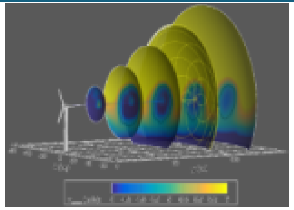
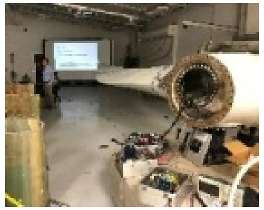
SAND2021-2872C

Sandia National Laboratories

Blades Global 2021: Erosion





PRESENTED BY

Josh Paquette, Sandia National Laboratories

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Trends driving leading edge erosion activity

Average tip speed in the US fleet has been gradually increasing in the US fleet since 2010. The increased tip speed drives erosion rates to the power of 6.7, perhaps even much more.

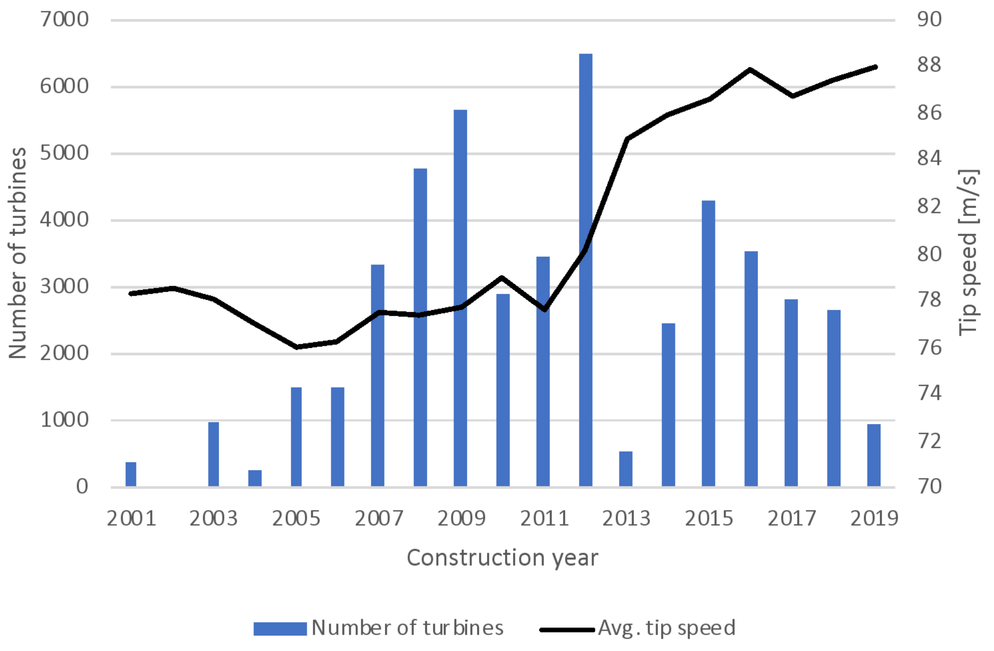
Rain droplets size and rain rates drive the damage mechanisms.

For the past 6 years, leading edge protection (LEP) is generally offered as an option for new turbines or installed later during repair

LEP is (was) not widely used in the US fleet:
- Extra cost
- Can reduce AEP between 0.8% up to 2.5%
- Poor adhesion, variable protection, resulting in low confidence

Wood Mackenzie estimate that half of the global blade repair market originates in LEE problems, globally exceeding $550M/year, (US ~$140M/year)

LEE is particularly harsh in the offshore environment due to higher tip speeds and additional droplets from ocean wave sprays



Included only larger wind farms constructed after year 2000 from USGS database.
- 48,536 turbines
- 925 wind farms
- 100 different turbine models
- Capacity of 92 GW

Credit: Carsten Westergaard (Westergaard Solutions)

Erosion Drivers

Leading edge erosion (LEE) is a prominent issue for wind turbine blade reliability

Causes gradual performance decrease and persistent maintenance costs

Main driver of erosion is the impact of rain droplets on leading edge of blade

Erosion rate typically has an incubation period with little damage, then a linear erosion period

