Technical University of Denmark

Leading edge erosion of wind turbine blades

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Leading Edge Erosion of Wind Turbine Blades

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23 May 2018 - 24 May 2018

DTU Wind Energy
Department of Wind Energy

Innovationsfonden

Leading Edge Erosion of Wind Turbine Blades

- Wind turbine blades erosion: Reducing the largest uncertainties (EROSION project)

- Extension of the life of blade leading edges by reducing the tip speed during extreme precipitation events

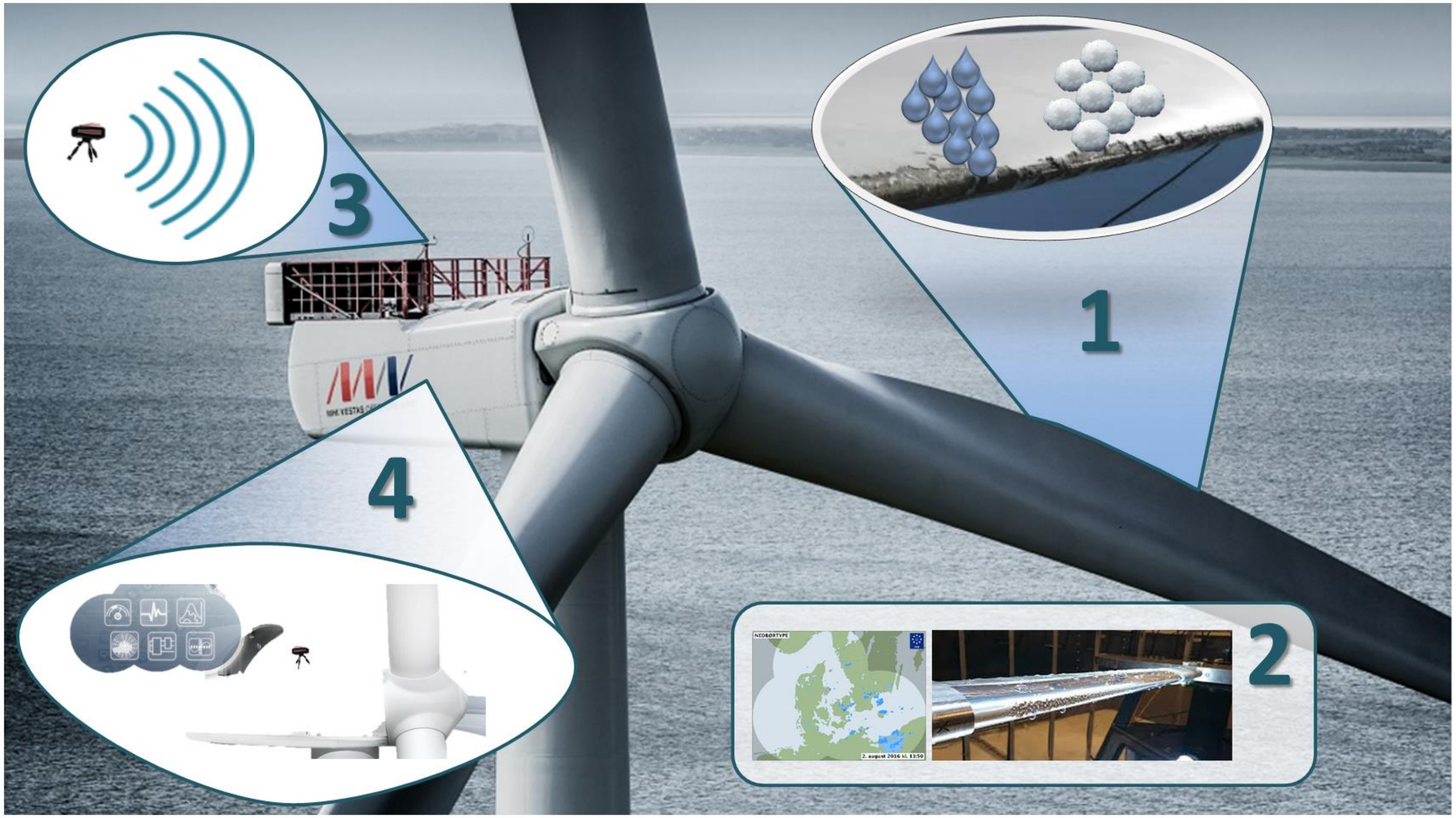
- The meteorological perspectives in rain erosion at leading edges of wind turbine blades

Content

- The EROSION project in brief
- Reducing tip speeds during rain events to extend the life time of blades
- Meteorological perspectives
- Conclusion

The EROSION project in brief

www.rain-erosion.dk



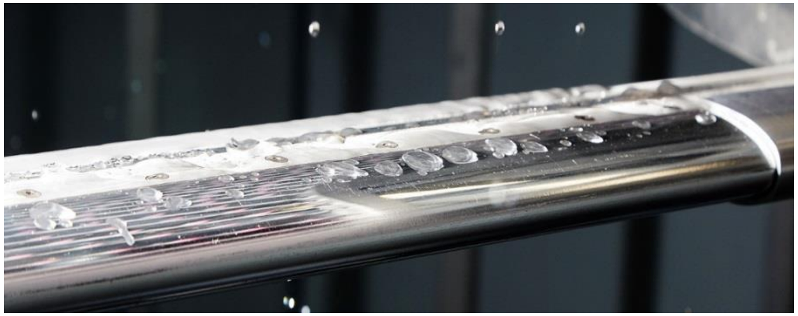
1. **Research hypothesis:** Erosion damage is mainly generated during heavy precipitation (big drops of rain or hail), which occurs in a very little fraction of the turbines operation time. By reducing the tip speed of the blades in these few hours a significant extension of the leading edge lifetime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

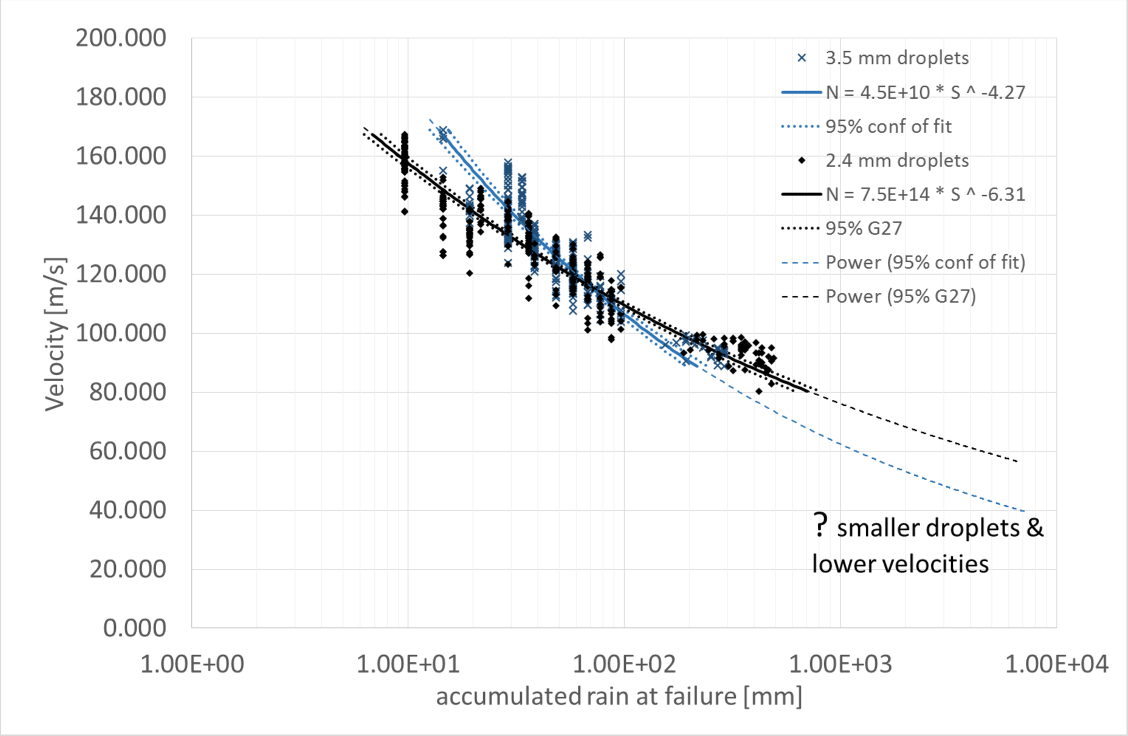
4. **Erosion safe mode:** A safe mode control based on the erosion classes to control the wind turbine, reducing the tip speed under severe conditions – preventing aerodynamic degradation and reducing maintenance costs.

