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Rain erosion of leading edges of wind turbine blades. What is up and down?

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Rain erosion of leading edges of wind turbine blades.
What is up and down?

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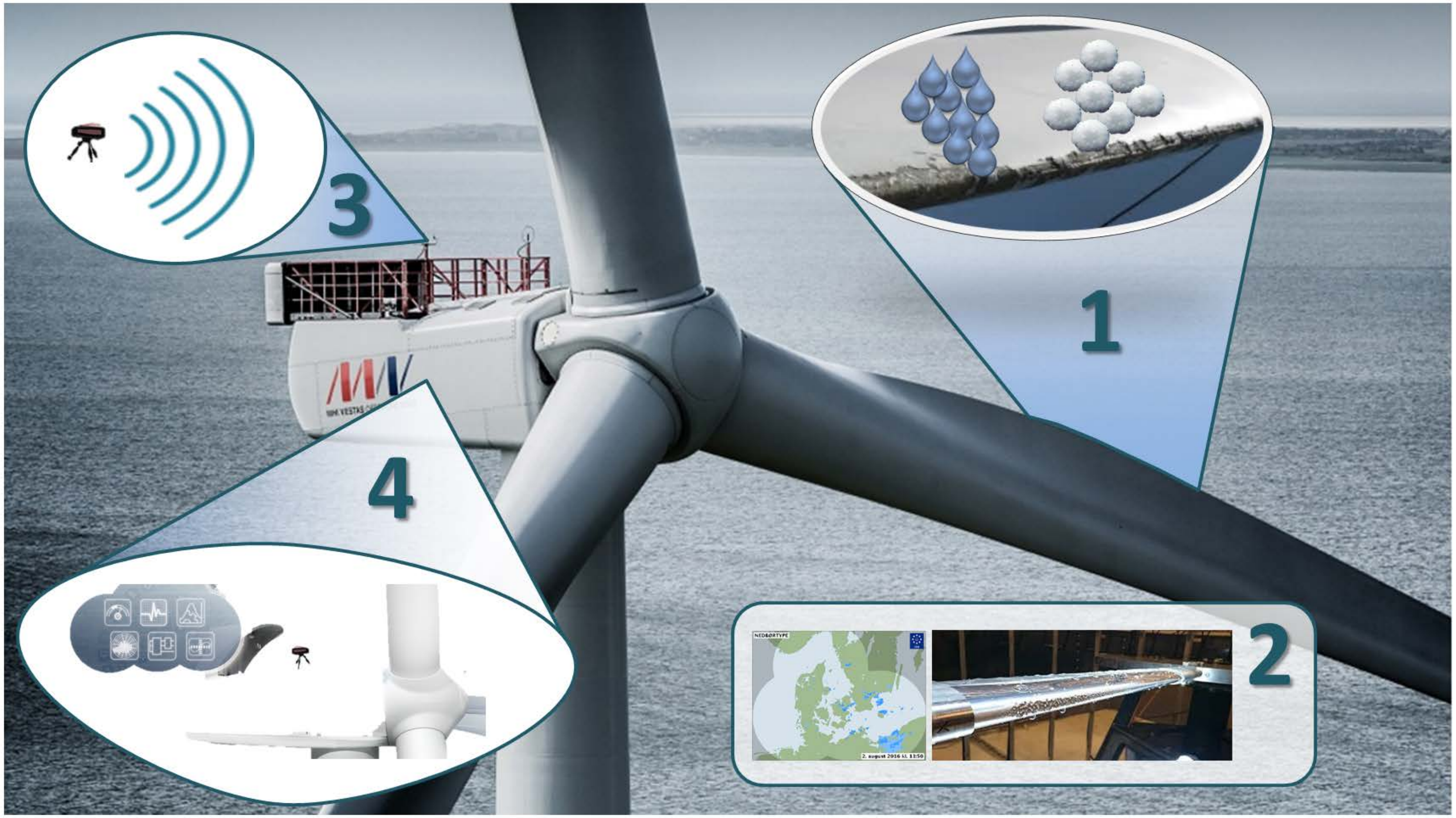
Working hypothesis



