PO.097

Solution to minimize leading edge erosion on turbine blades

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DTU, DMI, R&D, E.On, Vestas and Vattenfall

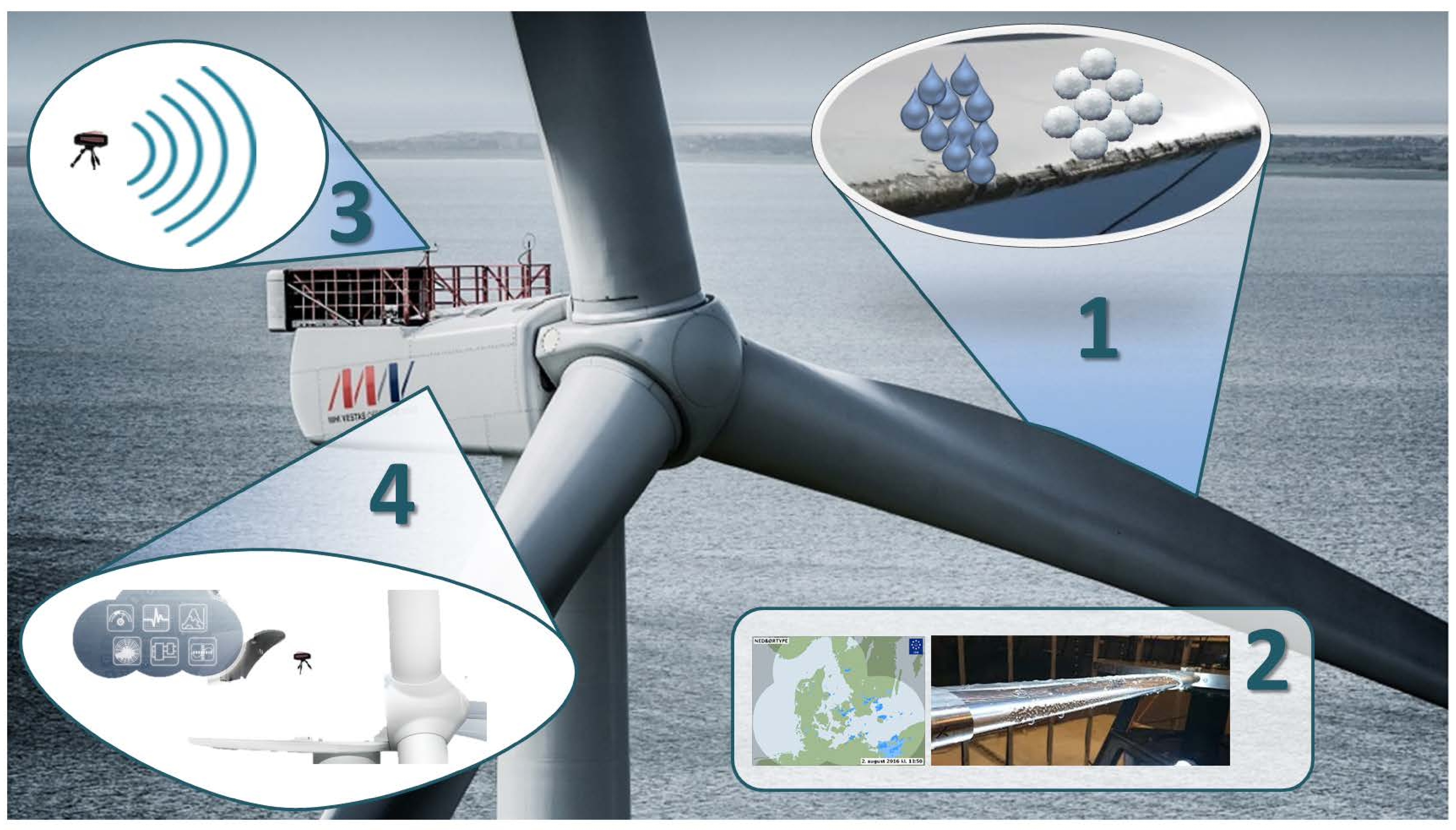
Abstract

A novel method is proposed to maximize the value of operating fleet of wind turbines suffering leading edge erosion. This method will ensure longer lifetime and reduce repair cost.

The challenge is to balance the cost of repair, downtime of wind turbines and loss of energy production due to leading edge erosion. Current practice is to inspect the turbines and repair when it is considered necessary from the point of loss of Annual Energy Production (AEP) or structural failure. The cost for repair is high and tends to get higher while the weather windows get narrower as turbines increase in size and stand further away from service ports.