Rain Erosion Tester by R&D Test Systems



Example of specimen

First results



3.5 mm droplets
Rain intensity 58 mm/hour

2.4 mm droplets
29 mm/hour

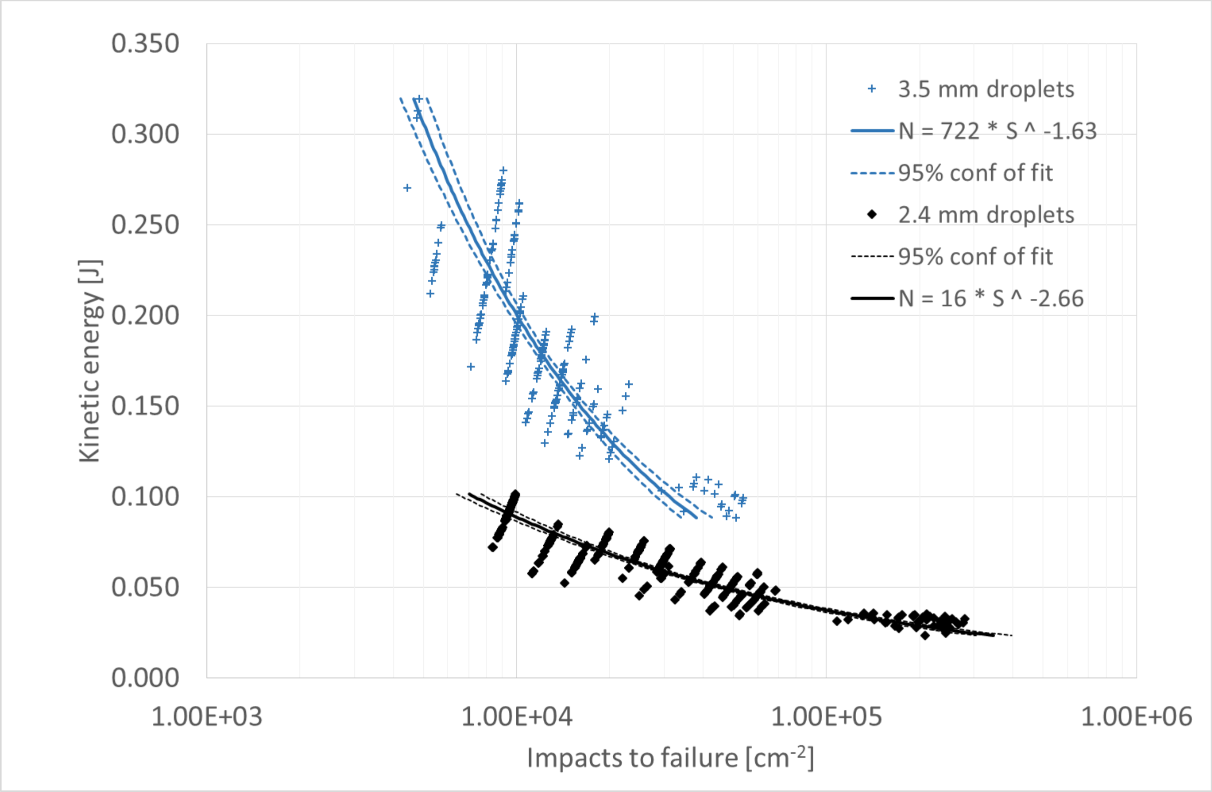
3 (4) different velocities

3 blades

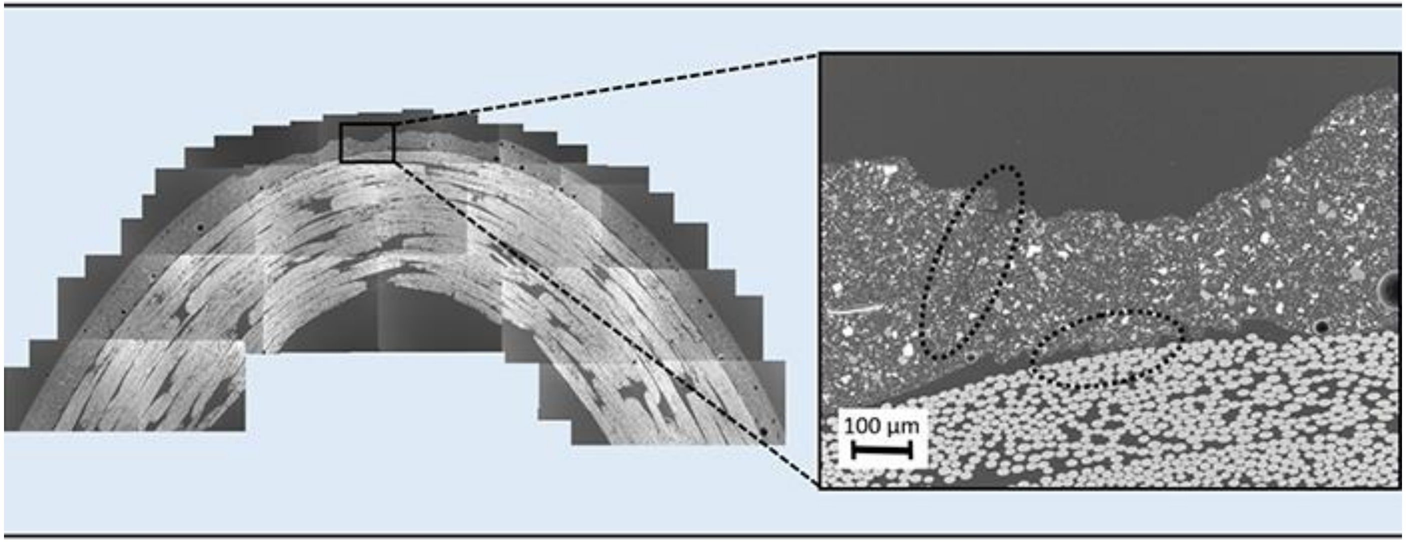
Stop frequently and map the new point damages each time

RET test results for EROSION specimen.
Damage is the first visuel damage point of erosion.

