

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

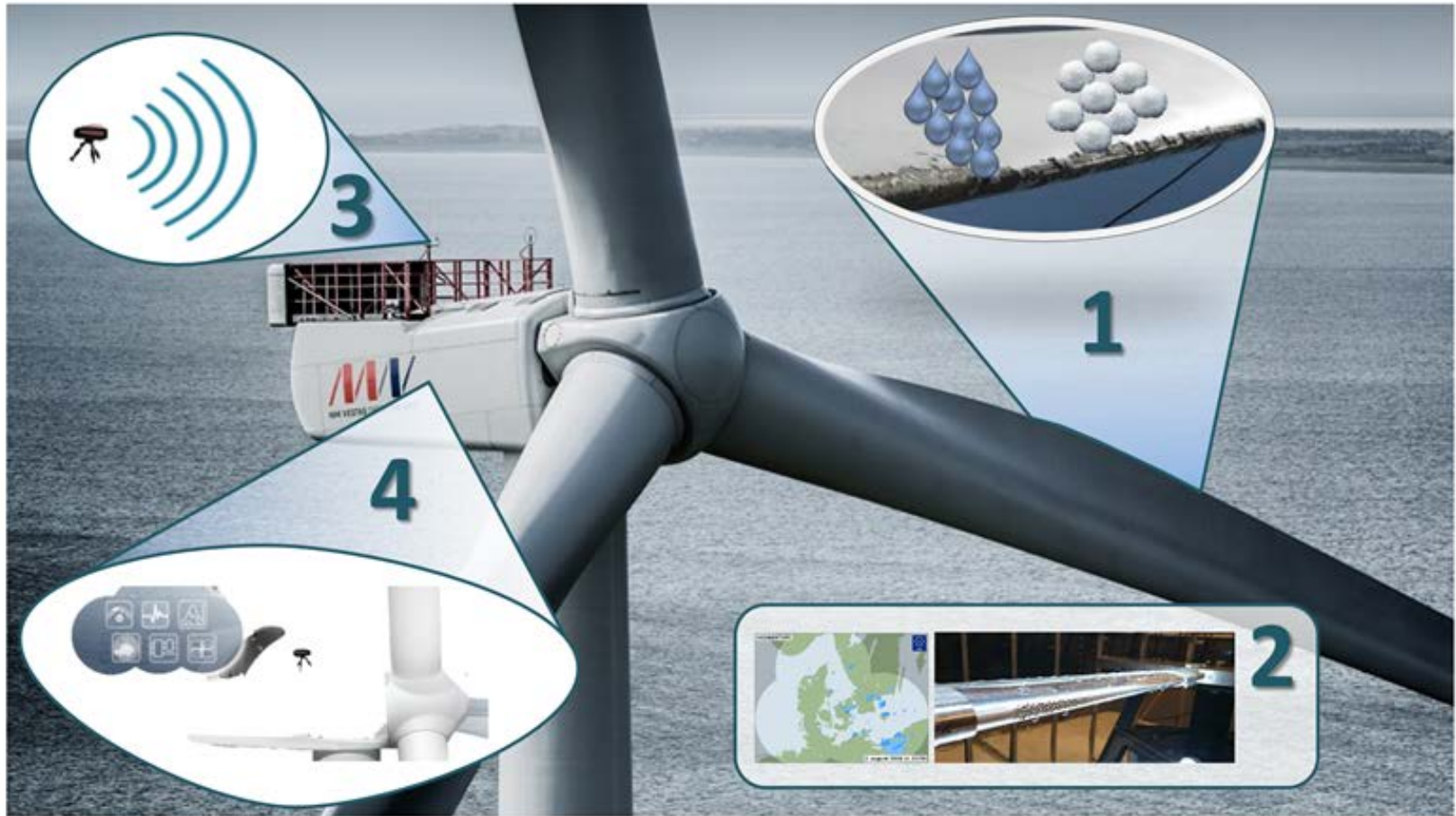
Jakob I. Bech, Charlotte B. Hasager, Christian Bak

