Fault Tree Analysis Of Wind Turbine Gear Box

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Abstract- With the growth of wind energy in the energy arcade, the design and execution of larger wind turbines has become a common occurrence. Unfortunately wind turbines have been overcome by a series of premature gearbox and drivetrain failures well in advance of the expected 20 year design life. With larger wind turbines, the cost of gearbox reconstructs, as well as the down time related with these failures consumes significant portion of the cost of wind power. In an effort to address and mitigate this problem, the possibility of reliability block diagrams and fault tree analysis of gear box in wind turbine is used. For fault tree, the series and parallel configurations are used. Gear box components and its sub components are considered for reliability calculation. In sub components, faults are varied. Based on failure rate, the series and parallel configurations are varied. The overall reliability equation of gear box is derived in this paper.

Keywords: Wind turbine, Gear box, Fault tree, Reliability

1. INTRODUCTION

Early wind turbine designs were troubled with fundamental gearbox design errors compounded by consistent under-estimation of the operational loads [1]. These problems has learned from industry over the past two decades with wind turbine manufacturers like bearing manufacturers, gear designers, consultants, and lubrication engineers all working together to improve load expectation, design, operation and fabrication. This collaboration has resulted in globally recognized gearbox wind turbine design standards [2]. Since gearboxes are one of the most expensive components of the wind turbine system, the higher than predictable failure rates are adding to the cost of wind energy.

Most of the problems with the current fleet of wind turbine gearboxes are general in nature, meaning that the problems are not exact to a single gear manufacturer or model of turbine. Over the years, most wind turbine gearbox designs have converged to a similar architecture with only a few allowances. Therefore, there is an opportunity to collaborate among the many stakeholders in the wind turbine gearbox supply chain to find root causes of failures and investigate solutions that may advance the collective understanding of the manufacturers.

Most gearbox failures do not begin as gear failures or gear-tooth design deficits. The observed failures appear to initiate at a number of specific bearing locations under certain applications. In later advance the gear tooth bearing debris and excess clearances cause misalignment and surface wear. Field-failure assessments indicate that up to 10% of gearbox failures may be manufacturing abnormalities and quality issues that are gear related but this is not the major source of the problem. The majority of wind turbine gearbox failures act to initiate in bearing area. These failures are occurring in spite of the fact that most gearboxes have been designed and developed using the best bearing-design practices available.

Most turbines in the market today follow a modular configuration comprised of a main shaft, gearbox, high speed shaft, and generator. Gearbox has the important task of increasing the slow rotor speeds to meet electromechanical requirements. These gearboxes are commonly composed of a planetary stage and several parallel shaft stages. The epicyclical, or planetary, design of the gearbox has many advantages compared to the traditional parallel shaft arrangement. Higher gear ratios can be achieved in a single stage, they are accomplished to carrying higher loads, and require less space than the traditional parallel shaft arrangement. For this intention, planetary gearboxes are commonly used in the first stage of wind turbine gearboxes. However, planetary stages are further complex than the typical parallel shaft arrangement and can be affected by deformation in the annulus, planet carrier deflections and bearing clearances. Unexpected levels of these motions can reduce their life expectation. This paper gives a brief overview of fault and reliability calculation of planetary gear box (1.25 MW) wind turbine.

2. APPROACHES OF SYSTEM RELIABILITY

In theory and in practical exists two basic approaches

• Analytical calculations

1. Static analytical calculations
2. Time-dependent calculations
   • Simulation calculations

Two types of analytical calculations can be performed using RBD or FTA: static reliability calculations and time-dependent reliability calculations. Systems can contain time-dependent blocks static blocks or a mixture of the two. Static analytical calculations are performed on RBD or failure trees that contain static blocks. A static block can be inferred either as a block with a reliability value that is known only at a given time (but the block’s entire distribution is unknown) or as a block with a probability of attainment that is constant with time [3].

Static calculations can only be performed in the analytical mode and not in the simulation calculations. The time-dependent analysis looks at reliability as a function of time. That is called a known failure prediction, is assigned to each component of wind turbine. The time scale can be any computable time measure, such as hours, months, years, seconds or minutes, and also units that are not directly related to time. It includes information on the repair and maintenance characteristics of the components and resources available in the system. Some of other information can also be analyzed/obtained, such as i.e. system availability, maintainability etc. This can be accomplished through discrete event simulation [3].