First results



Microscopy investigations enable direct identifications of fractures

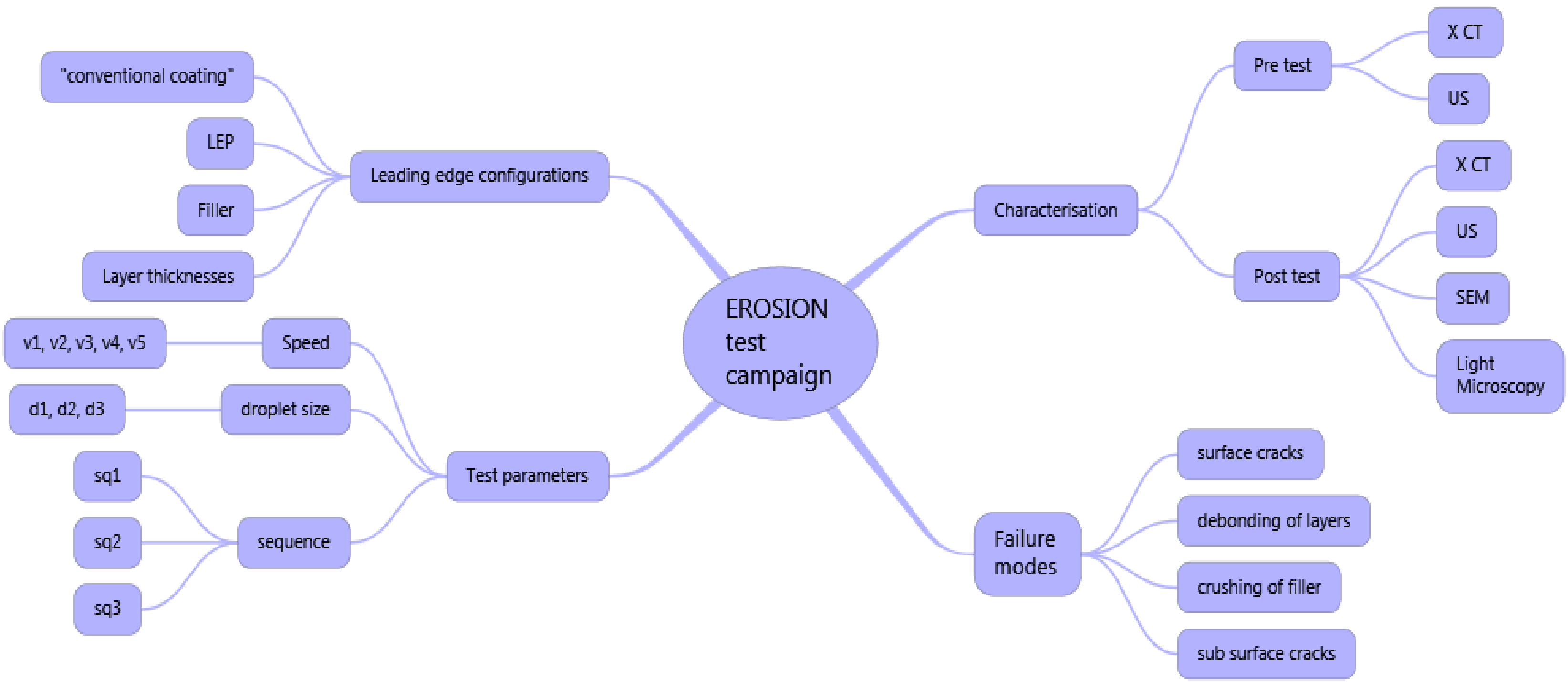


Rain erosion test samples with different degradation have been investigated by electron microscopy.

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 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

Wind Energ. Sci. Discuss., https://doi.org/10.5194/wes-2017-62
Manuscript under review for journal Wind Energ. Sci.
Discussion started: 21 February 2018

WIND ENERGY SCIENCE DISCUSSIONS

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

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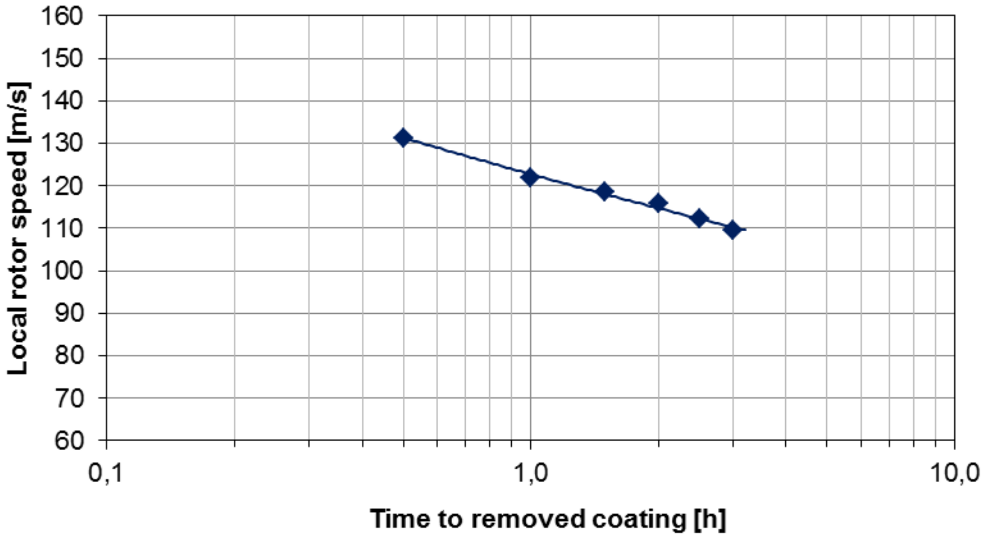
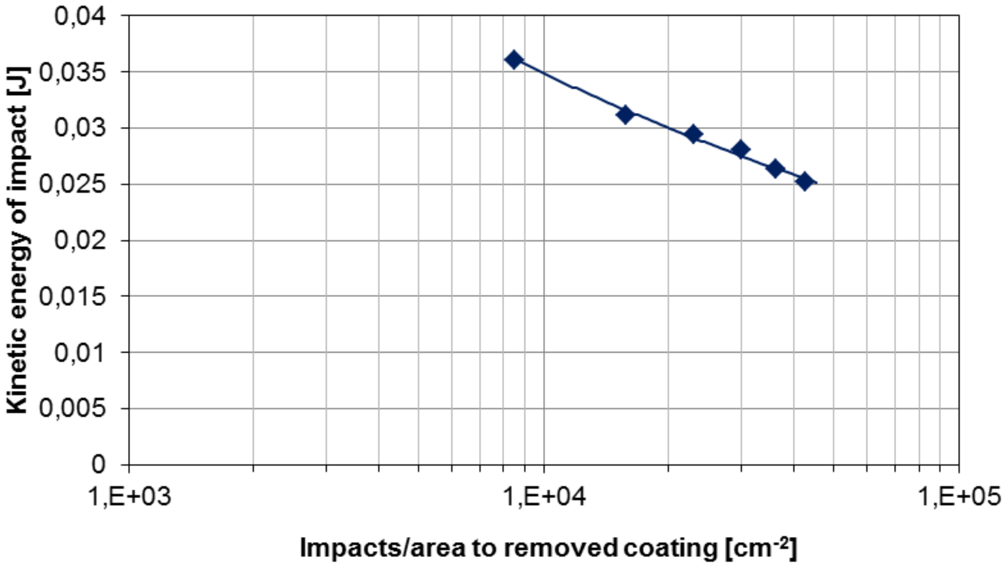
Rain erosion test data plotted as a Wöhler curve