Manuscript "WES-2017-62" in review at wind-energy-science.net



<http://www.rain-erosion.dk/>

# Erosion control



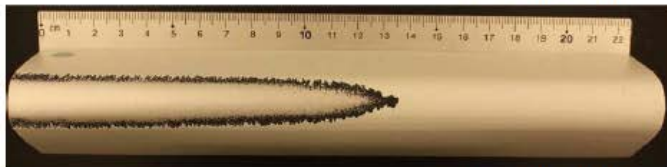
# Erosion test



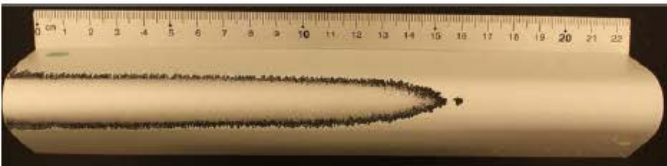
0 HOURS



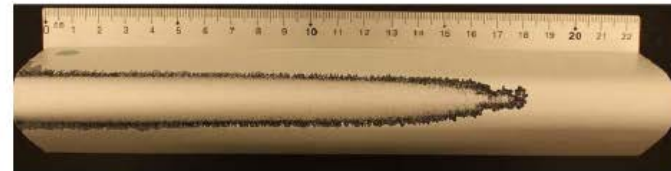
0.5 HOURS