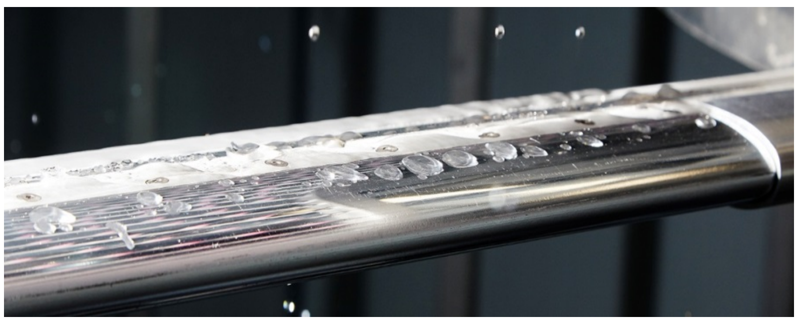
1. **Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime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

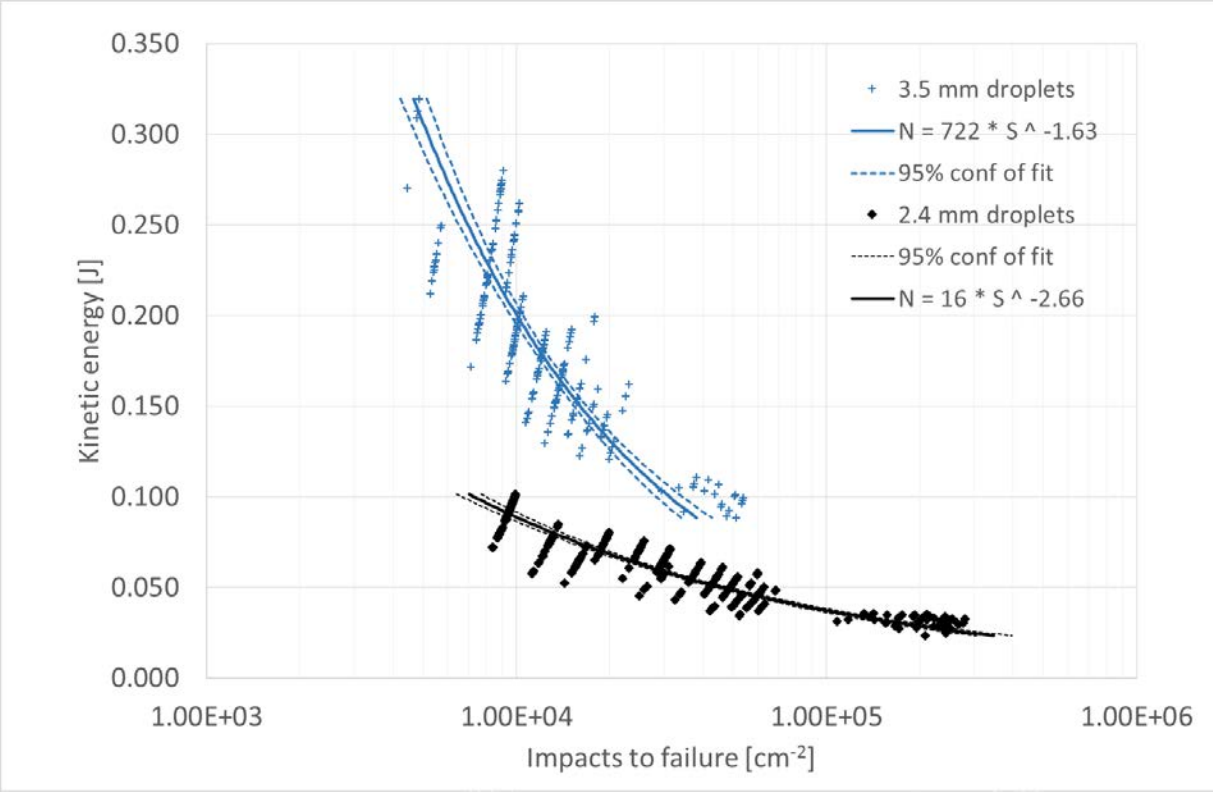
4. **Erosion safe mode:** A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

