WIND TURBINE RELIABILITY ANALYSIS

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Summary

Work Package 1 (WP1) of the EU Reliawind project is concerned with the analysis of the reliability of operational wind turbines. The overall objective of this work package is to identify the critical failure modes at the component, sub-system and system scale within wind turbines based on the analysis of available long term operational data and fault records logged by SCADA systems operating on wind farms around the world. The initial conclusions of WP1, presented in deliverable D1.3 [1], reveal trends in the reliability of wind turbines that appear to differ from those of other studies. The purpose of this paper is to highlight the differences between the conclusions of Reliawind WP1 and those of other studies. Additional records of wind turbine failure rates and downtime will also be analysed and compared to Reliawind. This paper will then consider the key differences between the studies in light of information about how their reliability data were derived. Through appreciating the various data collection, recording and processing methods it is hoped that the differing conclusions of the studies can be fully understood.

1. Introduction

1.1 Reliability Field Study

The Reliawind project is a European Union funded project, with an overall budget of €7.7M, involving 10 industrial and academic partners. Reliawind has the aim of identifying, quantifying and understanding critical failures and their mechanisms. The scope of the project is broad, but the first stage of this work has been a field study to measure the reliability of existing wind turbines at several operational wind farms. As part of this study, wind farm Owners and Operators have provided historical data from operational wind farms representative of those currently installed. These sources are discrete and often of varying quality, but the authors have developed systematic and consistent processes to connect these data. A significant amount of detailed data has been analysed; the results will be presented and compared against other studies. The results will be of interest to wind turbine Owners, Operators and Manufacturers.

1.2 Reliawind Data

The data used by Reliawind was provided by Reliawind partners Gamesa and Ecotecnia. These wind turbine manufacturers have access to SCADA data and maintenance records from turbines for monitoring and servicing purposes. The Reliawind database is currently being extended to include data from a 'Users Working Group' of wind farm owners; however, the comparisons made in this report are based solely on the data provided by the two manufacturers. Reliawind WP1 deliverable D1.2 [2] sets out the methods by which the data were collected and processed. This section summarises the main points of this document that are relevant to the comparison of Reliawind with other studies. In order to ensure that the data from each partner was comparable and relevant to the objectives of the project, turbine selection criteria were imposed [2]. To be included in the data set the wind turbine site should comprise at least 15 turbines and the turbines should have been running for at least two years since commissioning and should conform to the Reliawind generic 'R80' turbine: pitch regulated and rated at > 850 kW. No data from before commissioning was included as it is considered that this is not part of a turbines service life. The data used by Reliawind WP1 was obtained from various sources depending on manufacturer: 10-minute average SCADA data, fault/alarm logs, work orders/service records and O&M reports.

1.3 Reliawind Results

To date, around 300 onshore wind turbines operating for varying lengths of time have been analysed and around 31,500 'downtime events' have been identified. These downtime events have been classified within the standard turbine taxonomy to the best extent that the data permit. Having applied these sorting and cleaning processes, the data have been analysed by standard reliability methods. The analysis allows the calculation of the failure rate and downtime for each part of the turbine, for example as shown in Fig 1.

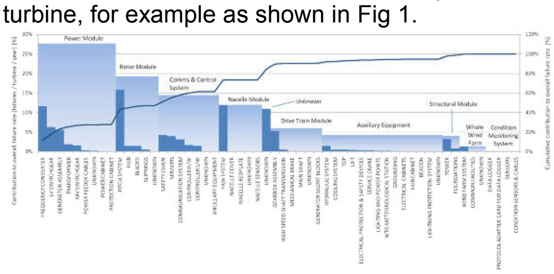

Fig. 1. Failure Rate from the Reliawind Data

2. Other Data Sources

Despite the existence of large wind industries outside of Europe there appears to be little publically available data regarding wind turbine reliability from those countries. In the US, efforts to collect reliability information are still in their early stages. The Sandia National Laboratories, for example, have begun a programme similar to Reliawind but as yet no results have been published. Within Europe however, various institutions and organisations have been collecting and publishing data from wind farms for over a decade. As well as energy production statistics, many of these collect component failure information. Sets of data that are compared to Reliawind include
- WindStats (Germany and Denmark)
- LWK
- WMEP
- Vinstat
- VTT