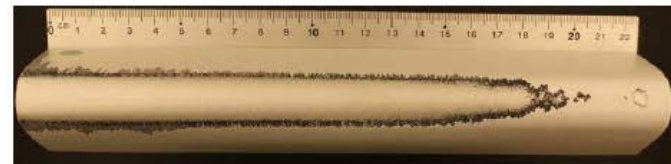
1.0 HOURS



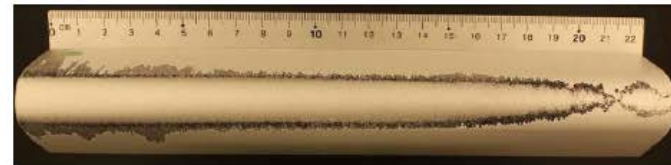
1.5 HOURS



2.0 HOURS



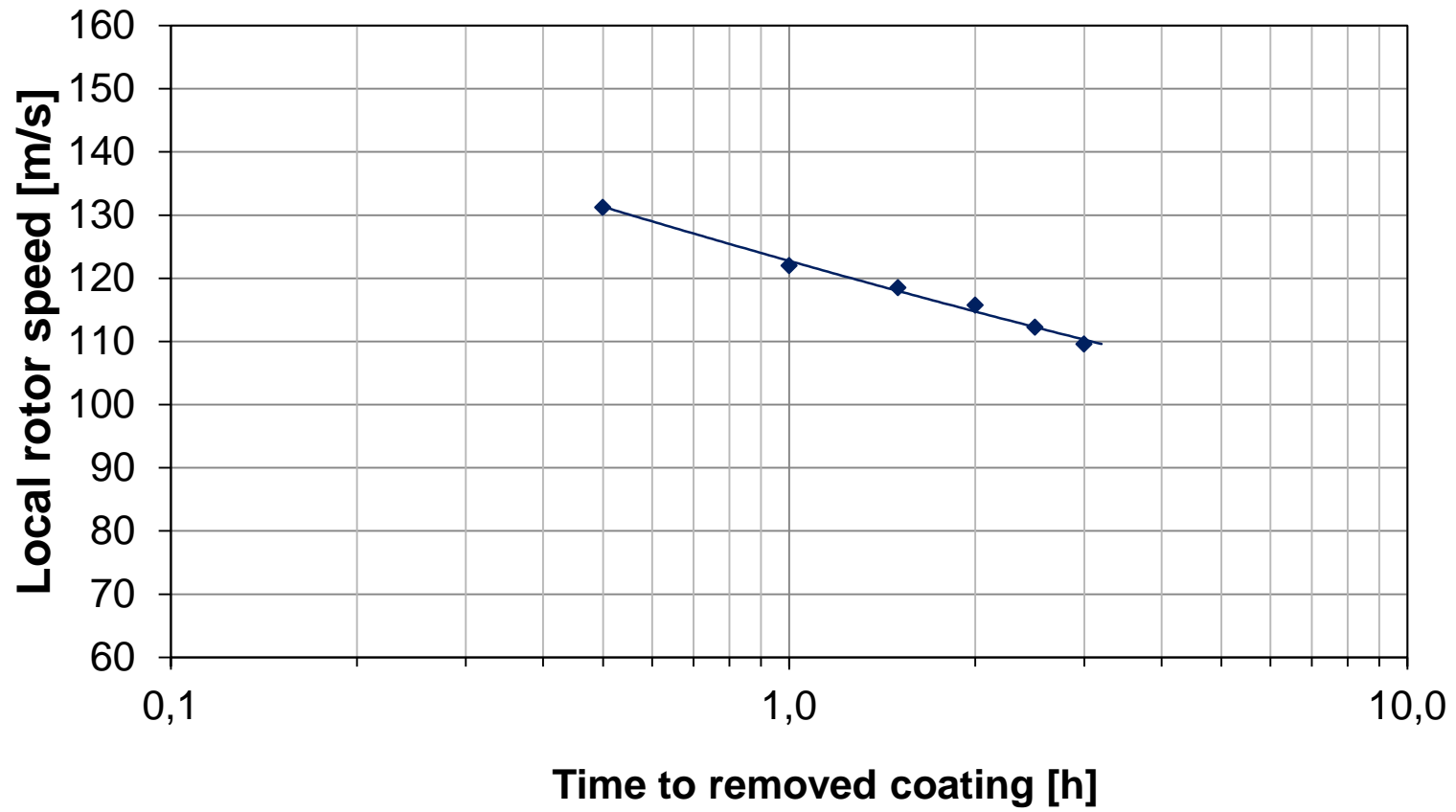
2.5 HOURS



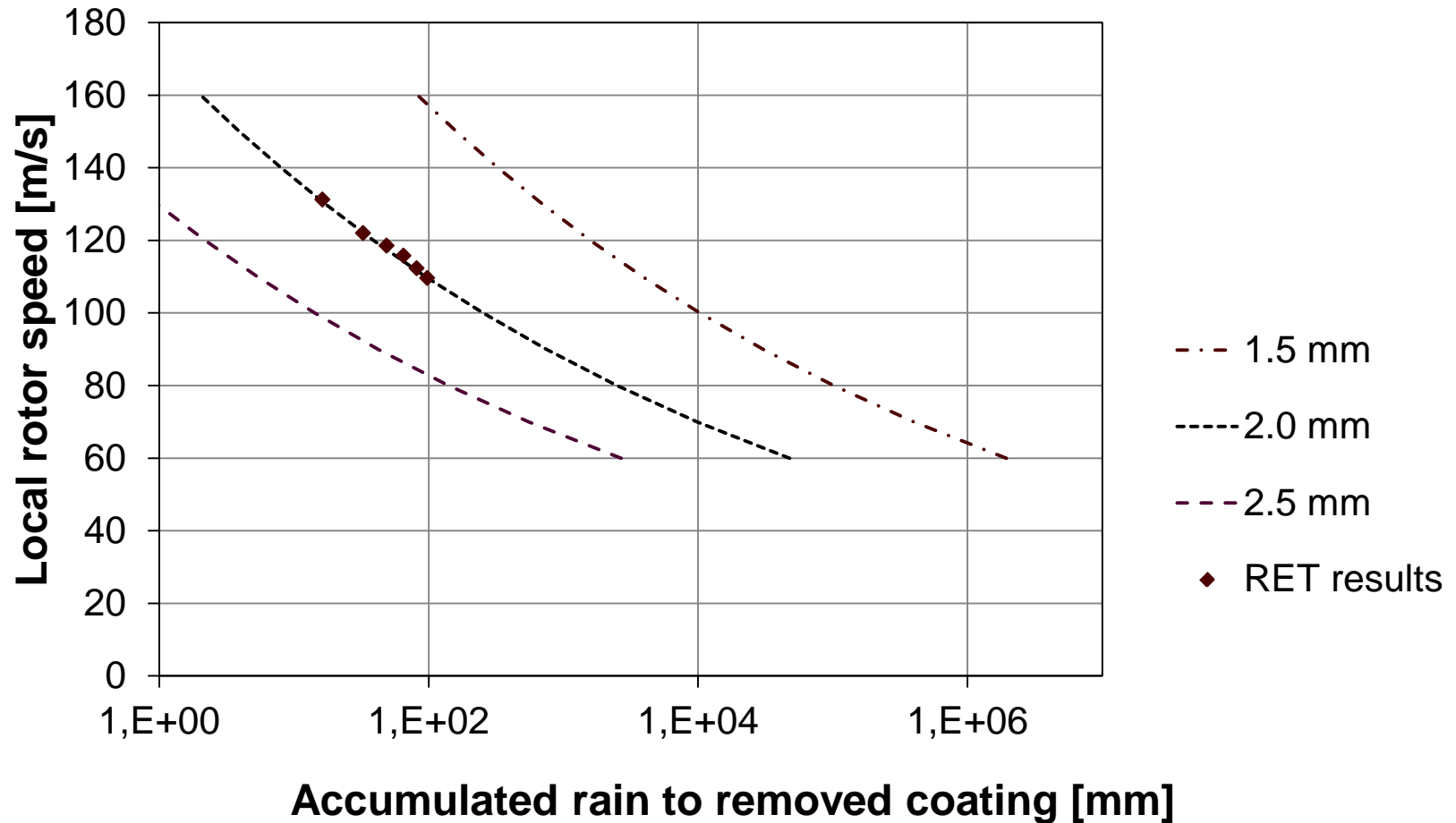
3.0 HOURS

**polytech**  
Beyond the idea

