Wind Turbine Reliability: A Brief Review

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Abstract: Energy plays an important part in the economic growth and the socio-economic development. With the increasing global energy demand and the depletion of fossil fuels renewable energy like wind energy have become not only an important source of clean energy but also important of a nation's energy security. The wind turbine industry as a result is rapid developing with a global capacity of approximately 230 GW and is expected to increase five times by 2020. As this industry is becoming more commercial manufacturers are incorporating technologies from other fields which are proven into the wind turbines. However, these technologies are sometimes not appropriate for the wind turbines, which then lead to high failure rate. Despite this issue there exits only a number of many studies on the reliability on the wind turbines. Hence, this paper aim is to provide a review on wind turbine and its sub-components reliability, providing an overview of components failure rate and downtimes.

1 INTRODUCTION

Since the first oil crisis in 1973, interest in renewable energy is growing and the industry has made positive advances since the protocol Kyoto 1997 where collective reduction in greenhouse gas emission were consented and numerous developments in this sector was encouraged by governments across the globe.

The wind energy industry has unquestionably responded. In 2009 about 39% of new capacity installed within EU was wind turbines [2] and in 2012 it provided nearly more than 6% of the region's electricity [3]. The world wind energy capacity was approximately 237 gigawatts (GW) in 2011 and has been doubling energy 3 years, and is projected to rise to at least 1000 GW by 2020 as per one forecast [4].

Due to the rapid development of the wind turbine (WT) industry, its design has evolved through time, with the aim of producing energy more efficiently and cost effectively. Therefore, WT manufacturers have explored different design topologies, such as horizontal or vertical axis of rotation and downward or upward placement of rotor, and also considered changes in smaller components like brakes and blade tips or using different control strategies. [5]

As the manufacturers are trying to make WT more commercial, they have looked into technologies in other fields which are proven, in many cases, components can be taken off the shelf. However, in some instances, due to insufficient knowledge of the WT operational condition, results show lower reliability than anticipated. For example, despite the commerciality of gearbox, in WT high failure rates are obtained. [5]

To study the reliability of WT there are not enough sources through time. There exits only a number of databases with failure information such as LWK [6] and WMEP [7] in Germany, Windstats Newsletter in Denmark [8], VTT in Finland and Elforsk in Sweden [9].

These are some of the data that have been used to study the reliability of WTs. Nevertheless, besides failure rates there are other aspects that are important to consider such as downtime by failures [9,10], effects of wind speed [11] and icing [12] on reliability. This paper therefore aims to provide a brief overview of WTs.

2 COMPONENTS OF WT

The main components of the typical WT are found in Fig. 1 [13]. Propelled by the wind, the blades are connected to the rotor hub which transmits mechanical energy by the low speed shaft through the gearbox to the highspeed shaft that is linked to the generator. The low speed shaft is held by the main bearings, and the gearbox regulates the speed. The yaw system that rotates the nacelle, is used for the alignment to the direction of the windspeed. Power going into the wind turbines are controlled by a pitch system that is mounted in each blade and also act as an aerodynamic brake. For the control of the pitch, brake and yaw systems, a meteorological unit may be used that provides weather data.

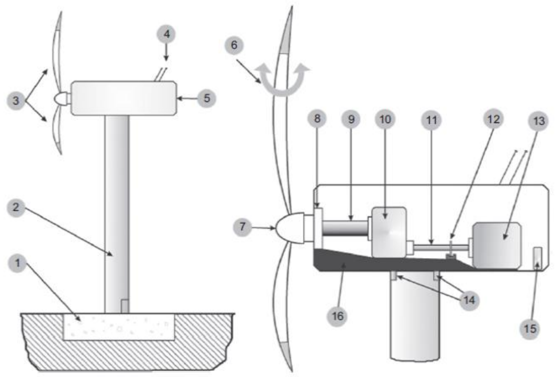

Figure 1: Components of WT: 1-base; 2-tower; 3-blades; 4-meteorological unit; 5-nacelle; 6-pitch system;7-hub; 8-main bearing; 9-low speed shaft; 10-gearbox; 11-high speedshaft; 12-brakesystem; 13-generator; 14-yaw system,15-converter, 16-bedplate. Drivetrain= 9-11 [13].

3 WT PERFORMANCE AND RELIABILITY

Through many years of research, scientists had developed numerous models for the estimation of the performance of WT system. A brief review of performance evaluation methods is discussed here.

Abderrazzag [14] investigated the performance of a grid connected wind farm during 6 years operation and reported variation in wind speed and energy production on a monthly and annual basis for the whole examined period. Another study by Castro Sayas and Allan [15] proposed a probabilistic model of a wind frame taking into consideration the complex nature of the wind, the spatial wind speed correlation and the failure and repair process of WT. A study by Dokopoulos et al. [16] proposed an approach for predicting the economic performance and reliability of autonomous energy systems consisting of diesel generators and wind energy converters (WECs) based on the Monte Carlo-based method.