2.1 Summary
Figure 2 summarises the parameters of the data sets used in the report.

	Reliawind	Wind Stats Germany	Wind Stats Denmark	LWK	WMEP	Vindstat	VTT
Region	Europe	Germany	Denmark	Schleswig-Holstein, Germany	Germany	Sweden	Finland
Period	Jan 2004 – Sep 2008	1996 – 2008	Q4 1994 – 2003	1993 – 2006	1989 – 2006	1997 – 2004	1999 – 2009
Reporting Interval	Event	Quarter	Month	Year	Turbine age (yrs)	Year	Year
Data Source	Gamesa, Ecotecnia	-	-	Chamber of Agriculture	-	Elforsk	-
Number of Turbines	283	1803 – 4924	851 – 2345	158 – 643	1500	342 – 1050	63 – 118
Power [MW]	366	597 – 6349	328 – 593	11.5 – 45	~250 (avg)	108 – 452	35 – 120
Average Rating [kW]	1293	331 – 1289	385 – 253	73 – 70	167	316 – 430	556 – 1017
Turbine Specification	Pitch, =850kW	>50kW	>50kW	>50kW	All	>50kW	>50kW
Reporting by:	Event	Cause of stop	Type of stop	Make & model	Make & model, turbine age	Type / cause of stop	Cause of stop
No. of Items in Taxonomy	253 (9 sub-systems)	14	18	16	56 (12 groups)	13 – 55	16 – 30
Number of Failures	Yes	Yes	Yes	Yes	Yes	No†	Yes
Hours Lost	Yes	Yes	No	Yes	No*	Yes	Yes

* WMEP downtime data exists but is not available.
† Number of failures is reported until 1999 but is not included in this study due to the length of this period

Fig. 2. Data Source Parameters

3. Comparison

3.1 Normalised Failure Rates
Figure 3 shows, for each data set in the study, how the failure rate is divided across the wind turbine sub-systems as a percentage of the total. Note that Vindstat is not included here as no failure rate figures are available.

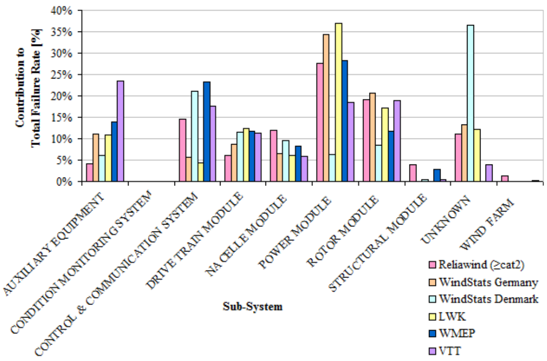

Fig. 3. Sub-System Normalised Failure Rates

3.2 Normalised Downtime
Figure 4 shows, for each data set in the study, the downtime attributed to each of the sub-systems as a percentage of the total downtime. WindStats Denmark and WMEP are not included here as downtime figures are unavailable.

