Title: Offshore Wind Turbine and Sub-assembly Failure Rates through Time

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Introduction: O&M costs can make up to 30% of the lifetime CoE of an offshore wind farm. As a means of reducing this cost operators and O&M providers need a better understanding of wind turbine reliability and failure rate with time. This paper shows the results of an analysis of offshore wind turbine annual failure rates over an 8 year period. The analysis is based on ~ 350 modern multi MW offshore turbines located in 5-8 offshore wind farms throughout Europe.

The analysis detailed in this paper builds on earlier work in [1], in which failure rates are provided for the population mentioned above. This paper builds on that work by providing failure rates for each subsystem each year allowing conclusions to be drawn on the failure behaviour of the different wind turbine subsystems with time. The paper also discusses why certain components/subsystems fail differently over time than others.

Although this type of failure rate vs. time analysis has been carried out before for an onshore population [2], a literature review has shown that this work and paper is novel due to the fact that such an analysis has never before been published for a population of modern multi MW offshore wind turbines. Reference [2] is based on a population of smaller older onshore wind turbines and only provides failure rates with time for the overall turbine, not for each turbine sub system. The authors feel that this paper is suited to the O&M & Logistics track at EWEA 2015. This work contributes to the wind turbine O&M knowledge by providing operators and maintenance providers with an overview of how wind turbines and their sub-assemblies fail in relation to time, which can be used in O&M modelling or to assist with O&M decision making.

Approach: The following approach was taken to complete this paper:

1. Offshore reliability data was obtained from industrial partners for the 5-8 wind farms throughout Europe

2. Data was processed (cleaned and organised) to ensure all failures from the list of work orders were captured and no scheduled operations were wrongly captured as failures.

3. Data was analysed to determine overall failure rates and modes for each turbine.

4. Data was analysed to determine overall failure rates per cost category for each subassembly of the turbine.

5. Data was analysed to determine overall failure rates for each turbine and subassembly vs. time.

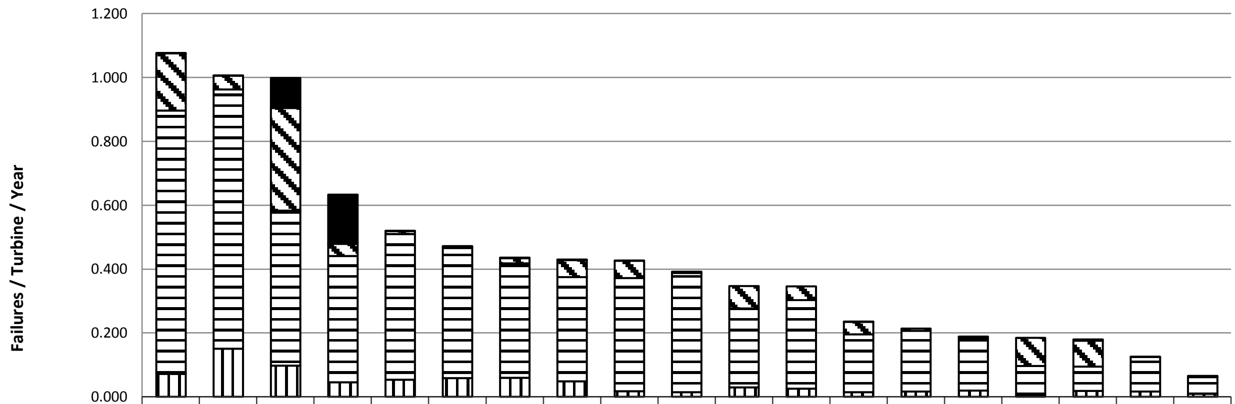
6. Annual Subsystem/component failure rates were combined and arranged in a Pareto chart

7. Conclusions were drawn on which turbine components / subsystems fail in the manner of a bathtub curve, which do not and why this may be the case.

Main Body of Abstract: The failure rate analysis in this paper is based on a number of wind farms that have been operating in Europe over an eight year period. In total this population provides 1768 years or ~15.5 million hours of turbine data.

All wind turbines in this analysis are of the same type, however in order to ensure confidentiality the exact number of wind turbines, number of farms, nominal power or rotor size of the turbine type used cannot be provided. It can however be stated that it is a modern MW scale turbine type with a rotor diameter between 80 and 120m and a nominal power between 2MW and 4MW.