Billinton and Guung studied the capacity generation associated with wind energy, using a sequential Monte-Carlo simulation and showed that the contribution of WECs to the reliability performance of a generating system is highly dependent on the site wind condition [17]. A sequential Monte-Carlo simulation technique, proposed by Billinton et al. [18] is based on an hourly random simulation for the appropriate evaluation of a generating system including WECS.

Besides, an advanced model, developed and proposed by Kariniotakis et al. [19], which is based on recurrent high-order neural networks for the prediction of the power output profile of a wind park. Holcher [20] presented new storm regulation software, which helps to stabilize the grid during a storm wind and permits additional energy yield. This can subject less stress to the converter as a result of the switch off and start up process at high wind velocities which are avoided, along with their associated load peaks. For the evaluation of short-term wind power fluctuations and their impact on electric power systems, Wan et al. [21] presented statistical properties of the data collected and discussed the results of data analysis. Additionally, through the examination and comparation of regression and artificial neural network models, Shuhui et al. [22] estimated the wind turbine power curves.

Camporeale et al. [23] proposed an electronic system for testing the performance of wind turbines. The main aim of this system is to increase the accuracy in the measurements of speed and torque for each steady-state point of the turbine characteristic power curve. Skiha et al. [24] suggested the steps that can be taken by the government agencies in order to ensure the desired growth of the wind industry in the country and to meet the technical challenges faced by the wind industry. Also, with regards to improving the performance of the wind farm, suggestion on the appropriate selection of the wind electric generator with an optimum rated wind speed was made.

WT life is typically for around 20 years and its failures are commonly predicted and assumed to follow a bathtub curve [25] (Fig. 2). Therefore, reliability of a system is its or its component capability to complete its required task under a certain condition at a defined period of time.

Tanver et al. [25] showed data from Germany and Danish turbines in their periods of early life and their period of usefulness, respectively. They failed to find any appropriate data for wear out periods as the WTs were relatively new and the WT that lose reliability tend to be taken out of service before wear out. In addition, a study reported that the early periods of failure of a WT appear to be getting longer [26].

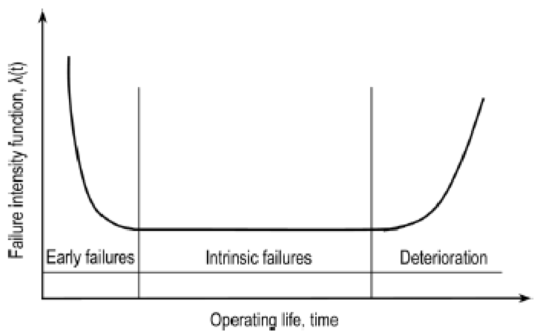

Figure 2: The ‘bathtub curve’ illustrating the reliability variation throughout the life of repairable machinery [13].

However, the typically reported average failure rate of the turbine per year is (1) [27],

$$f = \frac{\sum_{i=1}^{I} N_i}{\sum_{i=1}^{I} X_i T_i} \tag{1}$$

where, f is the failure per turbine per year, N_i is the number of failures, T_i is the time interval (I in total of 1 year each one), X_i number of wind turbines reported.

Similarly, the downtime is the time in which the WT is not operating dur to a fault, typically comprised of time for diagnostic failure, accessing the mechanism, gathering repair equipment’s and spare parts and repairing and restarting the WT. This can be calculated by (2) [27],

$$d = \frac{\sum_{i=1}^{I} d_i}{\sum_{i=1}^{I} X_i T_i} \tag{2}$$

where, d is the failure per hour per turbine per year, d_i is the lost productive hours, T_i is the time interval as a result of failure and X_i number of wind turbines reported.

4 FAILURE OF WT COMPONENT

There have been several studies conducted for the collection of reliability data, some of them including Germany, Sweden, Denmark and Finland. The data in all studies is presented in different forms, for instance, downtime distributions (%), failure rates as failures per turbine per year, failure distributions, downtime as hours lost per component. Also, factors such as types of WT, weather condition and location are also taken into account.

Tanver et al. [28] presented a correlation between weather, location and reliability of the WT due to the speed of wind. His later study [29] showed that there that is a stronger link between the temperature and humidity; weather conditions and failure rate on the reliability of the turbine than the wind speed.

