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Methodology and Results of the Reliawind Reliability Field Study

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Abstract

The EU FP7 Reliawind project has the aim to identify and understand critical failures and their mechanisms through quantitative studies of detailed wind farm data. A common wind turbine taxonomy and a universal database structure for storing downtime events from multiple manufacturer's turbines have been defined. Systematic and consistent processes have been developed to deal with historical data from wind farm Owners and Operators. Data including 10-minute SCADA, service records/work orders and alarm logs have been analysed to determine downtime events within the common taxonomy. The downtime events have been analysed to determine the distribution of failure rates and downtimes between the sub-assemblies. To-date 31,500 downtime events have already been added to the common database structure and the database is still under expansion.

1. Introduction

Quantitative studies of wind turbine reliability have been carried out recently [1]-[4]. The objectives of these studies were to extract information from existing commercial or public databases to understand wind turbine reliability from a statistical point of view and provide benchmark for further analysis.

The Reliawind project is a European Union 7th Framework Integrated Project, with an overall budget of €7.7M, involving 10 industrial and academic partners. Reliawind has the aim of identifying and understanding critical failures and their mechanisms. The results are being used to compare the reliability of operational turbines and ultimately to improve machine reliability through design for reliability and targeted condition monitoring.

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 including 10-minute SCADA data, automated fault-logs and O&M reports 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 also been provided from the wind turbine manufacturers who are part of the Reliawind Consortium.

The success of reliability analysis relies on the specification and rigorous application of consistent structures and processes. The Reliawind Consortium has developed a standard wind turbine taxonomy, which assigns each part to a subassembly, assembly and subsystem. A standard database format with a number of tables has also been developed, which holds information about all downtime events at each wind turbine. Events identified in the field study with a downtime greater than 1 hour and requiring at least a manual restart have been assigned to the relevant subassembly or part where possible. The result is a consistently populated database that allows quantitative results to be derived and comparisons made.

The database can be queried to extract the Time to Failure for each subassembly, which can be used to derive Reliability Profiles showing downtime and failure rate for each subassembly. The Reliability

Profiles are of benefit to Owners and Operators as they allow the comparison of their machines against a generic wind turbine from the whole database. As more data is added, more detailed comparisons can be made, such as comparing the reliability of machines by turbulence intensity or other site conditions. For wind farms approaching the end of the manufacturer's warranty, the Reliability Profiles can aid the Owner's decision making for future operation and maintenance strategies and expected costs.

The methodology and results of the field study will be presented and the benefits of the Reliability Profile metrics will be described. This will be followed by a discussion of some of the lessons learned and recommendations for the future application of the Reliawind processes, which will be of interest to all parties wishing measure, understand and improve the reliability of wind turbines.

2. Methodology

The Reliawind field study has been conducted to measure the reliability of operational wind turbines representative of modern technology.

Wind Farm Selection Criteria

It was necessary to impose common wind farm selection conditions to ensure results from each source are comparable and of relevance to the wider Reliawind project. These conditions are:

- Site – should comprise at least 15 turbines; and
- Turbines – should have been running for at least two years since commissioning.

Additionally, it was agreed that only modern turbines representative of standard technology should be included, leading to the imposition of the conditions that the turbines should be:

- Variable speed, pitch regulated; and
- Rated at > 850 kW.

Data Available from a Wind Farm

In general, modern wind farms have the following information available:

- 10-Minute average SCADA data;
- Fault / alarm logs;
- Work orders / service reports; and
- O&M contractor reports.

These sources are discrete and are not designed to easily allow reliability information to be extracted; a substantial effort has been invested in connecting these sources. Data for this study have been provided by wind turbine manufacturers who are members of the Reliawind consortium and wind farm Owners and Operators who are members of the Reliawind Users' Working Group.

Turbine Taxonomy

It is understood that various attempts at classifying turbines components have been made in the past and various standards exist e.g. the RDS-PP classification for power plants [5]. However, for reasons of practicality, and in particular the necessity to find a structure that could conveniently be applied to the turbines selected for the field study, it was decided that a new Reliawind taxonomy be developed. This is based on the terminology of System, Sub-System, Assembly, Sub-Assembly and Component/part. Examples of this terminology are as follows:

System	Sub-System	Assembly	Sub-Assembly	Part
Turbine	Rotor	Electrical pitch	Pitch motor	Brush
Turbine	Drive train	Gearbox assembly	Gearbox	Stage 1 planetary wheel
Turbine	Power	Generator assembly	Rotor	Rotor winding

Figure 1. Example from the Reliawind turbine taxonomy.