- Initial erosion labeled as category 1 or 2, up to 2% AEP loss
- Structural damage starts at category 3 erosion, and progresses to category 4 with up to 5% AE

Field measurements of erosion[4, 5]

Category 4 erosion

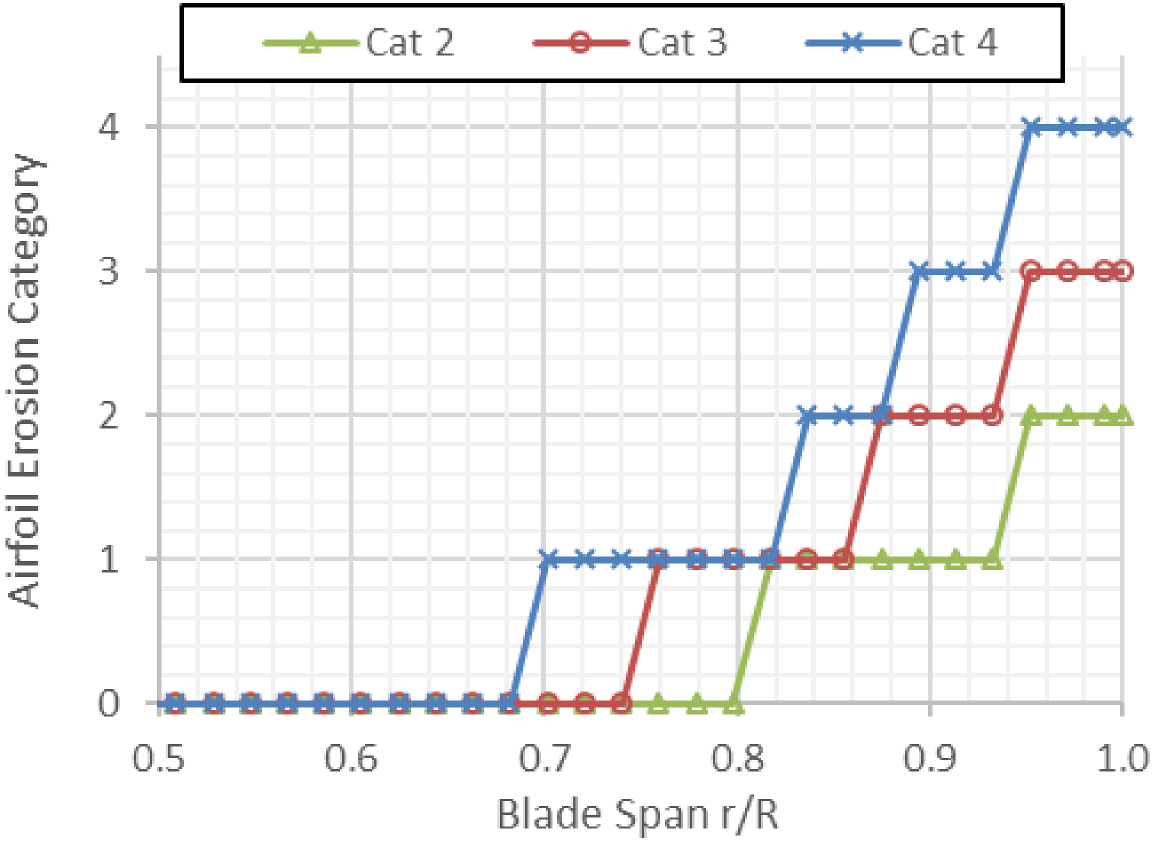
[4] Maniaci, David Charles, Ed White, Benjamin Wilcox, Christopher Langel, Case Van Dam, and Paquette, Joshua. *Experimental Measurement and CFD Model Development of Thick Wind Turbine Airfoils with Leading Edge Erosion*. United States: N. p., 2017. Web. doi:10.1088/1742-6596/753/2/022013.

[5] Ehrmann, Robert S., and White, E. B. *Effect of Blade Roughness on Transition and Wind Turbine Performance.*. United States: N. p., 2015. *Preprint, Web.* https://www.osti.gov/servlets/purl/1427238.

