How can more advanced failure modelling contribute to improving life-cycle cost analyses of offshore wind farms?

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Abstract

Accurate failure modelling is fundamental in reliability analyses and for optimisation of maintenance strategies to minimize life cycle costs (LCC) of offshore wind (OW) farms. Due to lack of (or reluctance among operators to share) sufficient wind turbine failure data, many operation and maintenance (O&M) models - simulating the operational phase of an OW farm with all maintenance activities and costs - rely on simple failure-time distributions for modelling failure events. The exponential distribution with its constant failure rate is widely used. It is often associated with the homogenous Poisson process (HPP) which assumes that a system is as good as new after repair.

Wind turbines' reliability is not necessarily improved by repairing components, and they are usually not as good as new unless completely overhauled. It was therefore investigated if a more advanced failure model, capable of taking such facts into account, was available for use in (models like) the Norwegian Offshore Wind cost and benefit (NOWIcob) model developed by NOWITECH.

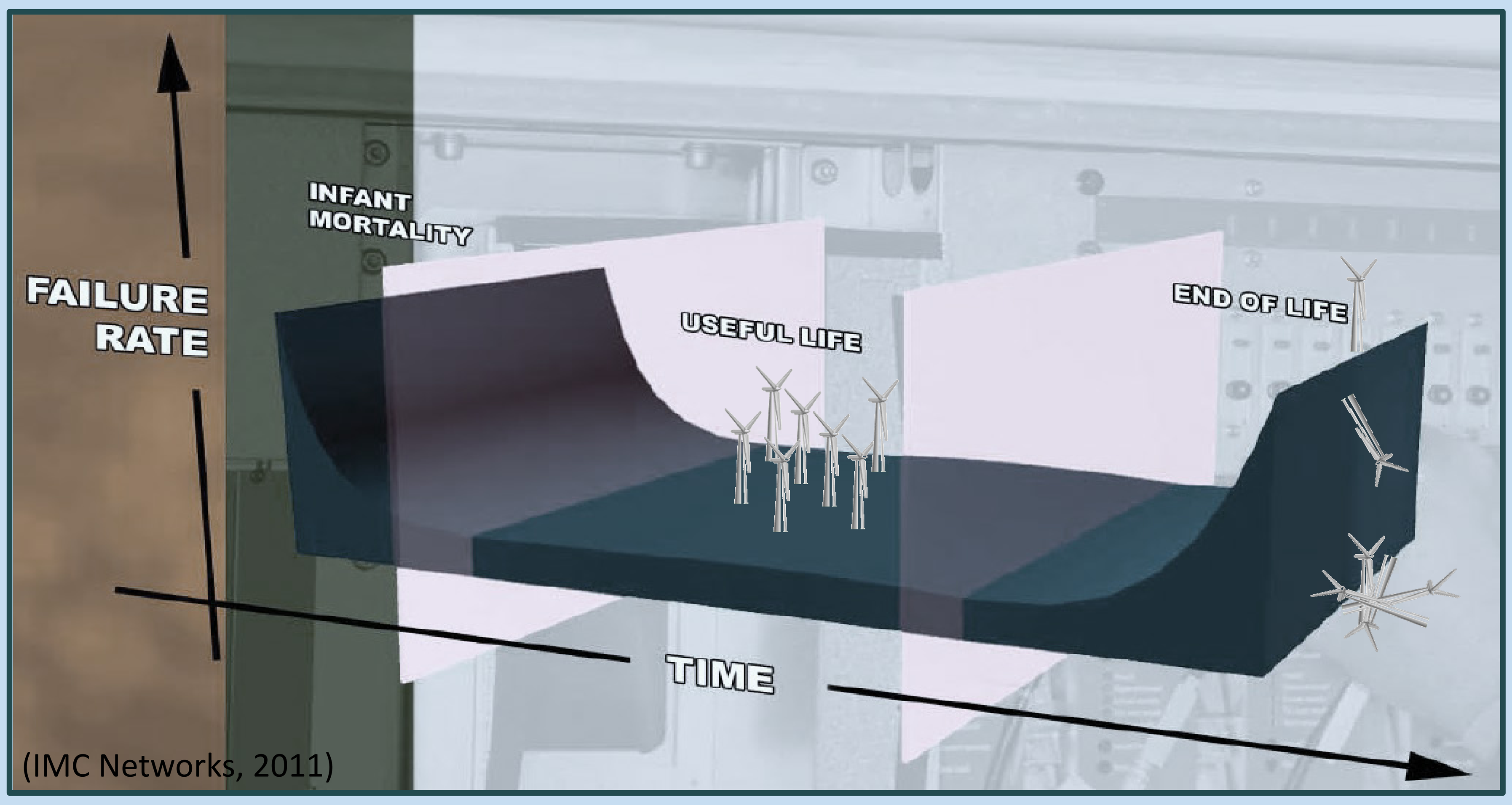
Objectives

- ✓ Establish and implement a new, more flexible failure model to test, on a representative base case, how it affects the results and if it can contribute to more accurately simulate a realistic O&M phase and associated LCC of an OW farm.
- ✓ Provide, through the resulting evaluation, an overview of the failure model's behaviour compared to the existing one and compared to governing background theory for verification.

