Operational Issues with Wind Turbine Blades in a Coastal Environment

Marianne Rodgers, Robbie Sanderson, and Heather Norton

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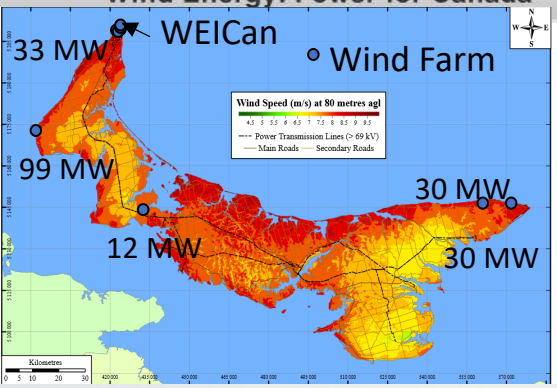
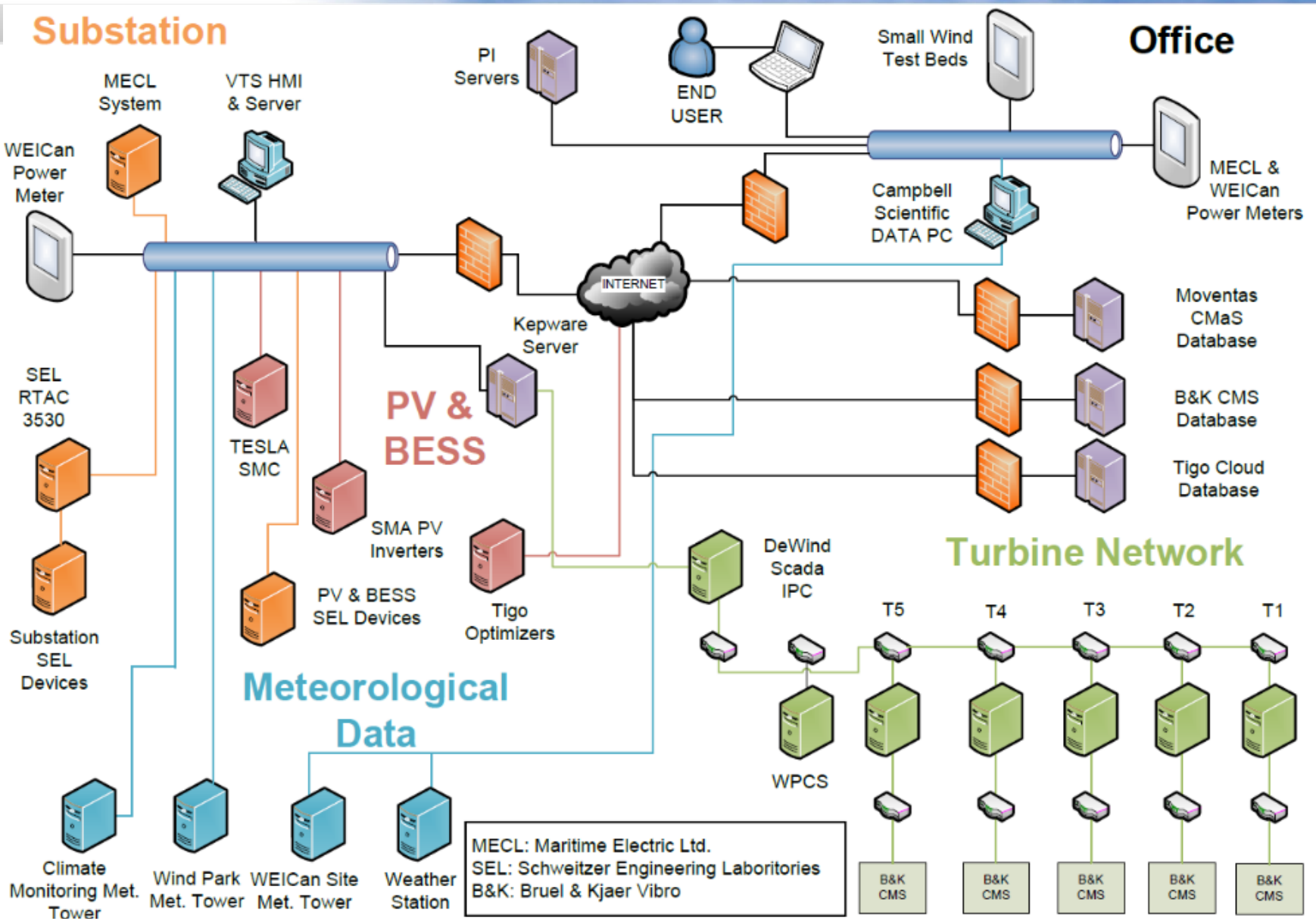


