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Uncertainty Quantification of Leading Edge Erosion Impacts on Wind Turbine Performance

Presented by

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Introduction to Leading Edge Erosion

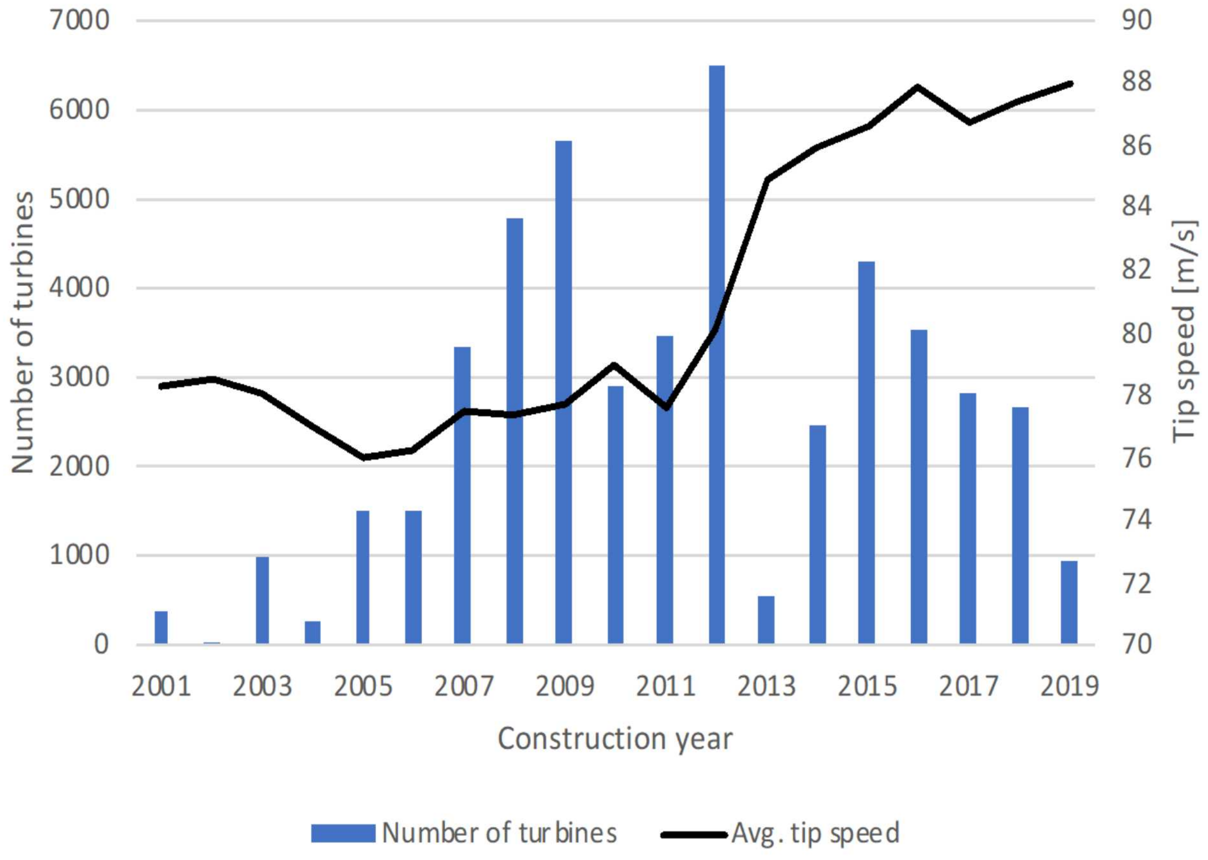
- Leading edge erosion (LEE) is a prominent issue for wind turbine blade reliability
- Causes gradual performance decrease and persistent maintenance costs
- Main driver of erosion is the impact of rain droplets on leading edge of blade
- Erosion rate typically has an incubation period with little damage, 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% AEP loss

