FMMA and FMECA for analysis of reliability of a wind turbine

I A Magomedov¹, V S Magomadov¹, A A Rahimov¹, S Kh Alikhadzhiev² and M-A A Gudaev³

¹Faculty of Information Technology, Chechen State University, 32 Sheripov Street, Grozny, 364024, Russia
²Department of Physical and Mathematical Research, Laboratory of Experimental Physics, 21 Staropromyslovskoe, Grozny, 364051, Russia
³Chechen State Pedagogical University, 33 Kievskaya Street, Grozny, 364068, Russia

E-mail: ismwork@mail.ru

Abstract. This work is designed to highlight the technical data regarding reliability and maintainability of a modern-day Wind Turbine. With the ever-increasing demand for cleaner energy and reduction of greenhouse gases, Wind Turbines offer a feasible solution in contributing towards a greener future as a whole. In spite of this, they must provide both a reliable form of energy production and an economic benefit to corporations investing in this technology, as an individual wind turbine can be considered a large financial investment, both to set-up and to maintain.

1. Introduction

In Modern day Wind Turbines are very sophisticated engineering systems which several components to both maximise efficiency and reduce maintenance. Regardless of their complexity and cost, they are still susceptible to failure and damage as they are often implemented in varying environments and have a high constant output. Wind-Turbines differ in size and location but they are all very similar in components and design, and all suffer from failures, many of which are common of all wind turbines. Following is a list of all components which are prone to failure and their role in contributing towards a Wind [1].

The blade are a very crucial component in making the wind-turbine function. They are the only component which actively capture the energy from the wind, and converting it into rotational Kinetic energy. These blades are extremely complex not only due to their aero-foil shape, but their building methods, maintenance and pitch system. All the other components rely on the ability of the blades to provide power to make the system work as a whole.

The main shaft is a shaft which connects the blades (through the rotor-hub) to the gearbox, with the high-speed shaft connecting the gearbox to the Generator. Both of these shafts deal with an exceptionally high torque and are under a constantly varying torsional stress. They are also vital as they can dictate where all the other components within the Nacelle lie, and must maintain perfect alignment to ensure no catastrophic failure.

A Wind Turbine has several bearings, which are all designed to constrain different components. The main bearing is designed to keep the rotors and shafts in position, whilst experiencing enormous
stresses from and frictional wear from the constant rotation of the shafts. In addition, there is also the bearing controlling the Yaw System, which is paramount to ensure that the wind turbine is always facing the wind and working regardless of the direction. This yaw bearing also must take the load of the entire Nacelle and transmit this load to the main stem of the wind turbine.

The Gearbox is by far the most complex system of the entire Wind-Turbine system. Its job is to increase and regulate the rotational velocity of the main shaft to optimise the electricity output and rate at which the Generator is working through the use of Planetary Gears. At low wind speed, it will reduce its gearing to ensure that the generator is still rotating and producing electricity, whilst at high wind speed, the gearing is increased to ensure the generator does not exceed its limit and fail. The gearbox is very prone to failure due to the extreme loads generated inside, along with constant working life cycle and constantly changing speeds. Due to its high cycle fatigue it not only will experience bearing failures and frictional wear, but wearing of the gears due to metallurgical deformations and phenomenon will occur, prompting constant monitoring of how healthy this component is. Generator is also extremely important in the drivetrain, as it is the sole producer of electricity by converting the shaft rotational energy into electrical energy which is then transmitted to the grid. The generator must be able to withstand a broad spectrum of speeds as the wind is always changing, whilst also continually producing electricity as long as the blades are turning.

Similar to the gearbox, this component dictates the performance of several other systems. The Hydraulics provide the power to engage the mechanisms in all the components including the Brakes and Gearbox. If this system fails, all the other components will stop until the fault is repaired. The brakes are required for safety in the event of a storm or catastrophic high winds. They work in a 2-stage system, with the first system slowing down the rotors through Hydraulics or resistance, and the second system mechanically stopping the rotors to very low speeds or a complete stop. These are a vital safety feature to prevent disasters such as in Nordstank in 2008 [2].

