Towards wind farm-wide fatigue monitoring, extrapolating fatigue measurements at a limited number of turbines to the entire farm

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Introduction

The main goal of the current research is to develop a novel methodology that can assess the consumed fatigue life of an entire wind farm and will serve as a support tool for end-of-life decisions and asset management for both onshore and offshore wind farm owners.
The proposed fatigue monitoring approach is to instrument a limited number of turbines, so-called fleet leaders, and extrapolate the measurements to the other turbines in the farm using empirical models based on structural information, meteorological and SCADA data.

Approach

The measurement campaign is performed at the Northwind wind farm, which consists of 72 Vestas V112 3MW wind turbines. The wind farm is located in the North Sea, 37 km off the Belgian coast. The campaign started in 2014 and is currently still ongoing.

For the current campaign two turbines, situated at the outer edges of the farm, were instrumented with accelerometers and (optical) strain gauges to closely monitor their dynamic behavior. Data is transferred continuously to an onshore server and is processed on a daily basis.
The current setup allows determining the resonance frequencies, damping ratios [1] as well as the bending moments at the Transition piece (TP) - Monopile interface and at the tower-TP interface. More importantly the setup also allows monitoring the consumption of fatigue life and the calculation of damage equivalent loads at the aforementioned interface connections. As a result this ongoing campaign has produced a database of over 50.000 instantaneous fatigue rates at different locations for each turbine.
Future developments such as virtual sensing will assess fatigue life at other fatigue-critical locations such as at the mudline [2].

While these results are very relevant for the fatigue assessment of the instrumented turbine, the results need to be extrapolated to the other turbines in the farm. To achieve this goal the monitored fatigue life is first analyzed for different operational cases (e.g. parked or rated power) and then modeled case-by-case using the available SCADA and meteorological data at the site. As two turbines are instrumented, the found model is validated by predicting the fatigue life consumption of the other fleet-leader and comparing these predictions to the actual measurements. In the final step the validated model allows to extrapolate the results to the entire wind farm.

Main body of abstract

Fatigue life is an important design driver for wind turbine foundations and the proper knowledge of the consumed lifetime of any turbine will serve as a valuable support tool for end-of-life and asset management. This knowledge is acquired by monitoring a limited number of turbines, so called fleet-leaders, and by extrapolating their results to the entire farm.

In this contribution we will model the consumption of fatigue life using the data acquired from the two instrumented wind turbines at the Northwind offshore wind farm. The approach starts from the large database of measured fatigue rates at the two instrumented turbines. As shown in Fig.1, the resulting fatigue spectra differ for different operational cases.

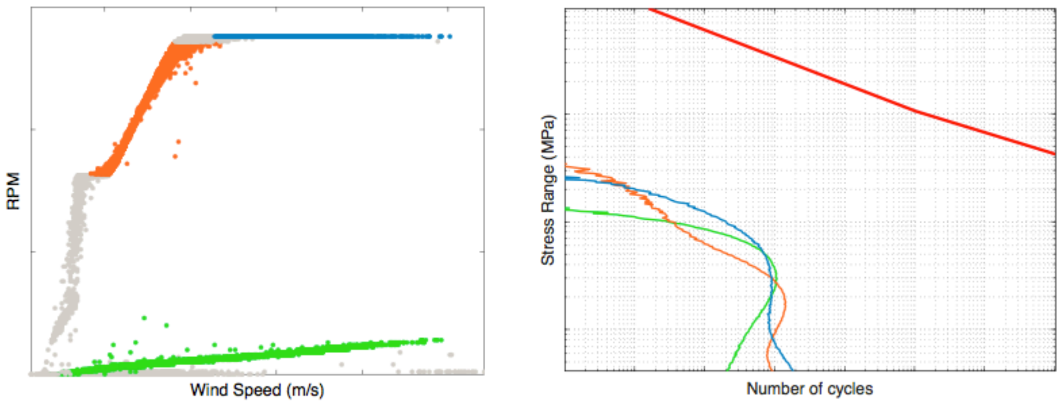

Figure 1: (left) RPM vs. Wind speed with indication of three example operational cases. (right) The three different cases yield three different fatigue spectra. A farm-wide fatigue assessment will need to incorporate these differences.

This implies that turbines that have been parked for a period of time will have fatigued differently than those that have been operating continuously. An accurate farm-wide fatigue assessment therefore will need to incorporate these differences and attribute different weights to periods of different operational cases.

A similar analysis needs to be performed with respect to the environmental conditions. Several environmental effects will have an influence on the fatigue consumption of individual turbines. In [3] and Figure 2 it is shown how turbulent air will accelerate fatigue life consumption. Turbines that are positioned down-wind to another turbine or any other obstacles for the dominant wind direction will fatigue differently. Consequently, a farm-wide assessment is only possible when including also parameters such as the turbulence and dominant wind directions.