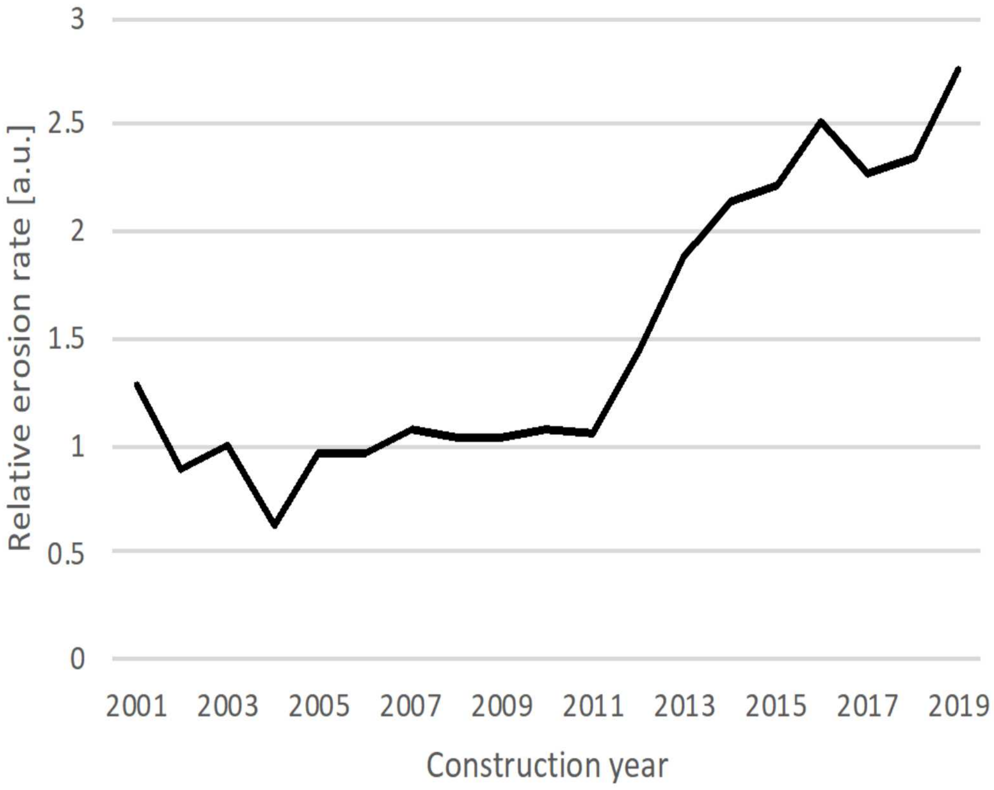
Field measurements of erosion[9, 12]