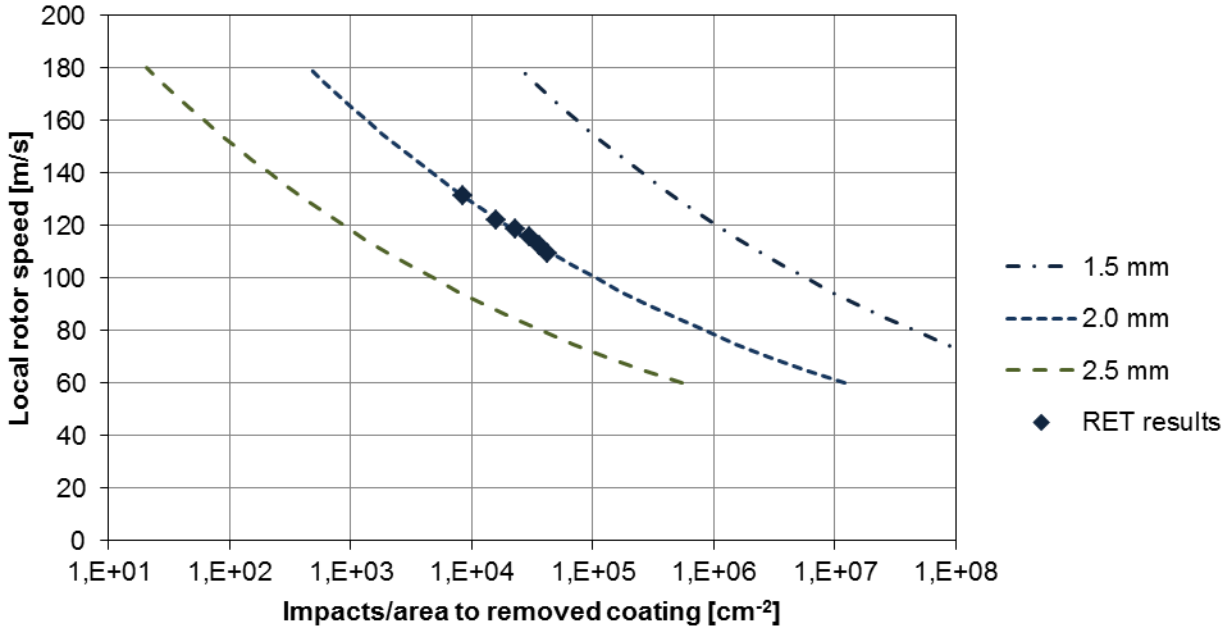


Rain erosion test data plotted as a Wöhler curve: Impacts per unit area to failure as function of the kinetic energy for each impact