Categories of Erosion Along Blade

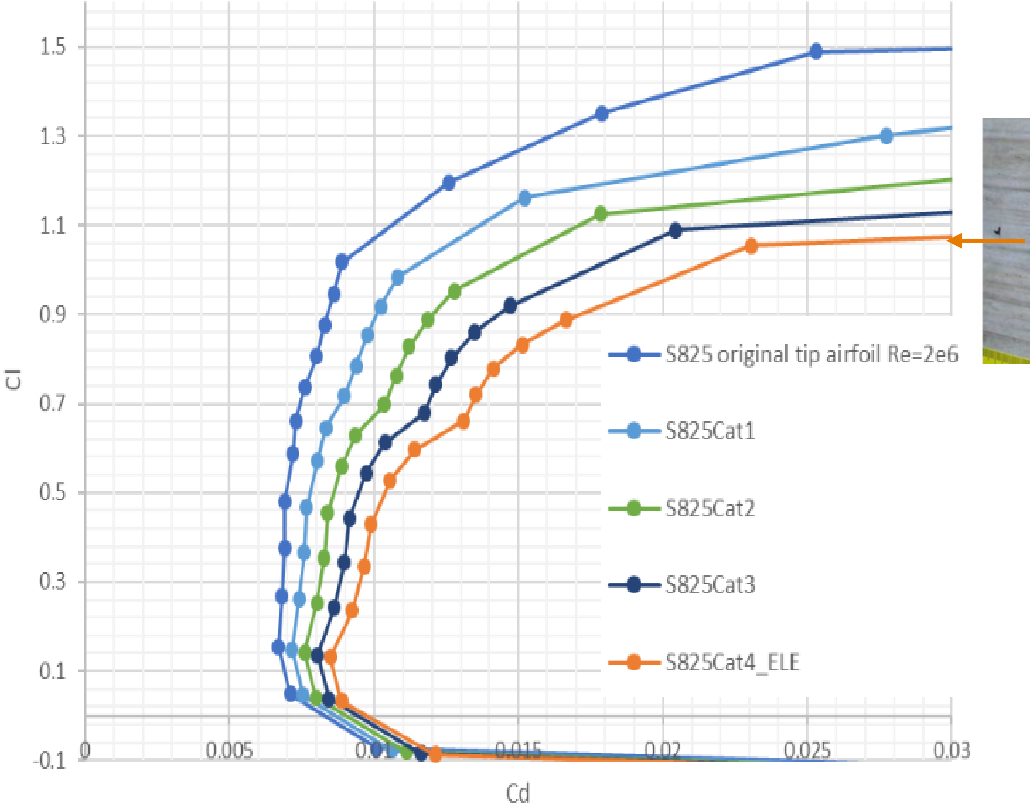
Blade erosion rates simulated using local blade velocity to the 6.7 exponent for erosion

Erosion categories along blade span



Airfoil performance for each erosion category based on wind tunnel testing of a similar airfoil

