Assessing Wind Speed Effects on Wind Turbine Reliability

Maik D. Reder and Julio J. Melero

CIRCE - Universidad de Zaragoza, C/ Mariano Esquillor 15, 50018, Zaragoza, Spain

E-mail: mreder@fcirce.es; melero@fcirce.es

Abstract. Wind Turbine (WT) component degradation is in many cases directly linked to the highly variable environmental conditions to which the WTs are exposed to. Understanding temporal combinations as well as their sequences, leads the way to develop more advanced WT reliability models and failure prediction tools. This, not only adds to the understanding of complicated component degradation processes under variable weather conditions, but can also significantly enhance Operation and Maintenance (O&M) strategies, aiming at decreased costs and efforts. This paper presents a profound study on the wind speed conditions that lead to failures of five main WT components. For this, failure data of modern WTs and meteorological data taken from the affected WT's Supervisory Control And Data Acquisition (SCADA) System, have been analysed and compared.

1. Introduction

Wind Turbine (WT) reliability degradation is often directly related to the highly variable environmental conditions under which WTs operate. As stated in Kuik et al. [1], to date there is still a significant research need to fully understand these conditions and their complicated combinations and sequences. Many studies have been carried out investigating the effects of wind speed, relative humidity and temperature on WT reliability. Examples are presented in Hahn et al. [2], Tavner et al. [3] and [4], Faulstich et al. [5], Wilkinson et al. [6] and Wilson et al. [7]. However, these studies still present some shortcomings as, for example, the limited amount of considered failure data or the fact of analysing exclusively out-dated turbine technologies. Also, meteorological data for these publications were taken from a nearby weather station, not at the affected turbine itself - resulting in a distorted picture of the real conditions at the turbine. Additionally, the weather and failure data were treated as monthly or yearly averaged data, not considering short-term changes, nor the actual time of failure occurrence. This work is addressing these shortcomings, by analysing wind speed conditions ahead of WT component failures, focusing on failure histories of modern WTs and meteorological data taken directly from the Supervisory Control And Data Acquisition (SCADA) System of the affected WTs, with respect to the actual time of failure occurrence. This knowledge will not only add to the understanding of WT degradation processes under complex weather conditions, but also helps to create cost effective predictive Operation and Maintenance (O&M) strategies.

2. Approach

The presented study is using failure logbooks from 544 modern operating WTs, with a rated power between 0.85 and 2 Megawatts each, and a total of 1088 operational years. Thus, the number of considered wind turbines and operational years is significantly higher than in previous studies. Five main components are analysed considering altogether 150 failures, containing 30 failures for each. In order to analyse the wind speed characteristics that reflect best the real conditions, meteorological data were taken directly from the affected turbine's SCADA Systems, not from nearby meteorological stations. A profound study is carried out applying statistical tools in order to characterize the wind speed conditions recorded throughout 30 days and one year prior to failures of five main component assemblies. This reveals long-term and short- term effects and will contribute to giving an holistic overview over the wind speed characteristics frequently causing component failures.

3. Main Body of the Abstract

The wind speed data were extracted from the SCADA data base for each recorded failure at the exact moment of occurrence, or the closest 10-minute time step - and tracing back respectively 30 days and one year. In order to characterise and compare the wind speed conditions, the following metrics were calculated using the time series data before each failures:

(i) Mean wind speed,
(ii) Mean maximum wind speed - taking the maxima of each time series and calculating their mean value,
(iii) Mean standard deviation for the wind speed time series,
(iv) Wind speed frequency density distribution,
(v) Fitted Weibull distribution. Despite the existing bi-modality, this distribution was considered a good representation here.

The standard deviations are calculated after de-trending the time series using moving averages, and ensuring their stationarity. This metric is used to analyse short term wind speed variations over the recorded periods.