A taxonomy of this type may be constructed on a functional or positional basis. The Reliawind taxonomy is a hybrid approach, with a positional grouping for mechanical components and a functional grouping for electrical elements. This reflects the fact that electrical energy may generally be transmitted between positional elements such as between the nacelle and base of the tower, whereas mechanical energy is generally confined within positional elements. The authors are involved in on-going work to unify this with other existing structures currently being implemented in other projects. A common approach would permit reliability data from different studies to be more easily compared.

Reliability Database

The paper has described the diverse data sets available from wind farms of different manufacturers. Extensive efforts have been devoted to cleaning and linking these data and it has been found that methods needed are strongly dependant on the type of manufacturer's SCADA system.. To permit data to be aggregated and for data from different partners to be compared in a meaningful fashion, it was agreed to work to a common approach for storing and processing these data. A set of 5 tables was developed, which allow data to be stored and compared in standard form:

- **Table 1 Events** A list of all fault events;
- **Table 2 Failure Rates** Failure rates (failures/year) by subassembly;
- **Table 3 Downtime** Number of hours by subassembly;
- **Table 4 Wind Farm Configuration** A description of the wind farms in the above tables; and
- **Table 5 Additional Turbine Information** Containing wind farm production and other lifetime related quantities.

This list of events in Table 1 is exhaustive within the following criteria:

- The event required manual intervention to restart the machine; and
- The event resulted in downtime ≥ 1 hour.

There are no missing events or missing time periods; or if there are, the missing time periods will be noted and the reasons stated. An example of data formatted into these requirements is given below and to date 31,500 downtime events have been added to the database:

TABLE 1 EVENTS

Wind Farm	Turbine ID	Date & Time of Event	Time to Repair TTR (hours)	Actual Repair Time ART (hours)	Sub-System	Assembly	Sub-Assembly	Part	Failure Mode	Root Cause	Maintenance Category	Severity Category	Additional information
A	1	2008-04-01 11:28:01	54.2	N/A	Drive train	Gearbox assembly	Gearbox	N/A	N/A	N/A	4	3	N/A
A	23	2008-04-24 01:56:11	168.4	3.5	Rotor	Pitch system	N/A	N/A	N/A	N/A	3	2	N/A
B	2	2008-04-25 08:43:24	2.5	1	Power	Generator assembly	Generator	Stator phase b winding	Open	Over current	1	1	Series defect
…	…	…	…	…	…	…	…	…	…	…	…		…

Figure 2. Example downtime events.

Each downtime event is also tagged with a maintenance category, which is a description of the maintenance impact of the fault, ranging from 1 to 4 with 1 being the least severe (manual restart) and 4 being the most significant (major replacement).

Reliability Analysis

Having been applied with the cleaning and sorting processes described above, the data are analysed using standard reliability methods. Such methods include a Pareto analysis for the average failure rate, which is an ordered visual representation of the failure rate value. In other terms the WT parts or sub-assemblies have been sorted by failure rate, as it results form the calculation.

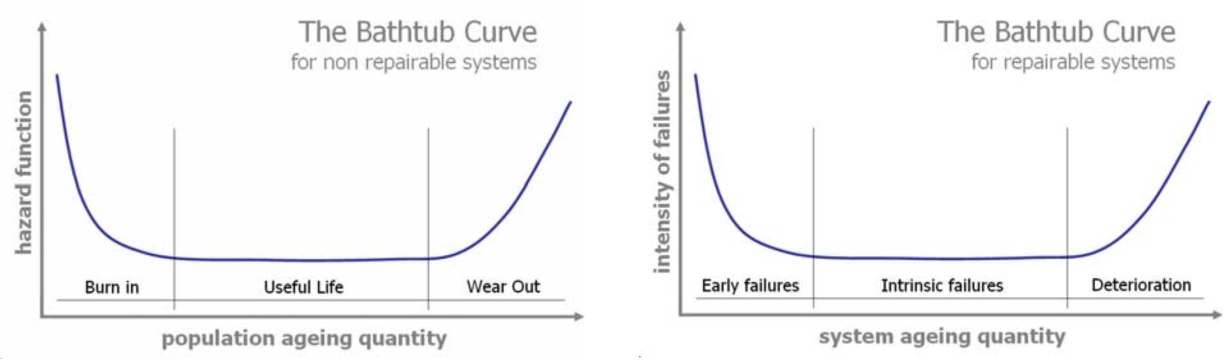
The average failure rate for sub-assemblies has been calculated over the entire recording period according to:

$$\lambda = \frac{\sum_i n_i}{T - \sum_k D_k}$$

where

- i = index counting the number of sub-assemblies failures
- n = number of sub-assembly failures
- T = total length of the recording period
- k = index counting the total number of downtimes
- D = downtime

The calculation of the average failure rate implies that the sub-assemblies are either perfectly repaired or made of non repairable components that are replaced at any action. In reliability terms this is equivalent of assuming the sub-assembly reliabilities lie in the constant, flat part of the bathtub curve. The bathtub curve represents the hazard function of a population and is constant when the related reliability is modelled by the exponential function, see Figure 3 (a).