Rain Erosion Tester by R&D Test Systems

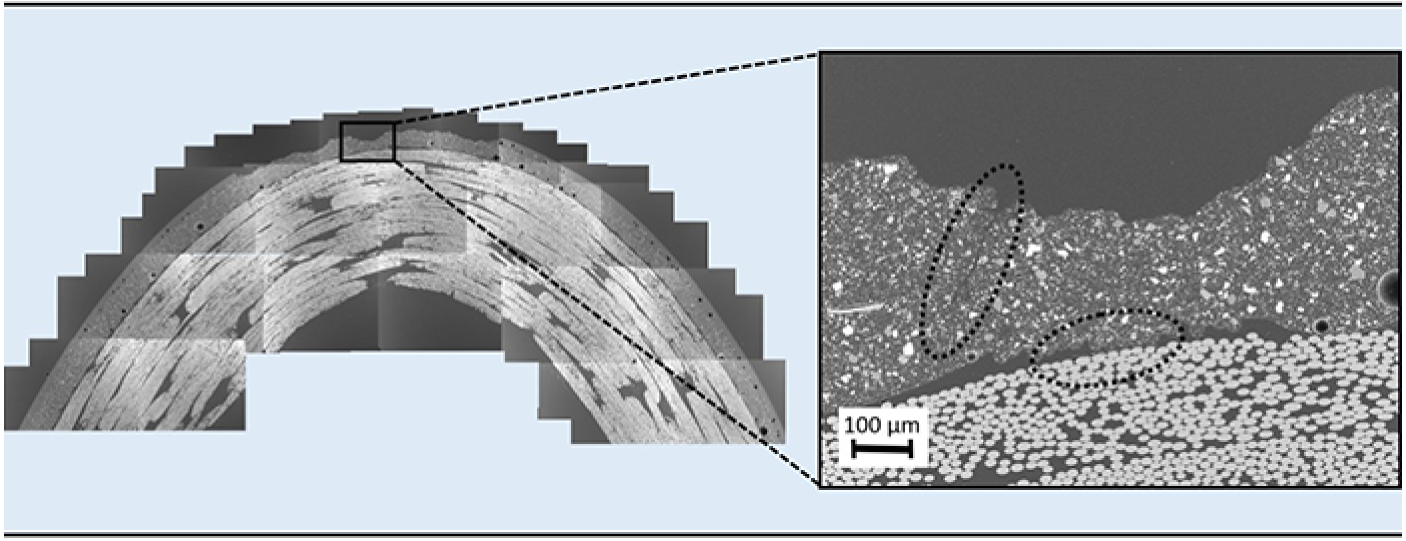


Example of specimen

First results



Microscopy investigations enable direct identifications of fractures

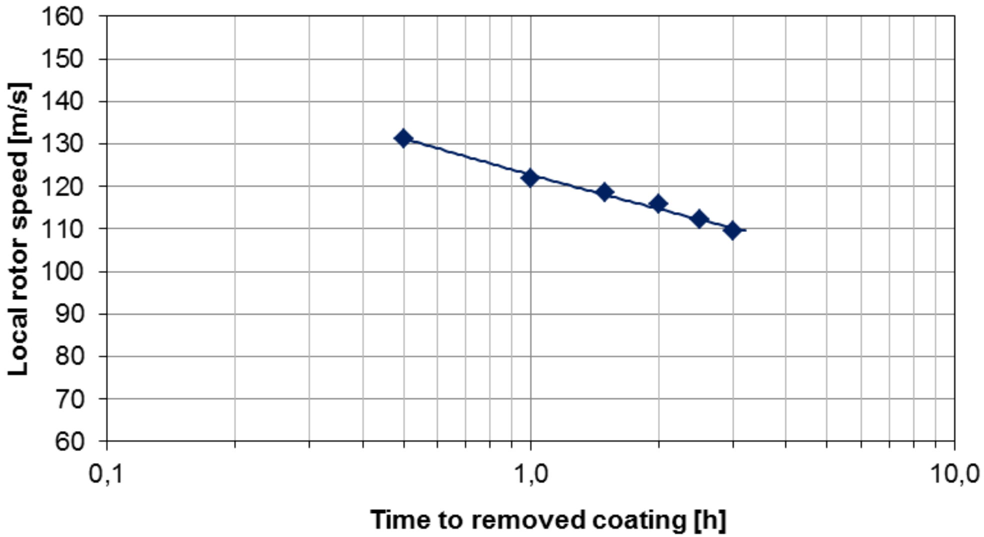


Rain erosion test samples with different degradation have been investigated by electron microscopy.