2. Methods

FMMA - Failure Mode and Maintenance Analysis. This method of determining failure modes is a very practical method, which will not only highlight areas of common/known failure, but provide an easy, representative way of testing or determining the health of the component by following easy, straightforward guidelines. Although this method may not harness the highest level of complexity, it provides a generic overview for any user to evaluate failure, with a basic idea of what needs to be implemented to test the component. This analysis is most suited to looking at a system as a whole as oppose to specific component, this is due the availability of other failure determination methods which favour the complexity of specific components as oppose to providing an overall summary of the expected failures in a system. By using a variety of sources, a good determination of what failures are commonly experienced on these complex machines. There are several components throughout a wind turbines, but a select few are significantly more complex and give rise to more failure opportunities than others. According to Andrawus, there are several sources cited from 3 main countries where Wind Energy is a significant aspect, Germany, the Netherlands and the UK, in which the thesis paper cites official sources to statistics and studies highlighting the most common failures observed on wind turbines in the respective country. These in conjunction with the European Wind Turbine Certification (EWTC) give a very good idea of what the common areas of failure are in wind turbines. According to Andrawus, 42% of all failures due to component failure, whereas only 21% is due to a failure in the control system. Although all the countries mentioned have different environmental conditions and different turbine manufacturers, they all share common faults. Those most prominently being the Gearbox, Generator, Hydraulics, Blades, Electrical Control and Yaw System. It is therefore logical to consider these components throughout the FMMA. In addition to all of the advantages of FMMA, it above all provides an insight into the most feasible ways of the monitoring the components which fail. It is also required that there be at least 2 different methods of detecting faults to ensure prevention of total failure [3]. FMEA and FMECA. The Failure Mode and Effect Analysis (FMEA) is the process using for estimating failure modes, their effect on system and sub components of the system. In FMEA, the probability and
on sequences of each failure mode is estimated and appropriate values assigned in scale of 1 to 10. The multiplication of these values determines the failure mode’s criticality rating. According to criticality ratings, each failure mode is categorised into 4 different severity classes. In both FMEA and tables, severity class 1 means failure has low severe and severity class 4 is failure has high severe consequences [4, 5]. Due to page limitation and similarities between FMEA and FMECA, only the result of FMECA is shown in table 2. The Failure Modes, Effects and Criticality Analysis (FMECA) is more detailed version of the FMEA mainly based on the loss frequency. FMECA is identifies failure modes, determines their effects and causes of those modes on the system, assigns severity, occurrence and detection and calculates the component loss frequency $\lambda_o$ [6]. In order to calculate the $\lambda_o$; failure mode proportion, probability of failure effect and the total failure rate of the item should be known. The formula for $\lambda_o$ is; $\lambda_o = \lambda_p \alpha \beta = \text{loss of frequency}$. Where $\lambda_p$ is total failure rate of the item, $\alpha$ failure mode proportion and $\beta$ probability of failure effect. $\alpha$ and $\beta$ are estimated value based on engineering judgment, regarding to results of the FMEA. The FMECA results are more detailed and overviewed found in the FMEA. The FMECA results are shown in the table 2.

### 3. Results

Table 1 presented results of FMMA and table 2 represents results gathered using FMECA.

**Table 1. Failure Mode and Maintenance Analysis.**

| Component | Cause | Consequence | Condition Monitoring |
|-----------|-------|-------------|----------------------|
| **Generator** | Insulation Degradation Worn Bearings Overheating | > Lost Energy. > Total Failure/Fire/ Catastrophe. | Bearing Vibration/Noise assessment. Possibly via CMS | Insulation test on component within Generator |
| **Blades** | Inside: Delamination, Air Inclusions, Missing Adhesive Outside: Erosion Impact, Laminate Deviation, Cracks | > Blade Inefficiency. > Fast Fracture/Total Failure. | Periodic Visual Checks Periodic Ultrasonic/Eddy Current Thermography | Periodic Optical/Thermal Thermography |
| **Gearbox** | Poor Lubrication Worn Teeth Worn Bearings | > Lost Energy. > Total Failure/ Catastrophe. | Periodic Visual Checks of Drive-shafts & teeth degradation. Vibration Signal Interpretation via CMS | Oil Debris Monitoring |
| **Hydraulics** | Oili Leak Pump Failure | > Failure of several other Components > Total Failure of other components. | Periodic Visual inspection of Lines & Fittings Periodic Monitoring of Oil (Milky, Debris, Foamy, Burnt) | Periodic Pressure Test to ensure no leaks. |
| **Yaw System** | Worn Bearings Worn Pinion/Gear Teeth Yaw Brake Failure Hydraulics Failure | > Inability to harness maximum energy. | Periodic Visual checks of components. i.e. Loud bearing, pitting. Check fluid levels & ensure integrity of Hydraulics | |
| **Control System** | Development bugs Electrical fault | > Loss of control of Wind Turbine | Periodic Testing of software integrity External Monitoring of control system. | Test of Wiring harness/Electrical integrity (sensors) |
Table 2. Failure Modes, Effects and Criticality Analysis.