(a) (b)

Figure 3: The bathtub curve (a) for non repairable systems and (b) for repairable systems.

However, the assumptions above can hide possible reliability time trends affecting the population. The analysis of reliability time trends may produce useful results [2]-[4], particularly for mechanical or electromechanical parts subject to wear and tear, for which the speed of the wearing is quantified.

An investigation of time trends shown by using consolidated methods such as the Crow-AMSAA model for fleet of homogenous systems [6] has been conducted. With this approach the reliability of the entire wind turbine fleet can be analysed and synthesised in a compact form. In this case the population can be considered as a repairable system for which the bathtub curve for repairable system applies. The Crow-AMSAA model can be reduced to the definition of the intensity function $\lambda(t)$, which assumes the following form:

$$\lambda(t) = \rho \beta t^{\beta - 1}$$

where

- ρ = scale parameter of the intensity function
- β = shape parameter of the intensity function
- t = time

The shape parameter can model different phases of the intensity function early failures (or debugging), intrinsic life or constant failures, and deterioration, as shown in Figure 3 (b).

It must be noted that in this case the bathtub curve models the intensity function of a Poisson Process rather than the hazard function related to a certain distribution. In practical terms this mathematical difference results in considering the failures of the repairable population related to one another rather than independent.

Some of the sub-assemblies analysed present an insufficient number of failures for a rigorous analysis, therefore a minimum of 5 failures has been adopted, although results have been critically evaluated for lower number of failures.

3. Results

To date 240 wind-farm months' worth of data have been added to the database, comprising 290 wind turbines operating for varying lengths of time. The downtime events from these turbines have been analysed by the methods described above and can be investigated in many ways such as:

- Matching the failure data with external conditions such as low temperatures, extreme gusts, wind direction, location in the farm, etc.
- Determining the failure rate of different severities of fault such manual restart, major replacement, etc. For example, manual restarts are much more critical offshore than they are onshore.
- Evaluating the number of failures in time: does this confirm the assumption of a Poisson Process confirmed or not?
- Investigating the sequence of failures, investigating the sequence of changes in the external conditions and failures (e.g. failures occurring soon after a grid failure, or after a cold start).
- Evaluating the distribution of fault statistics over the population.

Many of these aspects have been addressed, for example the following charts highlight the failure rates and downtimes on a per sub-system and per assembly basis. Only downtime events tagged with a maintenance category indicating a component replacement have been considered for these charts (i.e. manual restarts have been excluded). The data presented here are normalised relative to the overall failure rate / downtime, to show the percentage contribution to the overall failure rate / downtime. The large background blocks show sub-systems, the smaller foreground blocks show assemblies and the line shows the Pareto cumulative contribution.

