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Rain and erosion on turbine blades

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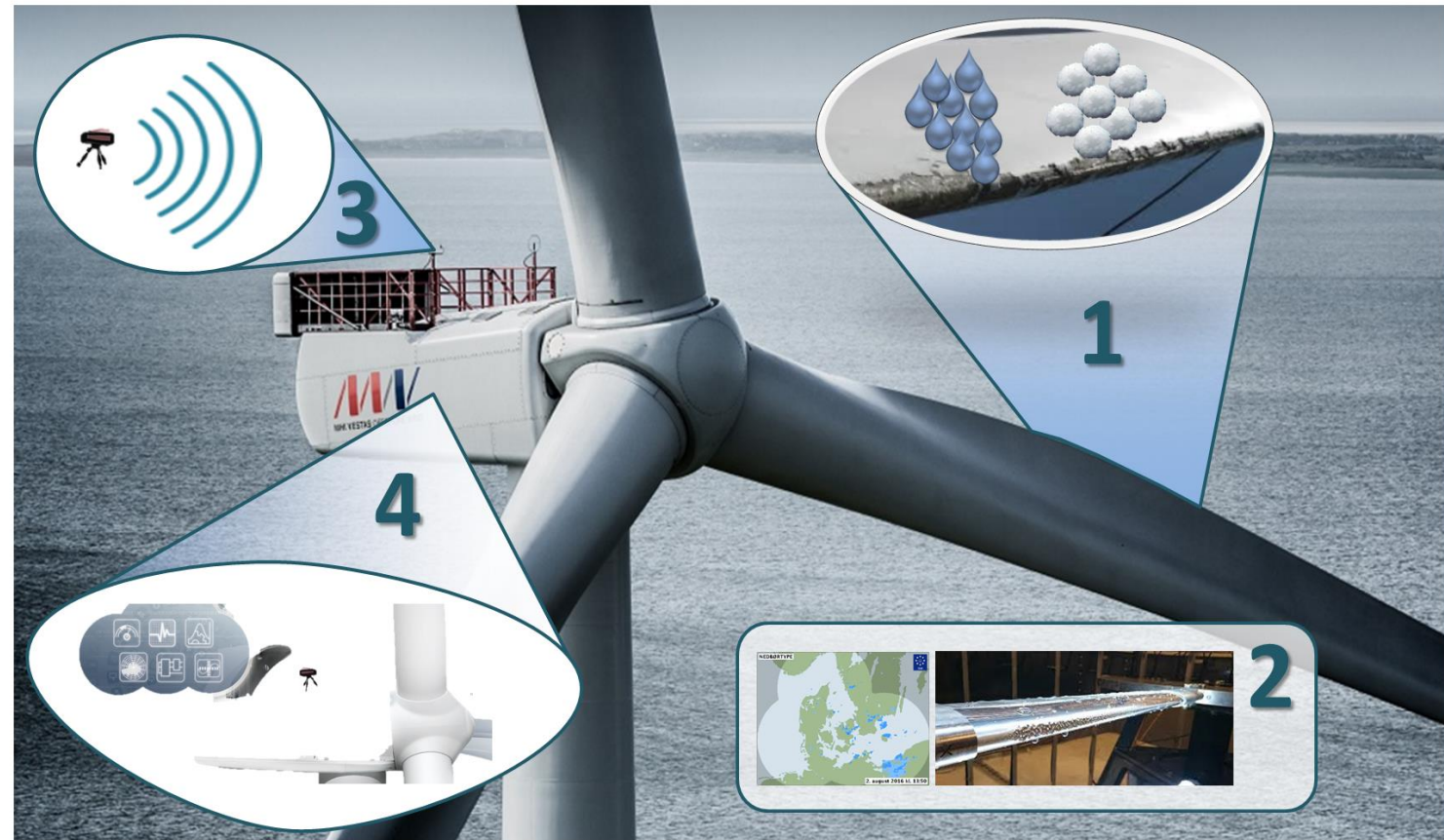
Morten Saldern (Vattenfall)

Kaj M. Halling (Vestas)