# Plot of test data



# Impact fatigue properties



# Rainfall rate frequency

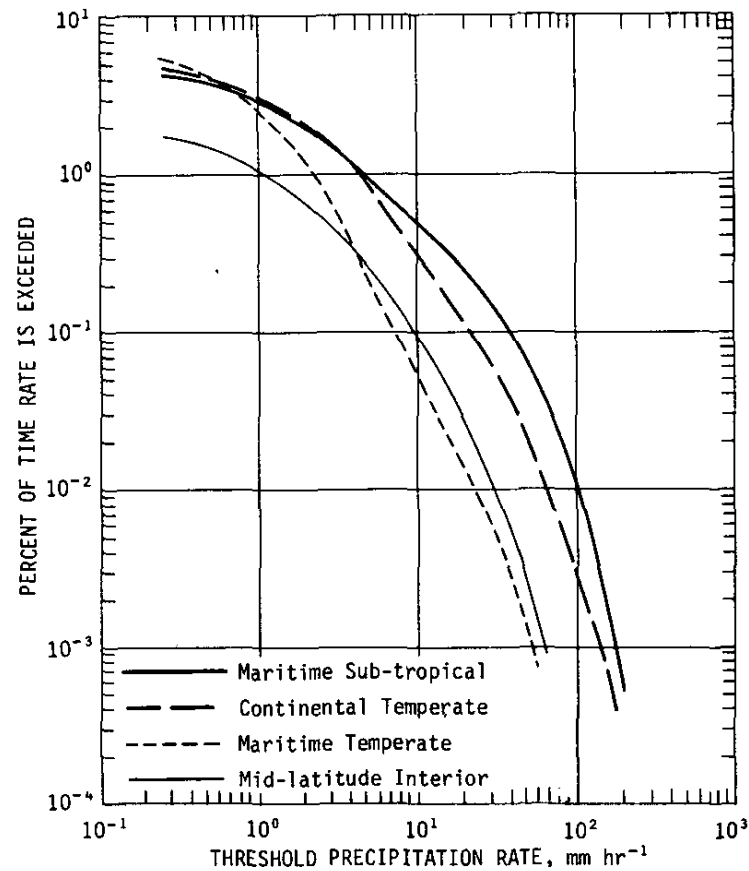
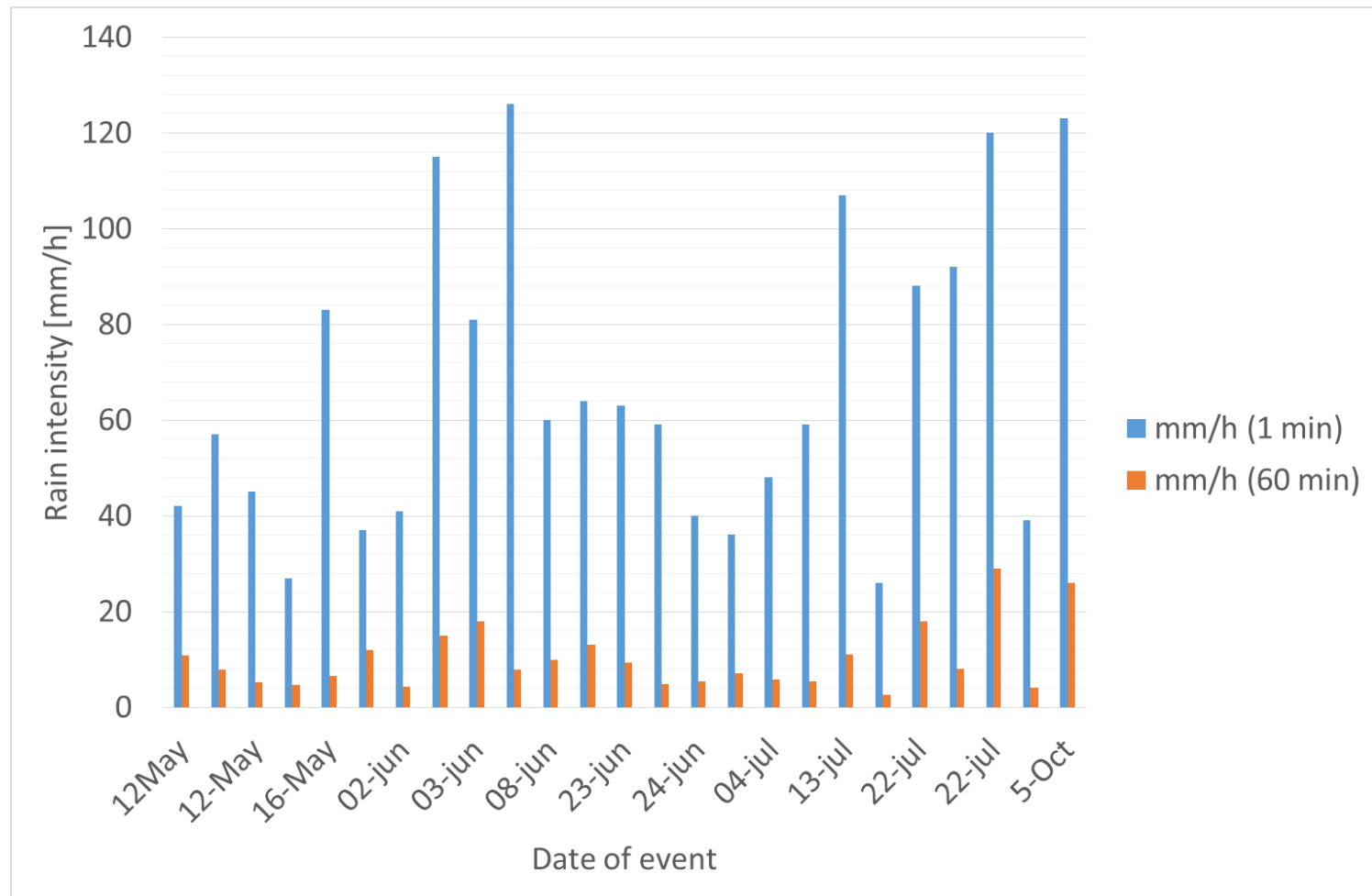


Fig. 5. Average rainfall rate-frequency relationships for four rain climates.

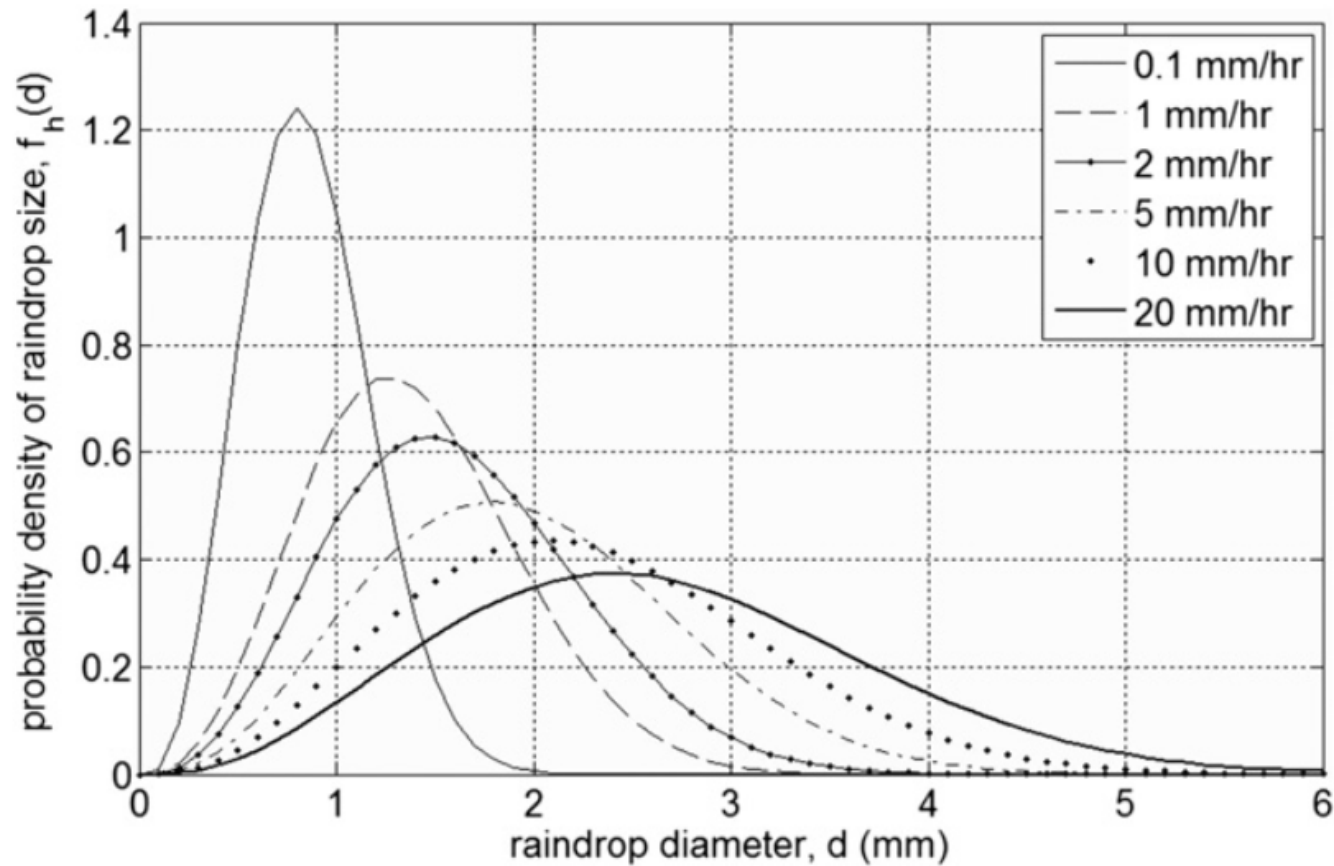
(Jones and Sims, 1978)

