Modelling the failure behaviour of wind turbines

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Introduction

Operation and Maintenance (O&M) for wind turbines has evolved as a sector with important levers to increase availability, energy yield and thereby increasing financial profits of wind farm projects. At the same time O&M costs are to be lowered constantly, mainly by shifting towards a more preventive approach on turbine O&M.

Especially in the offshore sector a wide range of O&M simulation and modelling tools are available on the market to support decisions on O&M strategy and resources like ships and personnel to be allocated in order to achieve the most efficient operational setup. The development of these tools is being supported by public research projects and industry partnerships.

While these tools strive hard to model the full range of the complexity of offshore O&M processes including weather and wave conditions and restrictions for vessel operations on the wind turbine service side there remains a large uncertainty on the demand side which is the characteristics of failure behaviour of wind turbines.

This paper aims to address the issue of modelling the failure behaviour in order to provide a better statistical fit to the real downtime and failure characteristic of wind turbines based on theoretical background and literature as well as on findings from failure mode effect analyses and empirical data.

Approach

First the failure models of existing offshore O&M tools are presented to show the state of the art. To show the areas of possible improvements strengths and weaknesses of the respective models are briefly discussed.

Then a conceptual framework for modelling different failure mechanisms of wind turbines is being presented. This framework takes into account the different wind turbine subsystems and structures as well as the failure modes of a component by applying several influencing factors representing wear and break failure mechanisms.

Main body of abstract

Existing failure models in offshore O&M tools

Existing offshore O&M tools have been compared in their capabilities and results by Dinwoodie et.al. [1] In the reference case for the comparative study the failure behavior was modeled by applying a constant failure rate for five different failure categories. This simplified approach is the basic starting point for modelling the failure behavior, which enables comparing different tools.

ECN uses failure frequencies of components based on event data from operational experience in the building block of its O&M cost estimator. Additionally it shows confidence intervals for the failure rates that have been derived from empirical data. [2]

The Far Offshore Wind Interactive Tool (FOWIT) developed by the University of Strathclyde references a study by Raademakers and Braam [3]. It uses five repair categories with different durations for repair actions and logistic efforts. [4]. In order to model early failures, intrinsic failures and deterioration, a poisson process has been applied to model the bathtub curve. [5]

The NOWIcob tool by SINTEF and the Offshore Wind Simulation Model by the University of Stavanger, which later has been taken forward as the commercial software MAINTSYS™ also use a homogenous Poisson function to model the dynamic behavior of the failure rate. [6]

Holmstrom has shown a validation of the rate of occurrence of failures with real farm data on a yearly basis over a 20-year lifespan. [7] This type of approach has been proposed by Slimacek [8] based on data analysis of the German scientific measurement and evaluation programme (WMEP).

Although these approaches succeed in varying the failure rate over time they neglect a number of known characteristics of failure behaviour. They do not take into account the failure modes and effects which are being analysed in FMEA studies in the design phase and they do not reflect the characteristics visible from empirical operation and event data.

Results of FMEA studies have been published by Spring [9], Bharatbhai [10] and Jung [11] and show the most critical failure modes and components. Among these are converter, pitch and yaw systems and the rotor blades with their respective failure modes.

Empirical data from the University of Strathclyde [12], Reliawind [13] and the WInD-pool [14] also provide data on the affected components. Moreover, the WMEP also shows statistics of failure causes giving shares of component failures and external causes like storm, lightning or icing. There is a seasonal pattern for the occurrence of failure due to these causes and it is also a known correlation that the failure probability increases at higher wind speeds. [15], [16], [17]

These effects are relevant for offshore O&M modelling as they affect the accessibility of turbines at the time the failure occurs. Therefore are more detailed approach is proposed in this abstract.

