Effect of Rank Priority Number in Prediction of Failure On Different Component of Horizontal Axis Wind Turbine

[1]Abhishek Choubey & [2]Prashant Baredar
[1]Mewar University Chittorgarh,(Rajasthan),
[2]Maulana Azad National Institute of Technology Bhopal (MP), India.

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ABSTRACT *Failure Mode Effective Analysis is a qualitative technique for identifying failure modes and their cause in any machine or system. It is very useful for prediction the probability of failure in component of wind turbine. With the help of this technique we enhance the reliability and reduce the breakdowns in wind turbine and also ensure the optimum performance at optimum running cost. This technique used for identifying the problem at initial stage of operation. In this technique we classify the components on the basis of severity and probability of the failure. A correct FMEA plan helps us to identify the failure modes on post occurrence with similar components in similar application. This technique is a great tool for increasing the performance and it is widely used in manufacturing industries in the various stage of product development. In this paper we use the concept of FMEA and apply it on the horizontal axis wind turbine and generate the results according to FMEA technique. The results of FMEA compare with the failure rate which occurs in similar components and collected by the experts by observation. The failure rate of gear box, blades and tower are 0.180, 0.175, and 0.145 respectively. And by the calculation in FMEA the risk priority number (RPN) value of tower (140) is highest than the other component of wind turbine. It indicates that the tower has highest probability of failure. In this paper we compare the result of RPN to the failure rate of wind turbine component.*

Keywords: *Wind turbine, failure mode and effects analysis (FMEA), risk-priority-number (RPN), probability*

1. Introduction

Wind Turbine - Wind energy is now the second fastest-growing source of electricity in the world, with a global installed capacity of 432,883 megawatts (MW) at the end of 2015. Wind energy technologies use the energy in wind for practical purposes, such as generating electricity, charging batteries, pumping water and grinding grain. Mechanical or electrical power is created through the kinetic energy of the wind. Wind power available is proportional to the cube of its speed, which means that the power available to a wind generator increases by a factor of eight if the wind speed doubles [2]. Wind energy outshines all other renewable energy resources due to the recent technological improvements. Electrical energy generation from wind power has increased rapidly and due to the increased interest many studies on efficient wind turbine design have been performed [3].

Wind turbines are mounted on a tower to capture the most energy. At 100 feet (30 meters) or more above ground, they can take advantage of faster and less turbulent wind. For the best utilization of wind turbines, they should be placed where wind speeds reach 16-20 mph and are at a height of 50m. It is also important that utility-scale power plants are located near existing power lines and in the windiest sites available [2]. The smallest turbines are used for applications such as battery charging or auxiliary power on sailing boats; while large grid-connected arrays of turbines are becoming an increasingly large source of commercial electric power.

A wind turbine is a device that converts kinetic energy from the wind into mechanical energy. If the mechanical energy is used to produce electricity, the device may be called a wind generator or wind charger. We know kinetic energy of wind is converted to electrical energy by using wind turbines. Mechanical power production of a wind turbine is given in Equation [4]

$$P_m = \frac{1}{2} .\rho .A. v^3 \cdot C_p (W)$$

Where P_m is turbine mechanical power output, ρ is air density, A is turbine swept area, v is wind speed and Cp is turbine power coefficient.