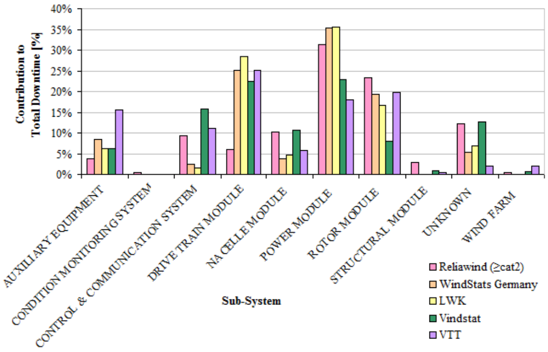

Fig. 4. Sub-System Normalised Downtime

3.3 Availability
With Reliawind reporting higher failure rates, the possibility of under- or over-reporting in the data sets should be considered. An indication of the exhaustiveness of the data may be found by looking at the average wind turbine availability that is reported by the data set. Availability is a well understood aspect of a wind turbine's operation and so existing knowledge can be used as a bench mark to compare against. Figure 4, the **Error! Reference source not found.** shows that the mean annual system availability of a wind turbine is 96.4%. From these figures it is apparent that the failure reporting in Reliawind (maintenance category ≥2) is fairly accurate. The same can be said of the VTT. WindStats Germany, LWK and Vindstat all claim above 99% availability. According to Figure 4 it is likely that the failure reporting in these studies is far from complete. Unfortunately availability figures are unavailable for WindStats Denmark and WMEP.

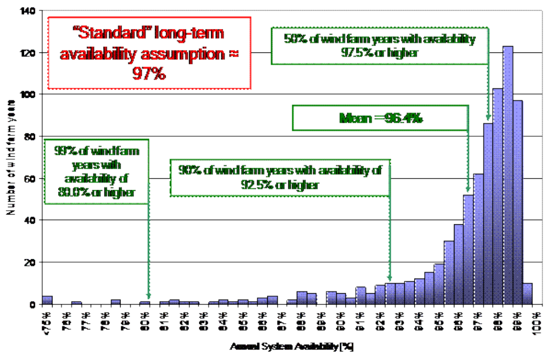

Fig. 4. Distribution of Average Annual Availability [3]

3.4 Reliawind Maintenance Categories
The failure rates presented in Reliawind WP1 Deliverable D1.3 were derived from failure events that were classed as maintenance category 2 or higher. It may be possible that due to the data collection methods used in the other data sets, only failures requiring a greater level maintenance were reported. For this reason it would be beneficial to

compare failure rates when considering failure events classed as maintenance category 3 or higher in the Reliawind data set.

3.5 Turbine Specification

Another factor that would result in Reliawind having relatively higher failure rates is the specification of turbines within the data sets. The Reliawind data was sourced solely from turbines that matched the Reliawind generic ‘R80’ turbine: pitch regulated and rated at ≥850kW. The range of turbines that the other data sets included was much broader. Most included turbines rated from 50kW and all included both pitch and stall regulated turbines. The LWK and WMEP data sets provided reliability information specific to turbine model. Figure 5 compares failure rate to turbine rating for models in the LWK and WMEP data sets and Figure 6 compares the availability to rating for models in the LWK data set (downtime and therefore availability data is not available from WMEP).

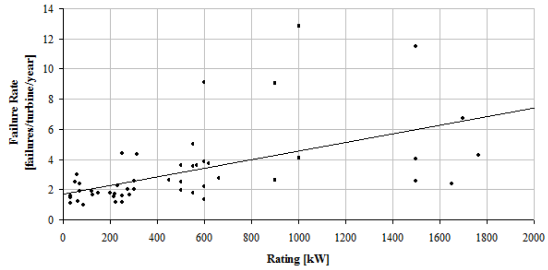

Fig. 5. Failure Rate vs. Turbine Rating

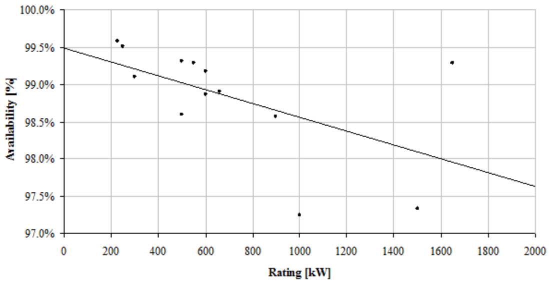

Fig. 6. Availability vs. Turbine Rate

Figure 5 and Figure 6 show a general trend in declining reliability as wind turbine rating increase. This would go some way in explaining the higher failure rates stated by Reliawind. However, in neither LWK nor WMEP does the failure rate approach 24.15 failures per turbine per year as suggested by Reliawind.