Framework for modeling different failure mechanisms of wind turbines

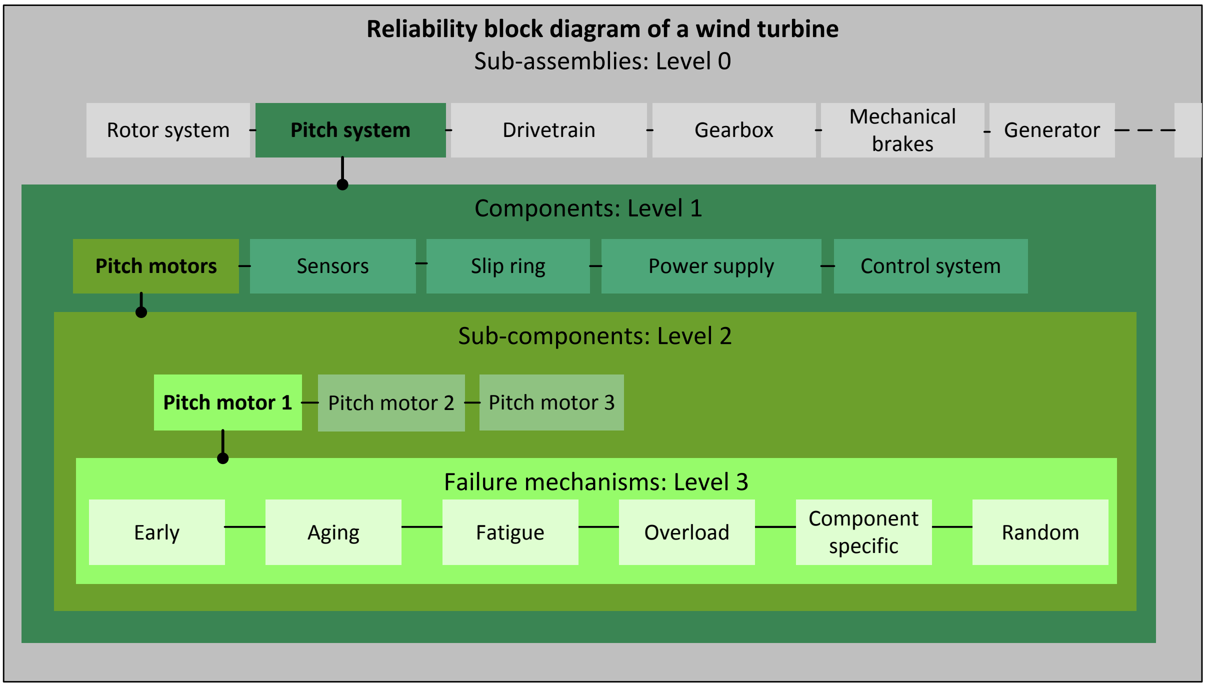

Figure 1: Reliabiltiy block diagram structure

The proposed approach builds on a reliability block diagram of the wind turbines sub-assemblies and components. Additionally an extra layer is inserted into the block diagram to represent the failure categories for different failure mechanisms.

The failure categories are derived from the bathtub curve and a general classification of failures of technical systems in wear and break mechanisms by Eichler [18]. Early failures are used to represent the infant mortality of turbines as a decreasing failure rate over the first years. Wear effects include aging and fatigue failures whereas overload refers to break mechanisms which may be due to heavy gusts of wind. Component specific mechanisms allow to model individual risks to a component that may be related to the specific time or place of the site e.g. lightning damages to the blades. Finally, there remains a random block with a constant failure rate that cannot be tied to other mechanisms.

Early failures and aging effects are modelled by using Weibull distributions. The Weibull parameters were adjusted to fit with the weighted empirical failure rates for the component. Random failures are characterized by constant failure rates over time. Fatigue is being modelled by tracking the turbine’s working hours and capacity factor and risk for overload failure is being based on the current windspeed with a progressive function beginning at cut-in windspeed ending just after the cut-out speed. However, the overall failure function as well as the choice of influencing parameters is strongly component specific. Further details will be presented in the full paper.

The failure categories are weighted system or component specific and then summed up to build an overall failure function. This requires modelling the different failure categories independently from one another.

$$\lambda(,t,E,v_w) = \lambda_{early}(t) + \lambda_{aging}(t) + \lambda_{fatigue}(E) + \lambda_{overload}(v_w) + \lambda_{component} + \lambda_{random}$$

Conclusion

Modelling the failure behaviour of wind turbines is an essential part of offshore simulation software as it forms the demand side for all O&M processes and related costs incurred. State-of-the-art O&M tools use advanced models to represent the failure behaviour of wind turbines but come short when considering characteristic impact factors on specific components or failure causes. Important effects not yet modelled include increased failure rates at higher wind speeds and seasonal effects on failures due to lightning or icing.

