Failure Modes and Effects Analysis System Deployment in a Wind Turbine at High Uncertain Wind Environment

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Failure Modes and Effects Analysis System Deployment in a Wind Turbine at High Uncertain Wind Environment

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This paper presents the results for the Failure Modes and Effects Analysis (FMEA) performed for the Wind turbines (WT) located in a high uncertain wind environment. The FMEA was carried out for Wind Turbine System (WTS) and its sub-assemblies to check the design reliability of twenty numbers of 250 kW WTs, located in Muppandal, India, over the span of 15 years. The WTs situated in high windy region have different kinds of modes of failure than the low wind region. The reliability software tool used to analyze this study is Reliasoft's Xfmea Version 5.1.1. The results show that considerable improvements in the reliability of WTs are obtained by modifying and redesigning some WT components, by implementing redundancy system for the yaw system and sensors, effective monitoring mechanism for brake system and gear system and proper preventive maintenance of all WT components.

Keywords: FMEA; Wind turbine; Severity; Occurrence; Detection. Risk Priority Number, Criticality.

1. INTRODUCTION

The wind energy stands out to be one of the most promising new and renewable sources of generating electrical power for any country. The wind energy is widely used because of its environmental friendliness and many countries have good wind potential to harness energy. China, USA, Germany, Spain and India are the top five wind power generators of the world [1]. P J Tavner et al [2] considered four criteria for ranking the severity, occurrence and detection for comparing WT with Doubly Fed Induction Generator (DFIG), Brushless Doubly Fed induction Generator (BDFIG). In this paper, the probability of occurrence is not differentiated for individual components. Rick Whitcomb and Mark Rioux [3] have applied FMEA to assess the potential failure modes and design in risk prevention measures for the semi conductor industry. William E. Kleinet et al [4] deals with FMEA to give a qualitative indication of the failure mode and added additional safety system to project management. Kennady M [5] determines the effects of the failure modes and the root cause of the failure modes to prioritize actions using a ranking system for failure mode effects in terms of failure mode occurrence probability, failure mode effect severity and failure mode detection probability for chip manufacturing

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2. WT SYSTEM

The WT consists of rotor system, gear system, brake system, generator system, hydraulics system, electrical system. The wind turbine is placed in the first stage (stage I); whereas, wind turbine subassemblies and parts are in the second (stage II) and third (stage III) levels respectively.

3. FMEA

FMEA is an important reliability tool to explore the ways or modes in which each system element can fail and assesses the consequences of each of these failures. The Severity (S) is used to estimate the most serious effect of failures. The Occurrence (O) is used to estimate the likelihood that the cause, if it occurs, will produce the failure mode and its particular effect of the system. The Detection (D) is termed as the effectiveness. It is used to estimate the effectiveness of the controls to prevent or detect the cause or failure mode. The S, O and D are rated on a scale from 1 to 10 in this paper, 1 means ‘No Effect’ and 10 means ‘Failure’ affecting the system. Risk Priority Number (RPN) is used to evaluate the risk associated with the potential problems and it helps to identify the critical failure modes associated with the design or process. The RPN can be calculated by using Eq. (1)”

RPN = Severity X Occurrence X Detection (1)

4. DISCUSSION

In this paper, seven major sub assemblies, rotor, gear box, brake system, generator, yaw system, rotor hydraulic control system and brake hydraulic system are considered. The sub assemblies considered for FMEA analysis include parts and its control system. The average severity of twenty numbers of 250 kW wind turbine is from 5 to 8 as shown in Fig. 1.