4. Comparison with other Reliability Studies

4.1 Spinato, F., The Reliability of Wind Turbines

In his PhD thesis ‘The Reliability of Wind Turbines’ [4], Spinato analysed WindStats Germany, WindStats Denmark and LWK data to reveal how wind turbine reliability varies with design concept and turbine age and also how failures and downtime are distributed across turbine sub-systems. For the purpose of comparing with Reliawind, only the information regarding the reliability of turbine sub-systems will be considered.

Figure 7 shows the normalised failure rates of wind turbine components. The ‘electrical system’ was found to be the cause of the highest proportion of failures. The total failure rates according to WindStats Germany, WindStats Denmark and LWK in the study are: 1.44, 0.73 and 1.85 failures per turbine per year respectively. Unsurprisingly, these are similar to the failure rates determined §**Error! Reference source not found.** for the same three data sources.

Figure 8 shows how the gearbox has, on average, the highest downtime per failure according to LWK data. However, when dividing the data up into turbine rating groups, as shown in Figure 9, it is apparent that a high gearbox downtime per failure is characteristic of smaller turbines. In larger turbines, gearbox failures result in less downtime. In his study, Spinato also concluded that the gearboxes in pitch regulated turbines suffered less downtime per failure.

Considering that the turbines in the Reliawind study are rated ≥850kW and pitch regulated, Spinato’s study supports the Reliawind results which showed the gearbox to have a relatively small proportion of downtime attributed to it.

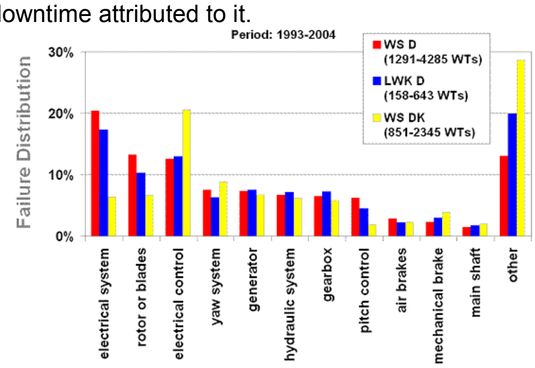

Fig. 7. Failure Distribution Across the Sub-Systems

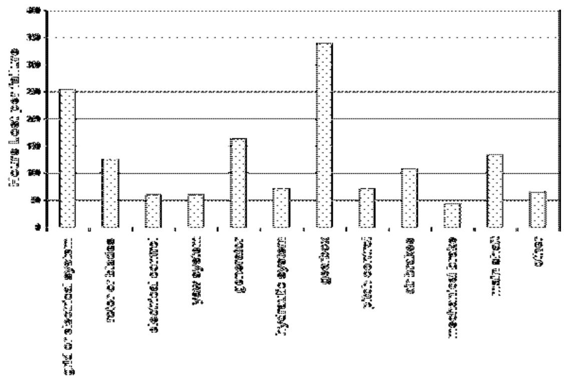

Fig. 8. Sub-System Downtime (from LWK Data)

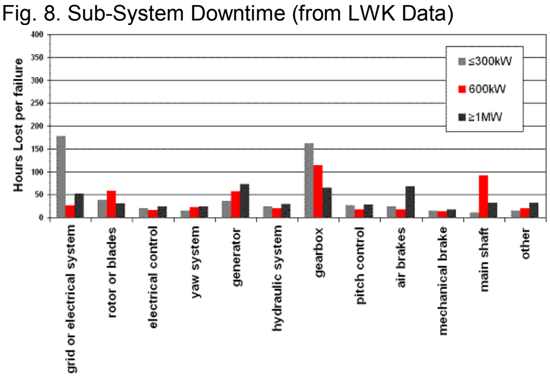

Fig. 9. Sub-System Downtime by Turbine Rating (from LWK Data)