To address these issues a failure model based on a reliability-block-diagram incorporating different failure mechanisms is proposed. It describes the failure behaviour based on failure categories derived from the bathtub curve and fundamental wear and break mechanisms and is fitted with available data to match empirical failure rates.

The failure model has been implemented in Fraunhofer IWES multi-agent-system for modelling O&M processes. The full paper will show the resulting failure characteristic, its effects on the outcome of simulation results and improvements to the status quo based on this approach. Further validation on large real operation data sets (WINDpool) is ongoing.

Learning objectives

The key messages of the paper may be summarized as:

- Be aware of the demand side in O&M simulations – vessels, spare-parts and technicians are only one side of the story
- Relevant characteristics of failure behaviour e.g. correlation with wind speed are relevant for turbine accessibility and not yet modeled in software tools
- Detailed modelling per component and failure mechanism enables more realistic failure behaviour of turbines for O&M simulations
- A detailed failure behaviour model is being presented with component specific approaches

Literature

[1] Dinwoodie, I. e. a.: Reference Cases for Verification of Operation and Maintenance Simulation Models for Offshore Wind Farms. In: Wind Engineering (2015) 39, S. 1–14.

[2] Rademakers, L.: How to assist operators? The development of low cost load monitoring and decision support rules. Delft 2013.

[3] Rademakers, I.; Braam, H.: O&M Aspects of the 500MW Offshore Wind Farm NL7. Delft.

[4] University of Strathclyde: The Tool.
URL: http://www.esru.strath.ac.uk/EandE/Web_sites/14-15/Far_Offshore_Wind/our_work/our_work_files/pages/the_tool.html#TUT.

[5] F. Spinato et al.: Reliability of wind turbine subassemblies. In: IET Renew. Power Gener. 3 (2008) 4, S. 1–15.

[6] Endrerud, J.-O.; Liyanage, J. P.; Keseric, N.: Marine logistics decision support for operation and maintenance of offshore wind parks with a multi method simulation model. In: Proceedings of the 2014 Winter Simulation Conference (2014), S. 1712–22.

[7] Holmstrøm, K.-M.: How can more advanced failure modelling contribute to improving life-cycle cost analyses of offshore wind farms? Trondheim 2014.

[8] Slimacek, V.; Lindqvist, B. H.: Reliability of wind turbines modeled by a Poisson process with covariates, unobserved heterogeneity and seasonality. In: Wind energy (2016).

[9] Spring, M. e. a.: Top 30 Charts of wind turbine failure mechanisms. Paris 2015.

[10] Bharatbhai, M. G.: Failure Mode and Effect Analysis of Repower 5M Wind Turbine. In: International Journal of Advance Research in Engineering, Science & Technology (IJAREST) 2 (2015) 5.

[11] Jung, H.: Abschlussbericht für das Verbundprojekt „Erhöhung der Verfügbarkeit von Windkraftanlagen". Dresden 2014.

[12] Caroll, J. e. a.: Offshore Wind Turbine Sub-Assembly Failure Rates Through Time. Paris 2015.

[13] Gayo, J. B.: ReliaWind final report. More efficient and reliable wind turbines by 2011 2011.

[14] Faulstich, S.: Performance and reliability benchmarking using the cross-company initiative WInD-Pool. Bremerhaven 2015.

[15] Tavner, P. J.; Greenwood, D. M.; Whittle, M. W. G.; Gindele, R.; Faulstich, S.; Hahn, B.: Study of weather and location effects on wind turbine failure rates. In: Wind energy (2012).

[16] Hahn, B.: Zeitlicher Zusammenhang von Schadenshäufigkeit und Windgeschwindigkeit. Leipzig 1997.

[17] Tavner, P. J.; Edwards, C.; Brinkman, A.; Spinato, F.: Influence of Wind Speed on Wind Turbine Reliability. In: Wind energy 30 (2006) 1, S. 55–72.

[18] Eichler, C.: Instandhaltungstechnik - Schädigungsarten. Berlin 1982.