Science meets industry Bergen, 13 September 2018, Bergen

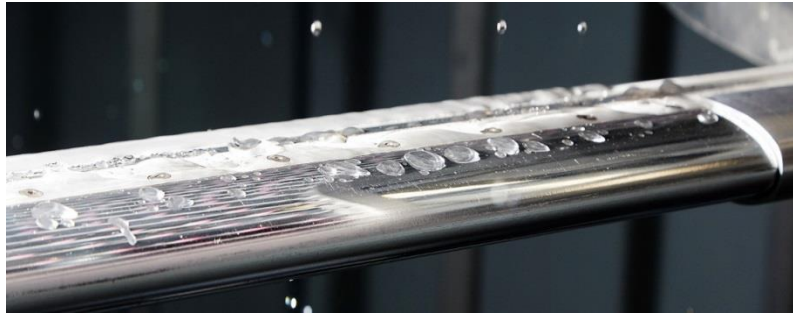


EROSION

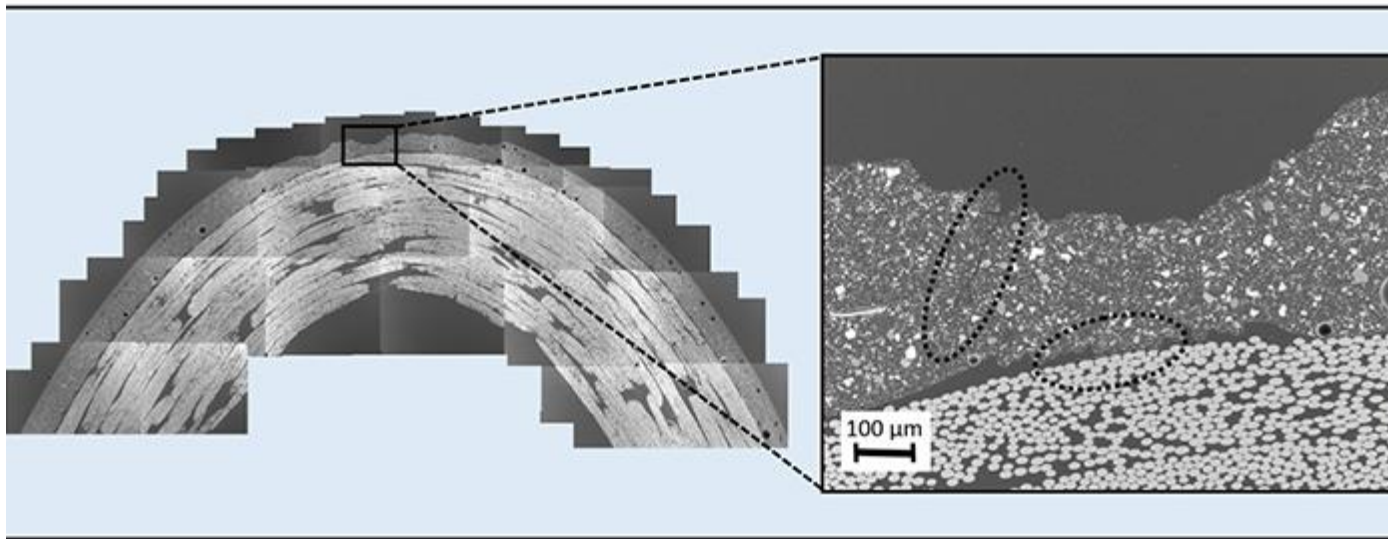


- 1. Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime 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.