Category 4 erosion

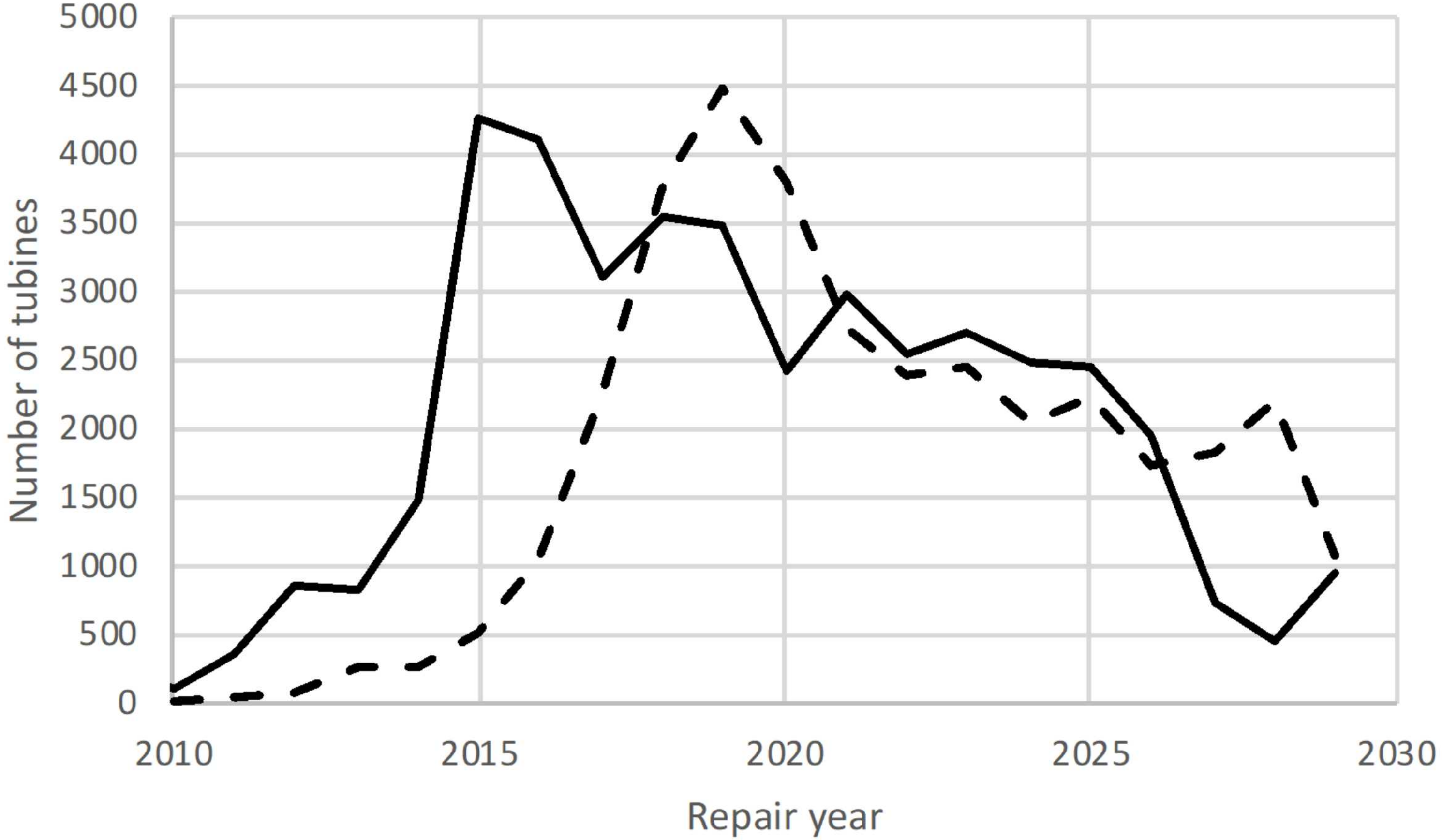
Industry-level Erosion Analysis

- Erosion rates can vary significantly between sites, depending on local atmospheric effects as well as turbine design and operation
- In general, tip speeds have been increasing leading to an increasing relative erosion rate