2 Failure Modes and Effects Analysis (FMEA) - FMEA has been shown to be an effective way of improving machinery design reliability. The FMEA is a powerful design tool that provides a means, from a risk point of view. The FMEA is also useful for considering designs improvements for a technology which is changing or increasing in rating, same as WT configurations. The FMEA is a formalized but subjective analysis for the systematic identification of possible Root Causes and Failure Modes and the estimation of their relative risks. The main goal is to identify and then limit or avoid risk within a design. Hence the FMEA drives towards higher reliability [6], higher quality, and enhanced safety. It can also be used to assess and optimize maintenance plans. The causes of failure are said to be Root Causes, and may be defined as mechanisms that lead to the occurrence of a failure. While the term failure has been defined, it does not describe the mechanism by which the component has failed. Failure Modes are the different ways in which a component may fail. It is vitally important to realize that a Failure Mode is not the cause of a failure, but the way in which a failure has occurred. The effects of one failure can frequently be linked to the Root Causes of another failure. The FMEA procedure assigns a numerical value to each risk associated with causing a failure, using Severity, Occurrence and Detection as metrics. As the risk increases, the values of the ranking rise. These are then combined into a Risk Priority Number (RPN), which can be used to analyze the system. By targeting high RPN values the most risky design elements can be addressed. RPN is calculated by multiplying the Severity, Occurrence and Detection of the risk. Severity refers to the magnitude of the End Effect of a system failure [7]. The more severe the consequence, the higher the value of severity will be assigned to the effect. Occurrence refers to the frequency that a Root Cause is likely to occur, described in a qualitative way. That is not in the form of a period of time but rather in terms such as remote or occasional. Detection refers to the likelihood of detecting a Root Cause before a failure can occur. Since FMEA is used by various industries, including Automotive; Aeronautical; Military; Nuclear and Electro-technical, specific standards have been developed for its application. A typical standard will outline Severity, Occurrence and Detection rating scales as well as examples of an FMEA spreadsheet layout. Also a glossary will be included that defines all the terms used in the FMEA. The rating scales and the layout of the data can differ between standards, but the processes and definitions remain similar [7]

3. Methodology

The goal of the failure modes and effects analysis is to anticipate, identify and avoid failure in the operation or new system while the system is still on the drawing board. The recent occurrence of failure in some new system in operation has had disastrous effects on many lives. These events promoted to evaluate the documented problems and to seek improvements in FMEA procedures and their applications.

3.1 FMEA Procedure - Failure mode and effects analysis (FMEA) is a widely used engineering technique for designing, identifying and eliminating potential also known as system failures. FMEA was first proposed by NASA in 1963 for their obvious reliability requirements. Then, it was adopted and implemented by Ford Motor [6] in 1977. Since then, it has become a powerful tool for risk and reliability analysis of systems in a wide range of industries including automotive [13], foundry [14], nuclear [15] and construction [16]. A failure mode is defined as the way in which a component, sub-system or system could potentially fail to perform its desired function. A failure cause is defined as a weakness that may result in a failure. For each identified failure mode, their ultimate effects need to be determined, usually by a cross-functional team which is formed by specialists from various functions [7].

The process for conducting an FMEA is straightforward. The basic steps are outlined below.

1. **Describe the product/process and its function:** An understanding of the product/process under consideration is important to have clearly expressed. This understanding simplifies the process of analysis by helping the engineer identify those product/process uses that fall within the intended function.
2. **Create a block diagram of the product or process:** A block diagram of the Product/process should be developed. This diagram shows major components or process steps as blocks connected together by lines that indicate how the components or steps are related.
3. **Identify Failure Modes:** A failure mode is defined as the manner in which a component, subsystem, system, process, etc. could potentially fail to meet the design intent.
4. A failure mode in one component can serve as the cause of a failure mode in another component. Each failure should be listed in technical terms. Failure modes should be listed for functions of each component or process step. At this point the failure mode should be identified whether or not the failure is likely to occur. Looking at similar products or processes and the failures that have been documented for them is an excellent starting point.
5. **Describe the effects of those failure modes:** For each failure mode identified the engineer should determine what the ultimate effect will be. A failure effect is defined as the result of a failure mode on the function of the product/process as perceived by the customer. They should be described in terms of what the customer might see or experience should the identified failure mode occur. Establish a numerical ranking for the severity of the effect. A common industry standard scale uses

1 to represent no effect and 10 to indicate very severe with failure affecting system operation and safety without warning.