Ribrant and Bertling [30] studied WT failure rate in Germany, Sweden and Finland. The failures data obtained for Germany was between 2003 and 2005 from 865 WTs, between 4% and 7% of the total. Failure rate was about 2.40 per turbine, mainly due to the faults in the sensors, hydraulic, electrical and control systems. Data for Sweden were collected between 2000 and 2004 from approximately 625 WTs ranging from 500-1500 kW. The average failure rate per turbine per year was about 0.4, newer WTs more than 1 MW had higher failures and most failures were in sensors, blades/pitch and electrical system [30-31]. Studies of about 72 WTs in Finland were done. The failure rate obtained was 1.38 per WT per year, mostly due to the blades/pitch, the hydraulic system and the gears. Overall, failures were common in sensors and blade, electrics, control and hydraulic systems in all countries. Gearbox failures accounted for the largest downtime in Sweden and Finland, followed by the control system in Sweden and blades/pitch in Finland. In Germany, generator failure accounted for the largest downtimes followed by gearbox.

McMillan and Ault [32] showed with Windstats data from Germany that the generator, rotor, main bearings and gears account for about 67% of downtime per failure. Similarly, Spinato et al. [33] analysed data from Winstats data [34] over a period of 11 years from Germany (WSD) and Denmark (WSDK). Along with this data, the study also studied data from Schleswig Holstein in Germany (LWK) [35]. From the findings, electrical systems had the highest failure rate, while gearbox led to the largest downtime per failure. Besides, larger WTs experienced higher failure rates [33] and higher costs [36].

Average failure rates of WT components are shown in Fig. 3 [13, 30, 31, 33, 37]. It can be seen that the control system, blades/pitch and electrical system have the cumulative highest failure rate, while Gears, yaw system, brake, generator are in the medium cumulative failure rate. The other components such as the drivetrain have low failure rate.

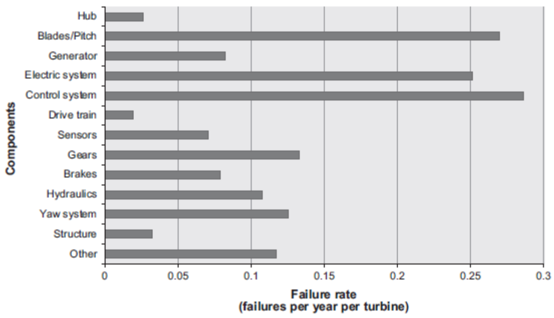

Figure 3: Average failure rate of WT components [13, 30, 31, 33, 37].

Bussel and Zaaijer [37-38] in a study presented that the blades have the highest failure rate of 0.72. Also, their work showed that the control system had failure rate per turbine per year in Germany of 0.66, but from the previous study by Ribrant and Bertling [30] it was about 0.40. Compared to Finland, Denmark or Sweden, electrical system in Germany fail more frequently [37], which could be due to the use of more electrical components in the WTs. None of the authors could find statistics or did not consider the failure rates of other components besides the ones described above, for instance, Spinato et al. [33] considered the failure rate of blades and hub combined as the rotor failure rate.

A different way of observing these studies from Germany, Sweden and Finland [31] is to look at the results as failure rates against hours lost per failure for each of the different components shown in Fig. 4. It should be noted that the hours lost per failure were obtained form downtime per turbine per year divided by failures per turbine per year.

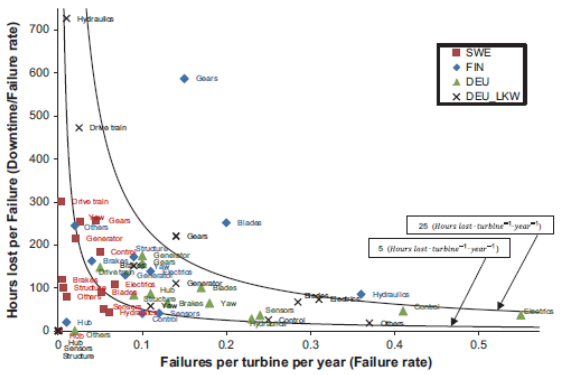

Figure 4: Rate of failure vs. hours lost per failure: Sweden (SWE), Finland (FIN) and Germany (DEU) [13, 30, 31, 33].

Also, the two curves superimposed on the plot are lines of equal downtime of 5 and 25 hours lost/turbine per year, which is just to ease the identification of components failure frequencies or the downtimes per failure.

5 CONCLUSION

- Between different studies the reported failure rates and downtimes of the generators, brakes, sensors, hubs, yaw system and structure do not vary much. The exception is the gearbox, blades and hydraulics;
- Most frequently cited components that experience failures are blades, electrical and control systems, while gearbox, blades and generator are considered to have the highest downtime;
- Gears, blades or hydraulics are considered to be the most problematic components affecting the reliability of WT, as the combination of failure rate and downtime per failure results in a high overall downtime.

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