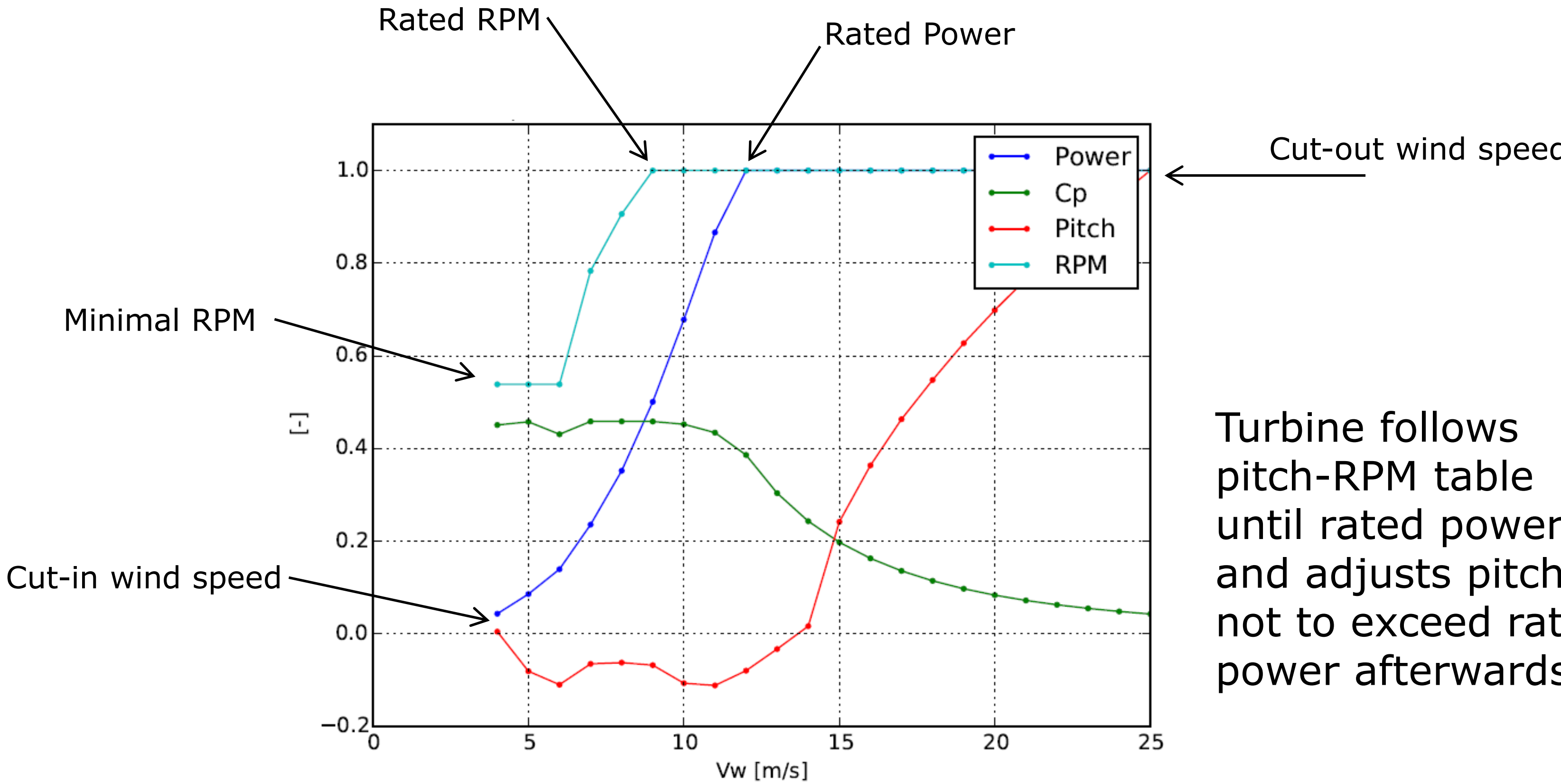


$$E_k = \frac{1}{12}\rho\pi D^3 v_t^2 \ [\mathrm{J}]$$

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



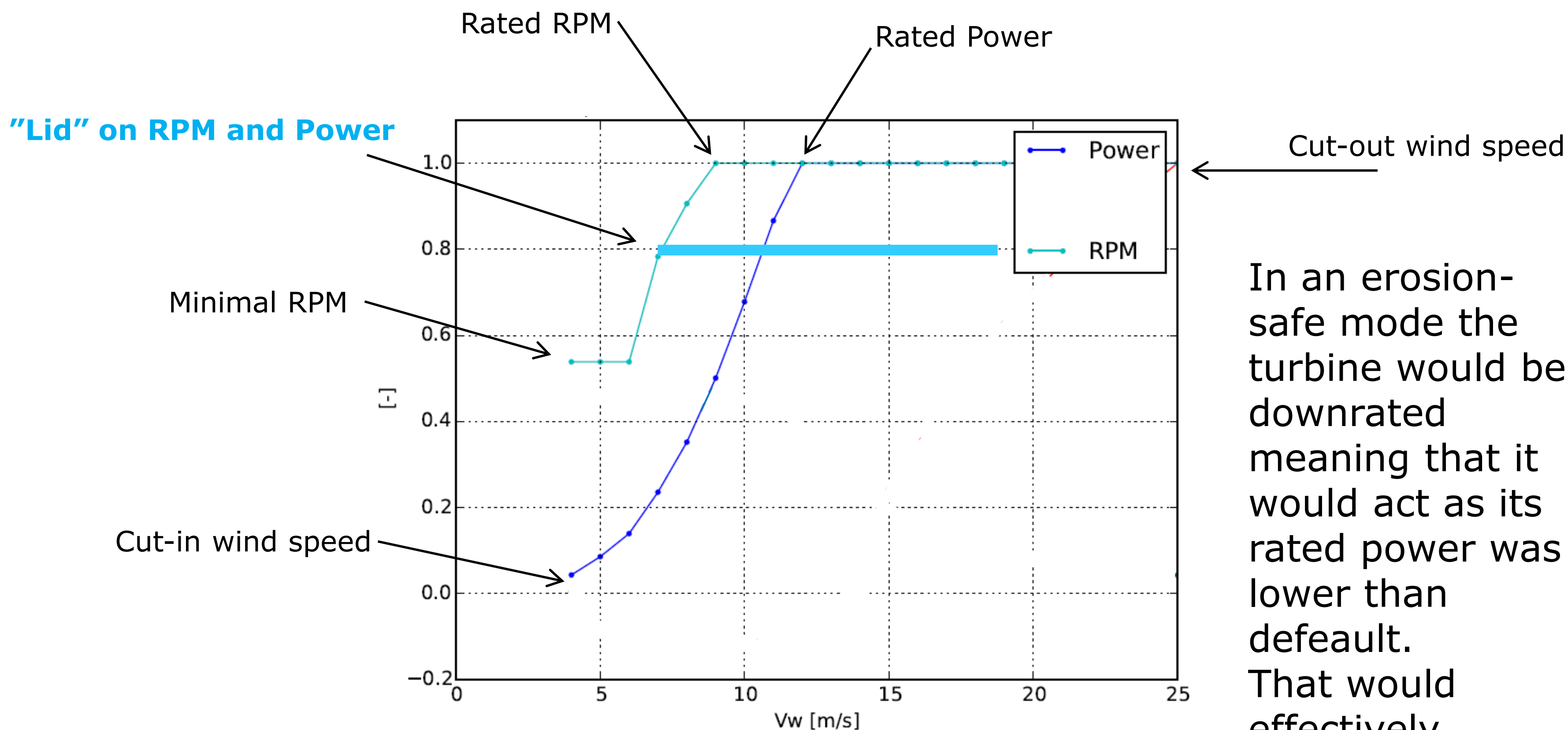
Control of turbine



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

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

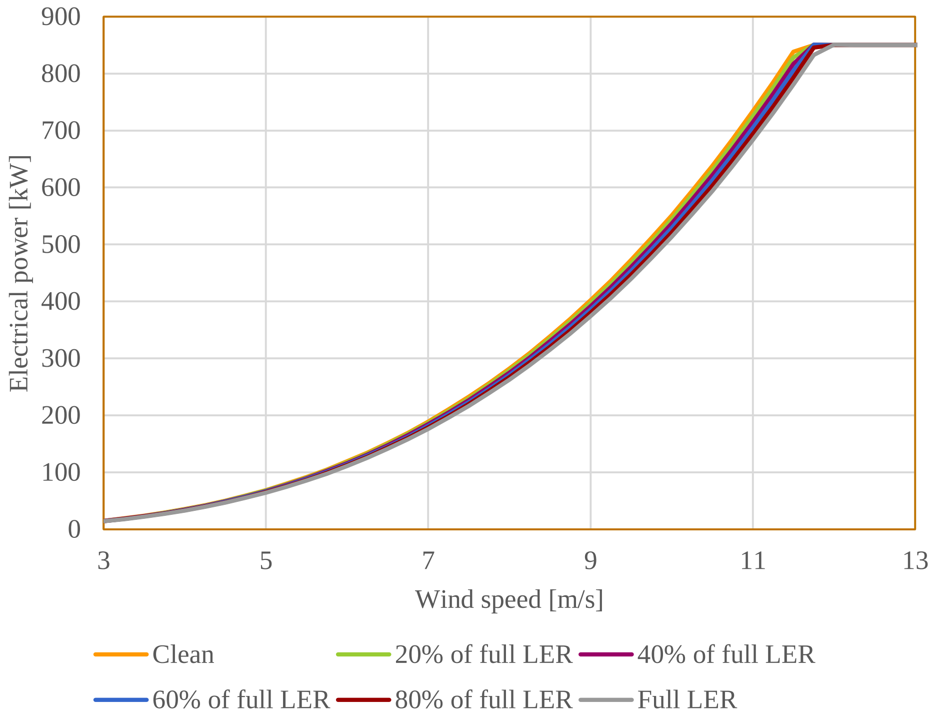
Calculation of the life time of the blade leading edge with reduction of the tip speed to 70m/s and 80m/s, respectively: Control strategy 2

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

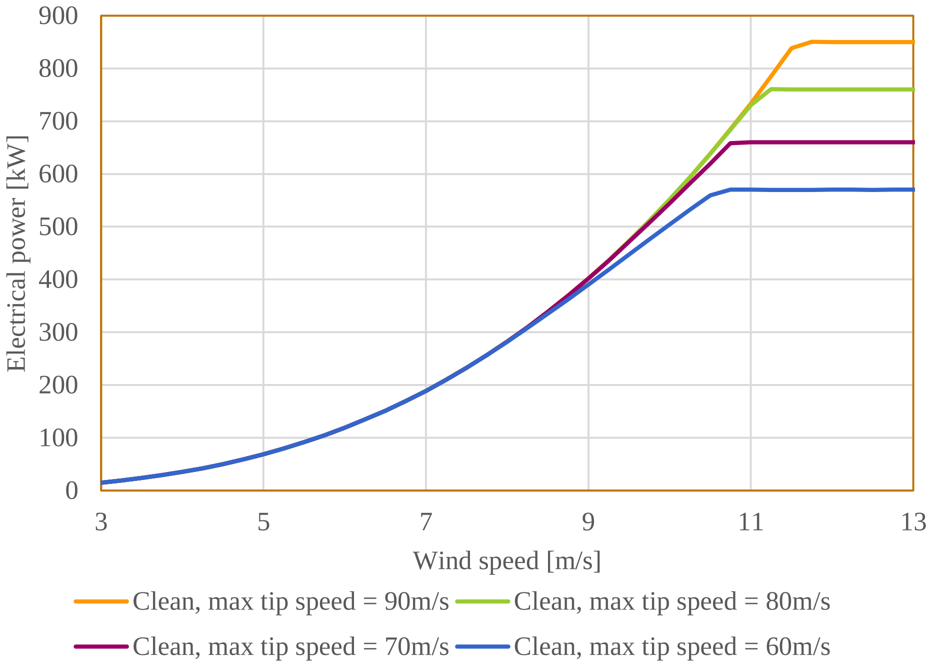
Calculation of the life time of the blade leading edge with reduction of the tip speed to 55m/s, 65m/s and 70m/s, respectively: Control strategy 5

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

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



Simulated power curves for the Vestas V52 for different maximum tip speeds



Cost of operation and maintenance

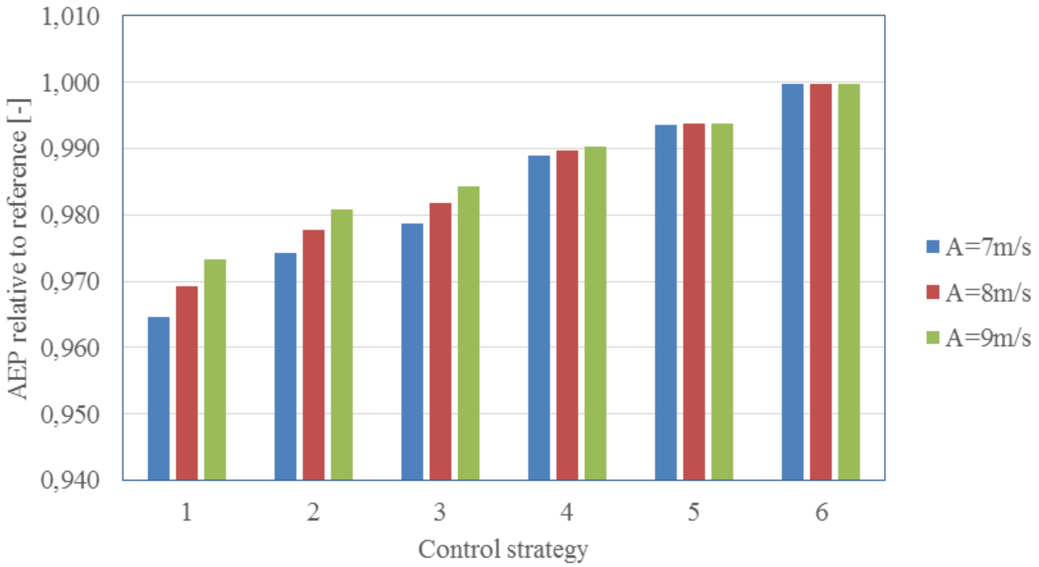
- Energy price:
  - 50 €/MWh
  - 250 €/MWh
- Inspection cost:
  - 500 €/rotor
  - 1500 €/rotor
- Repair cost
  - 10000 €/rotor
  - 20000 €/rotor