- Located in North Cape, Prince Edward Island.
- Independent, not for profit research organization advancing development of wind energy across Canada through research, testing, innovation, and collaboration since 1981
- Team of 12 permanent full-time staff plus students and interns
- Funding from wind park and external contracts
  - WEICan's location offers
    - 38 acres
    - 300° exposure to the Gulf of St. Lawrence
    - Strong wind resource (8.9 m/s @80 m) with low turbulence
    - Harsh marine, highly corrosive environment
    - Icing events during winter months
    - Large winter/summer temperature differences

- WEICan's Wind R&D Park includes:
  - Five 2 MW DeWind 9.2 Turbines
  - 80 m met. Mast
  - 109 kW Solar Array
  - 223 kWh BESS
  - Climate Monitoring Station
  - Robust data management system

WEICan Data Topology



AVEVA PI System
- Over 8500 data streams for Wind R&D Park and Site
- Most are 1 Hz data

Visual Systems
- Cameras in Nacelles
- Cameras on Nacelles
- Cameras for PV array

Research at WEICan

- Our greatest contribution to renewable energy development is our real-world operational data and expertise
- We have two main research areas
  - Asset Management
  - Grid Integration
- Asset management research focuses on understanding, predicting, and preventing component failures
  - As wind farms age, owners question whether to maintain assets, expand operations, or discontinue investments
  - How do factors such as complex terrain, high capacity factors, icing and severe weather, cold climate, delayed maintenance cycles impact service life and/or performance?
- How can we turn component failures into research opportunities?
  - Generators
  - Bearings
  - Blades

O&M Challenges – Blades major repair

September 2013 October 2013 August 2014

Example of a suction side delamination. The red and green circles mark the same locations on the blades

- April 2013 – Wind farm was commissioned
- Fall 2013 – Blade inspection found cracks in bonding seams, delamination near roots at the suction side. Repairs undertaken.
- Summer 2014 – Further inspections of T1-5 highlighted root core delamination as the biggest issue.
- 2015/16 – Blades were run through a duration and ultimate failure test at a test facility. They identify the same issues with delamination that WEICan experienced.
- 2016 – Consultant hired to develop repair instructions to reinforce the blades. Every blade reinforced under warranty along with a set of spares that WEICan purchased.
- 2016 – WEICan bought 12 more blades. These were not reinforced.

Blade Major Repair Timeline (Post Warranty)

- Summer 2020 – Inspection found crack near root at pressure side of 1 blade on T5. Blade was replaced and the rotor was re-balanced.
- Summer 2023 – Began repairs on another set of spare blades.
- October 2024 – Inspection found 4 blades with cracks near the root on the pressure side: 2 were on T4 and 2 on T5. Consultant hired to create reinforcement instructions for the pressure side. They recommended creating ‘splints’.
- November 2024 – 3 more blades were given core ramp/shear web retrofits along with “splints”

In summary: 6 reinforced spares (3 with splints) have been used. 9 spares remain.

Service Inspection September 2024

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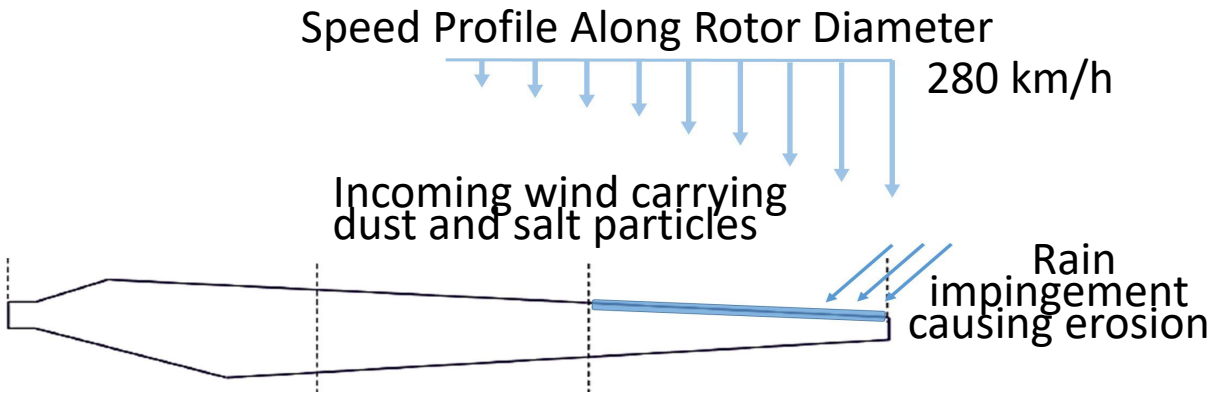
WEICan Blade Summary

