

Reliability Analysis of the Wind Turbine System

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ABSTRACT: Renewable energy sources like wind energy are copiously available without any limitation. Wind turbines are used to tap the potential of wind energy. The wind power has expanded greatly during the past few years, has served a growing market and has spanned the development of larger wind turbines. Reliability of wind turbine is critical to extract the maximum amount of energy from the wind. In this paper, the work is being carried out to check the Reliability analysis, this data is collected from the region of Dhule, Maharashtra which is the 1000 MW capacity project set up under the Suzlon Wind Energy. The data is collected from the site and various calculations have been carried out in this thesis using FTA for the reliability. For determining the Reliability it is very important to find out the Mean time between failures, (MTBF) of the different failures that causes the total shut-down of the system. After finding the reliability, the probability of the system is found out so that FTA should be verified. FMEA process is way to indentify the failures, effects, and risks within a process or product and then eliminate or reduce them. The relative risk of a failure and its effects is determined by three factors: severity, occurrence and detection. Then RPN is calculated for each potential failure and effect. After taking the remedial measures it has been found that the reliability of the system increases and the occurrence of the system decreases which directly reduce the RPN index. The work conceded in this thesis had never been proposed by plant personnel and promoter.

KEYWORDS: Mean time between failures (MTBF), Fault Tree Analysis (FTA), Risk Priority Number (RPN), Failure Mode and Effect Analysis (FMEA).

I. INTRODUCTION

The wind power industry has diverse during the past few years and the growth has mainly concentrated on a growing market and the development of larger wind turbines. Different designs have emerged and the technical knowledge makes it possible to put wind turbines off shore [1]. The fast expansion of the wind power market has also come with some obstacles. There is a notable need for improved reliability in the design, manufacturing quality, operation, and maintenance of wind turbines. Industry and others have acknowledged the importance of reliability in the continued growth and enlargement of markets for wind turbine technology. Reliable operations are critical for the hostile environments where turbines are sited and the impacts of reliability (or unreliability) are broad, ranging from economics to betterment of designs [2]. Reliability can be interpreted as the probability that a product will execute its intended function under stated condition for a specified period of time. Reliability analysis had a great influence on safety if the number of hazardous actions can be reduced through decreased failures rates and improved reliability. Early wind turbine designs were troubled with fundamental gearbox design errors confined with under-estimation of the operational loads. As we know gearbox is the most costly component of the wind power system, higher than the predictable failures rates are enumerating to the cost of wind energy. Gearbox failures do not begin as gear failures or gear-tooth design deficits. The majority of wind turbine gearbox failures act to initiate in bearing area. Gearbox has the prominent work for increasing the slow rotor speed to meet electromechanical requirements. Gearbox composed of planetary stage and several parallel shaft stages [5].

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- There are various methods for calculating the reliability analysis of wind turbine system one of them is the fault tree analysis and FMEA. Fault tree analysis and FMEA both are symbolic and analytical logic techniques that can be implemented to analyse system reliability and its associated characteristics.
- Review the process or product.
- Then, brainstorm potential failure modes.
- Make the list of potential effects of each failure mode.
- A severity Ranking is assigned for each failure mode.
- After that detection ranking for each failure mode or effect is assigned.
- Calculate the RPN for each effect.
- Prioritize the failure Modes for Action.
- Take action to eliminate or reduce high risk failure modes.
- Calculate the RPN again as the failure modes are reduced or eliminated.

II. PRESENT WORK

The work in present includes the case study of the Wind Farm (Dhule) Maharashtra to check the reliability of some of the components used in the wind turbine system by doing various calculations using the FTA and FMEA method. The fault tree analysis used to describe the complete set of system failures. The most popular and diagrammatic technique that is FTA, is used to analyse the undesired states of a system using AND gate and OR gate. The main indentified failures modes in the wind turbine sub-assemblies are listed as: fatigue, cracked, deterioration, misalignment, loose, deformed, collapse.

If the technique is being applied one should take the necessary steps:

- Using the list of information required for assessment, one should define the system that will be focused of the FTA.
- Identify what should be for the system either by indentifying the system purpose or goals or by defining the criteria.
- Then identify the factors that are in the top undesired event and that could be causing it.
- Working with an expert team on the system, build the fault tree and determine the top undesired event to identify the underlying causes. Write the top undesired event at the top of the tree.
- Look at each of the key factors identified in the previous step. Indentify the sub-factors and place them underneath the appropriate factor on the tree.
- Continue with the procedure building the tree like graphic until there is a general consensus that the tree is finished.
- Once the fault tree had been completed work with experts to carefully and systematically analyse it for accuracy. Compare the fault tree factors and structure against the actual system being analysed.
- Analyse the fault tree. The analysis done systematically through informal methods. To analyse quantitatively to determine the probability of all the contributing factors.
- By drawing the analysis one should be able to identify the potential factors for the performance problem that can be identified at the top undesired event.
- Focus particularly on the factor that appears lowest in the tree and apply remedial measures to rectify it.