Rain Erosion Tester by R&D Test Systems



Microscopy investigations enable direct identifications of fractures

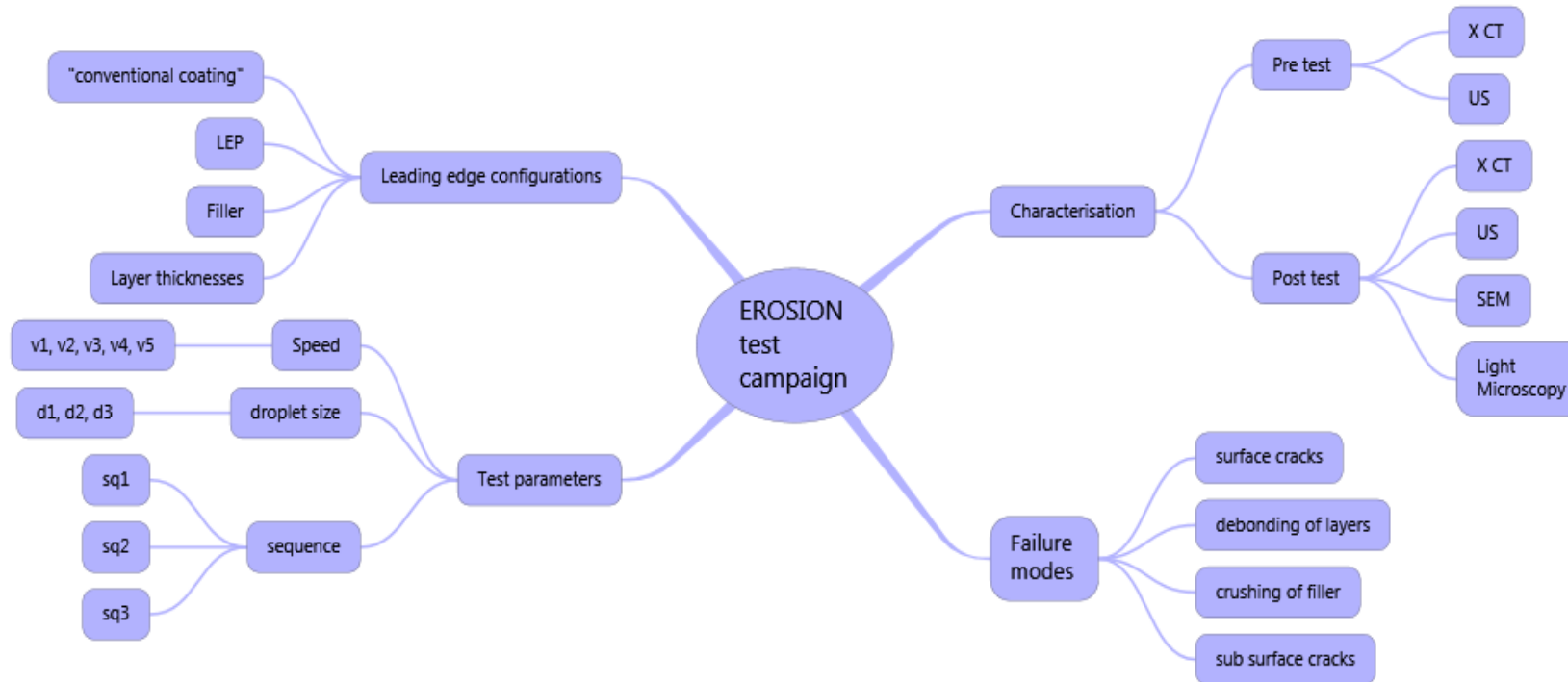


Rain erosion test samples with different degradation have been investigated by electron microscopy.

The erosion appears to start at the surface where the surface roughness increase. However at the same time as the top-coating and the filler slowly degrades microscale damage can be observed within the laminate. Cracks have been observed at the position of the peel fly as well as within the laminate.

Electron microscopy provide a snapshot of the degradation in a polished cross section.

Rain erosion specimen testing map



X CT: X-ray Computed Tomography
 US: Ultrasonic Scanning
 SEM: Scanning Electron Microscopy

Extending the life of wind turbine blade leading edges by reducing the tip speed during extreme precipitation events

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Manuscript under review for journal Wind Energ. Sci.
Discussion started: 21 February 2018
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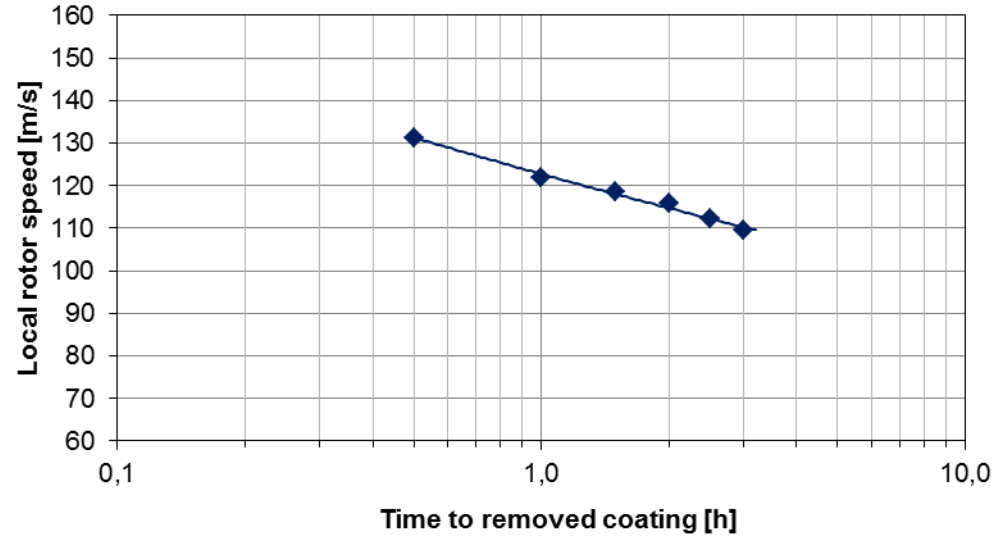
Extending the life of wind turbine blade leading edges by reducing the tip speed during extreme precipitation events

Jakob I. Bech¹, Charlotte B. Hasager¹, Christian Bak¹

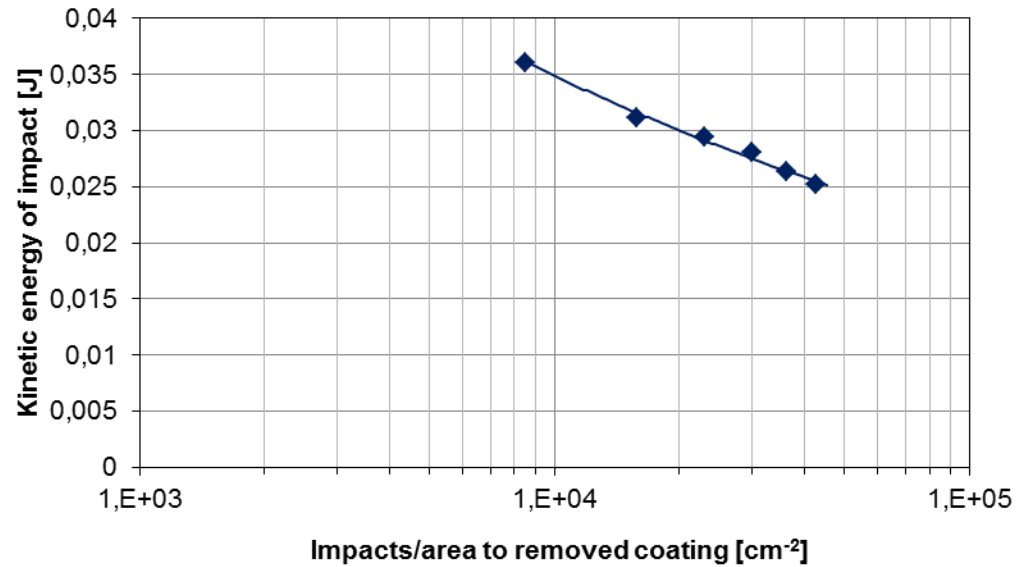
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Rain erosion test data plotted as a Wöhler curve