3. Fault Tree Analysis

Fault trees and reliability block diagrams are both symbolic and analytical logic techniques that can be applied to analyze system reliability and its interrelated characteristics. Fault tree and reliability can also be used to describe the interrelation between the components to define the characteristics. These blocks are connected with direction lines, that represent the reliability relationship between these blocks, it’s denoted as reliability block diagram (RBD). Fault tree diagram follows a top-down structure and represents a graphical model of the pathways within a system that can lead to a predictable, undesirable loss event. The pathways interconnect related events and conditions using standard logic symbols (AND, OR, etc.). Fault tree diagrams consist of gates and events connected with lines. RBD example is depicted on Fig.3.1.

![Fig.3.1 Example of reliability block diagram](image1)

The most fundamental difference between fault tree diagrams and reliability block diagrams is that you work in the "success space" in an RBD while you work in the "failure space" in a fault tree. The RBD looks at success combinations while the fault tree looks at failure combinations. In addition, fault trees have traditionally been used to analyze fixed probabilities. RBD include time-varying distributions for reliability equation and other properties such as repair or re-establishment distributions. In general a fault tree can be easily converted to an RBD. on Fig.3.2 is converted RBD from Fig.3.1.

![Fig.3.2 Example of fault tree](image2)

3.1 Serial configuration

Components with in a system may be related to one another in two primary ways: in either a series or parallel configuration. In series all component must function for the system to function.A parallel, or redundant, configuration has at least one component must function for the system to function. In the discussion that follows, all components are considered critical in the sense that their function must be performed in order for the system to continue to perform. In this concept, if either of two serially related components fails, the system will fail. The series relationship is represented by the block diagram of Fig.3.3. For serial configuration (OR) gate is used which is formulated as $R = R_1 R_2 R_3 \ldots [4]$.

![Fig.3.3 Reliability block diagram for components in series](image3)

3.2 Parallel configuration

Two or more components are in parallel, or redundant, configuration if all units must fail for the system to fail. Uncertainty one or more units operate, the system continues to operate. Parallel units are represented by the block diagram of Fig.3.4. For parallel configuration the logic gate (AND) is used, which can be formulated as $R = [1 - (1-R_1) (1-R_2)(1-R_n)]$.

![Fig.3.4 Reliability block diagram for components in parallel](image4)
4. FTA of gear box

The rotor turns the low-speed shaft at speeds ranging from 20 revolutions per minute (rpm) on large turbines to 400 rpm on residential units. Transmission gears increase the speed to the 1200 to 1800 rpm required by most generators to produce electrical energy. The planet carrier has the important structural task of maintaining the annulus-sun-planets’ center distances and alignments, it will also transferring the input loads to the different components of the planetary stage in gear box. Due to the high and varying loads and the light weight requirements of wind turbine gearboxes, the planet carrier is susceptible to deflections that could affect the performance and life of the planetary stage.

A problem present on wind turbine gearboxes is planet bearing failure. This can be attributed to many factors such as low lubricant film thickness due to low speeds and high loads, poor roller load distribution due to planet deformation, misalignment, and poor bearing load distribution among others. Intended for this reason, the exploration of bearing life reduction due to poor bearing load distribution resulting from planet carrier pin misalignment was worthy of further exploration. FTA gear box is represented in Fig. 4.1 and Fig. 4.2.

The individual component reliability and over all reliability of wind turbine is calculated as:

\[ R_A = [1 - (1 - R_1) (1 - R_2)] \]

\[ R_B = R_3 R_8 \]

\[ R_C = [1 - (1 - R_4) (1 - R_5)] \]

\[ R_D = [1 - (1 - R_6) (1 - R_7)] \]

\[ R_E = R_9 R_8 R_7 R_6 (R_4 R_5 R_10) \]

\[ R_F = [1 - (1 - R_11) (1 - R_12)] \]

\[ R_G = [1 - (1 - R_13) (1 - R_14)] \]

\[ R_H = R_9 R_8 R_7 (R_4 R_5 R_17 R_18 R_19) \]

**CONCLUSION**

The purpose of this paper was to show possibility of reliability block diagrams and fault tree analyses. The fault tree to reliability block diagram is easily developed. The overall reliability of gear box equation is represented. For reliability value the experimental analysis, field data or expert’s knowledge is used to find out life of gear box.

**REFERENCES**