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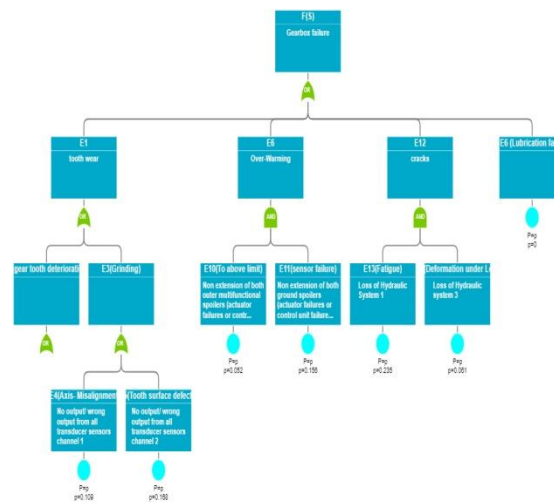


Fig. 1. Fault Tree Diagram of Gearbox Failure

The fault tree diagram of Gearbox determines the various defects and the reasons due to which it causes the failure of the over-all system. The diagram of Gearbox is constructed using Free Web fault tree Analysis (FTA) software tool. It calculates the probability and constructs the diagram with the help of logic gates.

S.NO	Failure Cause	No of failure	Failure time(t)	MTBF	Failure Rate(λ)	Reliability $e^{-\lambda t}$	Probability of Failure $P(t)=1-R(t)$
1	Tooth surface	20	80	434	2.30×10^{-3}	0.831	0.168
2	Axis Misalignment	10	100	866	1.15×10^{-3}	0.891	0.109
3	Gear-tooth deterioration	12	30	727.5	1.37×10^{-3}	0.959	0.041
4	Deformation under load	9.1	60	956.04	1.04×10^{-3}	0.939	0.061
5	Particle combination	9	30	970	1.03×10^{-3}	0.969	0.031
6	To above limit	9.27	50	939.5	1.06×10^{-3}	0.948	0.052
7	Sensor Failure	9.8	150	878.5	1.13×10^{-3}	0.844	0.156
8	Fatigue	9.18	250	927.01	1.07×10^{-3}	0.762	0.235
9	Oil Filtration	20	80	434	2.30×10^{-3}	0.831	0.168

Table 1:- Depicts the values of the failure rate and outage time which helps in calculating the MTBF of the system. The MTBF is defined as the mean time between failures and is used to calculate the reliability which is the ultimate criteria.

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III. FTA METHOD AND CALCULATION FOR GEARBOX FAILURE

From the codes assigned in the fault tree analysis of gearbox we can calculate the probability of the system as under:

E1=Tooth-wear, E2=Gear-tooth deterioration, E3 =Grinding of teeth, E4=Axis Misalignment, E5=Tooth-surface defects, E6=Lubrication fault, E7=Oil filtration, E8=Particle combination, E9=over-warming of oil, E10= To above limit (power supply), E11= Sensor failure, E12= cracks, E13=fatigue, E14=Deformation under load.

$$(E3) \text{ or } Pr (\text{ Grinding }) = E4 \quad E5 \quad (\cap = \text{ And }) (= \text{ or }) \quad \dots 1$$

$$Pr (E3) = Pr (E4).Pr (E5) \quad \dots 2$$

As we know the values of E2 and E3 from the table above, assigning the values we will get:

$$Pr (E3) = (0.891) (0.8319)$$

$$Pr (E3) = 0.740. \quad \dots 3$$

$$Pr (E2 \cap E3) \quad \dots 3$$

$$= Pr (E2) + Pr (E3) - Pr (E2) \quad \dots 4$$

$$Pr (\text{Tooth-wear}) = E2 \cap E3 \quad \dots 5$$

$$= (0.041) + (0.740) - (0.041 \times 0.740)$$

$$= 0.781-0.030$$

$$= 0.751. \quad \dots 6$$

$$E6= E7 \cap E8 \quad \dots 7$$

$$Pr (E6) = Pr (E7) Pr (E8) \quad \dots 8$$

$$= (0.168) (0.031)$$

$$= 5.208 \times 10^{-3} \quad \dots 9$$

$$E9= E10 \cap E11 \quad \dots 10$$

$$Pr (E9) = Pr (E10) Pr (E11) \quad \dots 11$$

$$= (0.052) (0.156)$$

$$= 8.112 \times 10^{-3} \quad \dots 12$$

$$E12 = E13 \cap E14 \quad \dots 13$$

$$Pr (E12) = Pr (E13) + Pr (E14) - Pr (E13 \cap E14) \quad \dots 14$$

$$= (0.235) + (0.061) - (0.235) (0.08) \quad \dots 15$$

$$= 0.296 - 0.014$$

$$= 0.282 \quad \dots 16$$

$$Pr (\text{ Gearbox failure }) \text{ or } F(s) = [Pr (\text{ tooth Wear }) \cap Pr (\text{ Lubrication fault })] \cup [Pr (\text{ over-heating }) \cap Pr (\text{ crack })]$$