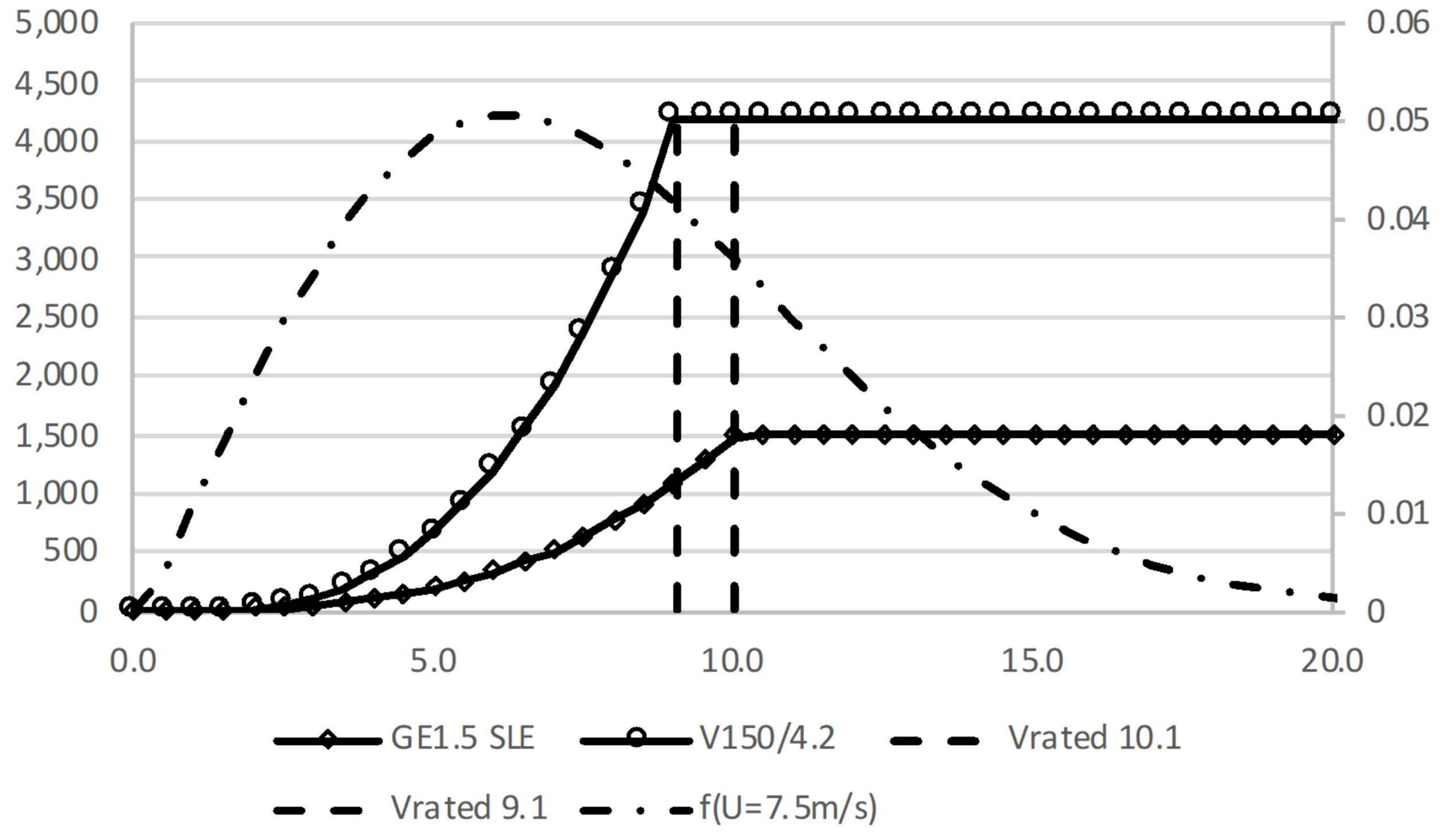
Number of Turbines Needing LEE Repair



- Number of turbines in the existing US fleet needing LEE repair, assuming 10 (solid) to 15 years (dash) offset time to repair.
  - The number of repairs tapers off because future turbine construction is unknown and thus not added.
- If the trigger point for repair is significant LEE detected by visual inspection, the associated annual energy losses are significant and increasing