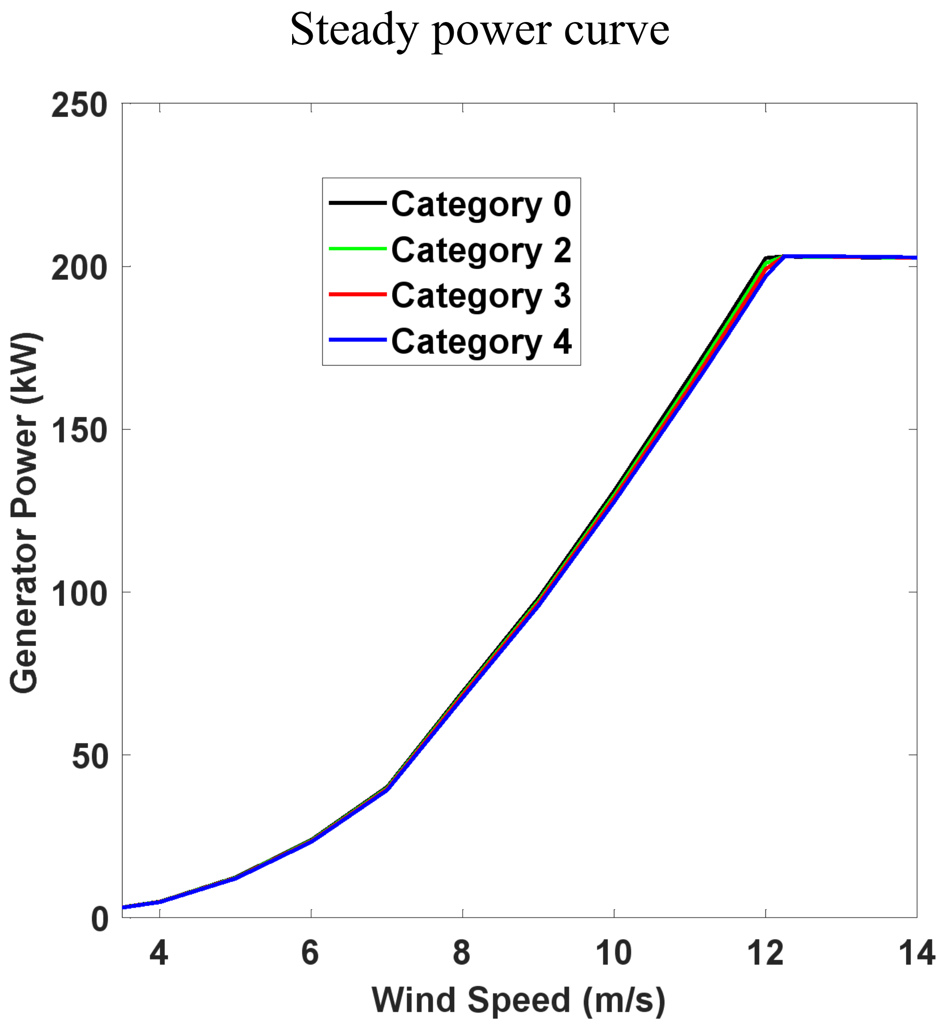
Airfoil performance for each erosion category