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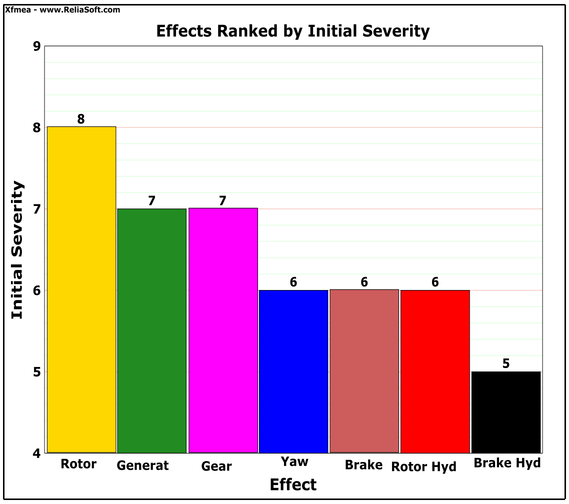

Figure 1. Ranking of Effects of WT by Initial Severity

The maximum severity 8 is allotted to rotor. The severity for rotor is high because if there is any mild crack or damage caused in the blade or tiny fault of the main bearing and rotor shaft, which will reduce the generation significantly. Next to rotor, the generator and gear box have a severity of 7. The present design of the gear box of the WT has short life due to improper material, improper lubrication system and inefficient cooling system Based on the individual component seriousness to the system, the severity is allotted.

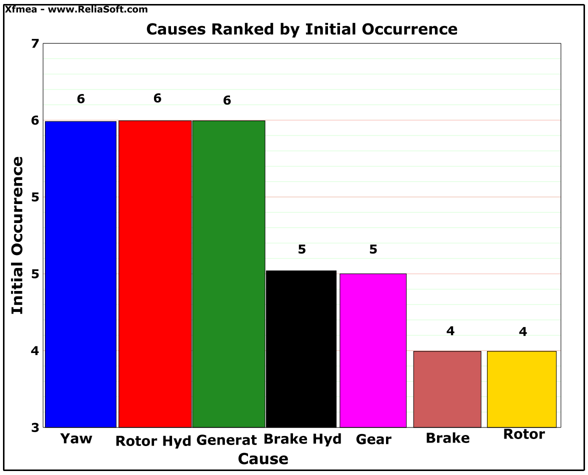

Figure 2. Ranking of causes of WT by Initial Occurrence

The high frequency of failures of yaw system, hydraulic system of rotor and generator had brought the occurrence rate to 6 as shown in Fig. 2. The reason for the variation of occurrence from 4 to 6 is that the single failure mode probability of failure occurs in between 0.0001 and 0.0004. In the constant pitch and constant speed wind turbine, the average failures of the yaw, rotor and generator lie between 0.00038, 0.000354and 0.000313.

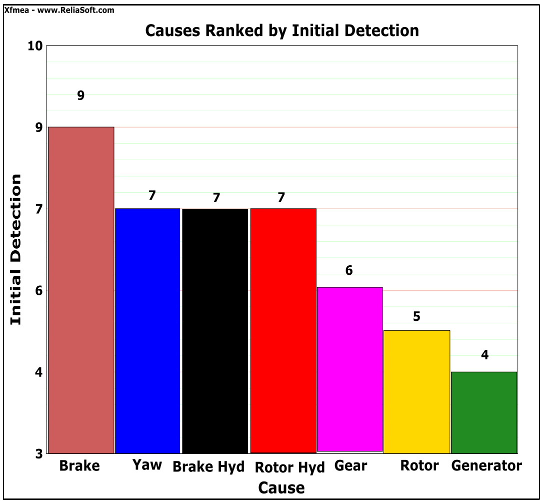

Figure 3. Ranking of causes of WT by Initial Detection

The brake system of the WT has poor level of design control of detection as indicated in Fig. 3, since it is difficult to identify the wear of brake pad. In the same way, the fault detection is unfeasible for the yaw system and all hydraulic rotor and hydraulic system of brake controls. The brake system, yaw system and hydraulic control of brake and rotor system require urgent action to detect the failure mode before it occurs.

5. MODIFICATION AND REDESIGN OF WT COMPONENTS

The modification and redesign is implemented on trail basis in a specific location number 11, where the failures of individual components are high. The failure of yaw system during high wind causes reduction in power generation and imparts high thrust on the blade which causes major failure. To reduce the yaw failure an active redundant soft yaw system is fixed.

The soft yaw system provides smooth start and stop without noise and yaw brakes are totally eliminated. Initially the numbers of failures were 6 to 10 per year over a span of fifteen years. After implementation the failures come down by 20 to 33 % when compared with conventional yaw system. The redundant yaw system not only affords smoothness to the system but eliminates the risks of the rotor system.