Effect of Modern High Capacity Factor Turbine

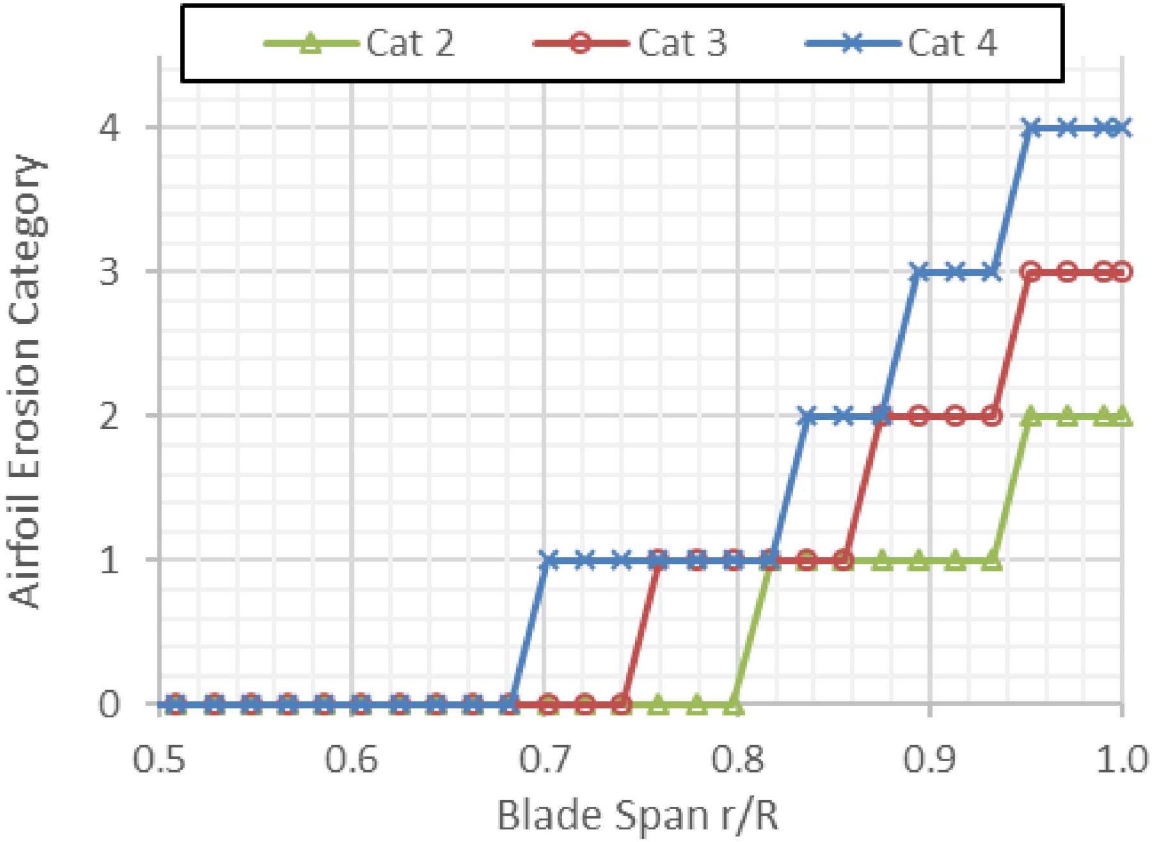
- Ideal power curves of a typical turbine constructed in year 2004 to 2011 and an example of a new high capacity factor IEC class III new turbine, which has not entered the market yet, shown with a Rayleigh distribution Uavg=7.5m/s.



