Applied Ocean Research 74 (2018) 69–79

Contents lists available at ScienceDirect

Applied Ocean Research

journal homepage: www.elsevier.com/locate/apor

Condition based maintenance optimization for offshore wind turbine considering opportunities based on neural network approach

Yang Lu [a], Liping Sun [a,*], Xinyue Zhang [b], Feng Feng [a,b], Jichuan Kang [a], Guoqiang Fu [a]

[a] College of Shipbuilding Engineering, Harbin Engineering University, Harbin, China
[b] Heilongjiang Water Transport Planning and Design Institute, Harbin, China

ARTICLE INFO

Article history:
Received 1 September 2017
Received in revised form
28 December 2017
Accepted 22 February 2018

Keywords:
Condition based maintenance
Offshore wind turbine
Artificial neural network
Opportunistic maintenance

ABSTRACT

A well-established condition-based maintenance (CBM) method based on condition monitoring information can be used to reduce maintenance costs by decimating unnecessary maintenance actions, reducing system downtime, and minimizing unexpected failures. In this paper, we propose an opportunistic CBM optimization approach for offshore wind turbines (OWTs) in which economic dependence exists among the components that are subjected to condition monitoring. An artificial neural network is used to predict life percentage by leveraging the condition monitoring information. A conditional failure probability value that is derived from the predicted failure-time distribution of the component was adopted to represent the deterioration of OWTs. Our maintenance method can be defined by a threshold with two-level failure probability. We propose a simulation method that can be used to calculate the optimal threshold values to minimize the long-term maintenance cost. Failure information and maintenance cost of OWTs are collected from existing articles to illustrate the proposed approach. Results show that the opportunistic CBM strategy can be effective and is established in the wind power industry. Moreover, the expense comparison between onshore and offshore WTs demonstrates the importance of this method.

1. Introduction

Maintenance cost is the major limitation for developing offshore wind turbines (OWTs). The operations and maintenance costs of a wind farm can contribute approximately 30% of the leveled cost of energy of an offshore wind farm [1] because additional inventory expenditure and certain transportation resources are required to supply maintenance sites for OWTs; furthermore, the accessibility of OWTs is insufficient given the unpredictable weather [2]. Moreover, extreme marine operating conditions, such as typhoon, sea ice, salt spray, and humidity, will result in higher failure rate than in onshore ones, thereby resulting in high maintenance costs [3]. In the present study, a maintenance cost model that corresponds to condition-based maintenance (CBM) strategy is established, and a cost-minimization method is developed.

Previous studies attempted to reduce the maintenance cost of onshore wind turbines (WTs). Hau [4] presented a set of fundamentals, technologies, and economics of WTs. Carlos et al. [5] reduced the maintenance cost for onshore wind farms based on a stochastic model. Laggoune et al. [6] considered grouping components to achieve an opportunistic replacement of components, in which component-wide replacement may not be optimal despite a possible system-wide optimization. Tian [7] developed a CBM strategy for WTs to reduce maintenance cost; the result showed that the CBM strategy is more effective than time-based maintenance policies.

Maintenance grouping optimization of OWTs has attracted increasing attention in recent years. Carroll [8] analyzed the failure rate, repair time, and unscheduled operations and maintenance cost of OWTs. Laura and Vincente [9] studied the lifecycle cost for offshore wind farms. Karyotakis and Bucknall [10] proposed mediation as an approach to the repair and maintenance of OWTs, whereas Sorensen [11] recommended a risk-based operations and maintenance planning mechanism for OWTs. Sarker and Faiz [12] proposed a multi-level opportunistic preventive strategy, which can be used to minimize the maintenance cost of OWTs based on the ages of components. Bertling and Nilsson [13] presented the effect of condition monitoring as the maintenance strategy for lifecycle cost on a single onshore turbine and an offshore wind farm. Their study revealed that the cost of the strategy and the maintenance management of the offshore power systems benefit from condition monitoring.

To date, the existing maintenance strategies for OWTs can be divided into preventive maintenance (PM), corrective mainte-

* Corresponding author.
E-mail address: sunliping196206@126.com (L. Sun).

https://doi.org/10.1016/j.apor.2018.02.016
0141-1187/

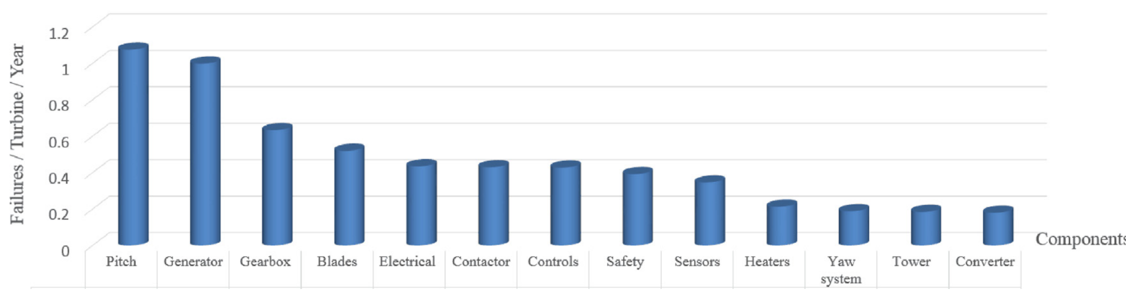

Fig. 1. Failure rate for main components of OWTs.