The gear oil test facility is incorporated in the site to test kinematic viscosity, density, flash point and metal content. The gear oil analysis is performed on site laboratories so that the information about the future damage and the correct time for oil change are easily revealed. The vibration meter is fixed on the various part of WT components like shaft, gear, yaw system, generator and various positions of the tower. Based on the outcome of the vibration meter, the bolts are adequately torque to make the structure rigid for increasing the span of MTTF. The pressure gauges have been set in rotor and brake hydraulic system to gauge the system pressure to ensure smooth

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operations of the turbine. Also the pump capacity has been increased from 0.5 to 0.75 hp. To measure the rate and extend of wear of the brake pads, infrared position sensor was installed at appropriate place. This helps for planning predictive maintenance instead of breakdown maintenance.

6. RANKING OF CAUSES BY INITIAL RPN

The Fig. 4 shows the relative risk of the WT components which have high priority. In this study, the highest value of RPN obtained is 252 for yaw system and the lowest is 160 for rotor. It is noted that the most of the failures are contributed by yaw, hydraulic control of rotor, brake and gear. The RPN in Yaw system and rotor hydraulic system are high and it is due to the high severity, absence of detective mechanisms and increased frequency of failures over a period of time.
After implementation, the RPN varies from 96 to 150 indicating reasonable improvement in reducing the relative risks considerably. In two other important components, the rotor and generator, due to less failure rate and high detection rate, the net RPN is relatively low though they have high severity indices.

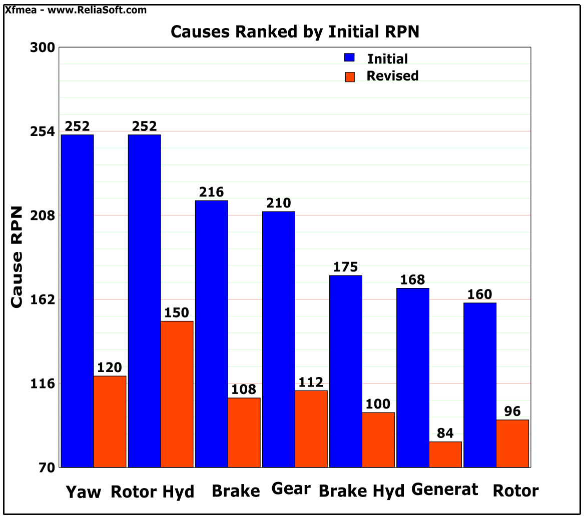

Figure 4. Ranking of causes of WT by Initial and Revised RPN

The gear system is ranked third in the RPN causes. It proved that the gear system is highly critical and it requires best control system. The hydraulic control of brake has the least RPN of 175. The improvements in the components RPN in term of percentage are represented in the graph shown in Fig. 5. It can be observed that it is maximum in yaw system as 52% and lowest of 40 %in the rotor. The highest reduction of RPN in yaw is due to the provision of active standby redundant yaw system.

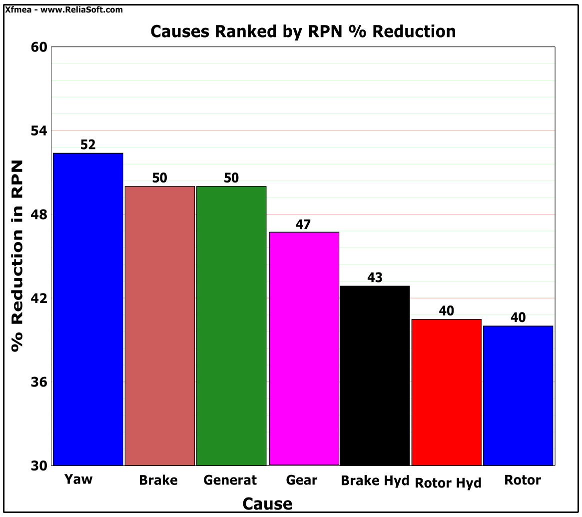

Figure 5. Causes Ranked by RPN % Reduction

The installation of the infrared position sensor in brake system resulted in 50% reduction in RPN. Simple periodic maintenance and predictive maintenance of shaft, sleeve ring, bearing and cooling system of generator brings the RPN reduction. The new design, pressure regulation system brought the improvements in hydraulic controls of brake and rotor

7. CRITICALITY ANALYSIS USING SEVERITY AND OCCURRENCE OF WTs

The Criticality Analysis is a procedure by which each potential failure mode is ranked according to the combined influence of Severity and probability of Occurrence. The criticality value is obtained by the product of severity and occurrence. The criticality of failure is independent of detection because detection is failure prevention through design.