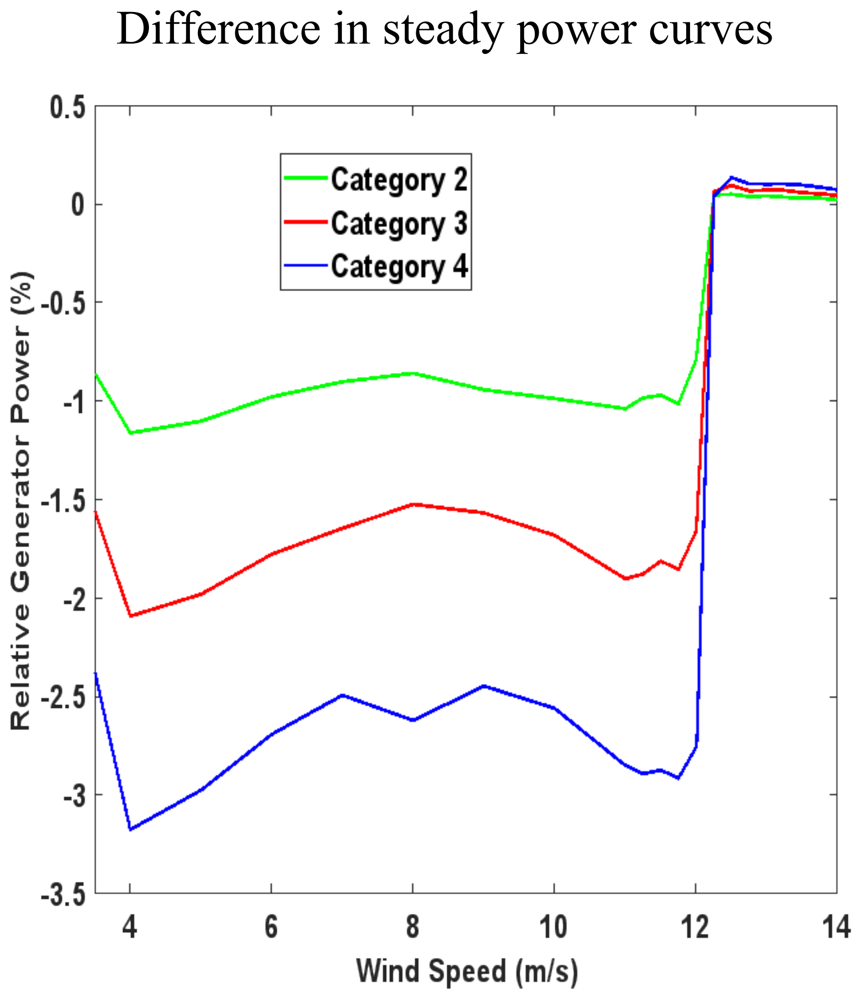


[9] Maniaci, D.C., Westergaard, C., Hsieh, A., and Paquette, J.A., Uncertainty Quantification of Leading Edge Erosion Impacts on Wind Turbine Performance, in Torque 2020. 2020.

Steady State Power Curve Erosion Effect

Steady state power curve of the NRT turbine simulated using AeroDyn from the OpenFAST code suite





[9] Maniaci, D.C., Westergaard, C., Hsieh, A., and Paquette, J.A., Uncertainty Quantification of Leading Edge Erosion Impacts on Wind Turbine Performance, in Torque 2020. 2020.

Probabilistic Power Curve Uncertainty Analysis

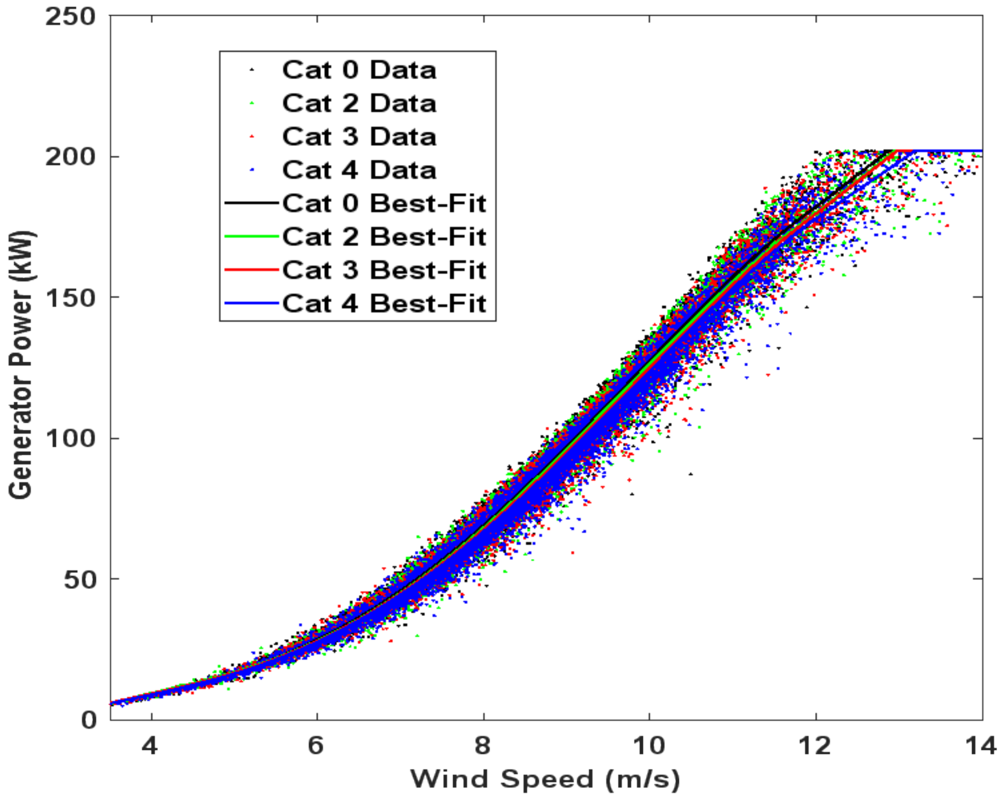
Monte Carlo sampling was conducted to randomly sample 10,000 simulations, each 10 minutes long, for each of the four erosion categories