# Rain intensity on 1 min and 60 min resolution



(Smith et al., 2009)

# Droplet size distribution



(from Kubilay et al., 2013, based on Best, 1950)



# Life time prediction

- Leading edge impact fatigue performance
- Operation and loads
- Damage accumulation law

$$N_{Ei} = c * \left( \frac{1}{12} \rho \pi D^3 v_t^2 \right)^{-m}$$

Particle collisions: number;  
size; speed; material  
(water, ice, SiO<sub>2</sub>)

$$M = \sum_{i=1}^J \frac{n_i}{N_i}$$

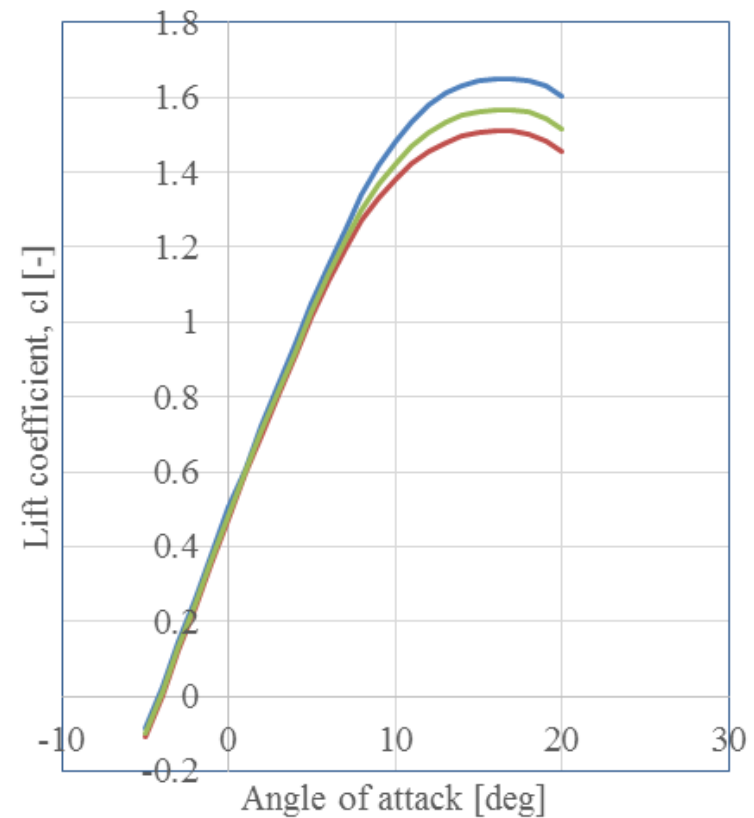
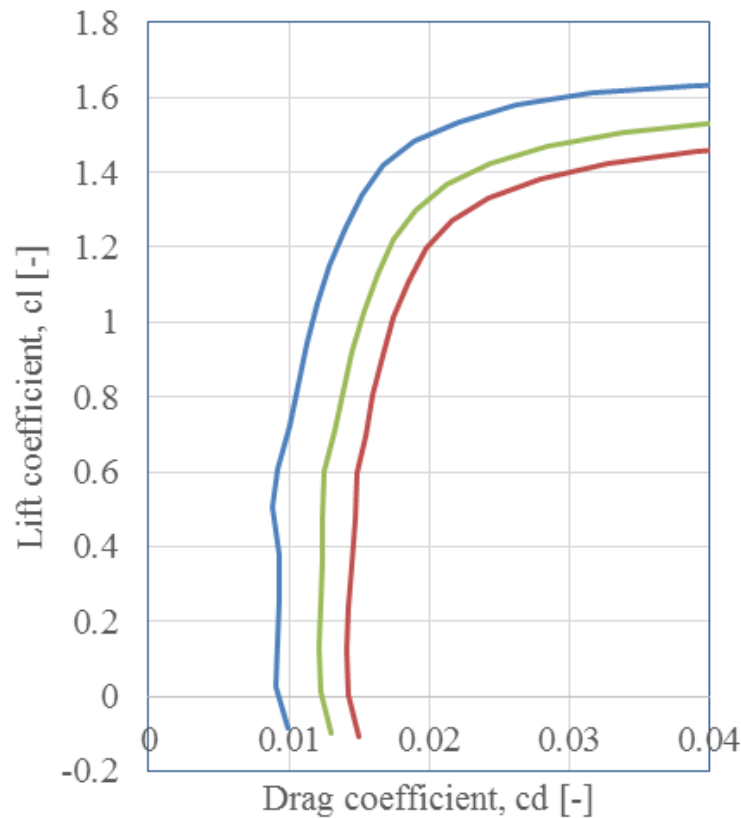
## Erosion life without control strategy: 1.6 year