- 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

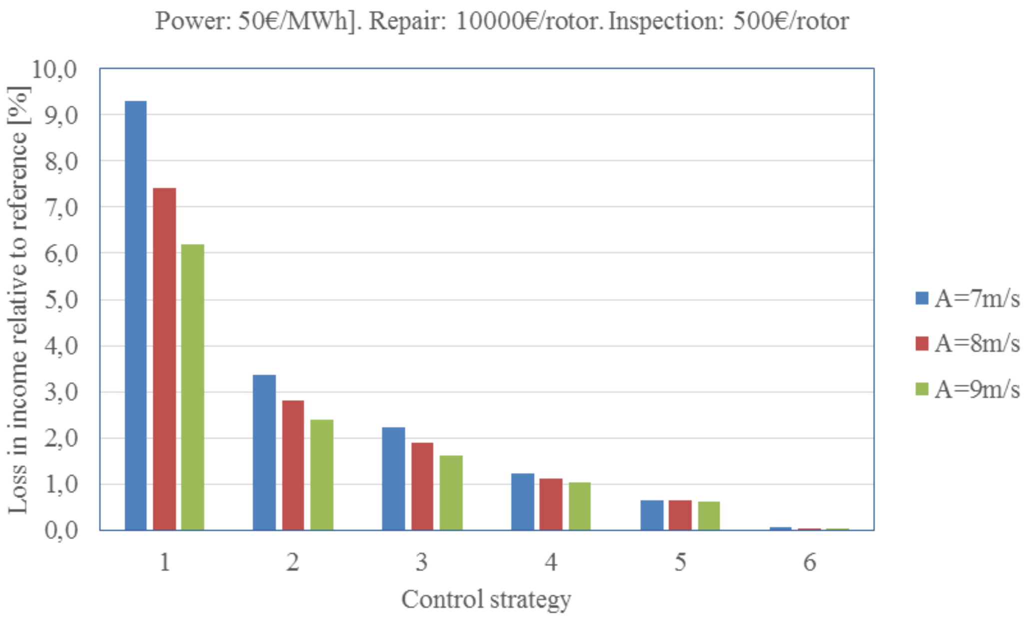
Stand still of 1 day inspected

Stand still of 2 days repaired

AEP relative to AEP with no erosion

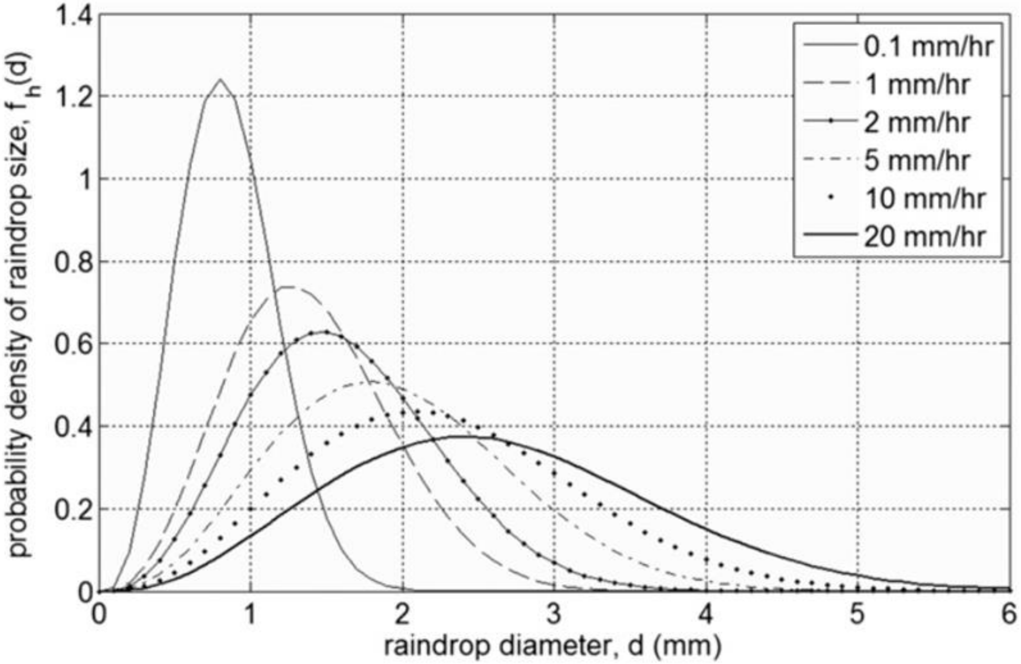


Loss of income due to erosion, inspection and repair

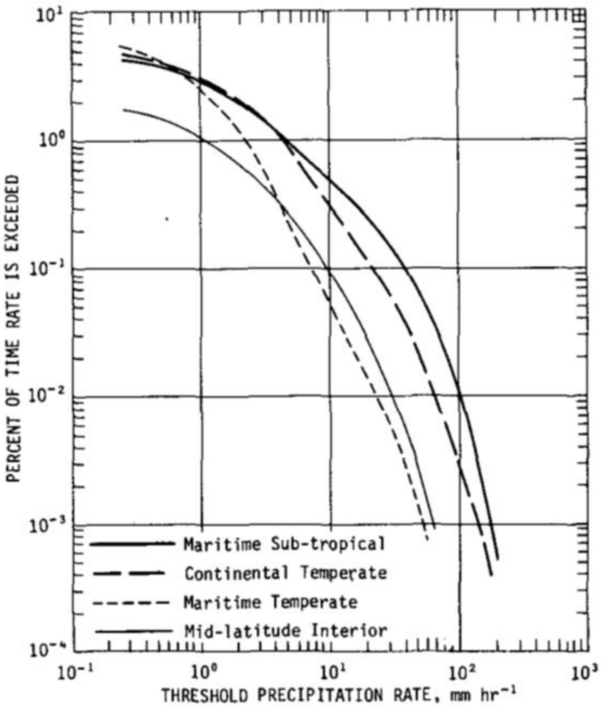


Meteorological perspectives

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) ©American Meteorological Society. Used with permission.



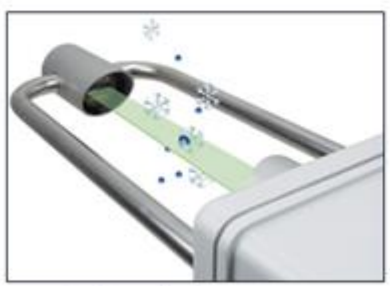
G. 5. Average rainfall rate-frequency relationships for four rain climates.