5. Conclusions

The distribution of failures across the turbine sub-systems reported by Reliawind is roughly consistent the other data sets. WindStats Denmark however, appears anomalous with a relatively low proportion of failures attributed to the power module and a high proportion that were attributed to 'unknown'. Reliawind, WindStats Germany, LWK and WMEP all rank the power module as the primary cause of failures.

The distribution of downtime across the turbine sub-systems reported by Reliawind is roughly consistent the other data sets. The exception to this however, is the drivetrain sub-system which is significantly lower in Reliawind, causing just 6% of downtime, than the other data sets which report 22% to 28%. The power module accounts for the most downtime in all but the VTT data sets, accounting for 25% to 36%.

The failure rates of the publicly available data are in the range 0.67 to 2.70 failures per turbine per year. The absolute failure rates of the Reliawind study cannot be published at this stage due to confidentiality reasons, but this may be possible as more data are added to the database. In GH's experience the publically available data failure rates are low for modern wind turbines. A possible reason for this may be a certain level of under reporting. Additionally, the differences between the specifications of the turbines included in the data, specifically the rated power, will lead to differing failure rates. The trend of decreasing reliability with increasing turbine rating means that Reliawind, having a much higher average turbine rating, will inevitably have higher failure rates.

It is unlikely however that these factors alone can account for the huge difference in failure rates. Considering that the downtime reported by Reliawind is justifiable, on account of the realistic availability, it may be the case that either Reliawind has reported multiple failures for what is essentially the same failure, or, due to the nature of the reporting methods, the other data sets have recorded multiple failures as a single failure. Because the Reliawind results were derived from failures that demanded the physical presence of engineers at the turbine, and assuming that each failure resulted in a separate call-out, it would not be appropriate to aggregate failures. This, therefore, implies that there is greater validity to the relatively high failure rates reported by Reliawind. However, further reliability analysis would benefit from the clarification of how similar failures that occur within a short time frame are counted.

Few original wind turbine reliability studies have been conducted and these few draw their conclusions from a limited pool of data sources. Because of this, the results of these studies are very similar to the reliability profiles derived from the same data sources in §3. However, the studies reviewed in this report offer insights that go towards understanding the differences between the results of Reliawind WP1 and those of the other data sets.

In Spinato's paper 'The Reliability of Wind Turbines', it was revealed that gearbox downtime per failure reduced as turbine rating increased. Additionally, gearbox downtime per failure was found to be less in pitch regulated turbines. This may explain the large difference, in terms of the proportion of failures attributed to the gearbox, between Reliawind and other data sources. Ribrant's study [5] confirms that the Reliawind gearbox reliability profile does not represent that of an 'average' turbine.

6. References

[1] Wilkinson, M.R., Spinato, F., Hendriks, B., 2010. *Report On the Wind Turbine Reliability Profiles, Technical Report*. Project deliverable: Reliawind D.1.3.

[2] Wilkinson, M.R., Gomez, E., Bulacio, H., Spinato, F., Hendriks, B., 2010. *Report On Quantification of Failure Rates and Repair Times, Technical Report*. Project deliverable: Reliawind D.1.2.

[3] Harman, K., Walker, R. and Wilkinson, M., 2008. 'Availability Trends Observed at Operational Wind Farms', *Proceedings of the European Wind Energy Conference*, Brussels, April 3, 2008.

[4] Spinato, F., 2008. *The Reliability of Wind Turbines*. PhD thesis, Durham University.

[5] Ribrant, J., 2006. *Reliability Performance and Maintenance – A Survey of Failures in Wind Power Systems*. Masters thesis, KTH School of Electrical Engineering.