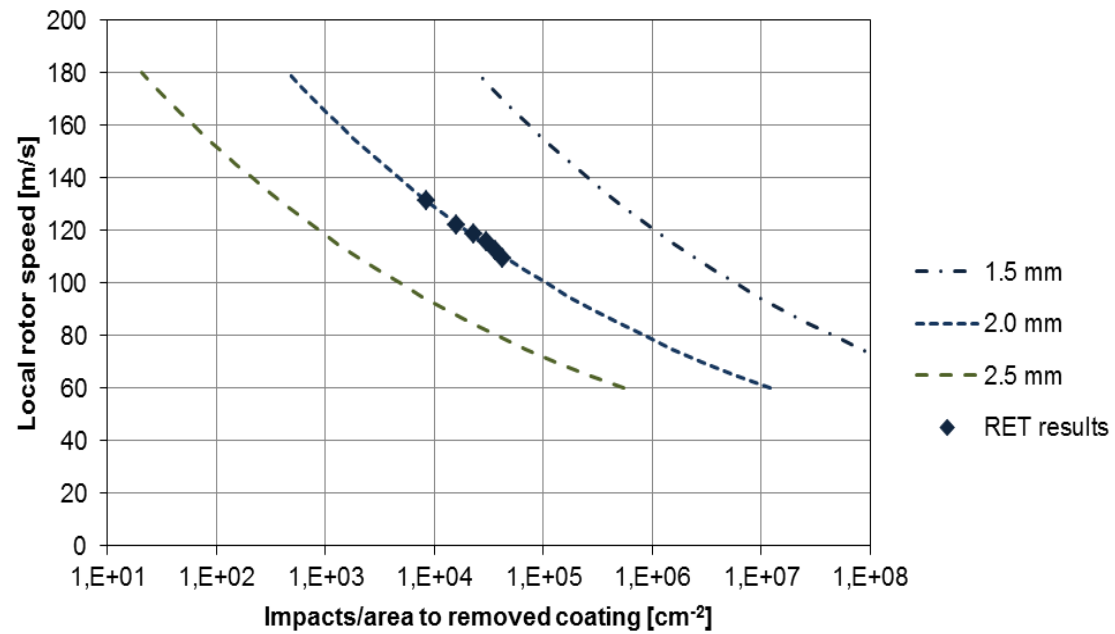


Rain erosion test data plotted as a Wöhler curve: Impacts per unit area to failure as function of the kinetic energy for each impact

