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Risk-based operation and maintenance of offshore wind turbines

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ABSTRACT

Operation and maintenance for offshore wind turbines is a large contributor to the total cost. Today corrective maintenance is usually used, meaning that components are repaired after they fail. The use of condition-based maintenance based on Bayesian decision theory has the potential to minimize the costs to operation and maintenance, and hereby increase the overall benefit. This paper outlines the basic concepts of condition-based maintenance.

KEYWORDS

Operation and maintenance, corrective maintenance, condition based maintenance, offshore wind turbines

1 INTRODUCTION

Costs to operation and maintenance for offshore wind turbines can be very large compared to other costs, and can be expected to increase when wind farms are placed at deeper water depths and in more harsh environments. For other offshore installations such as oil & gas installations, cost-effective procedures for risk-based inspection planning have been developed during the last 10-15 years and are used at several locations worldwide [1]. These procedures are based on pre-posterior Bayesian decision theory [2].

Maintenance activities can be divided in corrective and preventive maintenance, where the latter covers both planned and condition-based maintenance. Optimal the maintenance should be planned using a risk-based approach with pre-posterior Bayesian decision theory, as described in [3], with the use of observations from condition monitoring and inspections.

2 OPTIMAL PLANNING OF INSPECTION AND MAINTENANCE

2.1 Life Cycle Decision Model

A decision tree related to the life cycle of an engineering structure such as a wind turbine or wind farm is shown in Figure 1. The decisions taken by the decision maker (designer / owner / …) and observations of uncertain parameters that are unknown at the time of the decision are:

- At the design stage a decision on the optimal design parameters is made which in principle should maximize the total expected benefits minus costs during the whole lifetime such that safety requirements are fulfilled at any time.
- During the lifetime continuous monitoring of the wind turbines and inspections of critical components are performed. These are indicated in the box 'repeated inspection/maintenance' in Figure 1. Each box consists of: (1) a decision on times and types of inspection / monitoring for the rest of the lifetime; (2) observations from inspection / monitoring; (3) decision on eventual maintenance / repair based on the inspection / monitoring results.
- Realisation of uncertain parameters such as wind and wave climate, strengths, degradation, model uncertainties will take place during the lifetime.
- The total cost is the sum of all costs in the remaining part of the lifetime after the time of the decision.

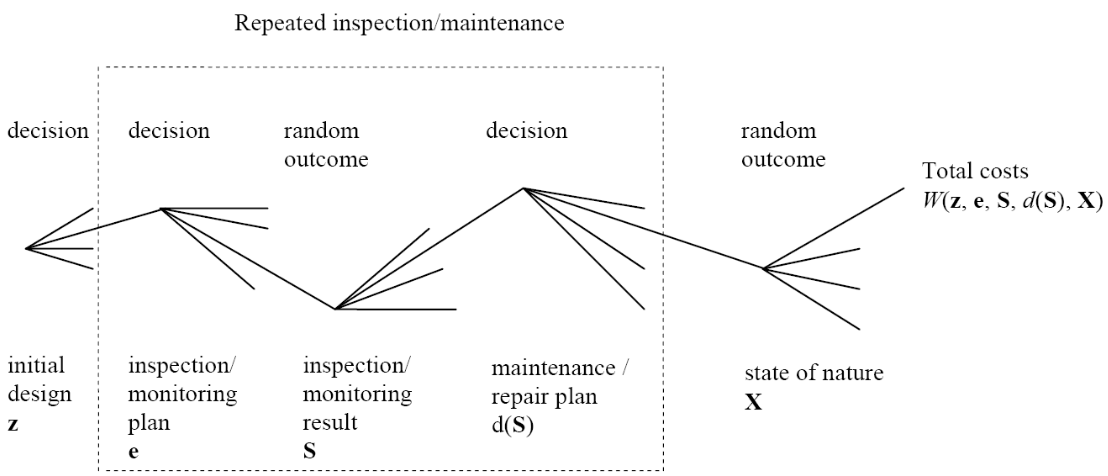

Figure 1: Decision tree for optimal operation and maintenance planning [3]

2.2 Damage and Uncertainty Modelling

Deterioration mechanisms such as fatigue, corrosion, wear and erosion are associated with significant uncertainty. Observations of the degree of damage $D(t)$ can increase the reliability of predictions using Bayesian statistical techniques as illustrated in Figure 2. Generally an inspection at time T_1 and associated maintenance/repair will decrease the uncertainty and the expected mean damage level at time T_2 will be smaller since most realizations with large damage level at time T_1 can be expected to be maintained / repaired.

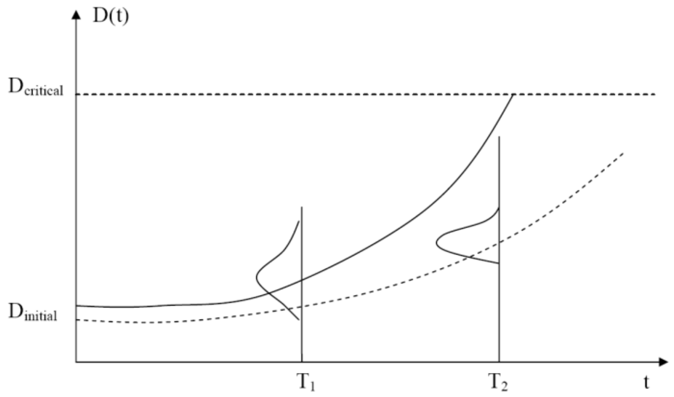

Figure 2: Damage model and updating by inspection at time T_1 [3]

2.3 Cost-Benefit Models for Optimal Decision Making

The aim is to maximize the total gain minus the costs, W, and the optimization problem can basically be written

$$\max W = B - C_I - C_{IN} - C_{REP} - C_F \quad (1)$$

where B is the benefits, C_I is the initial costs, C_{IN} is the inspection and service costs, C_{REP} is the repair and maintenance costs and C_F is the expected failure costs, and all values are functions of the design parameters, decision parameters for inspections, and decision rules for repairs.

3 COMPARISON: CORRECTIVE OR CONDITION-BASED MAINTENANCE

For corrective maintenance the costs (or lost benefit) are due to lost production, repair of damaged components and escalated damage due to failure of components. In condition-based maintenance monitoring and inspections will give an additional cost, but lost production and escalated damage is decreased. Simulation techniques can be used to determine the optimal planning for a given case. The major contributors to uncertainty should be included in the model, and are described in the following.

3.1 Uncertainties and Parameters

The weather has a major influence on several aspects within operation and maintenance of offshore wind turbines, e.g. damage accumulation, weather windows for repair, and (lost) production. The parameters in the damage model for the different components will vary due to natural variations in execution, and the model is uncertain too. When an inspection is performed, there is a probability that the damage is not found. This is described with a POD (probability of detection) curve, and in general it is easier to detect a larger damage. Also there is a possibility of false detections of damages that do not exist. When damage is detected, a decision rule determines whether a repair should be carried out. Optimal the decision rule should be based on a risk analysis for the rest of the lifetime of the component, but a simpler rule with a limit damage level might be easier to use. Dependent on the weather it might not be possible to access the wind turbine with a boat for some time, and the additional cost of a helicopter should be held against the expected cost of failure and loss of production. Often it will be less expensive to execute the repair before the component has actually failed. Of course the inspections will only have a positive effect, if the damage does not happen too abrupt to be detected during inspections.

4 CONCLUSIONS

A risk-based approach for planning of operation and maintenance of offshore wind turbines is described. Simulation techniques can be used to assess the gain of the use of condition-based maintenance compared to e.g. corrective maintenance.

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