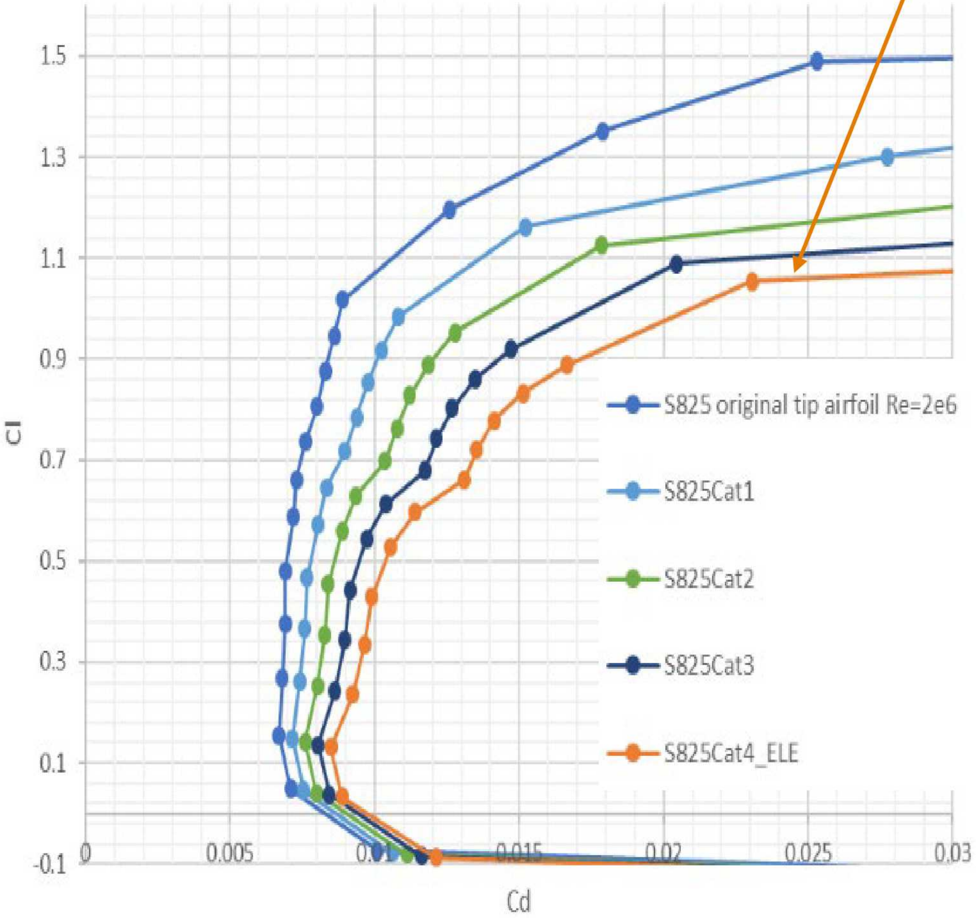
Categories of Erosion Along Blade

- Blade erosion rates simulated using local blade velocity to the 6.7 exponent for erosion
- Airfoil performance for each erosion category based on wind tunnel testing of a similar airfoil

Erosion categories along blade span



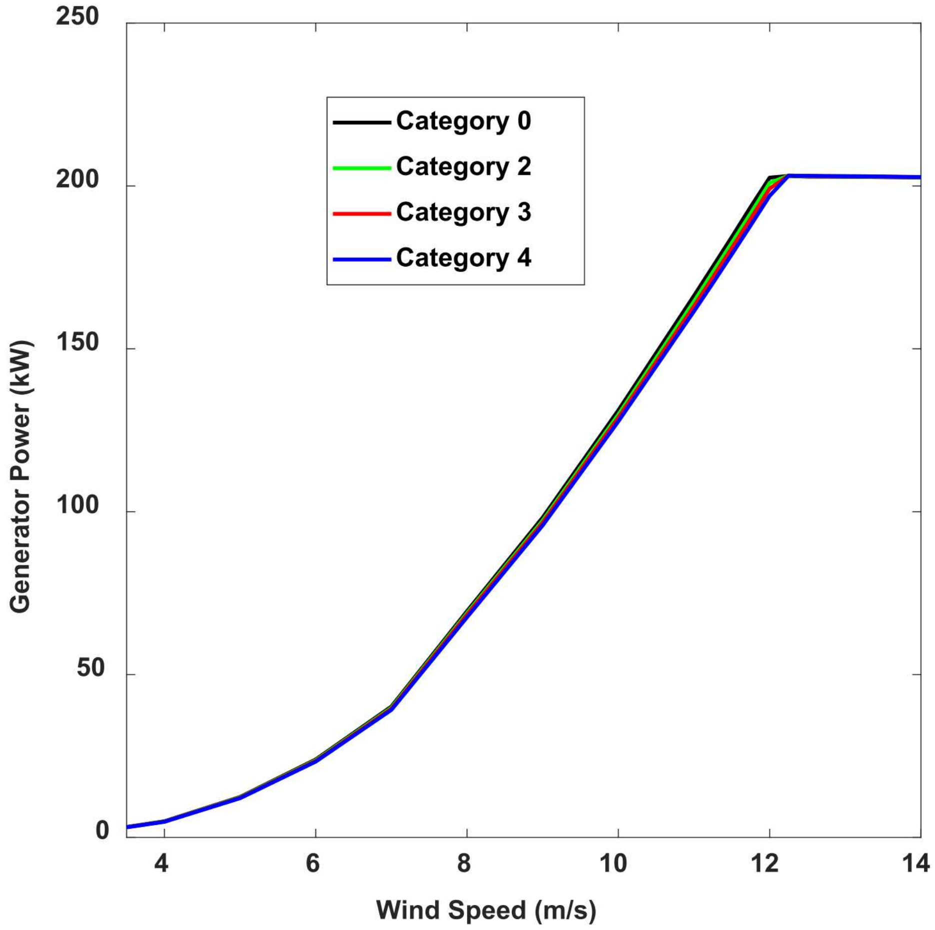
Airfoil performance for each erosion category