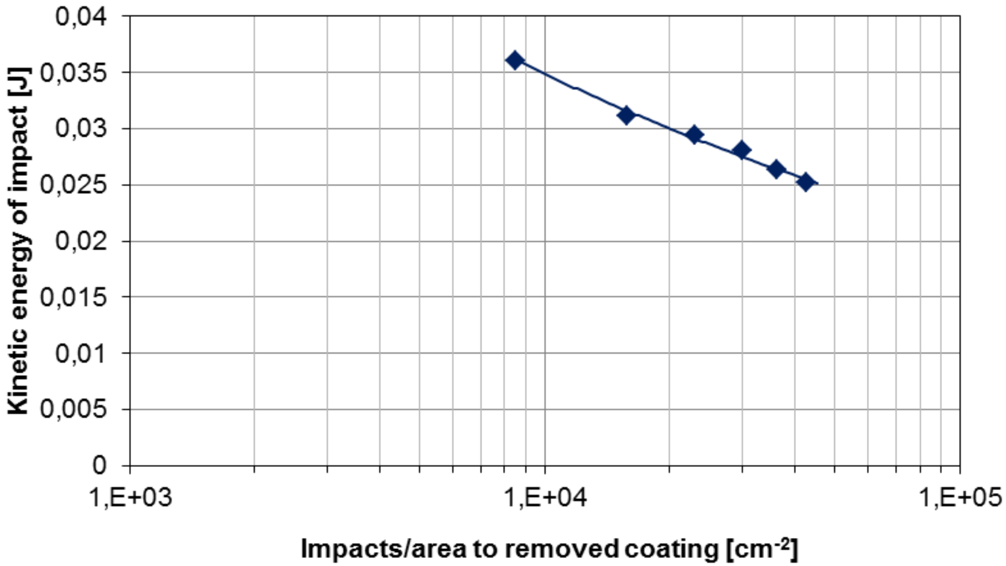
The erosion appears to start at the surface where the surface roughness increase. However at the same time as the top-coating and the filler slowly degrades microscale damage can be observed within the laminate. Cracks have been observed at the position of the peel fly as well as within the laminate.