Turbine	Blade	Blade Commissioned	Low-pressure side repair	High-pressure side repair
1	Blades 1-3	2013	2016	None
2	Blades 1-3	2013	2016	None
3	Blades 1-3	2013	2016	None
4	Blades 1-3	2024	2023-24	None
5	Blade 1	2020	2016	2024
	Blade 2	2024	2016	2024
	Blade 3	2024	2016	2024
4 (ground)	Blades 1-3	2013 (operated for 11 years)	2016	None
5 (ground)	Blades 1-3	2013 (blade 1 operated for 7 years, blades 2 & 3 operated for 11 years)	2016	None

- WEICan is interested in innovative research using both its damaged and operating blades to advance wind energy operations on two subjects:
  - Advance wind energy sustainability concerning blade end of life
    - Presently most end-of-life turbine blades are disposed of in landfills or incinerated – both can have significant negative impacts to the environment
  - Advance blade health monitoring
    - Blade monitoring options are under development and there are no off-the-shelf options

Leading Edge Erosion of Wind Turbine Blades



- Wind turbine blades are exposed to precipitation and airborne particles that can erode their surface coating
- Due to the blades' high tip speeds, the portion of the blade furthest from the base usually receives 70% to 80% of the erosion damage
- Untreated, leading edge erosion can reduce energy production, increase maintenance costs and downtime, and, eventually, affect the blades' structural integrity
- Many types of leading edge protection (LEP) materials have been designed to help prevent the erosion of the blade edge

Leading Edge Repair Timeline

- April 2013 – Commissioning (no LEP product, just paint)
- March 2014 - LE paint failure, erosion, pitting, first observed
- November 2014 – Repair work began
- Summer 2015 – Repair work complete
- November 2015 - Paint failure was again observed
- Summer 2016 - The turbine OEM proposed to address the issues through applying leading edge protection (warranty improvements)
  - WEICan begins field study with 4 LEP products

Until this point, work was under warranty with turbine OEM, after this WEICan took on the responsibility

- Summer 2019 – Reapplication of most products
- March 2021 – WEICan represents Canada on IEA Wind Task 46 – Erosion of Wind Turbine Blades
- Summer 2021 – Application of 5th LEP on T1 & T4 – T4 was rejected by manufacturer
- Summer 2022 – Application of 5th LEP on T2, T3 & T5, Reapplication on T4
- January 2023 – Inspections show 5th LEP detached from Blade 1 leading edge and started to bubble on Blade 2 of T1
- September 2023 – 5th LEP repaired on T1
- Winter 2025 – 5th LEP applied to new blades on T5; 6th LEP applied to new blades on T4
- Spring 2025 – bubbles on T3 and T5 LEP; tear on T4 LEP