The Pareto chart from [1] can be seen in Figure 1. As a means of gaining further insight into each of the subsystems in the Pareto chart further analysis was carried out.



	Pitch / Hyd	Other Components	Generator	Gearbox	Blades	Grease / Oil / Cooling Liq.	Electrical Components	Contactor / Circuit Breaker / Relay	Controls	Safety	Sensors	Pumps/ Motors	Hub	Heaters / Coolers	Yaw System	Tower / Foundation	Power Supply / Converter	Service Items	Transformer
Major Replacement	0.001	0.001	0.095	0.154	0.001	0.000	0.002	0.002	0.001	0.000	0.000	0.000	0.001	0.000	0.001	0.000	0.005	0.000	0.001
Major Repair	0.179	0.042	0.321	0.038	0.010	0.006	0.016	0.054	0.054	0.004	0.070	0.043	0.038	0.007	0.006	0.089	0.081	0.001	0.003
Minor Repair	0.824	0.812	0.485	0.395	0.456	0.407	0.358	0.326	0.355	0.373	0.247	0.278	0.182	0.190	0.162	0.092	0.076	0.108	0.052
No Cost Data	0.072	0.150	0.098	0.046	0.053	0.058	0.059	0.048	0.018	0.015	0.029	0.025	0.014	0.016	0.020	0.004	0.018	0.016	0.009

Figure 1: Pareto chart of offshore wind turbine subsystem / component failure rates [1]

The results of this further analysis can be seen in Figure 2. Figure 2 shows the same subsystems as Figure 1. However in Figure 2 each subsystem is represented by 8 bars. Each bar is the failure rate per year of operation from 1 to 8. It can be seen that some of the subsystems resemble the early “wear in” and “steady state” sections of a bathtub curve whereas some do not. The paper will provide further analysis on each of these subsystems and discuss reasons for failure trends. It will also provide further analysis on failure categories within each year by looking at whether the failures in each year are minor repairs, major repairs or major replacements, commenting on whether these categories also show “bathtub” curve like characterisations. In this analysis a minor repair is categorised as a failure that has a repair material cost of below €1,000 to repair, a major repair is between €1,000 and €10,000 and a major replacement is greater than €10,000.