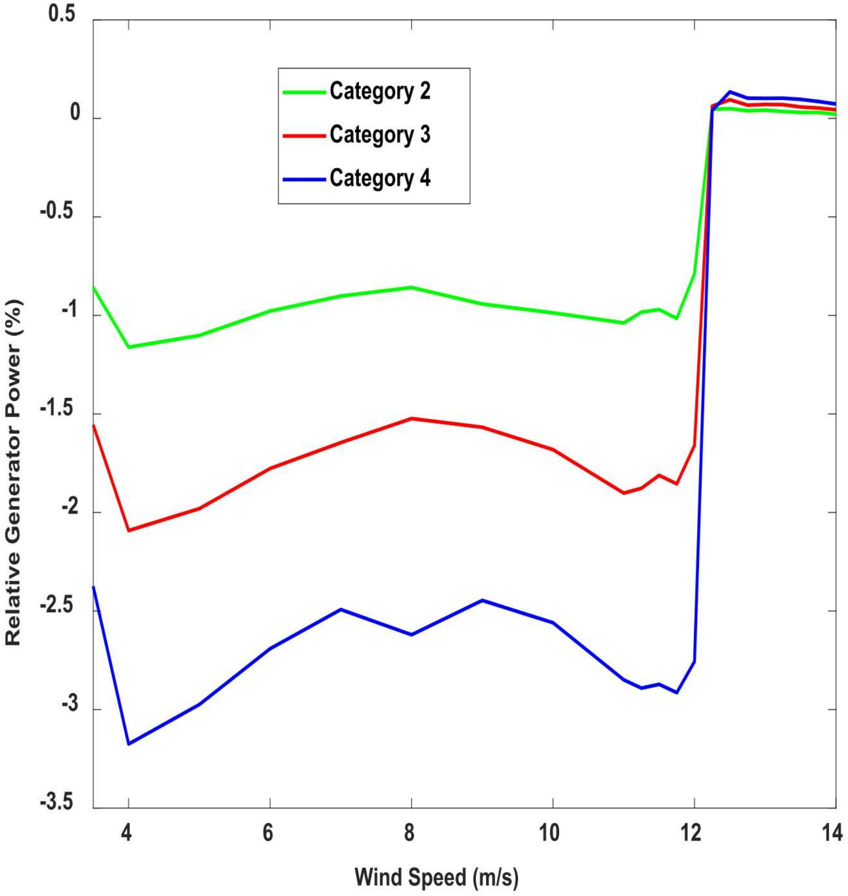
Steady State Power Curve Erosion Effect

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

Steady power curve



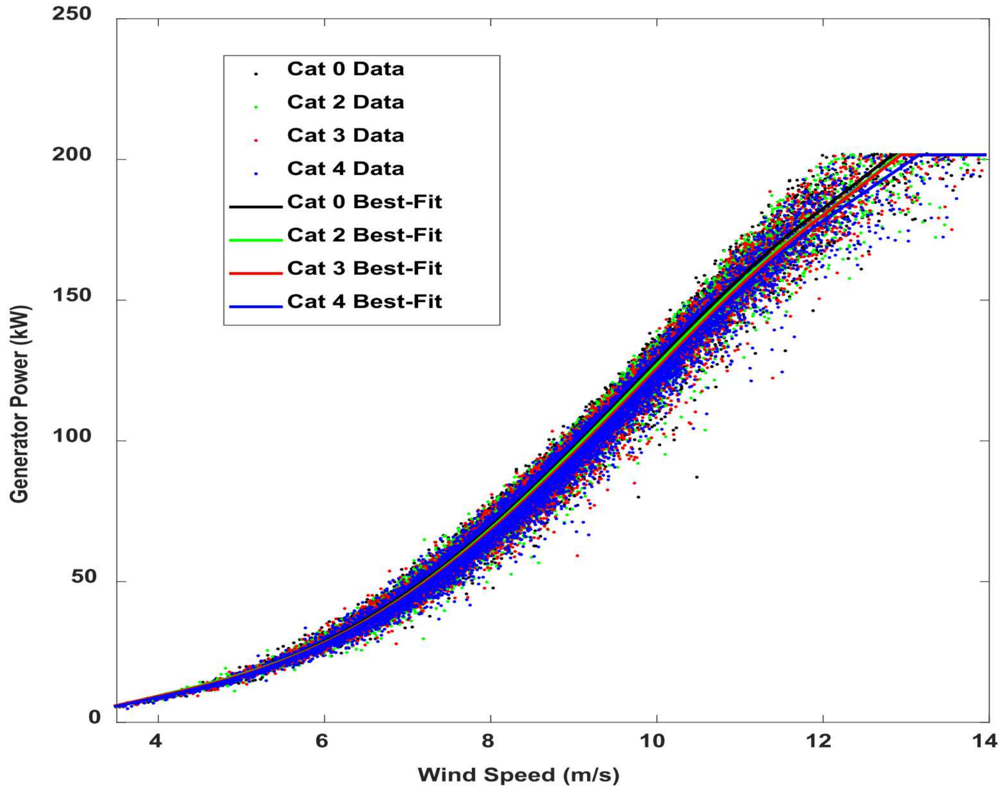
Difference in steady power curves



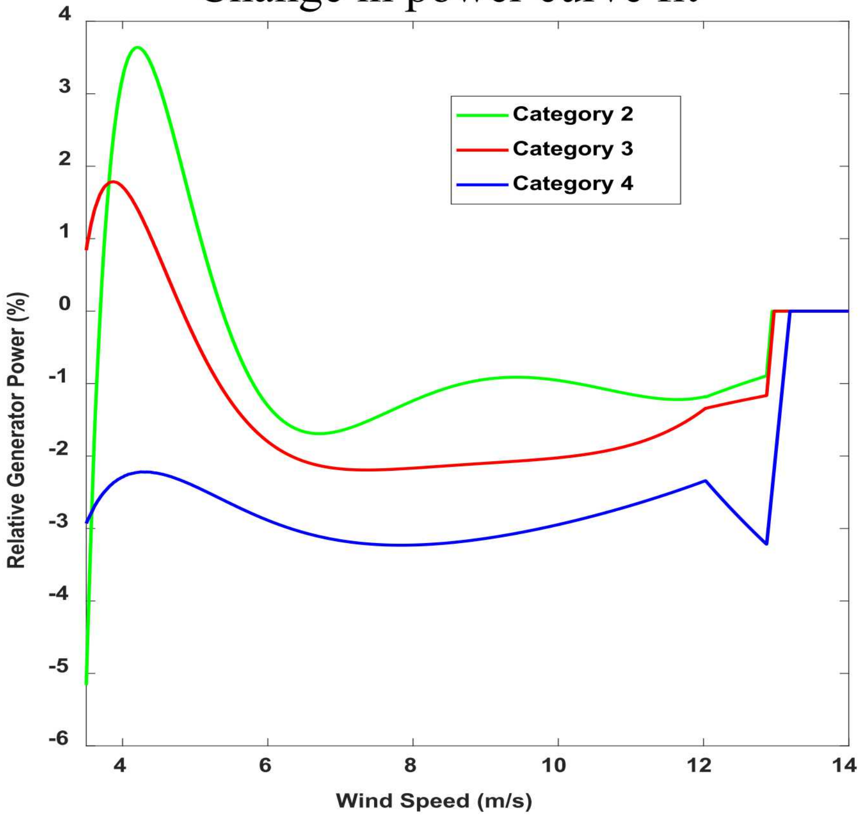
Probabilistic Power Curve Uncertainty Analysis

- 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



AEP Impact from Power Curve Uncertainty Analysis

- Annual energy production relative to no erosion for a range of mean wind speeds using a Rayleigh wind distribution, based on the probabilistic power curve cloud results.

	Mean Wind Speed (m/s)				
Erosion Category	4	6	7.5	8.5	10
0	0.0%	0.0%	0.0%	0.0%	0.0%
2	-1.0%	-0.9%	-0.7%	-0.6%	-0.4%
3	-1.9%	-1.6%	-1.3%	-1.1%	-0.8%
4	-3.0%	-2.6%	-2.2%	-1.9%	-1.6%

Summary of Torque 2020 paper on LEE

- Identified sources of uncertainty in quantifying leading edge erosion performance impact
- Predicted effect of erosion on power using a standard steady analysis and a probabilistic analysis
- Probabilistic analysis results indicate that erosion should be measurable in the field with calibrated instrumentation and a long enough sampling period

Thank you

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