Meteorological observation instruments

Raingauge

weather radar

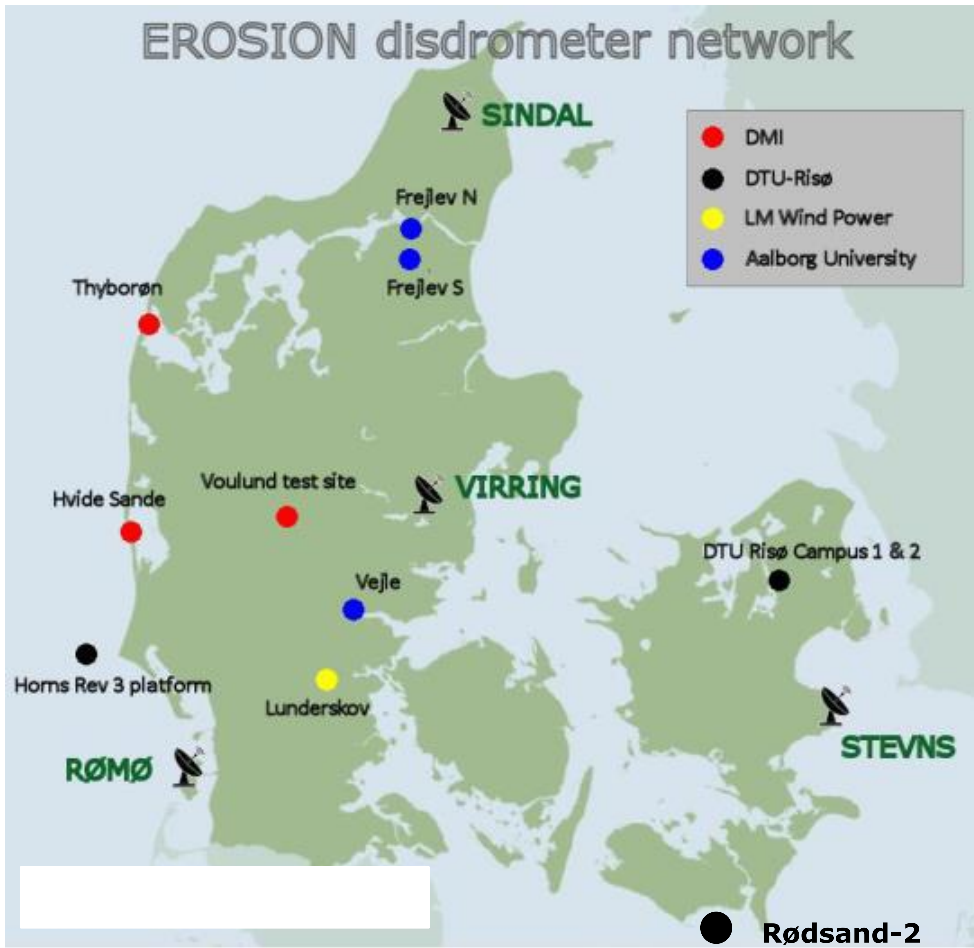
present weather sensor



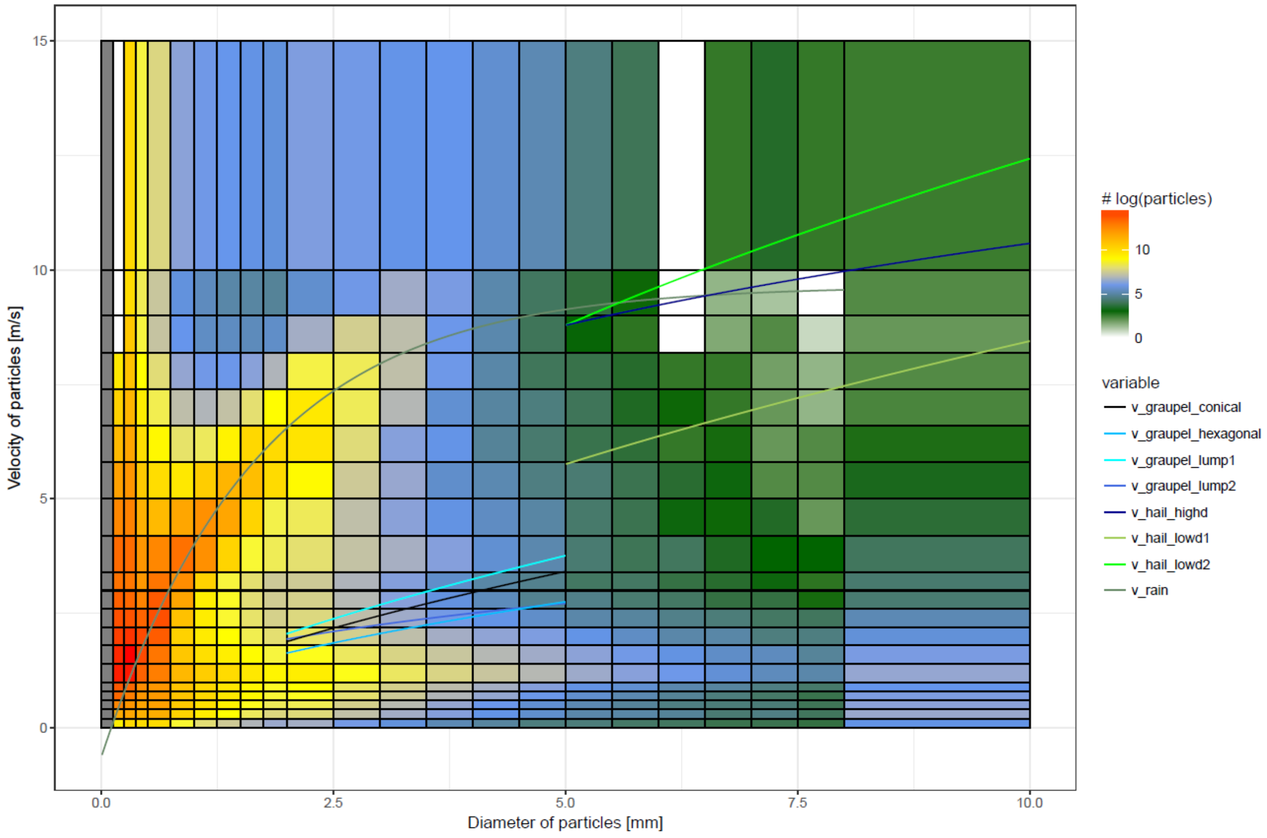
Thies disdrometer

Parsivel^2 disdrometer

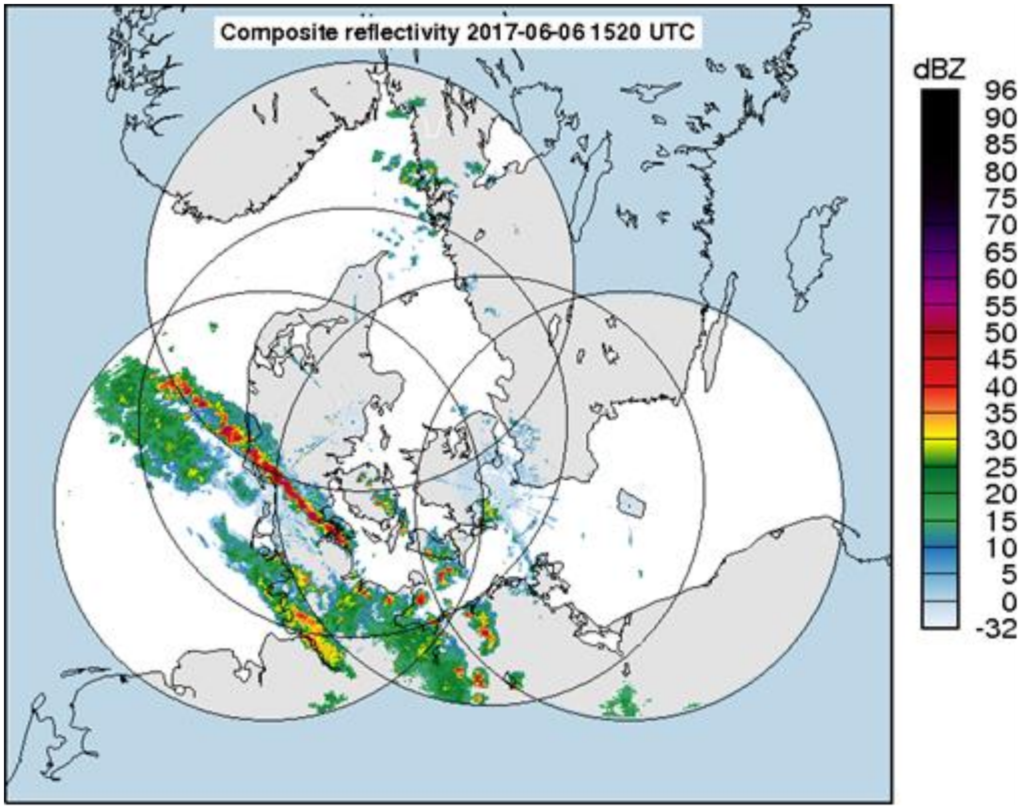
EROSION disdrometer network



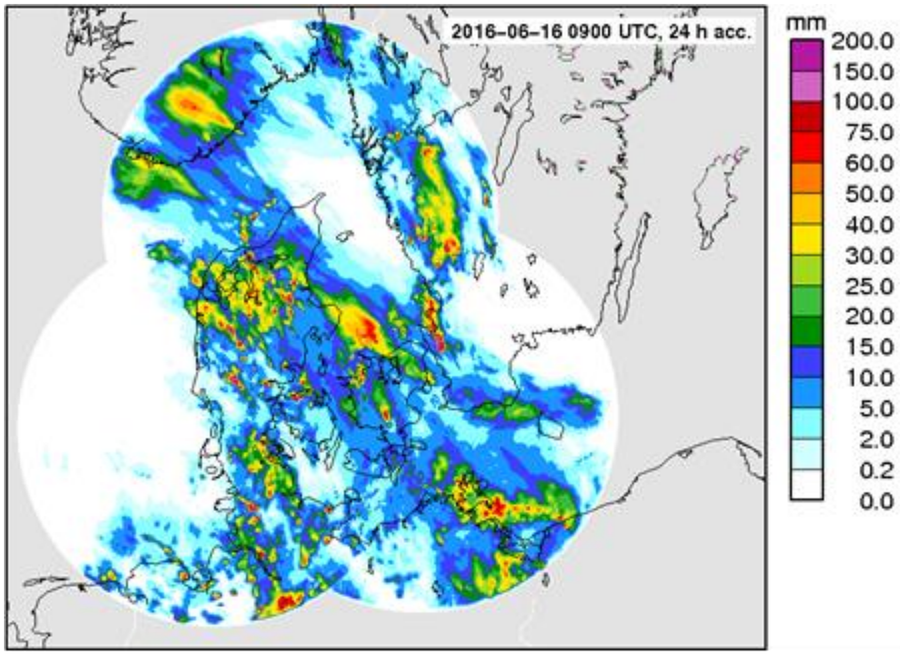
Size-Velocity histogram for year 2012 to 2017 at Voulund

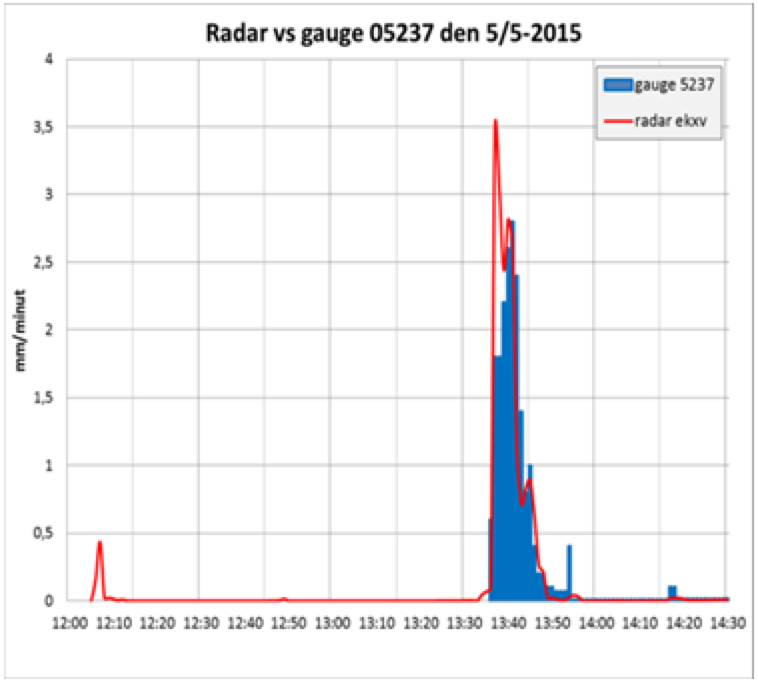