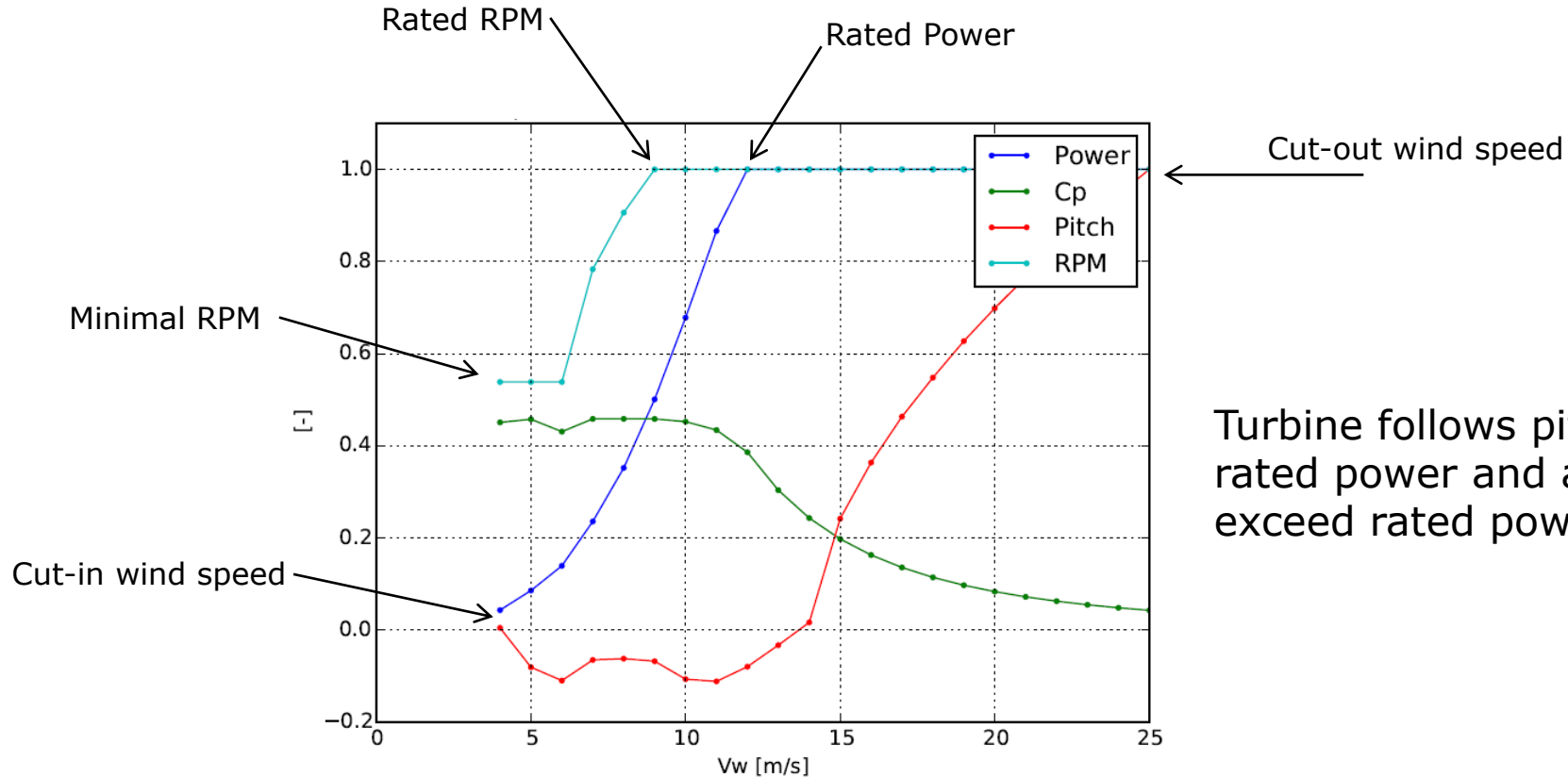


$$E_k = \frac{1}{12} \rho \pi D^3 v_t^2 \text{ [J]}$$

Wöhler curves for droplet diameters of 1.5, 2.0 and 2.5 mm



Control of turbine

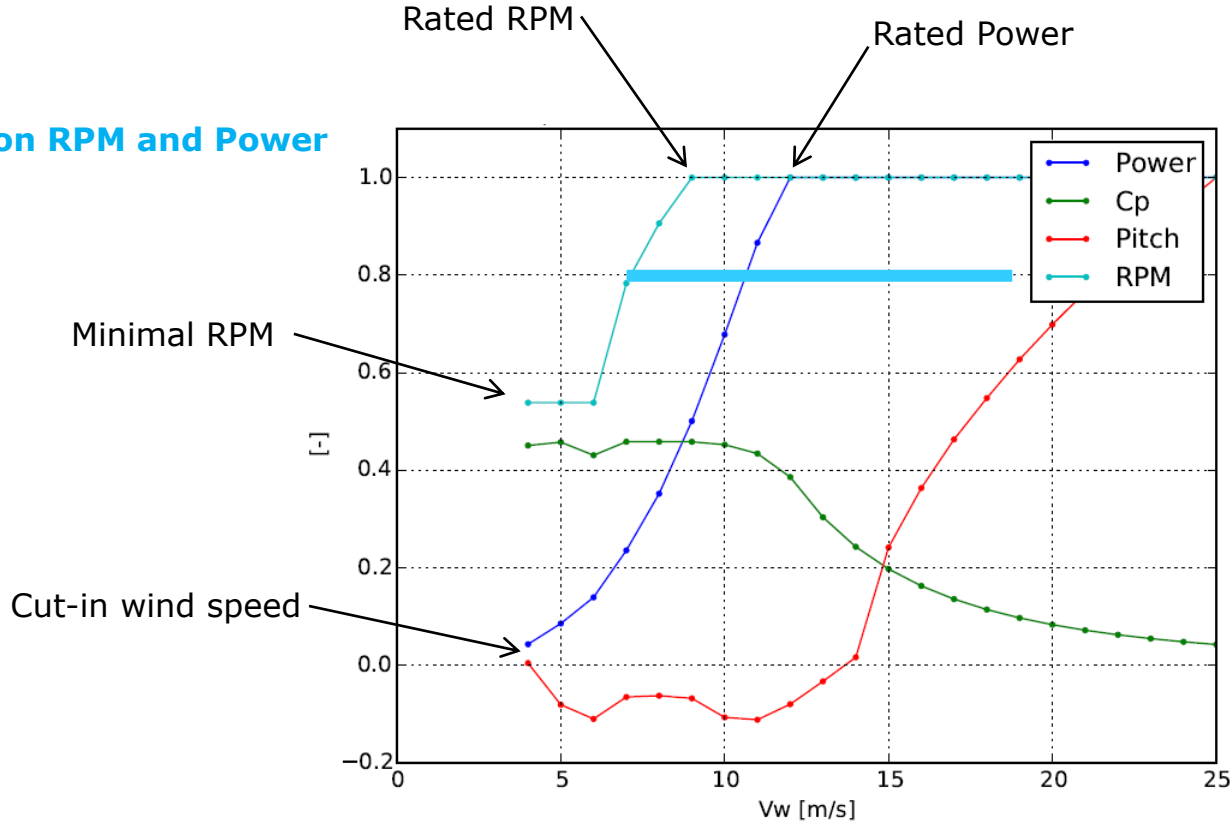


Turbine follows pitch-RPM table until rated power and adjusts pitch not to exceed rated power afterwards

$$\text{Power} = \text{Torque} * \text{Rotational_Speed}$$

Erosion safe-mode

"Lid" on RPM and Power



In an erosion-safe mode the turbine would be downrated meaning that it would act as its rated power was lower than default.

That would effectively decrease the rated RPMs.

$$\text{Power} = \text{Torque} * \text{Rotational_Speed}$$

Control strategies

Apart from a reference case where it is assumed that there is no erosion, six different control strategies are investigated based on the model for expected lifetime for the blade leading edge:

- Control strategy 1 with expected life time of 1.6 years
- Control strategy 2 with expected life time of 10.4 years
- Control strategy 3 with expected life time of 24.4 years