$$= [Pr (E1) + Pr (E6) - Pr (E1 \cap E6)] \cup [Pr (E9) + Pr (E12) - Pr (E9 \cap E12)] \quad \dots 17$$

$$= \{ [Pr (E1) + Pr (E6) - Pr (E1 \cap E6)] + [Pr (E9) + Pr (E12) - Pr (E9 \cap E12)] \}$$

$$- \{ [Pr (E1) + Pr (E6) - Pr (E1 \cap E6)] \times [Pr (E9) + Pr (E12) - Pr (E9 \cap E12)] \} \quad \dots 18$$

$$= \{ [(0.751) + (5.208 \times 10^{-3}) - (0.751) \times (5.208 \times 10^{-3})] + [(8.112 \times 10^{-3})$$

$$+ (0.282) - (8.112 \times 10^{-3}) \times (0.282)] - \{ [(0.751) + (5.208 \times 10^{-3}) - (0.751)$$

$$(5.208 \times 10^{-3}) \times [(8.112 \times 10^{-3}) + (0.282) - (8.112 \times 10^{-3}) (0.282)] \}$$

$$= [(0.756-3.91 \times 10^{-3}) + (0.290-2.28 \times 10^{-3}) - (0.752 \times 0.287)]$$

$$= (1.039-0.215)$$

$$F(s) = 0.824 \quad \dots 19$$

$$\text{Hence, the Reliability } F(s) = 0.176 \quad \dots 20$$

From the above calculation it can be concluded that the reliability of the gearbox is quite less and it need to improve by taking proper measures of prevention methods.

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IV. FMEA FOR GEARBOX

Failure and effect analysis of the Gearbox carried out with effect on wind turbine and failure cause. The FMEA with the detection values, occurrence and severity shows the higher values of RPN.

SYSTEM DATE SHEET		N-GF Gearbox Failure 24/12/2017 1 of 1					
FUNCTION: It is used to change the speed and torque according to the load conditions							
Failure cause	Effect on WT	Failure Cause	Detection Method	O	S	D	RPN
Gearbox failure	<ul style="list-style-type: none"> System Failure Effect on Gearbox Grid loss Shut-down 	<ul style="list-style-type: none"> Tooth surface contact fatigue Axis Misalignment Gear-tooth deterioration Grinding Lubrication Design Cracks due to bending moments 	<ul style="list-style-type: none"> Visual Inspection Wear debris Analysis Vibration analysis Oil debris Analysis 	4	8	7	224

Table 2 :- FMEA Spreadsheet of the Gearbox Failure

V. RESULTS AND DISCUSSIONS

In this paper the reliability of the turbine system is analysed. The various calculations has been done on the three main components of the turbine system first is the Gearbox then the Generator and lastly the wind turbine blades. The calculations to analyse their reliability and equally finding the probability using first the FTA method and then with the help of the FMEA their RPN is calculated. The FMEA is a systematic procedure in indentifying the modes of failure and evaluating their consequences. The essential work of an FMEA is to consider the major part of a system how it fail, detection method and the prevention method.

VI. THE RELIABILITY ANALYSIS OF THE GEARBOX

The below bar graph depicts the percentage of the reliability the Gearbox. From the graph, it can analysed the reasons behind the failure of the Gearbox is mainly due to the fatigue, oil filtration problem and then to some extent the wear and tear in the tooth surface. The least contributed is the combination of particles, the debris collected in the components of Gearbox.