3.1. Results and Discussion

The results for the mean, the mean maximum and the total maximum wind speed for each of the five components are summarised in tables 1 and 2 respectively. Figures 1 and 3 represent the frequency densities of the measured wind speed values. The fitted Weibull distributions to each of the data sets are visualised in figures 2 and 4. Many conclusions can be drawn from the presented findings, due to limited space some of the most significant results obtained shall be discussed in the following.

Table 1. Wind speed during 30 days before failure

Assembly	Mean $[\frac{m}{s}]$	Mean Max. $[\frac{m}{s}]$	Total Max. $[\frac{m}{s}]$	Standard Deviation $[\frac{m}{s}]$
Pitch System	6.697	21.299	36.680	2.213
Generator	6.461	20.745	27.486	2.058
Gearbox	7.664	21.773	34.300	2.119
Converter	7.204	20.547	33.924	2.211
Yaw System	6.306	21.366	34.840	2.109

Table 2. Wind speed during one year before failure

Assembly	Mean $\left[\frac{m}{s}\right]$	Mean Max. $\left[\frac{m}{s}\right]$	Total Max. $\left[\frac{m}{s}\right]$	Standard Deviation $\left[\frac{m}{s}\right]$
Pitch System	6.541	29.109	36.680	1.970
Generator	6.220	26.894	33.662	2.168
Gearbox	6.722	26.002	34.920	2.009
Converter	6.426	26.823	33.924	2.114
Yaw System	5.980	27.336	34.840	2.028