Dakota used for UQ analysis, with TurbSim for inflow and OpenFAST for turbine simulation

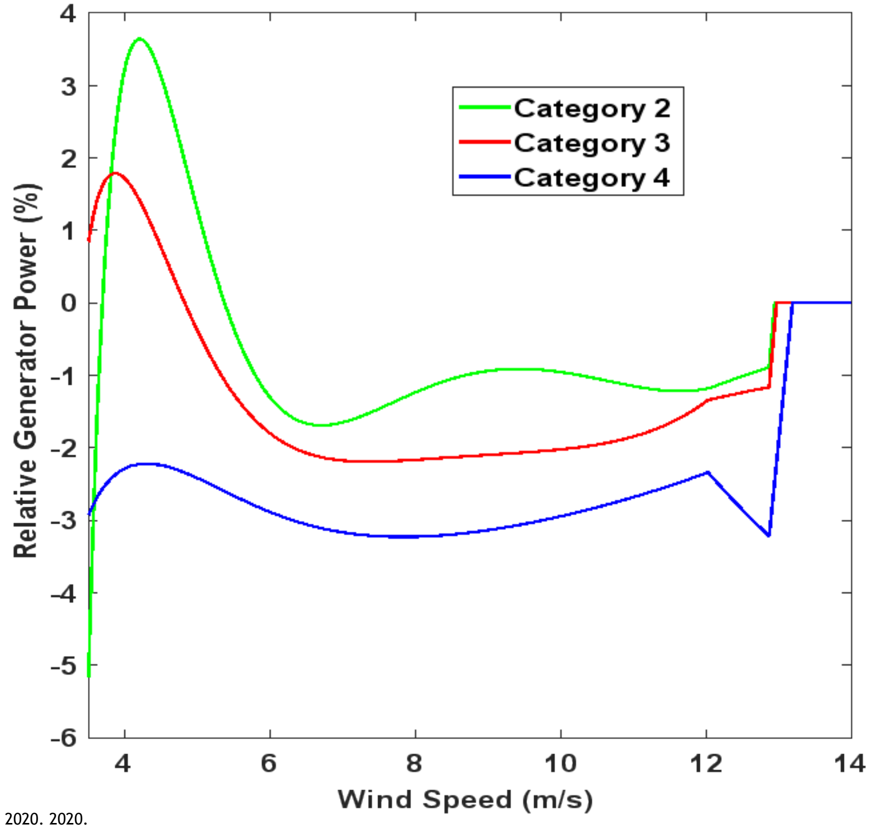
Uncertain aleatoric parameters: hub-height wind speed, turbulence intensity, shear exponent, air density, yaw offset, collective blade pitch

- Power increase at low wind speeds due to small number of samples relative to inflow variance