nance (CM), and CBM [14]. PM can be also regarded as time-based maintenance because maintenance activities are regularly conducted according to a scheduled time interval for the components of OWTs, which have two contradicting issues, namely, undermaintenance and overmaintenance. Undermaintenance leads to unexpected failures, which occur when the performance of the OWTs is not properly monitored. Overmaintenance can waste resources because maintenance activities are excessively conducted to eliminate unplanned down events. CBM, as an advanced maintenance strategy, is based on the performance and subsequent actions of OWTs [15], and the maintenance decision is made based on collected condition monitoring data from OWT components, such as temperature, acoustic emission, vibration, and oil analysis data [16,17]. The maintenance costs of OWTs can be reduced by undergoing PM only when necessary by leveraging condition monitoring information. Other components with high risks of failures can be maintained simultaneously when a turbine is stopped for maintenance given the economic dependence. Economic dependencies can be either positive or negative. Positive economic dependence implies that costs can be minimized when several components are jointly maintained instead of separately. Negative economic dependence between components occurs when the maintenance dates are advanced, thereby leading to the reduction of the service life of components. The objective of opportunistic CBM strategy for OWTs is identifying the time and component that should be subjected to PM based on the condition monitoring data to minimize the long-term expected cost; the obtained maintenance planning is frequently nonperiodic.

This paper proposes a CBM method that can be used to minimize the maintenance cost of OWTs. The proposed method, which allows evaluating the degradation of OWTs, is based on artificial neural network (ANN) for predicting life percentage, as proposed by Tian et al. [18]. A conditional failure probability value on the basis of the predicted failure-time distributions of components was adopted to represent OWT deterioration. Our maintenance method is defined by a threshold with two-level failure probability. To minimize the long-term maintenance cost, an optimization procedure is performed to obtain the optimal threshold values. The decisions on the time at which a maintenance team should be sent to the offshore wind farm and the components that should be maintained can be made based on the condition monitoring information. Failure information and maintenance cost are collected from existing articles to illustrate the proposed approach. A comparative study is presented to illustrate the effectiveness of the proposed method, and the expense comparison between onshore and offshore WTs demonstrates the importance of the CBM strategy for OWTs.

In the present research, a CBM policy is proposed to optimize maintenance cost for OWTs. The proposed method which allows evaluating the degradation of OWTs is based upon the ANN for predicting life percentage suggested by Tian et al. [18]. A conditional failure probability value based upon the predicted failure time distributions of components was adopted to represent the deterioration of OWTs. Our maintenance policy is defined by a threshold with two-level failure probability. To minimize the long-term maintenance cost, one optimization procedure is performed to obtain the optimal threshold values. The decisions on when a maintenance team should be sent to the offshore wind farm and which components should be maintained can be made based on the condition monitoring information. Failure information and maintenance cost are collected from previous literatures to illustrate the proposed approach. Comparative study is presented to illustrate the effectiveness of the proposed method and the necessity of OWTs CBM strategy is demonstrated through the expense comparison between onshore and offshore WTs.

2. System description and assumptions

2.1. System description

An OWT system consists of various components, which guarantee the performance of the entire system independently or in auxiliary. Carroll [8] analyzed the failure rate, repair time, and maintenance cost of OWTs. All of these statistics are based on 350 OWTs between 3 and 10 years old and are from 5 to 10 wind farms in Europe. The nominal power is from 2 MW to 4 MW, while the rotor diameter is from 80 m to 120 m, as a guide to the size of

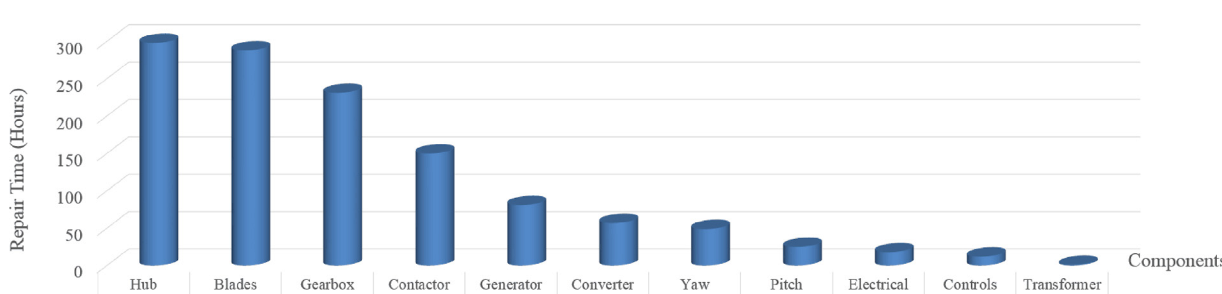

Fig. 2. Repair Time for main components of OWTs.