Optimal maintenancestrategy for wind turbines

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Abstract- Awind turbine (WT) maintenance strategyis examined in this research. In fact, this approach is usually used. It involves monitoring the (WT) temperature, to ascertain its condition. Once a predetermined temperature has been reached, the (WT) automatically slows its output rate to prevent damaging its components. In the process, a built-in cooling mechanism begins temporarily cooling the (WT) until it resumes energy production at a normal output rate. As the occurrence of the problem increases over time, the (WT) technicians will search for the defective component or components to either replace it with a brand-new one or subject it to an inspection.

Ananalytical modelis developed in this paper, the latter balances the charge of cooling the (WT) and the charge of production loss linked to that matter every time the worrying temperature is surpassed, the cost of the new components, and the logistical charge related to it in order to maximize the components renewal period

Keywords – Wind Energy, Optimization, Maintenance Strategies, Wind Turbines, Renewal strategy.

I. INTRODUCTION

One of the most significant renewable energy sources is wind power Márquez et al. (2020). Over the past few decades, wind energy became one of the most used renewable energy in the word Pellerin. (2005).According to the Global Wind Energy Council. (2021) and the Electricity Global Market Report. (2022) the generated wind power reached over 743 GW in 2021 making the electricity market attain its highest levels of $89.66 billion.

Based on J. Wang et al (2020) recent study, wind turbines are complex electromechanical systems. Thereprimary function in the production of wind energy is to use an electrical generator attached to a gearbox to convert air movement into electrical energy Hajej, Z.et al. (2020). To insure and increase the availability of wind resources, wind turbines are typically located in rural areas, where they are exposed to continually shifting weather patterns that quickly change the temperature, air pressure and overall load. These variations force the components to operate under high and fluctuating mechanical stress. According to Liu, Z. et al. (2020), high loads can readily destroy (WT) components such as bearings in certain extreme climatic circumstances. As a result, the wind industry experiences early failures of the primary components. For instance, early bearing cracks have been discovered after less than three years of operation, or 5–10% of the expected life Liu, Z. et al. (2020).

Due to this, maintaining wind turbines and increasing their dependability and availability became priority targets for the wind industry. Since it ensures not only a continuous revenue generation but a reduction in electric power drawn from non-renewable and more polluting sources Tamilselvan, P. et al. (2012).However, the operation and maintenance (OM) activities of wind turbines are the primary contributors for the wind energy costs as they represent 25% to 30% of the cost of producing wind energy Márquez et al. (2012). (OM) expenses have become significant barriers to achieving higher economic returns. Therefore, optimizing these costs aims to save expenses while maintaining availability and reducing downtime that generally results in large revenue losses.

The majority of (WT) maintenance consists of failure-based procedures that can be expensive as well as time-based activities carried out at regular and planned intervals. Little attention is given to whether the maintenance procedures or the activities they are connected with are appropriate, cost-effective, or necessary Baglee, D et al. (2016).

Routine equipment inspections, oil and filter changes, sensor and actuator calibrationand consumable replacements like brake pads and seals are typical preventive activities expected to be carried out on wind turbines. In the maintenance instructions provided by the turbine maker, the precise procedures and their frequency are frequently spelled out explicitly. The extensive range of potential component failures, including bearings, torque arms in gearboxes, drive electronics, and power electronics, implies that the operating and maintenance conditions are not fully known; meaning that prices for planned maintenance may be calculated quite precisely, but they may change depending on the cost of labor in the area, the accessibility of the site, and other factors Walford, C. A. (2006), for instance, a rebuilt gearbox will be three to four times as expensive compared to one for a 660 kW turbine and very probably require a lattice-boom crawler crane.

As a conclusion, it is imperative to research, to study and to develop new optimal maintenance strategies for wind turbines (WT). In his paper Igba et al. (2015) provided an approach for determining the appropriate PM period needed in order to maintain the desired reliability of a typical module or subassembly. This method makes use of past failure data. The authors show how history in-service failure data may be utilized to select PM tasks that have the lowest possible maintenance costs and the maximum possible availability.

Another (WT) preventive maintenance (PM) approach that considers the effects of wind speed, various (WT) failure types, and numerous maintenance procedures was put up by Zheng et al. (2020). Finding the most effective maintenance strategy for lowering the long-term average cost rate was the aim of their investigation. Serving the same purpose, a PM policy was presented by Raza and Ulansky (2019) and is based on imperfect continuous condition monitoring of (WT) components. According to the results of ongoing condition monitoring of degrading (WT) components, their research provides a mathematical model for calculating the probability of making the right and wrong judgments.

Last but not least Rasekhi Nejad et al. (2014)presented a reliability-based maintenance strategy for (WT) components. It is developed to target on the components with a higher risk of fatigue failure and a lower degree of reliability. This study's main objective is to provide a method for making a "vulnerability map" that maintenance teams might use to spot parts with lower reliability.

To the best of our knowledge, no optimal strategy for renewal of (WT) components has been provided. This paper's primary contribution is the development of such ideal maintenance policies.

This research was motivated by a maintenance issue that several (WT) operators encountered when servicing their wind turbines. These businesses have been keeping the (WT) in good working order by simply cooling it down whenever its temperature reaches a critical predefined threshold. Then, based on the maintenance agents' discretion, the damaged component is replaced with a new one that is identical after a predetermined number of cooling actions. While cooling does not help to lower the age or the failure rate of the (WT), it does cause the (WT) to operate at a lower speed, which results in a loss of production. In order to maximize the renewal period of the degraded component or components using this approach, it is our goal to establish an analytical model that balances the costs of production loss, cooling, and the cost of renewal.