6. **Identify the causes for each failure mode:** A failure cause is defined as a design weakness that may result in a failure. The potential causes for each failure mode should be identified and documented. The causes should be listed in technical terms and not in terms of symptoms
7. **Enter the Probability factor:** A numerical weight should be assigned to each cause that indicates how likely that cause is (probability of the cause occurring). A common industry standard scale uses 1 to represent not likely and 10 to indicate inevitable.
8. **Identify Current Controls (design or process):** Identify current controls are the mechanisms that prevent the cause of the failure mode from occurring or which detect the failure before it reaches the customer. The engineer should now identify testing, analysis, monitoring and other techniques that can or have been used on the same or similar products/processes to detect failures.
9. **Determine the probability of Detection:** Detection is an assessment of the probability that the Current Controls (design and process) will detect the cause of the failure mode or the failure mode itself, thus preventing it from reaching the customer.
10. **Review Risk Priority Numbers (RPN):** The Risk Priority Number is a mathematical product of the numerical Severity, Probability, and Detection ratings: RPN = (Severity) x (Probability) x (Detection).
11. **Determine Recommended Action(s) to address potential failures that have a high RPN:** These actions could include specific inspection, testing or quality procedures; selection of different components or materials; de-rating; limiting environmental stresses or operating range, redesign of the item to avoid the failure mode, monitoring mechanisms, performing preventative maintenance and inclusion of back-up systems or redundancy.
12. **Assign Responsibility and a Target Completion Date for these actions:** This makes responsibility clear-cut and facilitates tracking.
13. **Indicate Actions Taken:** After these actions have been taken, re-assess the severity, probability and detection and review the revised RPN's.
14. Update the FMEA as the design or process changes, the assessment changes or new information becomes known.

3.2 Failure rate of sub-component of 1MW wind turbine

The failure rate function, also called the instantaneous failure rate or the hazard rate, is denoted by λ (t). It represents the probability of failure per unit time t, the failure rate of a system usually depends on time, with the rate varying over the life cycle of the system. These are the values of failure rate of different component of wind turbine given by the observation of experts.

The failure rates for the sub-assemblies of the wind turbine system [8,9].

Table. 1

Sub-Component	**Failure Rate λ**
Braking System	0.014
Cables	0.008
Gearbox	0.180
Generator	0.150
Frame	0.011
Shaft	0.045
Housing	0.012
Pitch System	0.013
Rotor bearing	0.010
Blades	0.175
Hub	0.140

Tower	0.145
Yaw System	0.013
other	0.259
Total	**1.175**

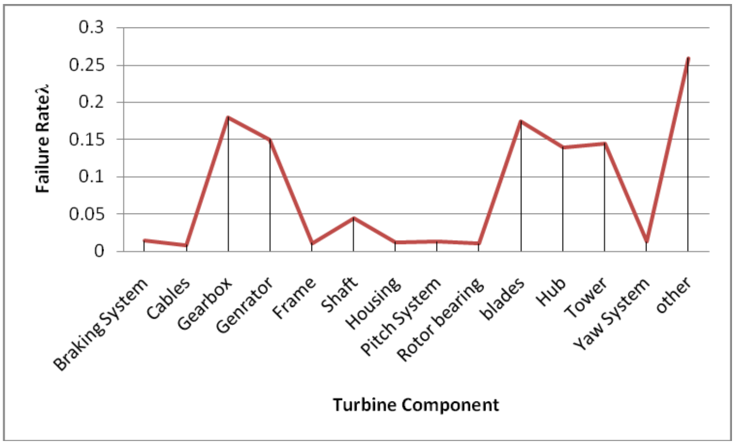

Figure 1.

3.3 Occurrence of failure S_f, severity of a failure *S* and detection of failure S_d

In general, the probability of occurrence evaluates the frequency that potential risk(s) will occur for a given system or situation. The probability score is rated against the probability that the effect occurs as a result of a failure mode. [12]. Severity assesses how serious the effects would be should the potential risk occur. In the example of a manufacturing process for a drug substance, the severity score is rated against the impact of the effect caused by the failure mode on the batch quality. A non-linear scoring scale can be applied to augment the effect of the severity criteria.

Detection of failure is the probability of the failure being detected before the impact of the failure to the system or process being evaluated is detected. The delectability score is rated against the ability to detect the effect of the failure mode or the ability to detect the failure mode itself.

Wind turbine of 1MW- FMEA ratings for occurrence of failure S_f, severity of a failure *S* and detection of failure S_d [12

Table. 2

Component	Occurrence of failure [S_f]	Severity of failure [S]	Detection of failure [S_d]
Braking System	2	2	7
Cables	2	3	1
Gearbox	5	3	7
Generator	5	2	7
Frame	2	4	4
Shaft	3	2	7
Housing	2	3	1
Pitch System	2	4	7
Rotor Bearing	2	3	4
Blades	5	3	7