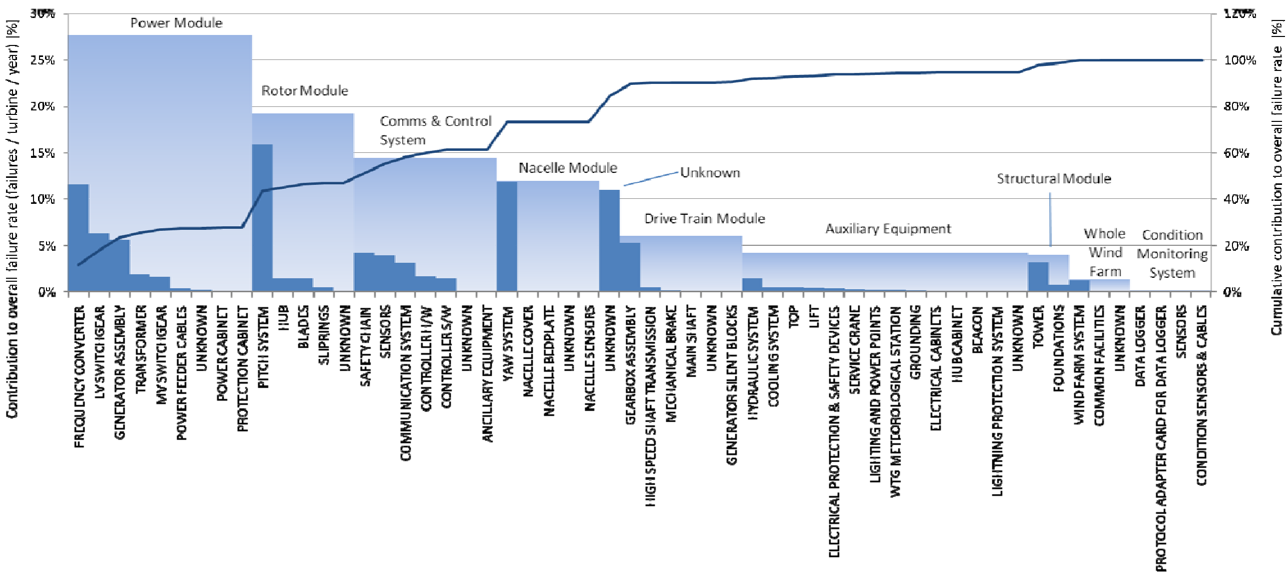


Figure 4. Normalised failure rate of sub-systems and assemblies for turbines of multiple manufacturers in the database.

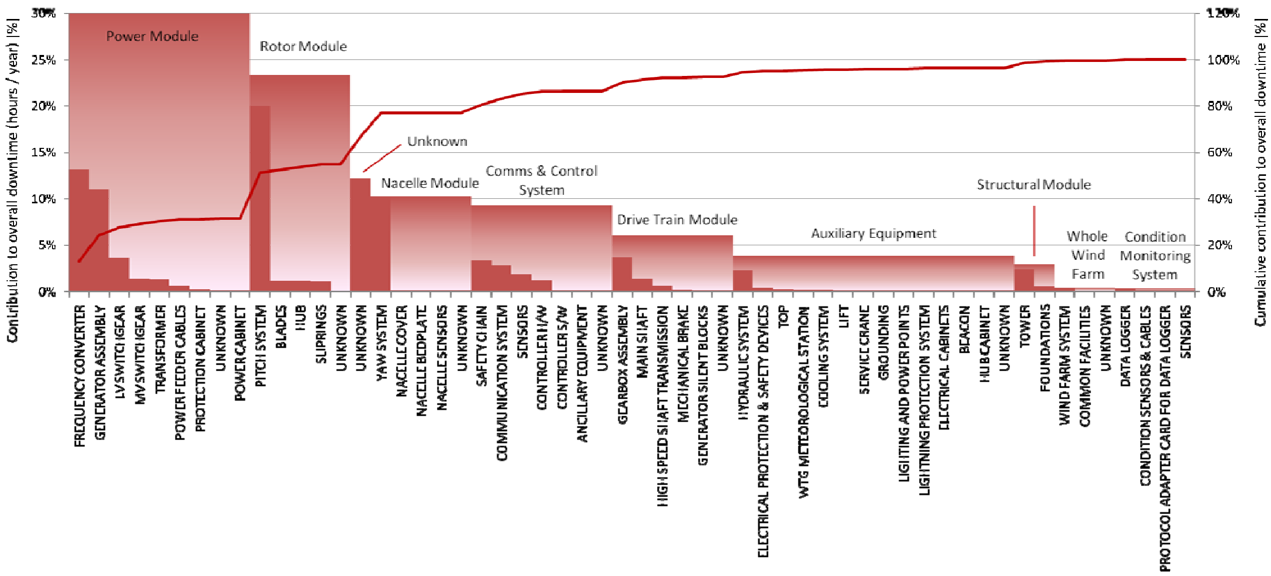


Figure 5. Normalised hours lost per turbine per year to faults in sub-systems and assemblies for turbines of multiple manufacturers in the database.

These results contain much information, for example, it can be seen from the failure rate chart that 50% of the contribution to overall failure rate stems from the power and rotor modules, with the most significant contributors being the frequency converter, generator and pitch system.

The authors have found that generally the data recorded at operational wind farms do not generally permit the determination of the root cause of the downtime and the results of Figure 4 and Figure 5 show the replaced component. It is noted that the "unknown" category is significant, representing around 11% of the contribution to the overall failure rate. This is to be expected given the source data and reflects experience of analysis of public surveys such as reported by Spinato et al. [4].

4. Conclusions

The Reliawind project is intended to address the need for a quantitative measurement, understanding and improvement of turbine reliability. The first part of this work is the field study, which has to date analysed data from 290 wind turbines from multiple manufacturers. The following achievements have been made:

- A common wind turbine taxonomy to describe the allocation of parts of the turbine has been defined;
- A database structure for storing downtime events from multiple manufacturer's turbines has been defined;
- 10-minute SCADA, service records / work orders and alarm logs have been analysed to determine downtime events within the common taxonomy;
- To-date 31,500 downtime events have been added to the common database structure;
- The downtime events have been analysed to determine the distribution of failure rates and downtimes between the sub-assemblies.

Acknowledgements

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