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Reliability-Based Inspection Planning of 20 MW Offshore Wind Turbine Jacket

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This paper presents the application of a risk- and reliability-based inspection planning framework for the InnWind 20 MW reference wind turbine jacket substructure. A detailed fracture mechanics-based fatigue crack growth model is developed and used as a basis to derive optimal inspection plans for the jacket substructure. Inspection plans for different inspection techniques are proposed, and recommendations on how to optimize inspection intervals are discussed.

INTRODUCTION

Upscaling current wind turbines to very large wind turbines is considered as one of the important ways to decrease the levelized cost of energy (LCoE) of wind energy. Steel jacket structures are one possible type of support structure for very large offshore wind turbines and have been considered in the EU InnWind project, INNWIND.EU (http://www.innwind.eu). Reliability with respect to fatigue failure is generally driving the design of offshore wind turbine jacket structures and is being considered in this paper in combination with applications of reliability-based inspection planning.

For oil and gas offshore steel structures, reliability-based inspection planning (RBI) has been developed during the last 25 years and is used in many practical applications. The developments have primarily been within inspection planning for welded connections subject to fatigue crack growth in fixed steel offshore platforms (see, e.g., Skjong, 1985; Thoft-Christensen and Sørensen, 1987; Madsen et al., 1989; Madsen and Sørensen, 1990; Fujita et al., 1989; Faber and Sørensen, 1999; Rouhan and Schoefs, 2003; Ersdal, 2005; Moan, 2005). A good example of RBI application for offshore wind structures is a comprehensive study for 5 MW wind turbine jacket substructure by Dong et al. (2012).

Generic and simplified approaches for reliability-based inspection planning have been formulated, making it possible to base inspection planning on a few key parameters commonly applied in the deterministic design of structures such as, for example, the fatigue design factor and the reserve strength ratio (see Faber et al., 2005; Straub and Faber, 2005).

A basic assumption made in risk- and reliability-based inspection planning is that a Bayesian approach can be used. This implies, among other things, that probabilities of failure can be updated in a consistent way when new information (e.g., from inspections) becomes available. Furthermore, the RBI approach for inspection planning is often based on the assumption that at all future inspections no cracks are detected. If a crack is detected, then a new inspection plan should be developed. Inspection planning based on the RBI approach implies, as a starting point, that single components are considered, one at the time, but with the acceptable reliability level assessed based on the consequence for the whole structure in the case of fatigue failure of the component.

Based on the above considerations, the following aspects are considered in this paper with the aim of developing the reliability-based inspection planning approach:

(1) For new (innovative) wind turbine support structures, the design is generally carried using safety factors that assume no inspections are performed during the design operational lifetime. However, it could be cost-effective to plan for operation and maintenance (O&M) actions (especially inspections) during the operational lifetime if the associated costs are smaller than the initial costs that can be saved by using smaller safety factors for the design. To account for the possible future inspections, maintenance, and repair actions, rational decisions have to be made. This paper describes how this can be done using preposterior Bayesian decision theory. Furthermore, application of a design approach, where inspections, condition, and structural health monitoring actions are performed for innovative wind turbine substructures, has the potential to uncover unexpected behavior of the substructures before failures happen.

(2) Systems effects due to common loading, model uncertainties, and correlation between inspection qualities implying that it can be expected that information obtained from inspection of one component can be used to update the inspection plan not only for that component but also for other nearby components.

The design of wind turbines is typically done based on the IEC 61400 series of standards, where IEC 61400-1 Ed.4 (IEC, 2017) is the basic standard specifying the requirements to structural reliability of wind turbines components and systems. General descriptions of reliability assessment of structural wind turbine components can be found in, for example, Toft (2010) and Sørensen and Toft (2010). In IEC 61400-1 Ed.4 (IEC, 2017), reference is made to ISO 2394 (ISO, 2015) as the standard specifying the basic reliability requirements, where three levels of decision making are described—namely, (1) the semiprobabilistic method (by safety factors), (2) reliability-based decision making (probabilistic design), and (3) risk-informed decision making. The risk-based approach is applied in connection with risk-based planning of inspections and in relation to the operation and maintenance of wind turbines. Furthermore, the risk-based approach is used to determine the reliability requirements to be used in a reliability-based design.

Sørensen (2012) considered the use of reliability-based calibration of required safety factors for the fatigue design of steel substructures for offshore wind turbines. A similar approach is considered in this paper, with more detailed formulations of the fracture mechanics modelling, and applied for the generic, innovative

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