Hub	5	2	4
Tower	5	4	7
Yaw System	2	2	4

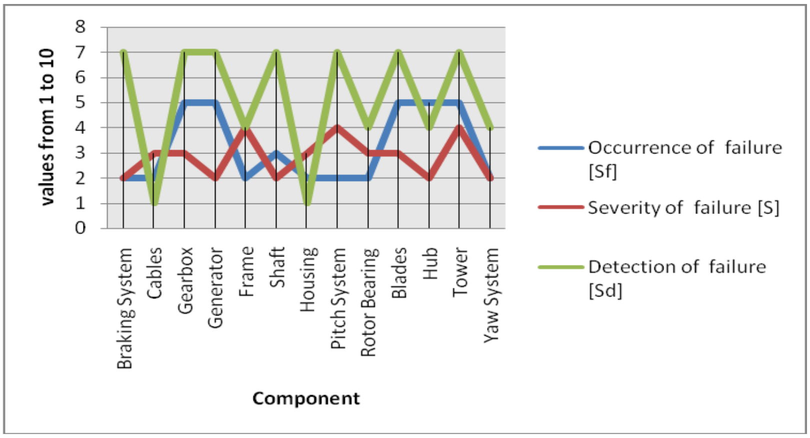

Figure 2.

3.4 RPN and Rank

The composite risk score for each unit operation step is the product of its three individual component ratings: severity, probability, and detect ability. This composite risk is called a risk priority number.

$$RPN = S_f \text{ x } S \text{ x } S_d$$

The RPN number is not absolute and should be considered in context with other factors that influence the product risk outside the scope of this evaluation. The RPN provides a relative priority for taking action the bigger RPN .the component with higher RPN value considered by top rank.The different assemblies of wind turbine with different RPN and Rank are as follows in table.

Table 3 RPN and Rank of 1 MW wind turbine

Assembly	Parts	RPN	Rank
Braking System	Disk, Spring	28	11
Cables	Cable	6	14
Gearbox	Gears Wheels, Hoses	105	2
Generator	Shaft, Bearings, Rotors	70	5
Frame	Frame	32	10
Shaft	Shaft, Bearings, Couplings	42	8
Housing	Housing	6	14
Pitch System	Gears, Motors	56	7
Rotor bearing	Bearings	24	12
blades	Blades	105	2
Hub	Air Brake, Body	40	9
Tower	Column, foundation	140	1
Yaw System	Motor, derive	16	13

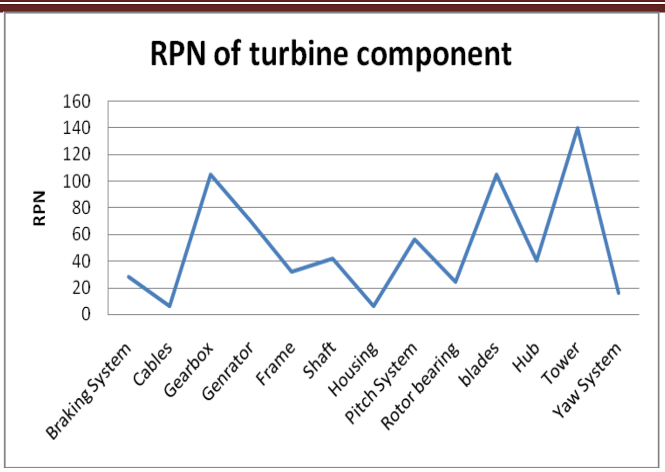

Figure 3.

Figure 4.

1. **Results and Discussion-**

We compare the results of wind turbine component on the basis of failure rate from the information given by the experts and the results generated by FMEA. After calculation we found that the tower has the highest probability of failure on the basis of RPN concept which is followed by the gearbox and blades. On the basis of previous or past data the gearbox has highest failure rate but by FMEA the tower has the highest RPN value and highest failure probability. The highest value indicates that highest possibility of failure. The comparative table is shown below on the basis of failure rate and RPN value.

Table. 4 Comparison of failure rate and RPN

Ranking on the basis of Failure Rate λ	**Ranking on the basis of RPN (Proposed Method)**
Gearbox	Tower
Blades	Gearbox
Generator	Blades
Tower	Generator
Hub	Pitch System
Shaft	Shaft
Braking System	Hub
Pitch System	Frame
Yaw System	Braking System

Housing	Rotor bearing
Frame	Yaw System
Rotor bearing	Cables
Cables	Housing

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