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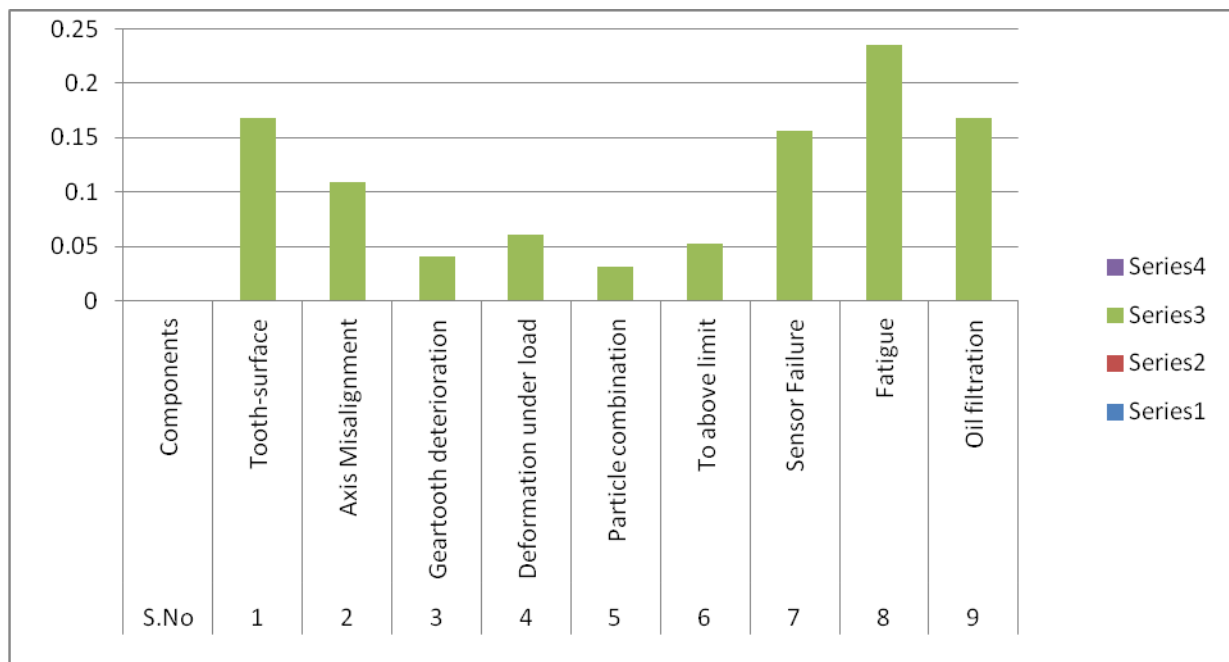


Fig. 2. The percentage of the Reliability of the gearbox and the reasons that contribute to the failure of the Gearbox. The following figure depicts their reliability in the range of 0 to 0.25

Failure Mode	Effect on WT	Failure Cause	Prevention Method	O	S	D	NEW RPN
Gearbox failure	Turbine downtime Failure of safety system No change in speed Noise and vibration Fracture Grid loss Generator Short-circuit High wind shut downs	Tooth surface contact fatigue Axis Misalignment Gear-tooth deterioration Grinding Lubrication Design Cracks due to bending moments	All gear teeth should be cut with protuberance cutters with full fillet radii to help avoid root notches. The shaft or the Axis alignment can be checked with lasers or dial indicators. Laser optic alignment devices are commercially available and should be used. Tooth contact patterns should be painted with soft making compound, such as Prussian blue. Then, the teeth are rolled through mesh so the compound transfers the pattern to the unpainted gear. The pattern is lifted from the gear with scotch tape and mounted on paper to form a permanent record. All gear teeth should be grounded on the flanks only. Grinding notches in the tooth flanks or the root fillets are not acceptable because they act as stress	2	8	7	112

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			<p>concentration.</p> <p>The choice of the lubricant depends on many factors, including viscosity, viscosity index, pour point, additives and costs. Synthetic oil can be started at a lower ambient temperature than one using comparable viscosity. Lubricant can be pre-heated for cold start-ups.</p> <p>Using of a compliant coupling on the rotor shaft that damps the rotor blades before they reach the gearbox.</p>			
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Table 3:- FMEA Spreadsheet of Gearbox Failure with Remedial Measures

VII. CONCLUSION

The benefits of the FTA and FMEA is been proved in the Reliability analysis of the Wind turbine. Probabilistic analyses to assess the safety and reliability of wind turbines constitute a necessary supplement to the deterministic studies and design rules to achieve a more balanced design. The calculations had been done with the help of FTA method so to calculate their reliability and the fault tree is constructed. In this thesis work, we analysed the failure mode of wind turbine system by the traditional FMEA method. The important features of this methodology can be summarised as follows:

- This methodology is based on the RPN index which is calculated by multiplying the occurrence (O), Severity(S), and the detection method (D) of a failure. While in the previous work CPN index is been used which is the product of probability of failure (O), cost consequence (C) and Detection possibility (D).
- The proposed FMEA methodology provides an organised framework to combine the quantitative knowledge for use in FMEA study.

The uniqueness of this paper is that we have calculated the percentage of reliability of each factor which leads to the failure of the Gearbox. In the previous there is no such work and afterwards the FMEA method is implemented to calculate RPN index showing the results of both the cases including the detection and the prevention methods. FTA tree is constructed of each components and each FMEA table is constructed.

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BIOGRAPHY



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