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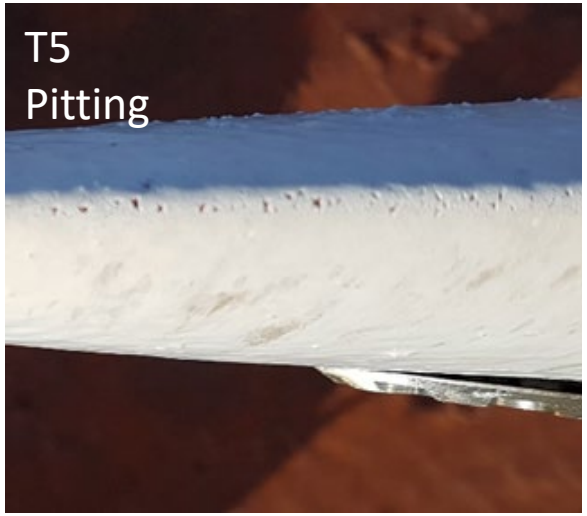
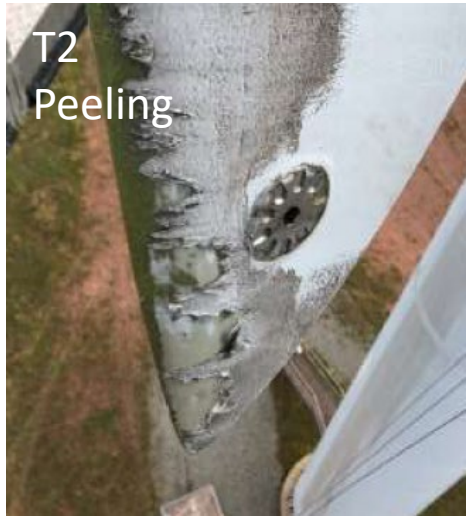
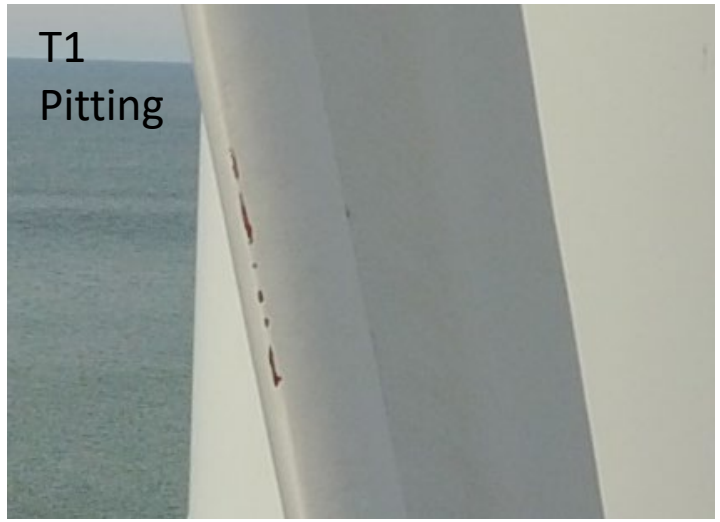
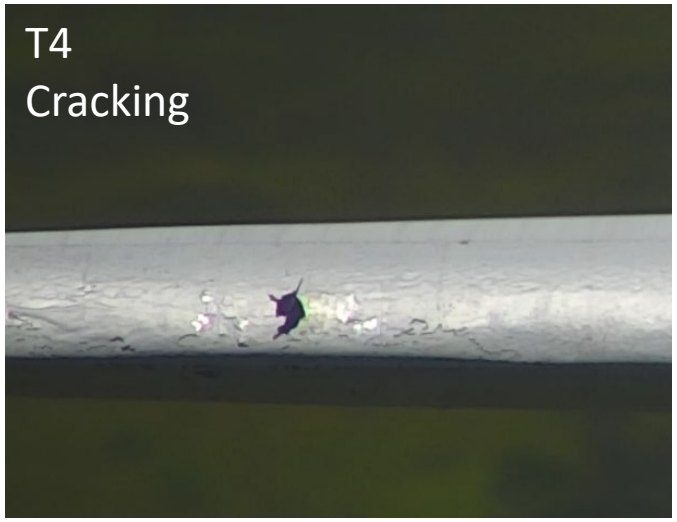
LEP Failure 2016 and 2019

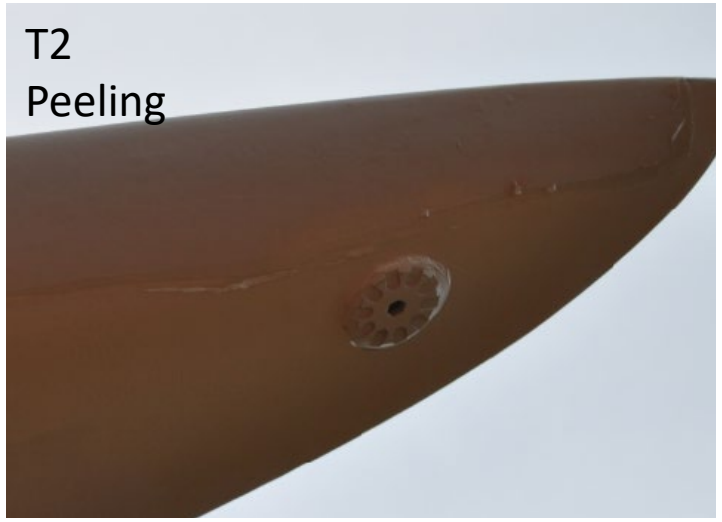
Leading edge damage was observed on most blades: - Pitting - Cracking - Peeling - Bubbling

