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Planning of operation & maintenance using risk and reliability based methods

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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 an application of risk- and reliability-based methods for planning of OM. The theoretical basis is presented and illustrated by an example, namely for planning of inspections and maintenance of wind turbine blades. A life-cycle approach is used where the total expected cost in the remaining lifetime is minimized. This maintenance plan is continuously updated during the lifetime using information from previous inspections and from condition monitoring with time intervals between inspections and maintenance / repair options as the decision parameters.

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

1. Introduction

Operation and maintenance (OM) activities have been shown to contribute to around 25 - 30% of the total energy cost from offshore wind power, leading to an increased effort for optimizing maintenance plans, with current industry practices relying mostly on a corrective/run-to-failure approach, and for certain aspects on time based preventive maintenance.

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This paper analyses the potential of implementing risk and reliability based approaches, with decision criteria formulated in terms of turbine failure probability. Although such methods have been successfully used in the offshore Oil & Gas industry, the risk acceptance criteria in this situation is unreasonably high for a direct implementation in the case of wind farms, where the financial and not the human life factor is design driver.

In the following, an application of risk and reliability planning is presented, concerning the optimum planning of inspections for blade maintenance using reliability as the decision parameter. The cost output for different reliability thresholds is determined using life-cycle simulator models and are compared with outputs from more traditional approaches such as corrective/time based maintenance.

Nomenclature

A	Paris law material parameter
a	Crack length
da	Increase in crack length
$f(\Delta s \vert u,I)$	Load cycle distribution
F	Time-to-failure distribution
ΔK	Stress intensity factor
Δs	Stress range
Δt	Time step
λ_w	Paris law material parameter
λ	Expected value of the smallest detectable crack size
m	Paris law material parameter
R	Stress ratio
POD	Probability of detection

2. Life cycle model

A framework for the basic life-cycle approach for planning of operation and maintenance has been described in [1] and is used as basis for the analysis in this paper.

In this section, a life-cycle simulator is described and used for analysing different maintenance strategies. The model is simplified in the sense that it simulates one NREL 5 MW offshore turbine, which is structurally described by a single component, namely a laminated carbon fiber blade, on which inspections and repairs can be performed using various decision parameters.

In the following, the various modules of the model are described.

2.1. Weather condition

The weather is modelled using wind and wave time series measurements covering a period from 2004 to 2012 at the FINO1 location 45 km off the coast of Germany into the North Sea.

The measurements are used to assess the appropriate working conditions, energy production and health condition of the components.

2.2. Damage and reliability model

The health state of the blade is described using a fracture mechanics based damage model that has been described in [2]. The model assumes failure results from crack development on the trailing edge of the blade and uses hub height wind measurements to compute the growth of a set of initial randomly generated cracks in the bond material. The model contains three stages, which are described in the following:

- defect initiation at the start of the blades life
- damage propagation during the blades lifetime