DMI’s weather radar network shown with an example from 6 June 2017 at 15:20 UTC. The unit dBZ indicates the relative rain rate.



Radar QPE (quantitative precipitation estimate) field on 16 June 2016 at 0900 UTC versus raingauge at Vejle Pumpestation.

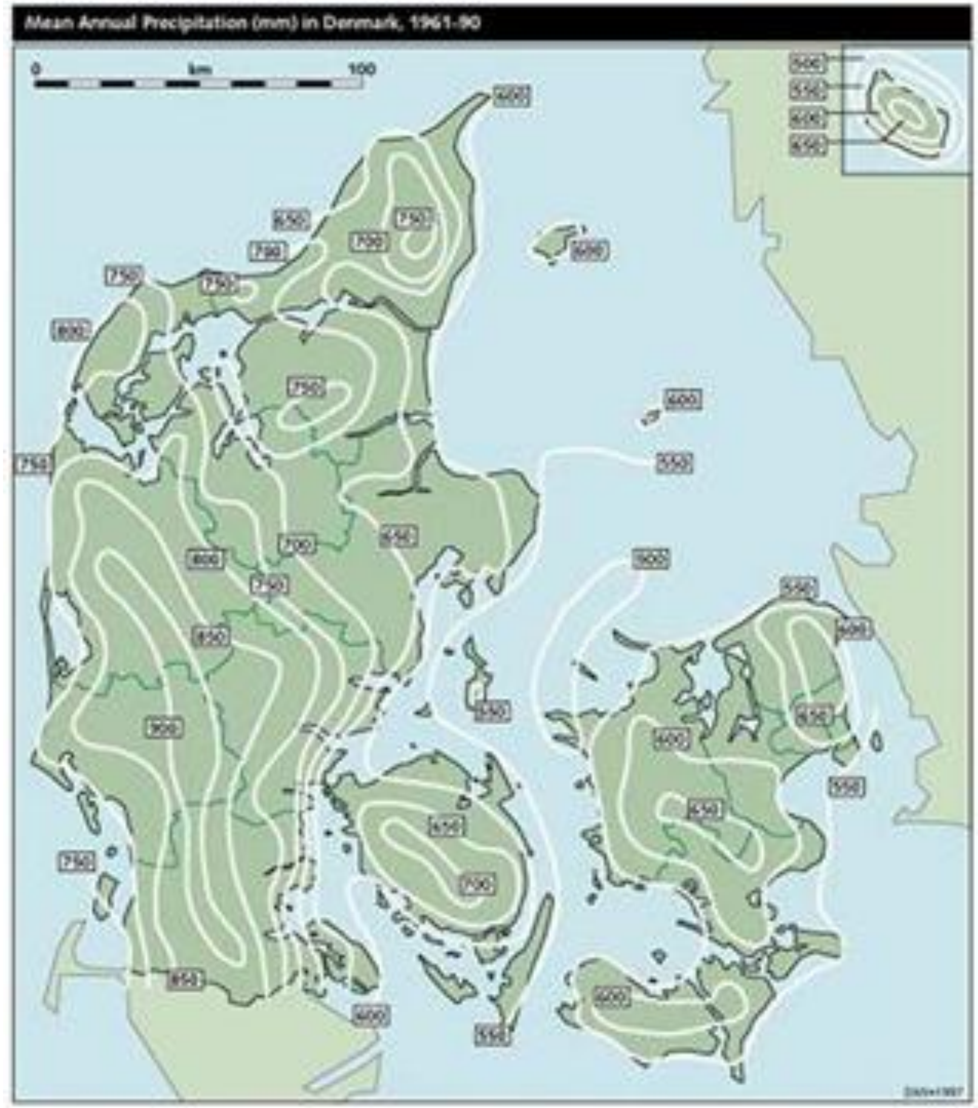




Annual rain in Denmark

The average yearly precipitation in Denmark in the reference period 1961-1990 measured in mm.

Source: DMI Teknisk Rapport 97-8.



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.