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

## Erosion life without control strategy: 54 years

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	60	222	0.8
10	2.0	0.1	8.8	70	1036	0.8
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 [%]:						1.9
Expected life [years]:						54

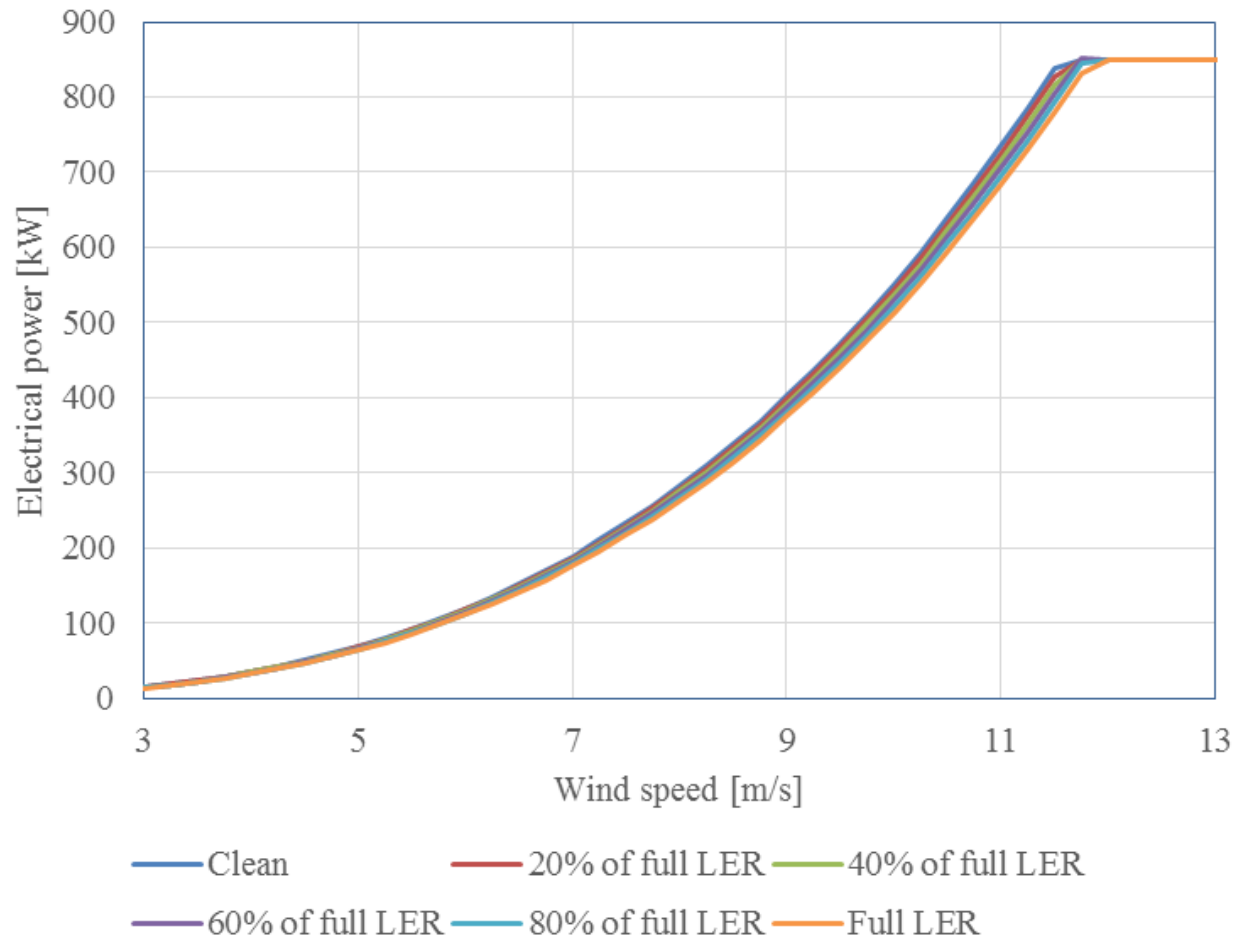
# Degradation of blade performance due to erosion