- Control strategy 4 with expected life time of 53.9 years
- Control strategy 5 with expected life time of 106.5 years
- Control strategy 6 with expected life time of infinite many years

Calculation of the life time of the blade leading edge with no reduction of the tip speed. Control strategy 1

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	90	3.5	51
10	2.0	0.1	8.8	90	79	11
5	1.5	1	88	90	3606	2.4
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
Sum of fractions [%]:						64
Expected life [years]:						1.6

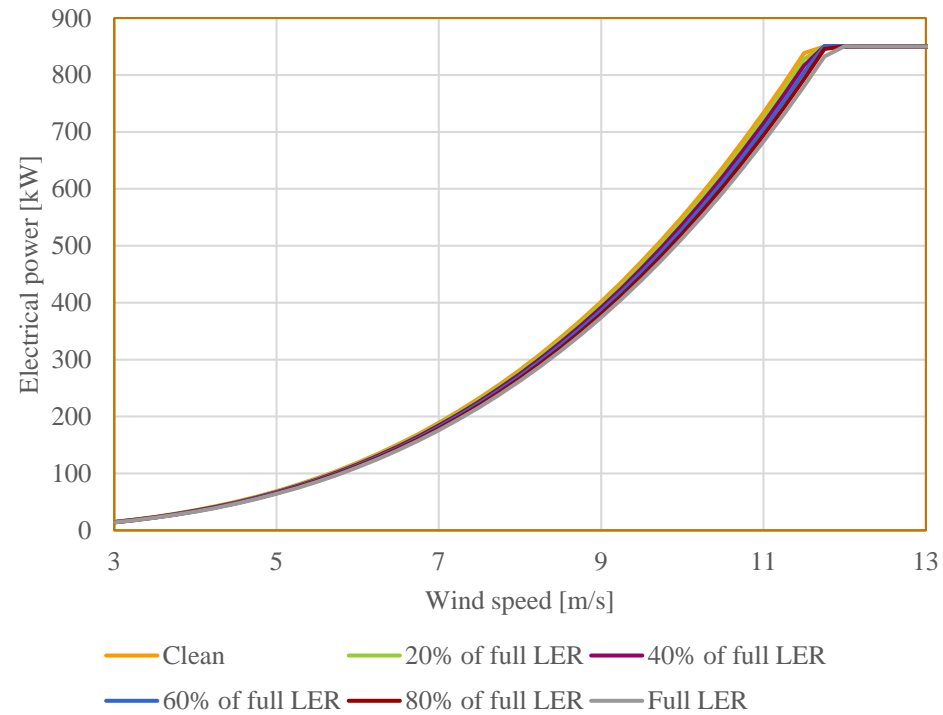
Calculation of the life time of the blade leading edge with reduction of the tip speed to 70m/s and 80m/s, respectively: Control strategy 2

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	70	46	3.8
10	2.0	0.1	8.8	80	263	3.3
5	1.5	1	88	90	3606	2.4
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
Sum of fractions [%]:						9.6
Expected life [years]:						10.4

Calculation of the life time of the blade leading edge with reduction of the tip speed to 55m/s, 65m/s and 70m/s, respectively: Control strategy 5