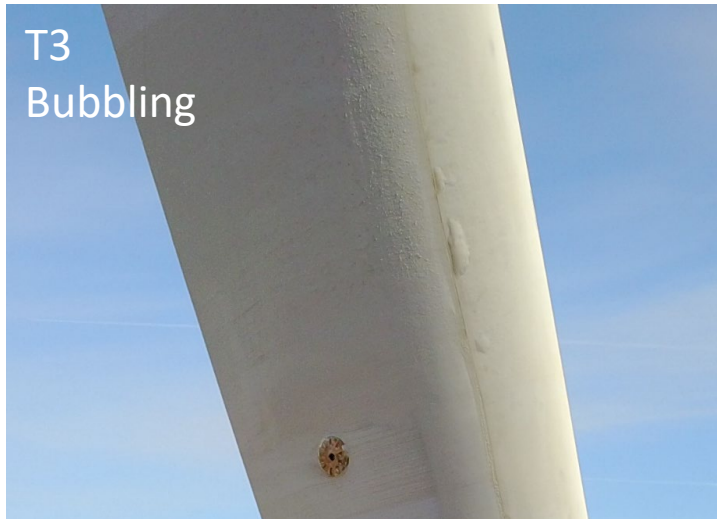












LEP Failures 2022, 2023, and 2025

T4 Tear

T4 Peeling

T5 Air bubbles

Failures observed in each turbine

LEP	Type of LEP	Turbine	Date Applied, Damage observed	Types of Damage Observed
1	Paint (2 component epoxy)	T1, T5	2016, 2017, 2019, 2021	Pitting, cracking, peeling, bubbling
2	Paint (polyurethane)	T4	2016, 2017, 2019, 2021	Pitting, peeling
3	Tape (2-component polyurethane)	T2	2016, 2017, 2021	Pitting, peeling, bubbling
4	Tape (2-component polyurethane)	T3	2016, 2019, 2021	Pitting, peeling bubbling
5	Shell (polyurethane)	T1, T2, T3, T4, T5	T1: 2021, 2023 T2: 2022 T3: 2022 T4: 2021, 2022 T5: 2022, 2025	Peeling, bubbling bubbling Peeling, bubbling bubbling
6	Tape (polyurethane)	T4	2025	Tear, peeling

Leading Edge Repair Work Instructions

- Each type of protection has specific application instruction. Instructions typically require
  - Filling, sanding, cleaning to achieve a smooth surface
  - Max and min temperatures and relative humidities for curing and drying
- Repairs uptower have wind speed restrictions, depending on method to access the blade

Causes of LEP Failures

- LEP providers attribute premature failures to improper/inadequate surface preparation and installation
- Usual causes:
  - Epoxies/adhesives not appropriately activated
  - Surface was not adequately cleaned
  - Blade repairs with fillers or coatings ahead of installation where still curing
  - Conditions may have been appropriate at the start, but were not sustained
  - Skills/experiences of technicians is not adequate
- Original blade manufacturing/blade quality is very important
  - How was it put together, filler, adhesion methods

Summary and Conclusions

- WEICan's heavily instrumented turbines and coastal site allow observations that are relevant to offshore wind considerations
- WEICan has had issues with their wind turbine blades since beginning operation
- As a research institute, WEICan turns these operational issues into research opportunities
  - Upon discovering cracks in their blades, WEICan put out a request for expressions of interest in 2025 for:
    - Blade monitoring options
    - Blade end of life options
  - Upon discovering blade leading edge erosion, WEICan carried out a field test for six different leading edge protection materials
    - All types of LEP showed damage in one to two years.
    - WEICan has noted that improper application and blade quality are the most important factors determining the longevity of the LEP materials, rather than the material itself
      - May be not practical to do "proper" application in the field

Questions

Contact:

Marianne Rodgers, Scientific Director

marianne.rodgers@weican.ca

WEICan is going to produce 500 GWh this fall!

Follow us to see the countdown!

https://www.weican.ca/counting-down-to-500gwh/

Find us on LinkedIn: https://ca.linkedin.com/company/weican