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Assessment of Wind Turbine Reliability Using Block Diagram Model

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Abstract
The present study analyzes the reliability parameters of a wind turbine system using a statistical / simulation approach. To this end, the Reliability block diagram has been used for modeling the problem which has the capability of analyzing complex systems with a high number of components while providing simplicity and transparency in the concept presentation. For the modeling and simulation, RAM Commander software developed by the ALD software company was utilized. The block diagram model was developed considering a series arrangement (8 subsystems and 94 components) and taking into account the probability distributions of failure time, repair time, and other reliability data for each block. results were then obtained by implementing the Monte Carlo algorithm. The results of this study contain the values of reliability, availability, and failure rate for a turbine during its lifetime. According to the results, the average availability of a turbine over a 20-year life span was more than 0.999. At 25 points, the turbine needed repairs, and the mean time between failures was calculated to be 7008 hours. The mean time between the system's critical (catastrophic) failures is 77928 hours. Also, the sensitivity analysis of the model is carried out.

Keywords: Reliability Analysis, Wind Turbine, Reliability Block Diagram Model, RAM Commander Software, Renewable Energy

1. Introduction

Renewable energy sources, including wind, solar and geothermal, are clean and renewable alternatives to fossil fuels and will contribute to the sustainable development of societies. Wind energy is one of the largest and most reliable producers of renewable electricity and its utilization is increasing rapidly worldwide. The capacity of installed wind farms has grown by 10.8% in 2017 and by 9.1% in 2018 [1]. Due to the increase in the application of wind energy, numerous subjects related to wind turbine performance such as turbine components fatigue, components failure, reliability and availability of the system, and operation and maintenance require further investigations.

The reliability of wind turbines has been investigated in recent years in the literature. The IEA report on wind energy is divided into several sections. Section 33 [2] describes how to collect and classify turbine failure statistics in studied countries, and introduces a plan for creating a comprehensive library of wind turbine reliability data. National Renewable Energy Laboratory (NREL) analysis on wind turbine subsystems reliability is one of the latest research in this field [3]. Supergen report analyzes the factors affecting the failure of offshore wind turbine components. According to the report, 75% of failures lead to only 5% of system downtime, and 25% of failures will cause the remaining 95% of downtime [4].

This study proposes a new methodology for numerical and graphical modeling of wind turbine reliability using the block diagram (RBD) model. The model is a powerful tool for predicting important reliability parameters such as availability, failure rate, and the time between turbine failures. Additionally, sensitivity analysis and the impact of components arrangement on system performance can be evaluated using the model.

2. Material and method

The RBD model is based on a network of blocks that represents the components of the system and the blocks contain failure information of the components. In the model developed for this study, all subsystems and components are in series arrangement and parallel arrangement is not used. Figure 1 shows the subsystems of the 2 MW turbine studied in this paper. The wind turbine consists of 8 repairable blocks that represent the subsystems and a total of 94 components.

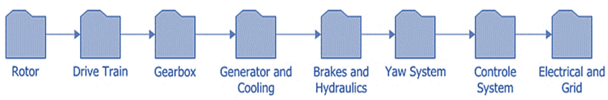

Figure 1. subsystems of wind turbine

The main assumptions considered in the modeling

process are as follows:
All components are repairable. Repairing each component requires a different amount of time and cost and is done by one worker at a time. It is assumed that workers are always available and the average time for each worker to reach the failed component is 1 hour. Spare parts are always available and no delay is considered in the supply of the parts.
The input parameters for the simulation are given as follows:

- simulation is done at a 20-year interval (lifetime of the turbine)
- results were collected every 876 hours (36.5 days)
- failure data are according to the 2013 NREL report [5,6].

3. Results and Discussion

3.1. RBD model simulation

According to Fig. 2, the average availability of a wind turbine is 0.999 in its lifetime. At 25 points, the availability value drops to less than 1, indicating component failure and repair. The mean time between failure (MTBF) for the whole system is 7008 hours. Also, the mean time between the system's critical failures (MTBCF) is 77928.7 hours.

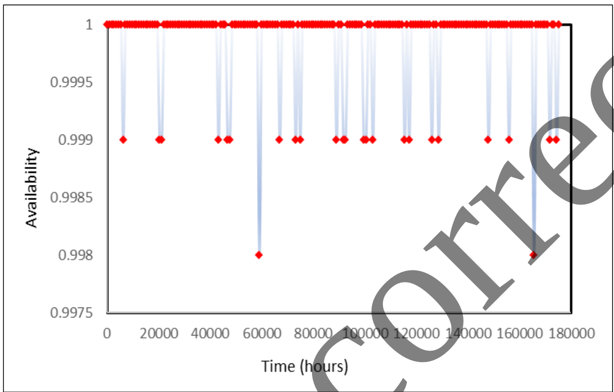

Figure 2. Availability of wind turbine

Eq.1 demonstrates the reliability function of the wind turbine time. The value of R^2 for the curve fitting is 0.999.

$$R_{(t)} = 4 \times 10^{-31} t^6 - 2 \times 10^{-25} t^5 + 4 \times 10^{-20} \; 3 \times 10^{-15} t^3 + 3 \times 10^{-12} t^2 - 2 \times 10^{-0.6} + 1.0035 \quad (1)$$

where R(t) and t(s) are reliability function and time, respectively.

3.2. Parametric study

The effect of component's maintainability on the availability of the whole system has been investigated. According to the results, reducing the maintainability (increasing the delay time) leads to lower availability (Eq.2).

$$A_{(t)} = -0.0011t + 0.9939 \quad (2)$$

In addition, the relation between the failure rate of components and system downtime is studied. Increasing the failure rate of the turbine's gearbox results in longer downtime of the turbine.

4. Conclusions

A reliability block diagram model is developed and utilized in this study to predict and analyze the reliability parameters of a wind turbine. The main findings of this study are as follows:

- the average availability of the wind turbine is 0.999 over its 20-year lifetime
- The mean time between failure (MTBF) for the whole system is 7008 hours.
- Both Decreasing the component's maintainability and increasing the component's failure rate reduces the wind turbine's availability.

The RBD model and methodology elaborated in this research can be employed to perform reliability analyses for various complex renewable energy-based systems.

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