Power curve cloud



Change in power curve fit



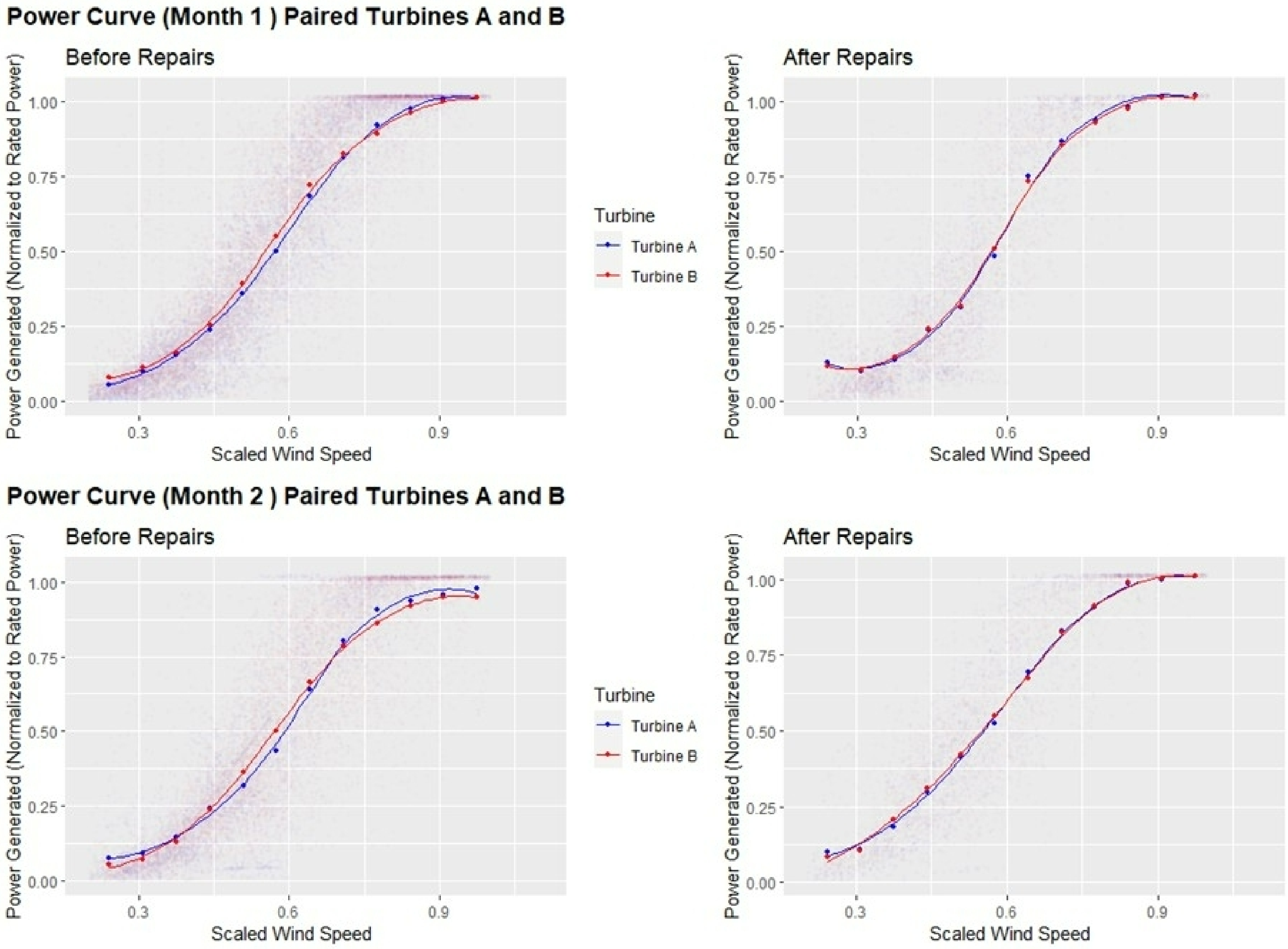
[9] Maniaci, D.C., Westergaard, C., Hsieh, A., and Paquette, J.A., Uncertainty Quantification of Leading Edge Erosion Impacts on Wind Turbine Performance, in Torque 2020. 2020.

Field Data Analysis

- Archival SCADA data from the turbines and nearby meteorological towers was collected in 10-minute records.
  - Measurements include windspeed, wind direction, temperature, atmospheric pressure, power production, turbine state, and nacelle direction, among other channels.
- The data is corrected by comparing multiple measurements of the same quantity when possible. Power curves are then calculated according to IEC 61400-12 [10] for each turbine over smaller time intervals.
- The power curves were then quantified by mean, standard deviation, and other metrics over windspeed bins.
  - Combining these data points across all the smaller intervals gives a multivariate time series. From this, any systematic reduction in productivity was identified.
- Specifically focusing on a pair of Class 4 level erosion wind turbines, **Turbine B** was repaired in September 2019, while its pair **Turbine A** was not repaired.
  - Comparing the power generated by each turbine at a given 10-minute time bin will allow the change in performance based on the repairs.
  - The data to compare these turbines spans from January 2016 to June 2020, which does limit the data available post-repairs.

[10] IEC 61400-12-1:2017 Wind energy generation systems - Part 12-1: Power performance measurements of electricity producing wind turbines, International Electrotechnical Commission, 2017.