Rain intensity [mm/hr]	Droplet size [mm]	Percent of time [%]	Hours pr year [hrs/year]	Blade tip speed [m/s]	Hours to failure [hrs]	Fraction of life spent pr year [%]
20	2.5	0.02	1.8	55	541	0.3
10	2.0	0.1	8.8	65	2215	0.4
5	1.5	1	88	70	47514	0.2
2	1.0	3	263	90	745710	0.0
1	0.5	5	438	90	2830197826	0.0
Sum of fractions [%]:						0.9
Expected life [years]:						107

Simulated power curves for the Vestas V52 for different leading edge roughness levels



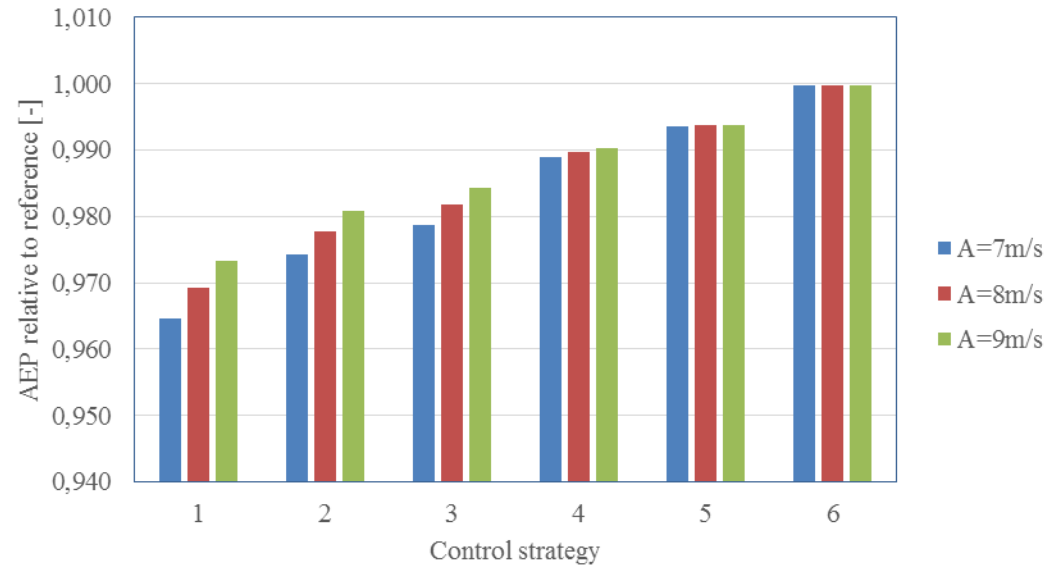
Cost of operation and maintenance

- Energy price:
 - 50 €/MWh
 - 250 €/MWh
- Inspection cost:
 - 500 €/rotor
 - 1500 €/rotor
- Repair cost
 - 10000 €/rotor
 - 20000 €/rotor