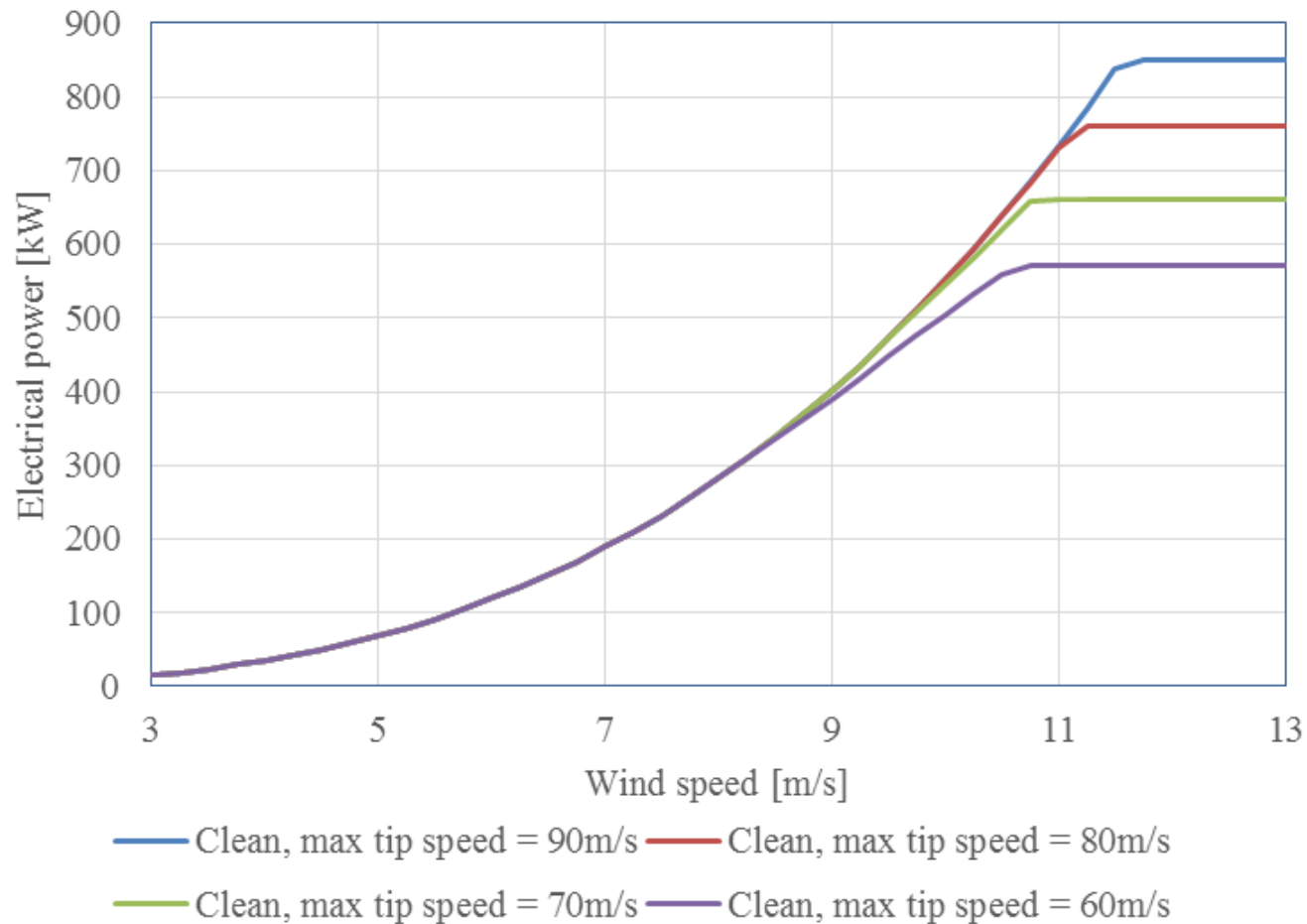
- t/c=15%, Clean
- t/c=15%, Full LER
- t/c=15%, Interpolated, 60% full LER

- t/c=15%, Clean
- t/c=15%, Full LER
- t/c=15%, Interpolated, 60% full LER

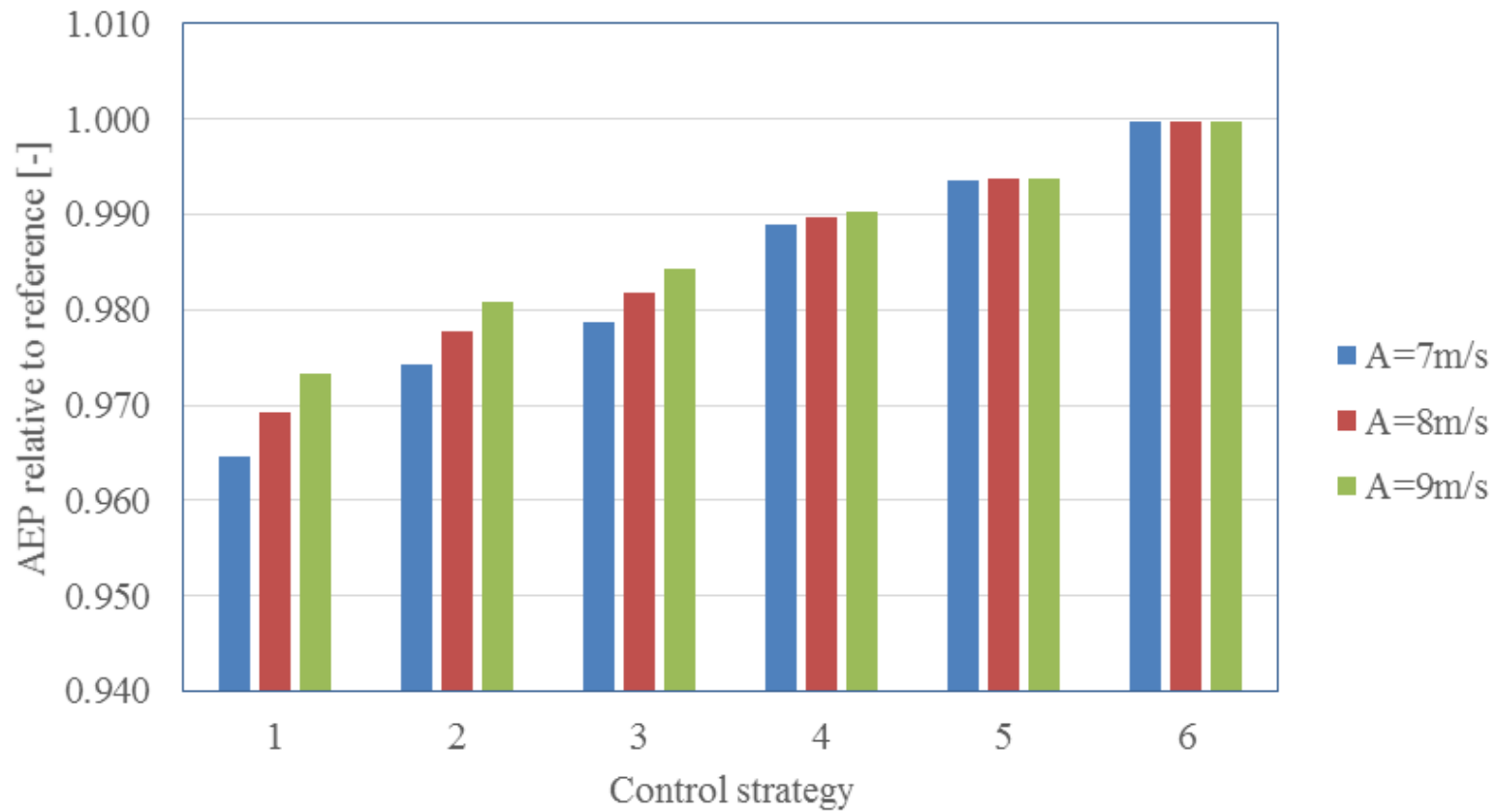
# Power curves for different levels of erosion