| Component          | Failure Mode                     | Failure Effect                                      | Severity Class | \( \lambda_p \) (F/Year) | \( \alpha \) (%) | \( \beta \) (% Prob) | \( \lambda_o \) (F/Year) | \( \lambda_o \) (F/MH) |
|--------------------|----------------------------------|-----------------------------------------------------|----------------|--------------------------|-----------------|---------------------|--------------------------|--------------------------|
| Wind Turbine Blade | Crack in blade                   | Weakened blade structure                            | 2              | 1.45                     | 70              | 100                 | 1.0150                   | 115.9130                 |
|                    | Gear teeth slip                  | Problems with adjusting angle of attack             | 3              | 1.45                     | 30              | 70                  | 0.3045                   | 34.7739                  |
| Gearbox            | Gear teeth slip                  | Transmission of rotation to generator prevented     | 3              | 5.88                     | 10              | 70                  | 0.4116                   | 47.0047                  |
|                    | Fracture occurred in gear teeth  |                                                     | 2              | 5.88                     | 40              | 20                  | 0.4704                   | 53.7197                  |
| High Speed Shaft   | Cracks caused by Fatigue         | Generates cracks in shaft resulting collapse of wind turbine system | 2              | 0.47                     | 60              | 100                 | 0.2820                   | 32.2044                  |
|                    | Distorting at shaft shape        | Collapse of wind turbine system                     | 4              | 0.47                     | 25              | 0.0705              | 8.0511                   |                          |
| Hydraulic Brakes   | Wear due to working cycle       | Uncontrolled speed of rotor caused gearbox and generator to overload          | 3              | 0.47                     | 75              | 10                  | 0.0353                   | 4.0256                   |
|                    | Overheating due to low level hydraulic fluid | Decreasing efficiency at breaking                                  | 3              | 0.47                     | 40              | 85                  | 0.1598                   | 18.2492                  |
| Generator          | Loading / Fatigue / Misalignment cause failure | Generator failure (unable to generate electricity)                           | 3              | 0.47                     | 30              | 90                  | 0.1269                   | 14.4920                  |
|                    | Bearing failure or misalignment | Cause vibration leads to damage at shaft, stator and rotor of the generator | 3              | 0.01                     | 10              | 15                  | 0.0002                   | 0.0171                   |
|                    | Overheating of generator (inefficient cooling) | Damage the winding and rotor of generator                | 2              | 7.16                     | 7               | 40                  | 0.2005                   | 22.8948                  |

4. Conclusion
The FMMA concludes that there are several points of failures when looking at the wind-turbine as a whole system. These are often due to small components within the larger components failing. It is also safe to assume that many of these failures which cause large economic loss and reduction to grid power can be avoided by regular maintenance and monitoring. With the technology available today, monitoring these points of weakness can be made very easy and remotely as sensors and gauges have become so
advanced; and in spite of their being a large cost associated with the initial setting up of these monitoring devices, this method of preventative maintenance is very effective in the long run, significantly lowering the sudden extreme costs associated with component failure or wind-turbine damage.

The Failure Mode and Effect Analysis (FMEA) and The Failure Modes, Effects and Criticality Analysis (FMECA) are used together to understand for estimating failure modes, their effect on the system and sub-components of the system. During FMEA analysis components and their possible failure causes were scored and divided into four classes according to their severity.

In order to define a natural safety factor all of the scores higher than 60 very considered in highest severity class – 4.

During FMECA analysis, total failure rate of each system or components were taken from previous studies. Although many detailed searches were done, the values for $\alpha$ (Failure mode proportion) and $\beta$ (probability of failure effect) were unable to found. Therefore, those numbers were estimated with using engineering sense according to their severities and possible consequences.

FMECA results were calculated as failure rate per year and failure rate per million hours which is around 114.2 years. According to numerical results, most of the components have reasonable results.

References

[1] Chun S, Yang Y, Xiaolin W, Zhaoyong H 2016 Failures analysis of wind turbines: case study of a chinese wind farm. Prognostics and system health management conference p. 3-4
[2] Stiesdal H 1998 The wind turbine components and operation, special issue of the bonus-info 1998 newsletter. Retrieved from: http://windmission.dk/workshop/BonusTurbine.pdf
[3] Andravus J A 2008 Maintenance optimisation for wind turbines, The Robert Gordon University. 21(4)-22(3) 22
[4] Chiang J H, Yuan J 2001 Optimal maintenance policy for a Markovian system under periodic inspection, Reliability Engineering and System Safety 71 (2)165-72
[5] Cox S, Tait R 1998 2004 Safety, Reliability and Risk Management, ButterworthHeinemann.
[6] Massimo B, Maurizio B, Roberto 2004 FMECA approach to product traceability in the food industry, Science Direct 98(6)
[7] Daimler Chrysler Corporation, Ford Motor Company, General Motors Corporation, Third Edition, April, 2001, Potential Failure Mode and Effects Analysis (FMEA) Reference Manual by Adare Carwin Limited.
[8] Deshpande V S, Modak J P 2003 Maintenance strategy for tilting table of rolling mill based on reliability considerations, Reliability Engineering and System Safety 80 1–18
[9] Eyre-Jackson D, Winstone N 1999 Full life cycle asset management. Its role in enterprise wide change: Part I”, Maintenance and Asset Management 14 (3) 3-10