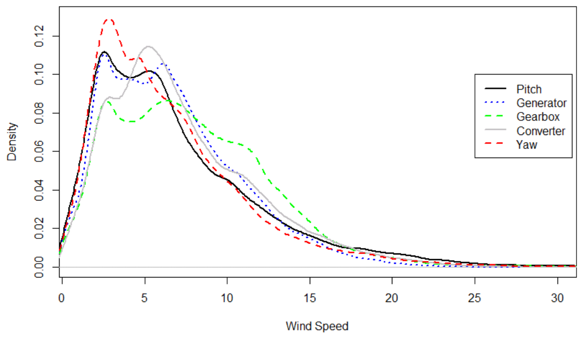

Figure 1. Frequency density during 30 days before failures

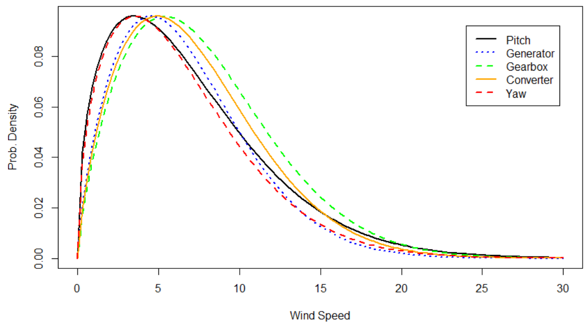

Figure 2. Weibull distribution for data recorded 30 days before failures

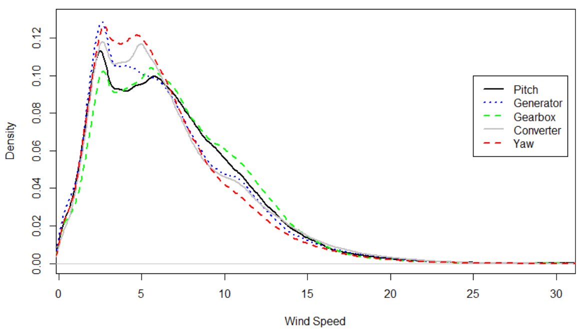

Figure 3. Frequency density during one year before failures

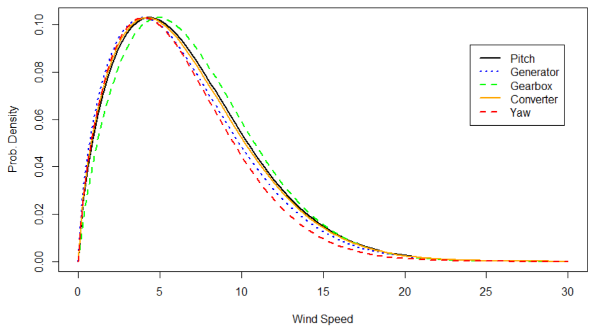

Figure 4. Weibull distribution for data recorded one year before failures

As expected, the mean wind speeds during the last month before failure were higher than the ones recorded one year prior to the failures. This indicates, that failures occurred generally during months with higher mean wind speeds. The pitch system showed the highest total and mean maximum wind speed throughout the year. The standard deviation, indicating wind speed changes, showed the lowest value throughout the year, however, during the last month the highest value compared to the other components. An increased appearance of high wind speeds (above 17 m/s) during the last month was also recorded. The gearbox seemed to be affected significantly by wind speeds between 8 and 16 m/s, denoted by an increase in measurements within this range during the last month before failure. Also, the yearly mean and monthly mean wind speeds presented the highest values. The standard deviation increased within the last month's data, compared to the annual value. For the yaw system, the wind speed conditions throughout the year and during the last month did not differ significantly. The lowest mean wind speeds, the second lowest standard deviations and high mean maximum and total maximum wind speeds were recorded. The generator failures showed the lowest monthly but the highest yearly standard deviation in the measurements. The wind speeds prior to converter failures were characterised by very high standard deviations, both during the last month and the whole year. Also, the mean wind speed during the last month increased significantly compared to the one obtained during one year.

4. Conclusion

As demonstrated above, certain components are more affected by variable wind speed conditions than others and increased mean wind speeds favoured failure occurrences of all components. The pitch system is affected by changes in wind speed in combination with high mean wind speeds and very high peaks. Under these conditions the pitch mechanisms are challenged the most. The gearbox was affected mostly by high mean wind speeds and high peaks, but less by wind speed variability. The wind speeds recorded throughout one year before generator failures showed high standard deviation, mean and maximum wind speed values, but a decrease during the last 30 days - leading to the conclusion, that this component is less influenced by the short-term effects during the last month. The conditions leading to yaw system failures during the last month prior to failure did not differ significantly from the ones throughout one year. This component might not significantly be affected by high wind speeds, rather by variable wind directions or relative humidity. Converter failures were characterised by high mean values and changes in wind speed. Especially during the last month this component seemed to be affected strongly by the high wind speeds and their high variability.

5. Learning Objectives

The aim of this study was to analyse short- and long-term wind speed characteristics responsible for causing failures of the five presented WT components. In future research studies, we will analyse the effects of temperature and relative humidity data. Also, pattern recognition techniques will be used to investigate reoccurring patterns in combinations of several meteorological conditions leading to component failures.

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References

[1] Kuik G A M V, Peinke J, Nijssen R, Lekou D, Mann J, Ferreira C, Wingerden J W V, Schlipf D, Gebraad P, Polinder H, Abrahamsen A, Bussel G J W V, Tavner P, Bottasso C L, Muskulus M, Matha D, Lindeboom H J, Degraer S, Kramer O, Lehnhoff S, Sonnenschein M, Morthorst P E and Skytte K 2016 *Wind Energy Science* **1** 1–39 ISSN 2366-7443

[2] Hahn B 1997 *FGW-Workshop Einfluss der Witterung auf Windenergieanlagen,*

[3] Tavner P, Edwards C, Brinkman A and Spinato F 2006 *Wind Engineering* **30** 55–72 ISSN 0309-524X

[4] Tavner P, Greenwood D M, Whittle M W G, Gindele R, Faulstich S and Hahn B 2013 *Wind Energy* **16** 175–187 ISSN 10954244

[5] Faulstich S, Lyding P and Tavner P 2011 *European Wind Energy Conference*

[6] Wilkinson M, Hassan G L G, Vincent S, Lane S, Bs B, Delft T V and Harman K 2012 *European Wind Energy Conference*

[7] Wilson G and McMillan D 2014 *Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013* 801–809