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Risk-based planning of operation and maintenance for offshore wind farms

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Abstract

Operation and maintenance (OM) of offshore wind turbines contributes with a substantial part of the total levelized cost of energy (LCOE). The objective of this paper is to present how applications of risk and reliability based methods for planning of OM, can positively impact the cost of maintenance. The study focuses on maintenance of wind turbine blades, for which a fracture mechanics based degradation model is set up. Based on this model, and the uncertain input in terms of cracking on the blades at the start of the lifetime, an initial reliability estimate is made. During the operation period, inspections are performed at regular time intervals, and the results are then used to update the reliability estimates using Bayesian networks. Based on the updated estimate, decisions on repairs are taken, thus potentially minimizing the maintenance effort while maintaining a target reliability level. To showcase the potential cost reduction, a study is made using a discrete event simulator. Two different preventive approaches are used. The first is a traditional time/condition based strategy, where inspections are made with a fixed annual frequency and defects are repaired on detection. The second approach consists of risk based inspection planning, using the methodology described in the first part of the paper, and the cost and availability savings relative to the previous strategy are underlined. A detailed description on the advantages of disadvantages of the risk strategy is given in the end of the paper.

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Keywords: risk; reliability; offshore; life-cycle; maintenance; turbine; blade

1. Introduction

With the rapid growth of the offshore wind industry over the past two decades, and the implicit growth in the size of wind turbines, Operation & Maintenance (OM) has become a major focus point in the attempt to lower cost of wind

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energy to market competitive prices. It is in general estimated that OM operations account for around 25% of the levelised cost of energy [1].

Current practices in the industry rely heavily on a combination of reactive/corrective maintenance and time-based inspections. This leads to a relatively high number of breakdowns in the turbines, which require expensive replacement/repair operations, significantly impacting the cost of energy. In a number of situations, degradation of a component can be detected either with online condition monitoring or offline inspections and failure prevented by using an early, much cheaper repair. The result is a reduction in both cost and downtime.

However, the amount of effort put into preventing failures also needs to be limited, since a high number of preventive repairs and inspections leads to unnecessarily large expenses and downtime. Time-based inspections are commonly used, where inspections are carried out at regular time intervals, and repair decisions are made only depending on the size of the observed damage. This paper proposes an application of an alternative strategy for preventive maintenance for turbine blades, namely by risk-based planning of inspections [2], [3], [4].

This topic has been addressed by the authors in previous publications ([5], [6]) where degradation modelling and reliability updating in the context of maintenance optimization was described. The present paper expands the model, focusing on optimal decision making. Unknown results from future inspections are included in the decision process using a Bayesian decision tree model, and the maintenance strategy is updated after every inspection.

In the first part of the paper, a description of the probabilistic degradation model for turbine blades is made, along with an update model using Bayes update rule. The models are used together with a risk based maintenance framework in the second part of the paper to optimize lifetime expenses, and finally a comparison is made with output from a traditional condition based strategy.

Nomenclature

a_m	Measured size of crack
B	Lifetime benefits
C_F	Expected cost of failure
C_I	Initial cost
C_{IN}	Cost of inspection
C_{REP}	Expected cost of repair
C_{total}	Total cost function
ΔP_F^{max}	Maximum allowed failure probability
$\Delta P_{F,t}$	Annual probability of failure at time t
$f(a_m\|q,v)$	Likelihood function
$f'(q,v)$	Prior density function
$f''(q,v\|a_m)$	Posterior joint density function
IP	Vector containing inspection plan
P_i	Probability for a category i crack
P_{in}	Probability of inspection
t_0	Starting time
t	Time
thr	Threshold for repair
T_L	Service lifetime

2. Methodology

In [2], a general framework for optimal risk based inspection planning for wind turbines/components using pre-posterior decision theory is described. A decision tree for the lifetime of a turbine is shown in Fig. 1.