Turbine Data Comparative Analysis



IEA Wind Task 46: Erosion of Wind Turbine Blades

Lead by VTT (Finland) and DTU (Denmark)

Work Packages:

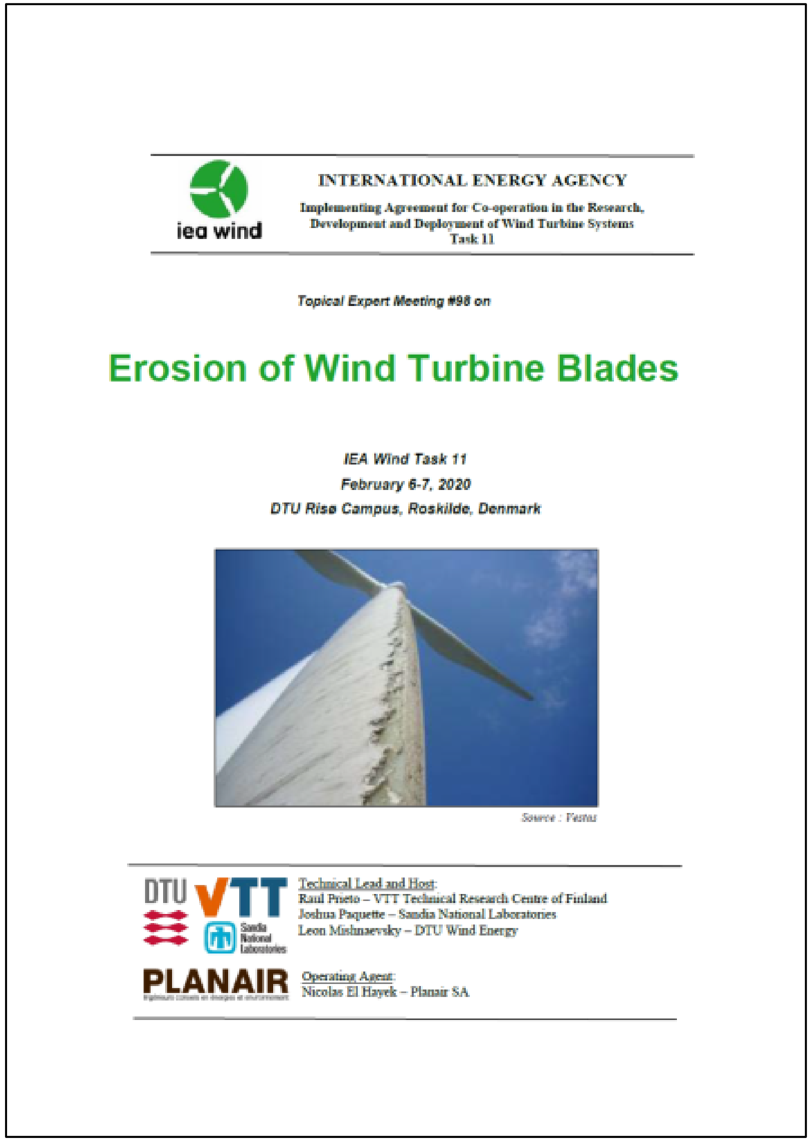
Climatic Conditions Driving Blade Erosion (Cornell University & Ørsted)

Wind Turbine Operation with Erosion (Sandia)

Laboratory Testing of Erosion (DTU & Hempel)

Erosion Mechanics & Material Properties (CEU Cardinal Herrera University & University of Bergen)

Please contact me if you're interested in participating!


INTERNATIONAL ENERGY AGENCY

Implementing Agreement for Co-operation in the Research, Development and Deployment of Wind Turbine Systems

Task 11

Topical Expert Meeting #98 on

Erosion of Wind Turbine Blades

IEA Wind Task 11

February 6-7, 2020

DTU Risø Campus, Roskilde, Denmark

Source : Vestas

Technical Lead and Host:

Raul Prieto – VTT Technical Research Centre of Finland

Joshua Paquette – Sandia National Laboratories

Leon Mishnaevsky – DTU Wind Energy

Operating Agent:

Nicolas El Hayek – Planair SA

Thank you!

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