Method

Knowing that wind turbines are repairable, electro-mechanical systems that degrade with time, it was assumed that their overall failure behaviour follows the bathtub curve (BTC) through three distinct life-phases:

1: Burn-in period (decreasing failure rate, "infant mortality")
2: Useful life (constant, low failure rate, random failures)
3: Burn-out period (increasing failure rate due to aging, wear and tear)



(IMC Networks, 2011)

Potential stochastic failure models were investigated and evaluated in terms of their complexity and capability of representing the three phases. A more advanced model, and a natural extension (being a generalisation) of the HPP used in NOWIcob, is the Non-Homogenous Poisson Process (NHPP) which with a proper failure intensity function λ(t), can handle trends, aging or reliability growth (Kim, 2009).

An example is the NHPP with Power Law (PL) intensity (NHPP_PL):

Rate of Occurrence of Failures (ROCOF) = $\lambda(t) = \frac{1}{\alpha}\beta t^{\beta-1}$

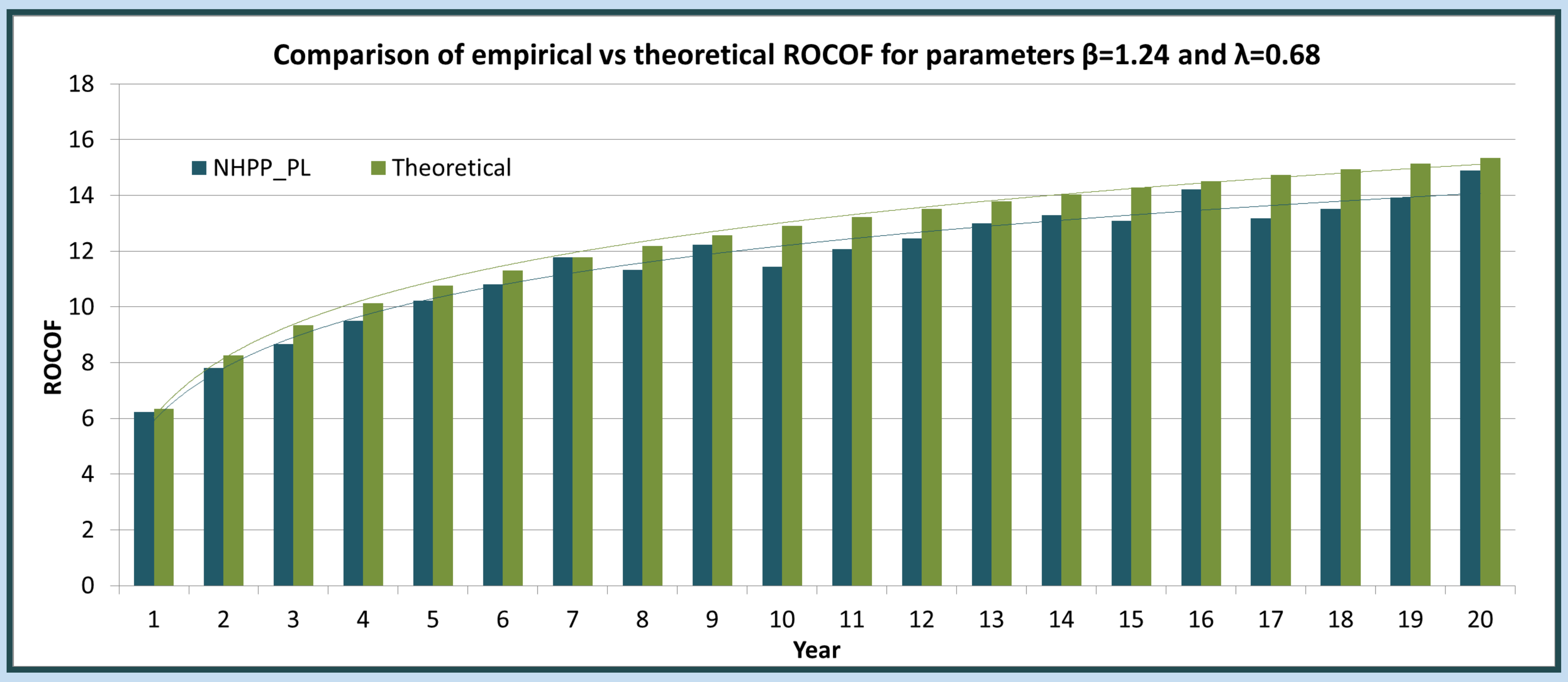
By changing the β-value, the NHPP_PL can be used to model systems in which ROCOF increases with time (β >1), decreases with time (β <1), or remains constant with time (β=1 → NHPP=HPP). NHPP assumes that a system is as bad as old after repair, and that repair time is negligible.