The remaining sections of the article are structured as follows. The description, mathematical modeling, and optimization of the renewal policy are covered in the next section. In the final section, conclusions and future directions for research are going to be presented.

II.OPTIMAL RENWAL STRATEGY

A. Problem description –

Our interest in the issue of (WT) maintenance is a result of worries expressed by wind farm operators. The (WT) is frequently subjected to unpredictable stress variations because of the changing wind speed. Frequently, the temperature inside a (WT) will rise dramatically. The components of the (WT) are degrading more quickly as a result of this matter. Due to that, the (WT)'s current maintenance strategy involves keeping an eye on its condition by measuring its temperature. The (WT) is slowed down, reducing the pace at which energy is produced as a result, and it is cooled for a predetermined amount of time before returning to the desired output rate. The (WT) operators will choose to replace the damaged component or components depending on the situation with a new one that is identical to it or undertake an overhaul that results in a condition that is as good as new. Unfortunately, this incidence occurs more frequently over time, generating significant production losses.

The renewal's timing is determined only by the operator's judgment, sometimes it can be too early for the renewal action as much as it can be so late. As a result, our goal in relation to this renewal policy is to improve the decision process about the time of the components renewal bydeveloping a mathematical model to ascertain the best period of renewal PR* for these components while balancing the costs of production loss and cooling whenever the threshold temperature is reached with the cost of renewal, all of that in order to minimizes the overall cost of maintenance OCM*.

To determine the period PR*, many inputs were taking into consideration such as the average cooling operation cost CCO, the average nominal cooling period CP, the average cost of new components CNC and the logistic cost COL related to the renewal action such as transportation from and to the different sites, usage of dedicated equipment like cranes, and specific tools.

B. Analytical model –

The overall cost of maintenance per time unit will be expressed as a function of the decision variable which is the renewal period PR. The cost of cooling, revenue losses RL from operating at a lower capacity while cooling is being done, and the cost of renewal COR, which accounts for the cost of new components and the logistics of the renewal operation, are all included in the mathematical model. The logistics involved in the renewal operation include the transportation of the maintenance team as well as the assembling, putting in place, and disassembling of all required heavy and light equipment.

Additionally, by cooling the (WT) for a predetermined amount of time, the system can resume operating at the desired output. It does not, however, lessen the frequency of (WT) component failure. Therefore, we regard all cooling procedures carried out in between renewals as minor repairs.

C. Notation –

The used notation is shown below.

TABLE1. NOTATION

PR	**Renewal period (Decision variable)**
CP	Average nominal cooling period
RL	Estimated renewal charge
COR	Average revenue loss per time unit
CCO	Average cooling operation cost
□(t)	Function of the component system's realistic rate of failure
COL	Renewal action's logistics cost
OCM(T)	Overall cost of maintenance per time unit

As a result, the following is the formulation of the overall cost of maintenance per time unit.

$$\text{OCM(t)} = (\text{COR x CP} + \text{CCO}) \text{ x } \left(\int_0^T \lambda(t)dt\right) + (\text{RL} + \text{COL}) /\text{PR} \quad (1)$$

II. EXPERIMENT AND RESULT

A. Numerical example –

Equation 1 has been developed to reflect the overall maintenance cost per time unit, and by employing the MATHEMATICA® (V10.2-2015) software, the optimal renewing time has been established for each scenario of the issue given a collection of input criteria. The example given below is just one of many numerical ones we used to evaluate the model.

A Weibull distribution defines component failure rates. Because of its many established applications, the latter was chosen. The failure rate is addressed in the way that follows:

$$\lambda(t) = \left(\frac{\beta}{\alpha}\right)\left(\frac{t}{\alpha}\right)^{\beta-1} (2)$$

The table 2 displays the input data that were utilized.

TABLE2. Data Input

β	Shape parameter β=2
α (h)	Scale parameter α = 200
RL	1100
COR	2000
CCO	20000
□ (t)	800
OCM(T)	11

TABLE 3. The optimal renewal period obtained and its according minimum expected total cost per time unit

PR*	**OCM***
245 Weeks	171.26 Euro/Weeks

Every 245 weeks (R* = 245 weeks), or every 4.5 years, the components would need to be replaced with new, identical ones according to the recommended renewal approach.

IV.CONCLUSION

The maintenance issues that (WT) operators were having with certain components served as the imputes for the research. Simply allowing the (WT) to cool down on its own whenever its temperature crosses a critical level has allowed them to keep it in operating condition. Following many cooling processes during which the (WT) produces less electricity, the components of the (WT) are replaced with new, identical ones. The renewal time is decided by the maintenance agents' discretion.

Enhancing the renewal time is essential for such businesses due to the large costs involved, particularly the cost of replacing the (WT) components. Therefore, a mathematical model has been developed and used to express the overall cost of maintenance per time unit as a function of the renewal period PR. The ideal renewal period for every PR* (WT) component can be determined using this formula. Additional related research is now being done with the goal of reducing the (WT) failure rate to a number between the current rate and the rate of a brand-new identical one by performing an imperfect (PM) action each time the temperature threshold is met.

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