Reliability Assessment of Offshore Wind Turbines Considering Faults of Electrical / Mechanical Components

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ABSTRACT
For offshore wind turbines, the cost contribution to Cost of Energy from inspections and Operation & Maintenance can be substantial, and can be expected to increase when wind farms are placed at deeper water depths, further from the coast and in more harsh environments. Estimates of the reliability of structural, mechanical and electrical components are important, in order to optimally plan Operation & Maintenance strategies. A general model for reliability estimation of structural, mechanical or electrical components is described. For a representative failure mode a corresponding limit state is considered and related to reliability estimation by taking into account faults e.g. due to failure of an electrical component or loss of grid.

KEY WORDS: Offshore wind turbines; reliability; faults; operation & maintenance planning

INTRODUCTION
Generally, wind turbines (WT) are designed for 20-25 year lifetimes defined by the International Electrotechnical Commission standards (e.g. IEC 61400-1 (2005)). WTs are complex systems, which consists of electrical, mechanical, hydraulic, structural and software subsystems. The main purpose of WTs is to transform kinetic energy from wind speed to electrical power. Offshore WT power has the advantage to be green, ecosystem friendly, be located off-shore in deep seas and economically justified for a reasonable period of time. However, all these aspects are influenced by the reliability of the WTs. WTs with low reliability can increase the Operation & Maintenance (OM) costs and thereby increase the Cost of Energy (CoE). Thus, it is important to be able to estimate the reliability of all WT components and to design the components to have a cost-optimal reliability level. Different subsystems of WTs can have different levels of reliability. For example, WT blades are designed for an annual probability of failure between 10^{-4} and 10^{-3}, see Sørensen (2012). Recently many studies are devoted to the reliability assessment of electrical components in WTs, which is explained by the high failure rates of electrical systems, typically between 0.05 and 0.2 per year. High failure rates in electrical systems affect profitability via increase in CoE and OM costs. The environment under which the electrical components are utilized is directly influencing the reliability of the electrical components. Failure of electrical components can e.g. cause the WT blade to be stopped at an unfavorable position and thereby result in increased extreme and fatigue loads. It might take significant time until the failure can be fixed, so WT structural components will be damaged from both fatigue and extreme loads, and further no electricity is produced. In this paper, a general model for reliability estimation with faults attention is considered.

OPERATION AND MAINTENANCE PLANNING
OM planning strategies are decisions that operators or owners of WT should take during the WT life (they are not fixed and might be changed during the WT life by a learning process). Recently many studies are devoted to identify the optimal OM strategies that will overcome the high cost of unexpected failures. Generally, OM might be classified into two groups: corrective and preventive OM strategies. Corrective OM (COM) is performed after the failure event has been observed, while preventive OM (POM) is implemented while the failure event is not observed (any time within the start until the time when the failure event occurs). Further, POM might be performed based on usage age, periodically scheduled (calendar), condition based and risk (probability) based maintenance strategies. To determine an optimal OM strategy, the objective functions should be determined (minimization or maximization) during the service life or infinite time horizon, subject to the model limitations. Objective functions to be minimized might be defined based on costs or downtimes, whereas objective functions to be maximized could be defined based on profits (benefits) or availabilities.

Downtimes play an important part and might influence the choice of OM strategy. It is important to include it into the considerations, as far as in offshore WT applications, time to repair might take significant time. In addition, downtimes could be increased by weather conditions. Altogether, a significant downtime might be observed, during which a parked WT might be affected by the extreme or fatigue wind loads,