Based on the NHPP_PL a new model for the time to the next failure was established using the inverse transform method (Crow, 2004) and the condition that the previous failure-time is known. The model was coded in MATLAB and implemented in NOWIcob.

$$t_{next} = \left[\frac{\ln(1-U)}{\lambda} + t_{previous}^{\beta}\right]^{1/\beta}$$

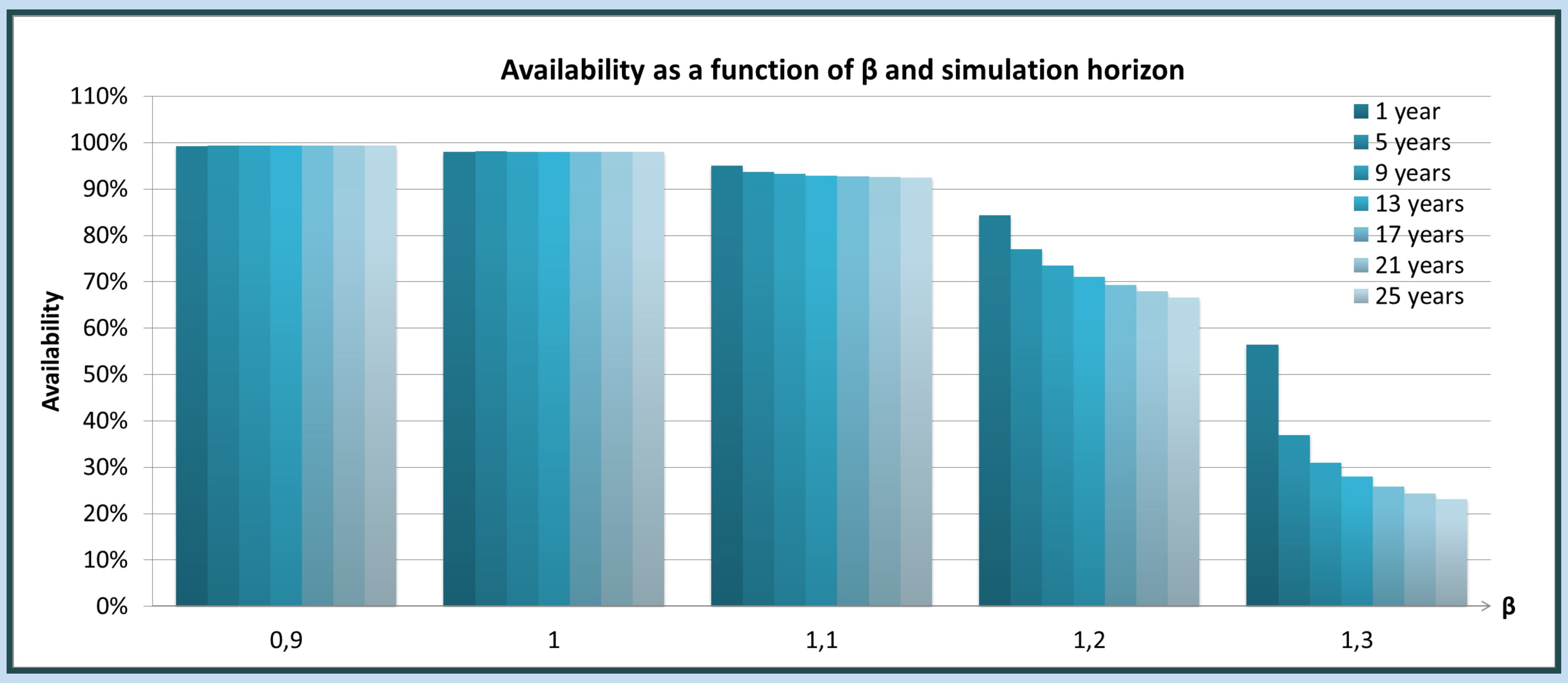
To verify correct implementation, the model it was run under various combinations of the input parameters and empirical results were compared to theoretical ones. Further verification was done by confirming the time-dependency of the intensity function.

Results



The new failure model, NHPP_PL, behaves according to theory, and can be used to model both increasing, decreasing and constant ROCOF development. In the example above, ROCOF is increasing with time for β >1. Empirical values are slightly lower, and the difference increases with time, because repair time associated with the failure scenario modelled is not negligible like theory assumes.

The higher ROCOF the lower availability. The capability of modelling time-dependent failure intensity is an important feature of the NHPP_PL model. The chart below shows how the availability decreases more and more with increasing β for longer simulation horizons.



Conclusions

Models simulating the operation and maintenance phase of offshore wind farms often rely on failure models based on the simple exponential distribution. The non-homogenous Poisson process with power law intensity has great potential for improving wind farm life-cycle cost analyses in such models. More advanced failure models are available, but data requirements as well as their complexity might consequently make them harder to implement.

Until sufficient failure history from a representative number of offshore wind farms become available, it is reasonable to assume that on a system level, wind turbines' failure behaviour follows the bathtub curve. The flexibility of the power law makes it possible to model a time-dependent rate of occurrence of failures, which opposed to the constant rate modelled by the exponential distribution, is more realistic for wind turbines as they are known to degrade with time.

References

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