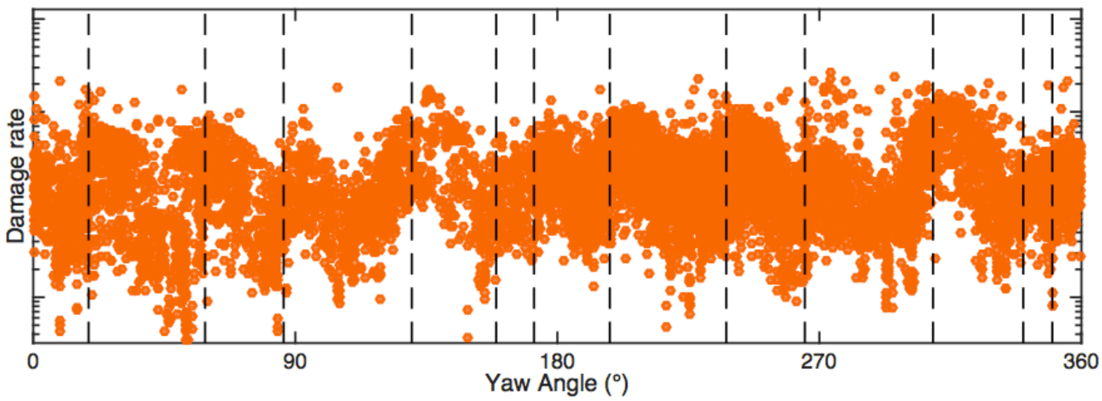

Figure 2: Instantaneous fatigue rate of a monitored turbine. Dashed lines indicate wind directions for which another wind turbine is found down-wind. The results show how wind direction will be an important parameter in farm-wide fatigue assessment.

Aside from the given examples an empirical fatigue-model will also incorporate other known phenomena such as the low (aerodynamic) damping of side-to-side vibrations [1]. In addition

it is necessary to determine the effect of events, such as rotor stops, on fatigue life in order to act accordingly.
A final challenge will lie in the proper modeling of the individual turbine dynamics. The effect of rotor-induced vibrations needs to be identified and added to the model. An effect that can be modeled through the measured or numerical resonance frequencies of each individual turbine.

The current contribution will focus on the two currently instrumented turbines and use the measurements on both turbines to validate the proposed methodology. When the current method is validated the measurements at the fleet leaders are extrapolated to perform a farm-wide fatigue assessment, as shown in Figure 3.

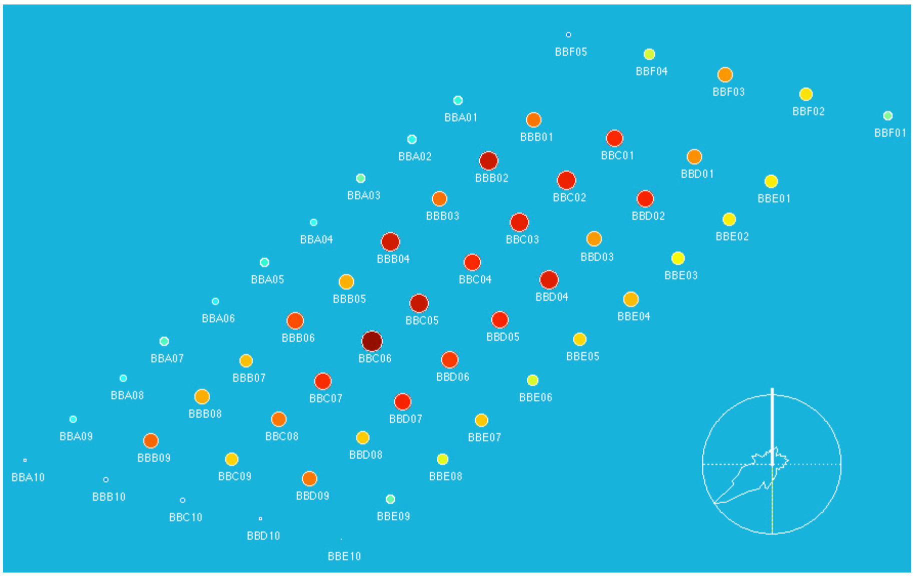

Figure 3: A farm-wide fatigue assessment, here shown for an offshore wind farm, can serve as a valuable tool for end-of-life decisions as it allows to identify potentially fatigued turbines.

Conclusion

This contribution aims to illustrate the behavior and progression of fatigue life in an offshore wind farm. A methodology to use the measurements of a limited number of instrumented turbines, so called fleet-leaders, and available SCADA, meteorological data and structural information to model the progression of fatigue life was introduced and evaluated on two instrumented turbines in a Belgian offshore wind farm.
Key parameters that need to be taken into account are the different operational conditions of the individual turbines as well as environmental parameters such as the turbulences in the farm.
The developed methodology will allow to perform a data-driven fatigue assessment of an entire wind farm and serve as a valuable tool for decision support.

Learning objectives

The goal of our research is to develop a methodology for data-driven fatigue assessment of an entire wind farm based on a limited number of instrumented turbines in the farm. These findings serve to support at end-of-life decisions of older (onshore) wind farms and support asset management for wind farm owners. Lessons learned can also flow back into design to achieve a more cost-effective and correct fatigue-life assessment in the construction of future offshore wind infrastructure.

References

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