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

Rain erosion test data plotted as a Wöhler curve

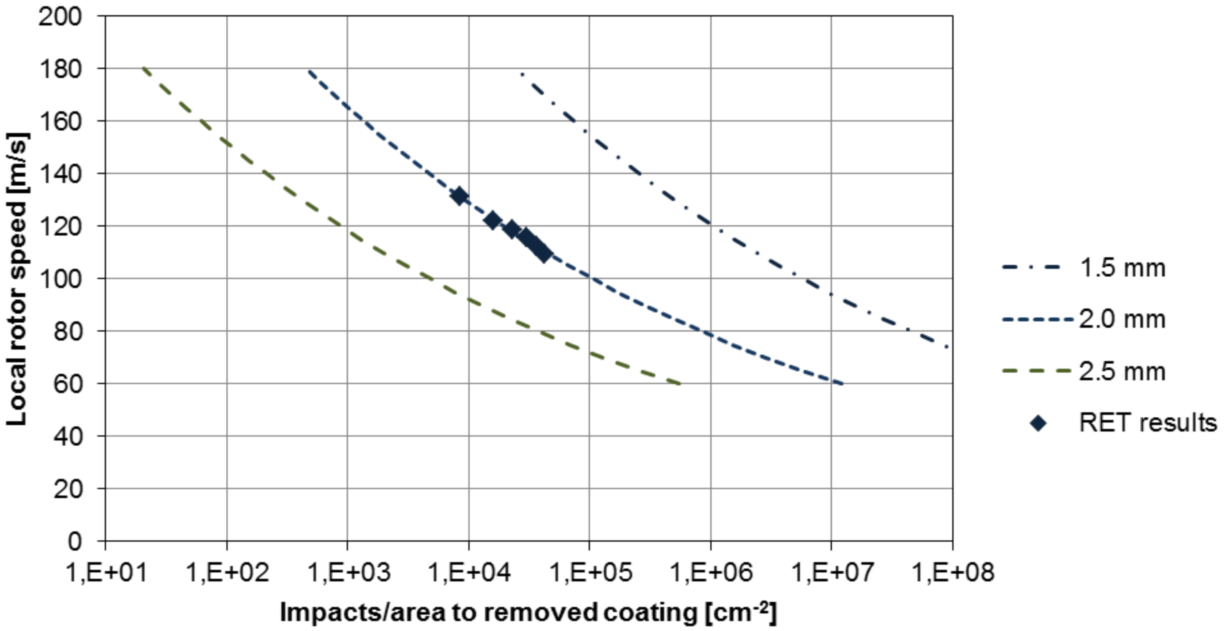


Rain erosion test data plotted as a Wöhler curve: Impacts per unit area to failure as function of the kinetic energy for each impact