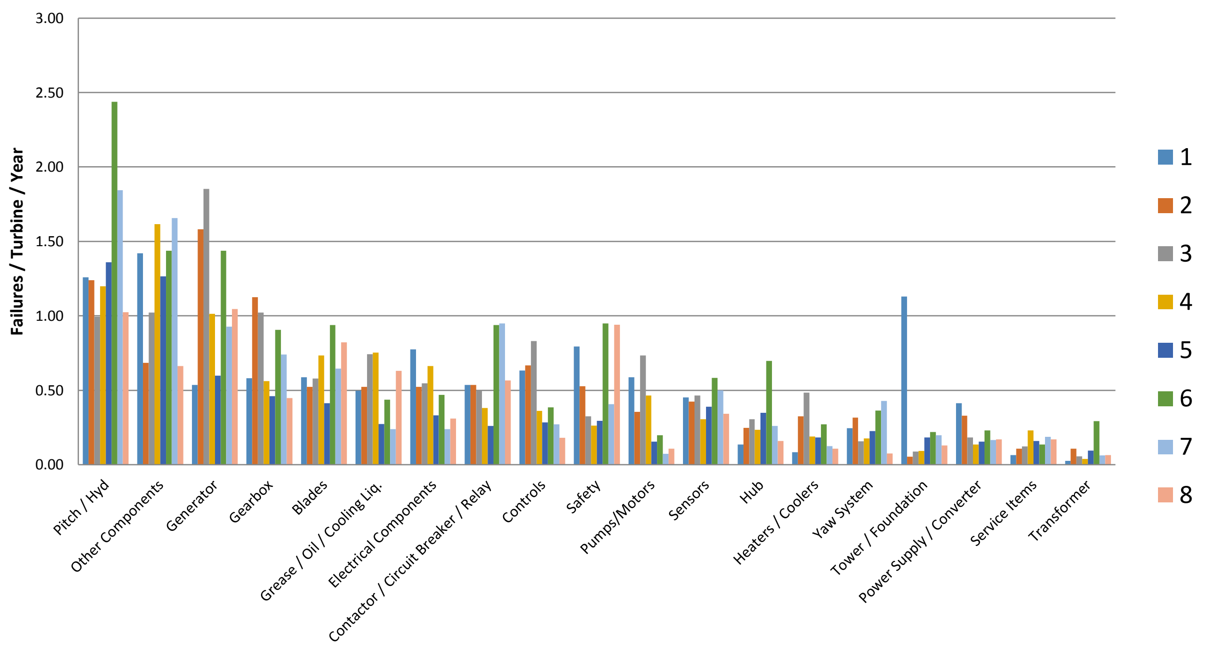


Figure 2: Pareto chart of offshore wind turbine subsystem / component failure rates vs. year of operation

Initial studies have shown that when considering all failures in a sub-system, electrical components and the power supply / converter groups follow the bathtub failure trend whereas the subsystems like the Pitch/Hydraulic group do not. This is highlighted in Figure 3. The paper will provide similar analysis for each of the subsystems.

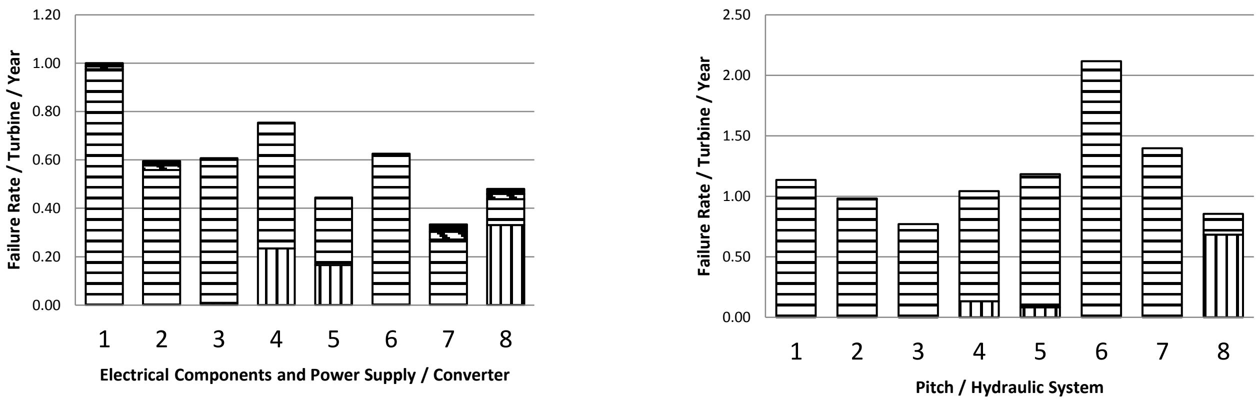


Figure 3: Failure trends with time and cost category for two sub systems

Conclusion: This paper provides failure rates for the overall wind turbines and its subassemblies arranged by year of operation. It can be seen that certain components / subsystems failure rate reduces with time, some increase and some are random. The largest contributor to the overall failure rates is the Pitch/Hydraulic system. It can be seen that this failure rate varies each year with no apparent trend. A spike in failures can be seen in year six. The electrical components and power supply / converter subsystems show more of a downward trend with time. The submitted paper will show further analysis on each of these subsystems and their cost categories and draw conclusions on why each sub system fails as it does.

Learning Objectives: Following the reading of this paper the reader will be able to:

- Compare and understand wind turbine sub systems failure trends with time from a number of European offshore wind farms.
- Identify failure trends with time for minor repairs, major repairs and major replacements.
- Identify and plan which subsystems will need repair resources in each year of operation.
- Use the offshore sub-assembly failure data provided in this paper for further work, such as O&M and Cost of Energy modelling.

References:

[1] Carroll J, McDonald A, McMillan D. Failure Rate, Repair Time and Unscheduled O&M Cost Analysis of Offshore Wind Turbines. Accepted and in press with Wiley Wind Energy Journal. April 2015.

[2] Hahn B, Durstewitz M, Rohrig k. Reliability of Wind Turbines – Experiences of 15 years and 1,500 WTs. 2007. Available at: Available: http://renknownet2.iwes.fraunhofer.de/pages/wind_energy/data/2006-02-09Reliability.pdf