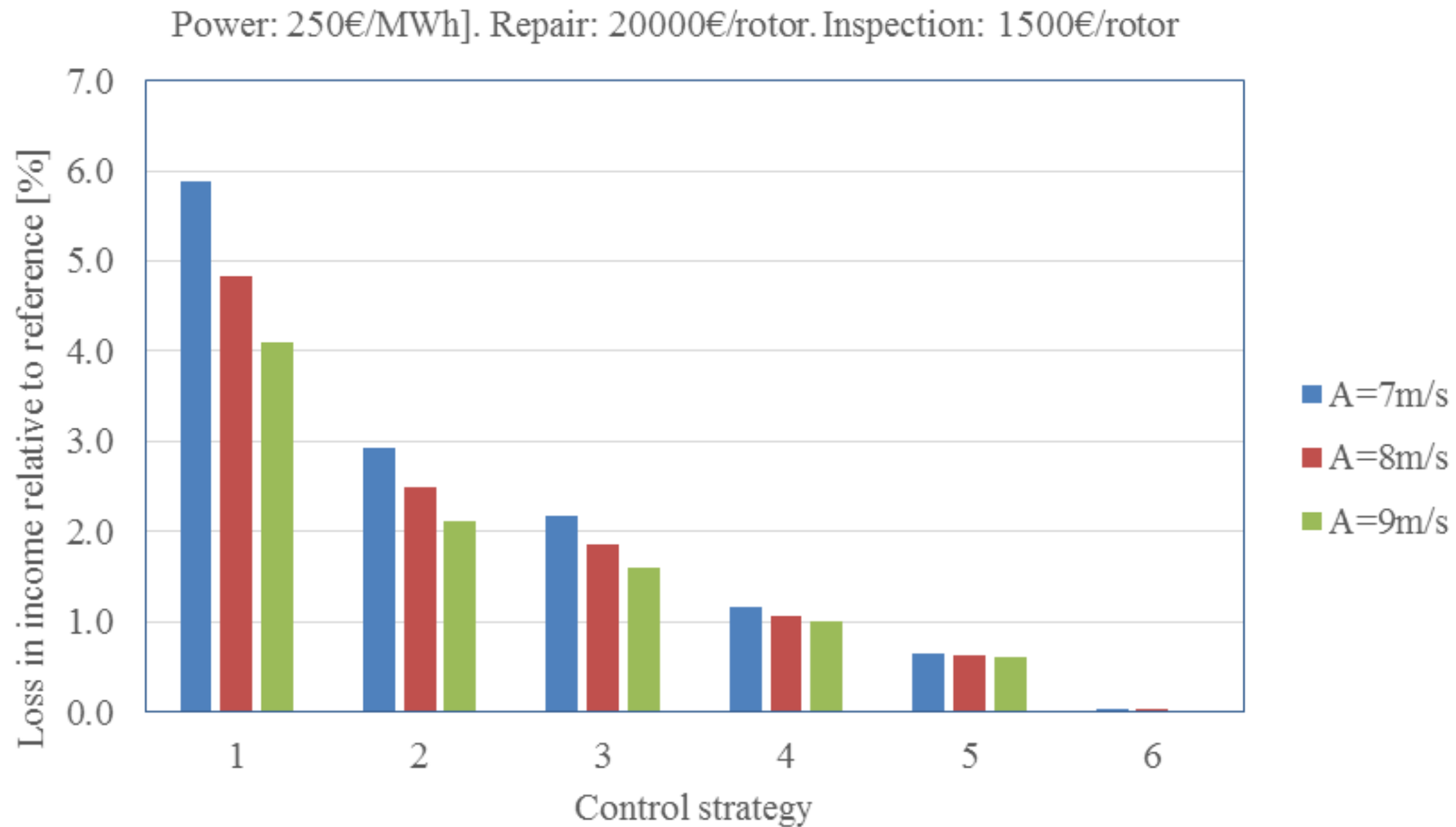
# Power curves for different max tip speeds



# Reduced AEP due to erosion



# Loss of income for different control strategies





## Summary

- Erosion due to extreme precipitation events of short duration
- Erosion can be eliminated by tip speed reduction a few hours pr year
- It's economically feasible
- Based on many assumptions. More knowledge and data needed: IFD EROSION
- Manuscript "WES-2017-62" in review at wind-energy-science.net

# Acknowledgements and Questions

*Acknowledgements to Innovation Fund Denmark for support to the  
EROSION project Sagsnummer: 6154-00018B*

Questions?