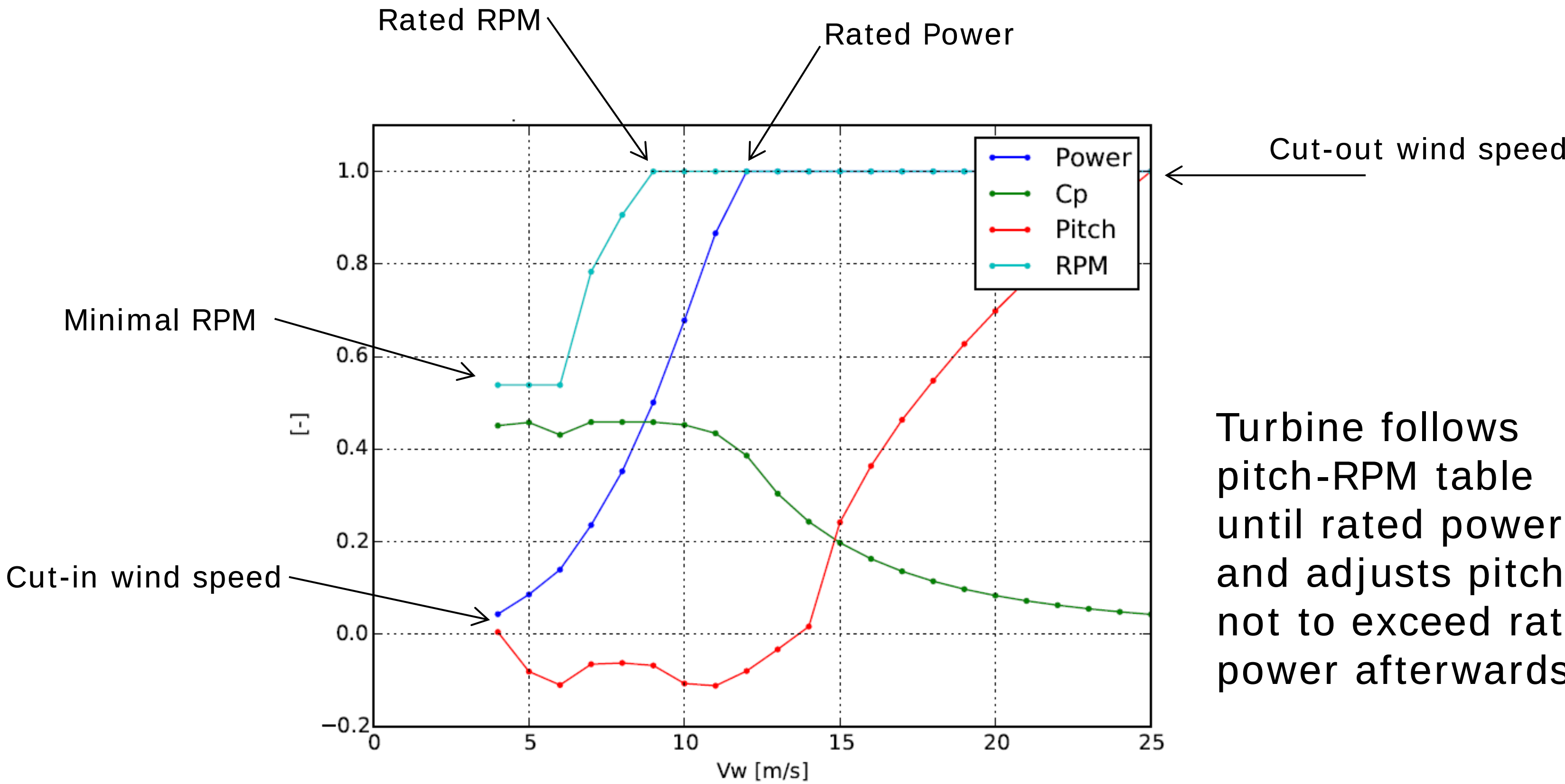
$$E_k = \frac{1}{12}\rho\pi D^3 v_t^2 \ [\mathrm{J}]$$

