A Generic Reliability and Risk Centered Maintenance Framework for Wind Turbines

Dwarakanath Jagannath
Faculty: Pingfeng Wang
Department of industrial and Manufacturing Engineering

Abstract: Operation and maintenance (O&M) are significant contributors to the cost of energy in wind industry. To reduce the cost, effective maintenance strategies have become an indispensable part of operational decision-making for wind turbines. This research presents a generic framework for the maintenance planning of wind turbines. Within the proposed framework, the performance degradation of wind turbines over time is characterized with stochastic damage growth models. Costs incurred during the life span of wind turbines are modeled mathematically to compute the accumulated risks involved in the O&M process. Probabilistic models are used to characterize the maintenance activities and a unified maintenance optimization platform is then formulated to derive optimal maintenance strategies. A case study of offshore wind turbines is used to demonstrate the proposed methodology.

1. Introduction

Wind turbine O&M activities are the primary cost contributors for the wind energy industry. Maintaining wind turbines in top operational condition ensures not only a continuous revenue generation but a reduction in electric power drawn from non-renewable and more polluting sources of fuel. Despite tremendous research efforts on improving the wind turbine system reliability through utilizing advanced turbine designs and employing real time condition monitoring systems, the decision making process related to the cost effective O&M strategy and its implementation on large scale wind farms remains as a major challenge to wind turbine operators. This paper presents a generic reliability and risk centered maintenance framework to facilitate the O&M decision making of wind turbines. Section 2 details the proposed methodology with a case study on offshore wind turbines O&M strategies. Section 3 summarizes the presented work and future research directions.

2. Reliability and Risk Centered Maintenance Framework

Within the proposed framework, stochastic damage growth models are employed to characterize the performance degradation of wind turbines over time. Various costs incurred during the life span of wind turbines are modeled mathematically to compute the accumulated risks involved in the O&M process. The effectiveness of maintenance activities such as health monitoring and the damage detection is modeled in a probabilistic sense to account for the uncertainties involved during the wind turbine O&M process. A unified maintenance optimization platform is then formulated to derive optimal maintenance strategies.

Damage Growth Model: The performance degradation of wind turbines [1] is modeled with a damage growth model with stochastic model parameters based on the Paris Law as:

$$\frac{dD}{dt} = \frac{dN}{dt} \cdot \beta \cdot C \cdot (H_s \cdot X_s \cdot \sqrt{\pi D})^m \tag{1}$$

Damage level 'D' of wind turbine components is given on a relative scale, where 0 indicates no damage in the system and 1 indicates complete failure of the system. Where *dN*/*dt* is 360/hour, C is the damage coefficient, m is the damage exponent, H_s is the load acting on the wind turbine, and Xs is the proportionality factor. Damage growth over a period of time is updated using the Euler method. Damage growth is estimated for every 3 hours by

$$D_{t+\Delta t} = D_t + \frac{dD}{dt} \cdot \Delta t \tag{2}$$

Risk Model: The risk of the O&M activities is measured by the cost induced by the O&M event, such as inspection, part repair or component replacement, and the probability of occurrence of the event. The various costs occurred during the life span of wind turbines such as repair costs, inspection costs and costs due to component failures, are modeled mathematically to compute the accumulated risks involved in the O&M process. The total maintenance costs incurred can be give as

$$TMC = C_{insp} + C_{rep} + C_{failure} \tag{3}$$

where C_{insp} is inspection costs, C_{rep} is the repair costs and $C_{failure}$ is the failure costs incurred due to loss of production. The primary objective in O&M is to minimize the total maintenance costs [2].

Probability of Damage Detection: The probability of detection of damage is estimated based on current damage level which can be given as

$$\text{PoD} = P_0\left(1-e^{(-D/\lambda)}\right) \tag{4}$$

Where P_0 is the Maximum probability of detection, λ is the expected value of smallest detectable damage.

O&M Optimization Platform: With the damage growth of wind turbine units, the maintenance activities can be planned based on a well-designed wind turbine O&M strategy. An optimum O&M strategy can be obtained through an O&M optimization platform. In this research, two O&M case studies of wind turbines with 500KW capacity are considered in order to develop the optimal strategy for O&M of wind turbines. Case I considers single wind turbine component with a failure rate of 0.5/year and case II considers two wind turbine units with failure rates of 0.5/year and 0.7/year respectively. The life span of wind turbines is assumed to be 20 years. The stochastic parameters affecting the O&M of wind turbines are estimated based on the respective failure rates of the units. Damage growth model parameters are given in Table 1 whereas the associated cost parameters are shown in Table 2. The critical damage level (D_C) of the system to perform the repair activity is set to 0.2 in both 'case1' and 'case 2'. Simulations are performed in various scenarios to assess the damage growth during the life time of wind turbines and the various costs incurred. Fig.1. shows the damage growth of wind turbine units and Fig.2 presents the total maintenance costs for both of two cases under current O&M strategy.

Table 1: Parameters affecting Damage Growth

Parameters	Mean	COV	Distribution
C	9.26e-10	0.2	Lognormal
Xs	11.5	0.1	Lognormal
m	2	-	Deterministic
β	1	-	Deterministic

Table 2: Cost parameters

Parameters	Symbol	Value
Repair cost	C_r	40000 $
Inspection cost	C_{insp}	2500 $
Power price	b	.04$/KWH
Rate of interest	r	5%/year

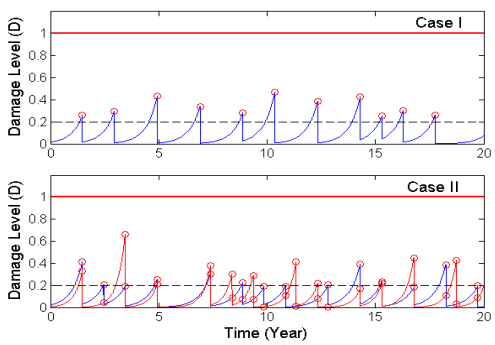

Fig.1. Damage growth in of wind turbine units

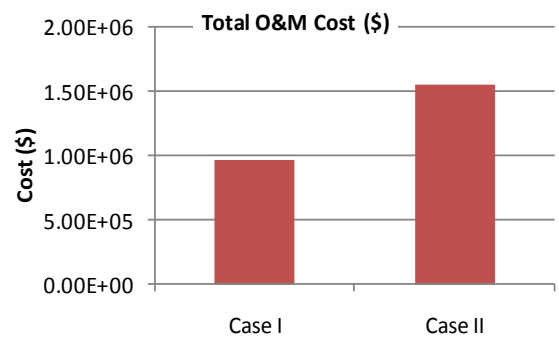

Fig.2. Total maintenance for the case study

3. Conclusions

This paper presented a generic reliability and risk centered maintenance framework for wind turbine O&M decision making. Stochastic simulations were performed for two different scenarios to identify the effect of O&M decision parameters on the total maintenance costs of wind turbines. The simulation results indicated that not only the failure rates of the wind turbine units but the O&M decision making parameters such as the critical damage level D_C and the effectiveness of the damage detection have major impacts of the total maintenance costs. An optimal O&M strategy can be derived through joint optimization of O&M decision making variables.

References

[1] J.J Nielsen and J.D Sorensen, On Risk-based Operation and Maintenance of Offshore Wind Turbines, Reliability Engineering and System Safety, 2010

[2] E. Byon, Optimal Maintenance Strategies for Wind Turbines under Stochastic Weather Conditions, IEEE Transactions on Reliability, 2010