The novel method called 'erosion safe mode' can be implemented readily to the operating fleet of turbines as well as to new wind farms. The method is cost effective.

Research hypothesis



1. **Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime can be obtained with negligible loss of production.
2. **Methodology:** Define rain and hail erosion classes to quantify leading edge blade in-field and in lab testing. Correlations between rain intensity, droplet size, impact speed, materials properties, etc. will be established.
3. **Measurement Device:** Low-cost prototype for precipitation measurement on site and real time warning device enabling modern control of wind turbines.
4. **Erosion safe mode:** A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

Methods

Rain erosion at leading edges is much dependent upon the occurrence of rain and wind. The rate of leading edge erosion is higher during heavier rain and stronger winds. High non-linearity exists between different rain-wind climate conditions; thus to predict optimal erosion safe mode reliable information on the rain and wind conditions is needed.

The erosion safe mode method is simple as follows. The tip speed is reduced say 30% during the most extreme rain-wind events, 20% during lesser extreme events and 10% during moderate events, see Bech *et al.* 2018.

Examples of erosion safe mode at Danish land of offshore sites are calculated based on 16 years of 10 minute observations of rain intensity (mm/h) and wind speed at meteorological stations. The joint distributions of the exceedance levels of rain intensity as a function of wind speeds are used as input in a model for the leading edge erosion. The SN-curves are based on novel results from rain erosion testing in a whirling arm laboratory with variable speeds and drop sizes. The specimens are similar to current days wind turbine blades.

Implementation

In order to implement the erosion safe mode only two things have to be in place:

- Rain sensor at or near wind turbine, plus now-casting of rain from weather service.
- Turbine control established to reduce tip speed based on rain-wind input and desired lifetime.

First, it is proposed to use maintenance-free rain sensor giving information on drop-let size distribution and rain rate. The now-casting typically will be based on tailor-made weather service with the expected rain minutes to hours ahead. The erosion safe mode control should only be activated in case both provide valid rain data (or alternative, two rain sensors located at turbine site to ensure redundancy).

Second, the choice of erosion safe mode control will be based on the desire from the wind turbine operator to enable longer leading edge lifetime according to the internal business model, the turbine type, leading edge protection available and the prevailing rain-wind climate.

Case of savings

As example for real-life savings a case is presented in brief below. Imagine a turbine with maximum tip speed of 90 m/s operating in a rain-wind climate in which violent rain (>20 mm/h) occurs 0.02% of time (1.8 hours during one year), heavy rain (>10 mm/h) occurs 0.1% of time (8.8 hours) and moderate rain (>5 mm/h) occurs 1% of time (88 hours). For normal operation, i.e. 90 m/s during all conditions the selected wear model (SN-curve) estimates that the blade can only operate 3.5 hours before failure due to violent rain, 79 hours before failure due to heavy rain and 3600 hour before failure due to moderate rain. In other words, the fraction of lifetime spent in violent rain corresponds to 51% of the total erosion, while heavy rain causes 11% of erosion and moderate rain causes 2.4% of wear. The sum of wear gives expected lifetime of the blade 1.6 years. Reducing the tip speed to 70 m/s in violent rain and 80 m/s in heavy rain gives expected lifetime of 10.4 year because wear rates are much reduced.

The cost calculation for the above example is as follows. In case power cost is at 50 euro/MWh, repair cost at 10.000 euro per rotor and inspection cost at 500 euro per rotor, the loss in income is **9.2% with normal strategy and 3.3% for erosion safe mode** (both percentages are compared to reference of maintenance free blade). Further assumptions are Weibull A of 7 m/s and AEP loss due to aerodynamic degradation of 0.964 and 0.974, respectively, for the normal and erosion safe mode operations

Conclusions

The novel method called 'erosion safe mode' may be implemented readily to the operating fleet of turbines.

The method appears to be cost effective from the calculations.

Full scale testing is in planning.

References and Acknowledgement

- Bech, J.I., Hasager, C.B., Bak, C. 2018 Extending the life of wind turbine blade leading edges by reducing the tip speed during extreme precipitation events. *Wind Energy Science.*, 3, 729-748, 2018, https://doi.org/10.5194/wes-3-729-2018 https://doi.org/10.5194/wes-2017-62

- We gratefully acknowledge funding from Innovation Fond Denmark for the EROSION project, Project ID 6154-00018B.

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