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



Extending lifetime

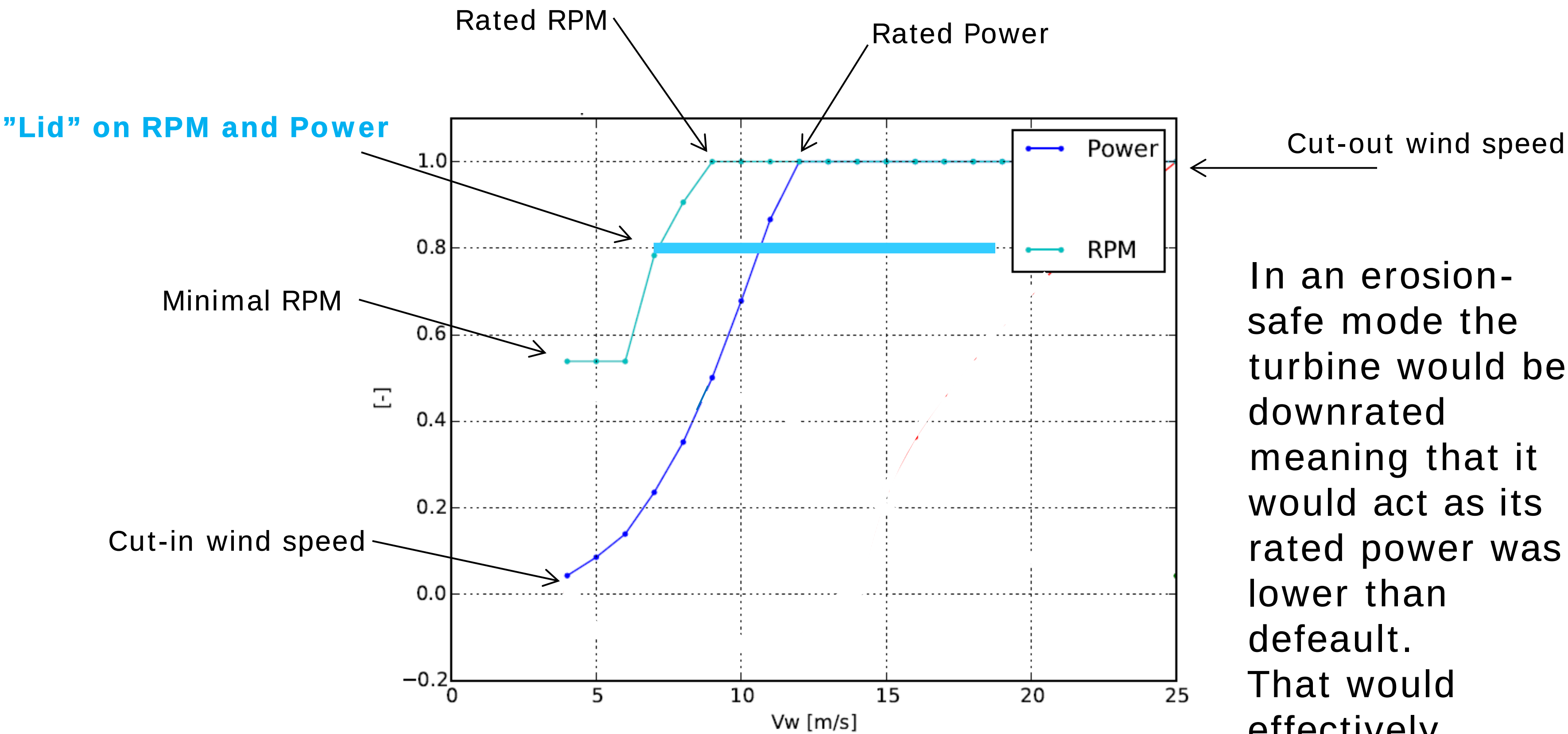
Control of turbine



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

Power = Torque * Rotational_Speed

Erosion safe-mode



In an erosion-safe mode the turbine would be downrated meaning that it would act as its rated power was lower than defeault. That would effectively decrease the rated RPMs.

Power = Torque * 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

Cost of operation and maintenance

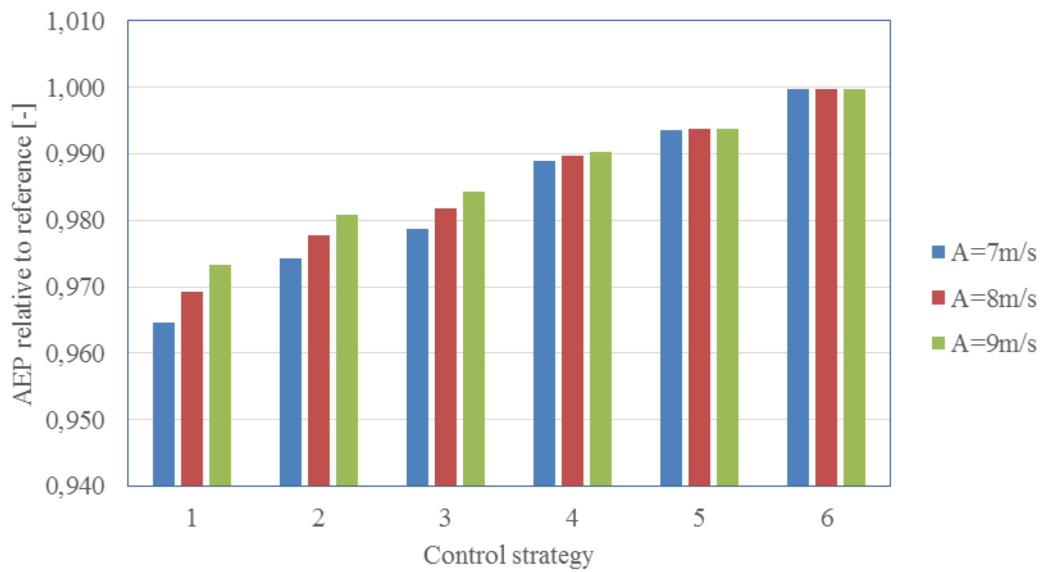
- Energy price:
  - 50 €/MWh
  - 250 €/MWh
- Inspection cost:
  - 500 €/rotor
  - 1500 €/rotor
- Repair cost
  - 10000 €/rotor
  - 20000 €/rotor

