the same deterioration process. The submerged components, for instance, are subjected to corrosion and present similar degrees of thickness loss and pitting formation. Cyclic loads caused by wind and turbine's rotor expose all structural components to fatigue. Waves, in other hand, mainly affect the components close to the water level, contributing the fatigue damage with additional cyclic loads. The intensity variation of any mentioned deterioration processes affects all components related to it. These components are, thus, correlated by the same deterioration process. In other words, these components are correlated by the deterioration process or inter-dependent.

This part of the work addresses the feasibility and advantage of modelling the inter-dependencies among structural components for I&M planning. It explores inspection and maintenance actions to diverse components of the monopile structure, adding flexibility to the I&M strategies [4].

2.3 Neural Networks for Cyclic Load Estimation

Neural networks (NN) were also employed to estimate cyclic fatigue loads of structural components based on SCADA data, marks a notable advancement in structural health monitoring [5].

These methodologies offer adaptive policies in I&M planning, considering factors like deterioration models, failure criteria, and inspection method sensitivity. Moreover, Bayesian neural networks (BNN) enable stochastic modelling and uncertainty quantification, presenting an advantage in announcing model uncertainty for farm-wide monitoring. Looking forward, further enhancements in virtual monitoring, including improved data estimation and uncertainty measurement, promise to refine decision-making processes and optimize infrastructure maintenance practices for greater efficiency and reliability.

3 Conclusion & remarks

This study offers an insight study that presents a forward-thinking approach to ensuring the structural integrity and operational efficiency OWTs. Through detailed articles, the research provides advanced exploration into structural reliability modelling and integrated Inspection and Maintenance (I&M) planning, highlighting current challenges and proposing innovative approaches to improve the reliability and sustainability of OWT systems.

By identifying key areas for further research and development and leveraging advanced computational techniques such as neural networks and structural analysis, this study contributes to the optimization of I&M strategies and the resilience of engineering structures, paving the way for continued progress in offshore wind energy. The research offers a new approach to address challenges in infrastructure monitoring and maintenance. One of the key suggestions is to employ virtual monitoring to measure uncertainties better. This means trying different ways to estimate information and finding better ways to know if our data is accurate. Doing this can make virtual monitoring systems more dependable and precise, which is pivotal for keeping OWTs running smoothly.

Acknowledgements

The authors would like to acknowledge the financial support granted by the Belgian Energy Transition Fund (FPS Economy) through Phairywind (https://www.phairywind.be) and MAXWind. project.

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