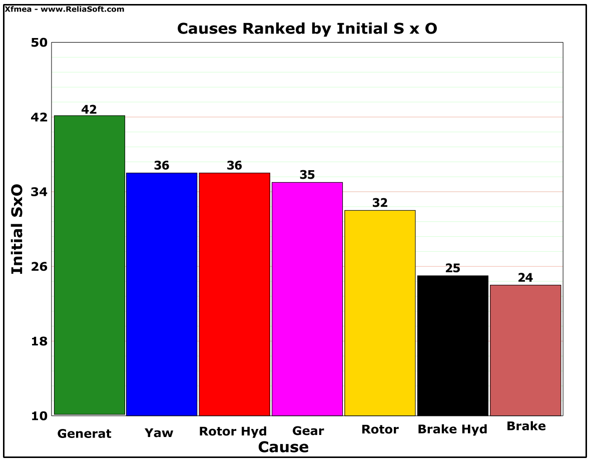

Figure 6. Criticality Ranking of WT

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The generator is considered as a highly critical component and it has a criticality value of 42 as shown in Fig. 6.

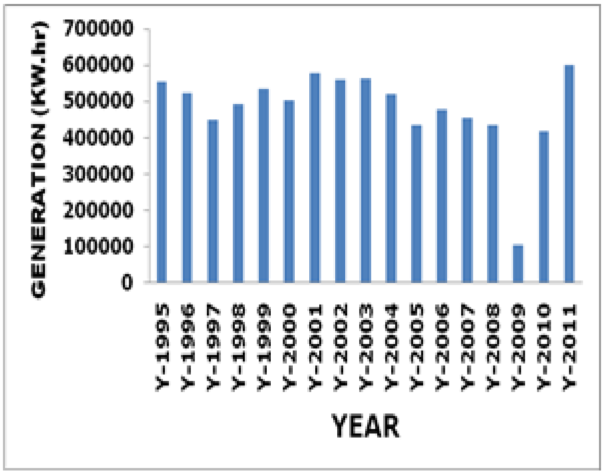

Figure. 7: Yearly generation at redesign implemented location

After implementation, the generation obtained in the year 2012 is 599874kW.hr as shown in Fig. 7, which is very high when compared with the past generations over 15 years.

8. CONCLUSION

The FMEA study carried out successfully to twenty numbers of constant speed and constant pitch 250 kW WTs over the span of 15 years by using Xfmea software. This study has a prospective of improving the reliability and availability of WTs by modifying and redesigning the components, redundancy system, effective monitoring mechanism and proper preventive maintenance. It is evident that immediate actions are required in generator, yaw system, rotor system and gear system.

The generator is constructed overhanging and this leads to repeated misalignment of shaft due to vibrations. The high uncertainty wind causes voltage fluctuations and the inadequate performance of sleeve ring, carbon brush and bearing diminish the reliability and availability of the generator. The failures in the generator are early detected and restricted with help of the continuous monitoring of vibration meter. It is inevitable that the yaw system requires redundant system to increase its performance.The improvement in lubrication system and efficient cooling system makes 47% improvement in RPN of the gear box. The rotor is overstressed due to the frequent failure of yaw mechanism. It is found that the smooth and efficient yaw mechanism with active redundancy reduces 52 % of RPN. The crack on the blade edge and tip, improper blade material and fatigue load brought down the rotor efficiency. It is necessary to set up design control for detecting the brake failure. The frequent inspection of the brake pad with a help of infrared position sensor, reduces failure to 50%. It is suggested that the yaw system and brake system should be inspected in weekly schedule and preventive maintenance be carried out effectively.

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