- Control strategy 1: 10 inspections and 9 repairs
- Control strategy 2: 10 inspections and 1 repairs
- Control strategy 3: 5 inspections and 0 repairs
- Control strategy 4: 5 inspections and 0 repairs
- Control strategy 5: 2 inspections and 0 repairs
- Control strategy 6: 2 inspections and 0 repairs

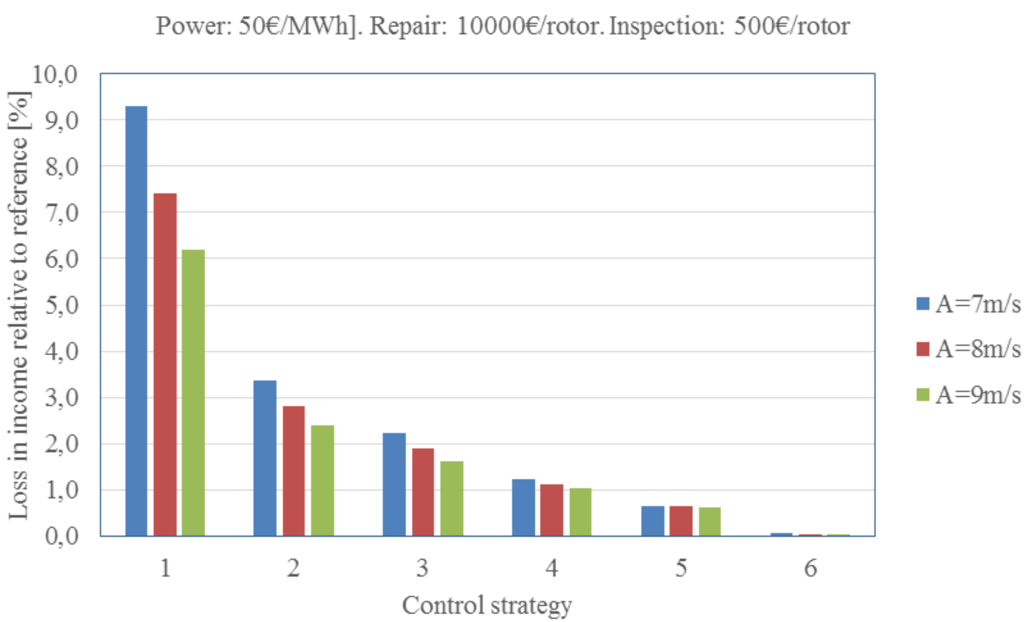
Stand still of 1 day inspected

Stand still of 2 days repaired

AEP relative to AEP with no erosion



Loss of income due to erosion, inspection and repair



Conclusions

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What is up and down?

Up:
Knowledge on rain and leading edge erosion
Concept for erosion safe mode
Balance sheet: extension of lifetime pays

Down:
Full scale testing in progress
Ideal method for the rain warning to be evaluated

Acknowledgements

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www.rain-erosion.dk