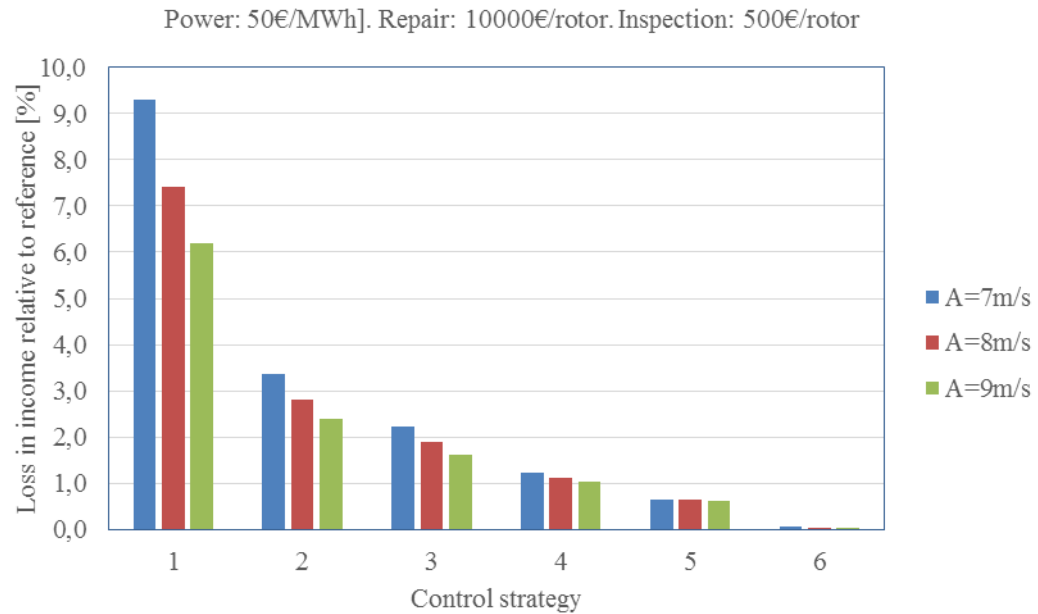
Stand still of 1 day inspected

Stand still of 2 days repaired

AEP relative to AEP with no erosion



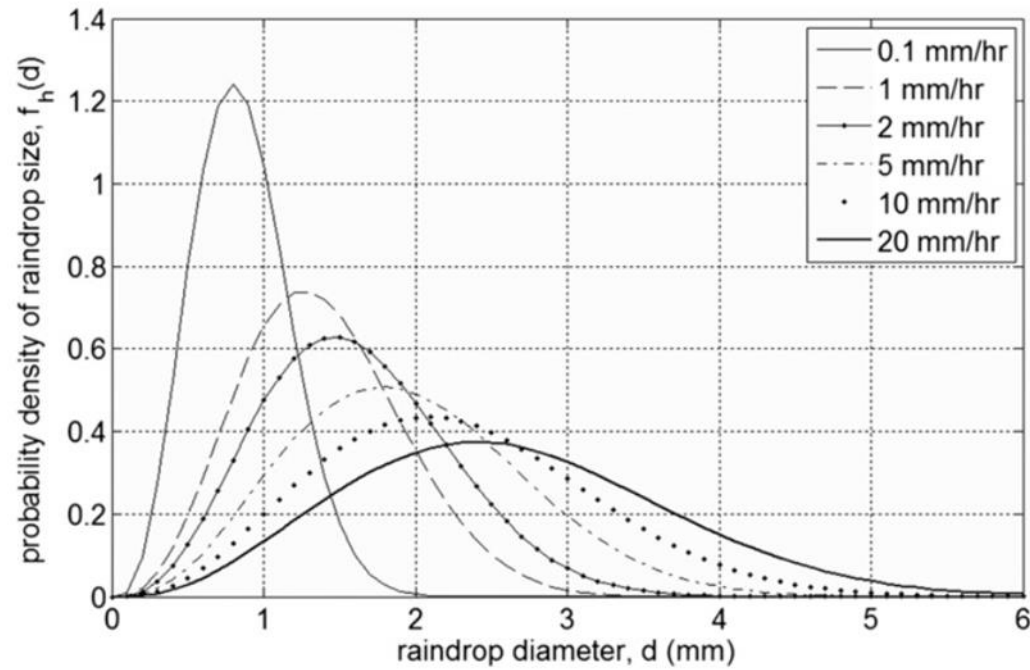
Loss of income due to erosion, inspection and repair



EROSION

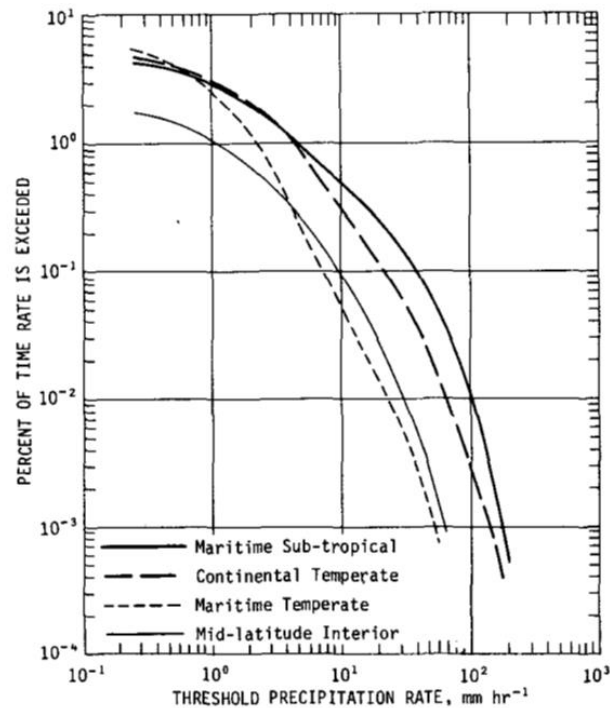
Meteorological perspectives

Raindrop size distribution through a horizontal plane with the rain fall intensity as a parameter (from Kubilay et al., 2013, based on Best, 1950)



Average rainfall rate-frequency relationships for four rain climates (Jones and Sims, 1978)

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g. 5. Average rainfall rate-frequency relationships for four rain climates.

Meteorological observation instruments



Raingauge



weather radar

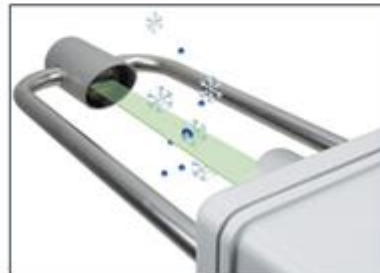


present weather sensor



Parsivel 2

WS100



Thies disdrometer



Parsivel² disdrometer

Annual rain offshore

At offshore sites there are no rain gauges thus approximation and/or extrapolation is necessary.

The new offshore disdrometer data may prove useful for radar-based rain mapping offshore.

Conclusions

The extension of blade life time using erosion safe mode is calculated based on assumptions on erosion related to rain events.

The erosion safe mode control strategy is outlined and the expected reduction in operational cost is estimated.

First tests in rain erosion tester have been completed and preliminary results on damage in specimen are available.

Precipitation data will be collected during next one year.