U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

NREL Transforming ENERGY

Photo by Dennis Schroeder, NREL 49408

T09 – Wind Turbine Drivetrain Reliability

Technology RD&T and Resource Characterization
Materials and Manufacturing

Jonathan Keller
NREL

8/3/2021

FY21 Peer Review - Project Overview

Project Summary:

- Wind plant operations and maintenance (O&M) costs $12/megawatt hour and accounts for 25% to more than 35% of land-based and offshore wind levelized cost of energy. Pitch system, main bearing, and gearbox reliability are significant contributors to O&M costs. The predominant failure modes are not accounted for in design standards, not attributable to material deficiencies or manufacturing quality control, and independent of specific component suppliers. Characterizing failure modes, developing rating life and remaining useful life models, and developing mitigation strategies will increase drivetrain reliability and turbine availability by reducing premature failures, unplanned maintenance and O&M costs.
- Winergy, SKF, Technical Univ. of Denmark, and Vrije Univ. Brussel.

Project Objective(s) 2019-2020:

- Investigate influence of main bearing axial motion on lubricant film thickness. Develop and validate gearbox bearing roller slip model and white-etch crack (WEC) rating life and probability of failure model. Assess gear micropitting safety factor model.

Overall Project Objectives (life of project):

- Develop rating life models, mitigations to increase design and service life, and tools to predict remaining useful life and increase availability.

Project Start Year: FY18
Expected Completion Year: FY21
Total expected duration: 3 years

FY19 - FY20 Budget: $2,949,463

Key Project Personnel: Jonathan Keller, Shawn Sheng, and Yi Guo

Key DOE Personnel: Mike Derby, Brad Ring, Lillie Ghobrial, and Tyler Christoffel

Photo by Mark McDade, NREL 49050

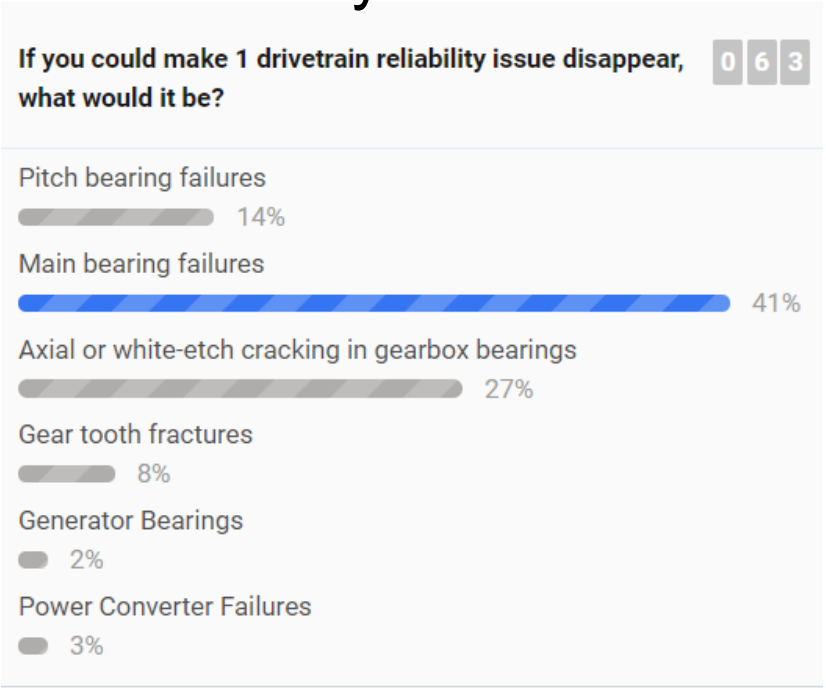
Project Impact

- **O&M costs are an important part of cost of energy!**
  - Account for 25% to 35% of levelized cost of energy (LCOE), representing $5B annual market in the United States
  - O&M costs are higher than expected; can account for 10% (land-based) to 50% (fixed offshore) of reduction in LCOE

Program Performance – Scope, Schedule, Execution

- **Reliability continued from prior peer review period (FY15-18)**
  - Completed planet bearing fatigue, spline coupling rating, and compact filter testing tasks
- **Reliability merit-reviewed and was continued (FY19-21)**
  - DOE1.5 drivetrain tests
  - Characterization and rating life development for WECs
  - Characterization and axial motion study for main bearings
  - Gear micropitting case studies
  - Additional main and pitch bearing work delayed

Reliability Poll Result



Program Performance – Accomplishments & Progress

Drivetrain Reliability Research
Pitch, Main, and Generator Bearings and Gearboxes

- Identify failure modes
  - Prevalent, costly, and uncharacterized

DRC Workshops, Failure Database, ESIG

Start

Characterize Failures
Cracking, wear, micropitting, fretting…

Quantify Damage Contributors
Load, stress, cycles, slip, friction, current…

Develop Rating or Life Model
Fatigue, friction energy…

Verify Life Model
Predictions vs actual failures (hindcast)

CRADAs and TCFs

Finish

Planet Bearing Fatigue

Spline Coupling Wear

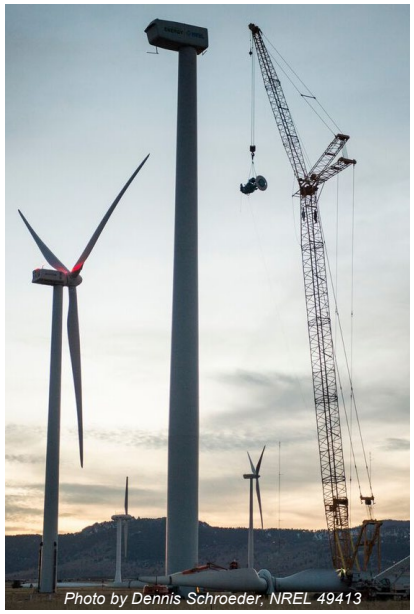
- Improve designs
  - Components, controls, materials, coatings, lubricants…
- Predict remaining useful life (RUL)
- Optimize O&M
- Improve standards
  - AWEA Recommended Practices
  - IEC 61400-4 and AGMA 6006

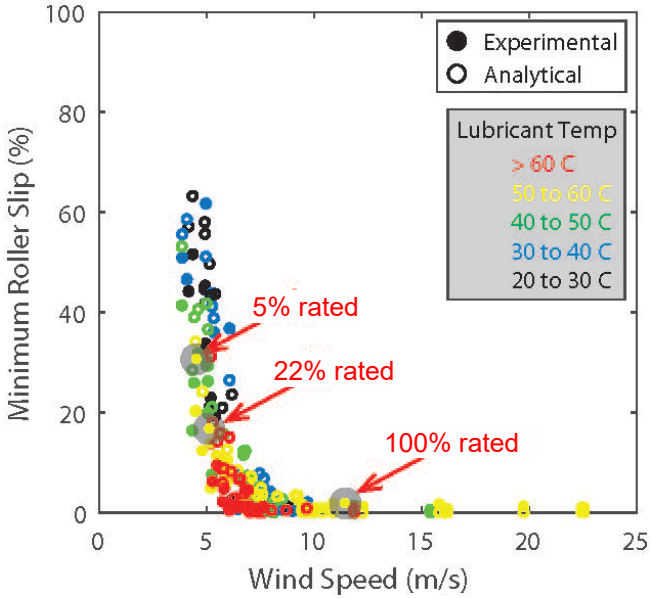
Program Performance – Accomplishments & Progress

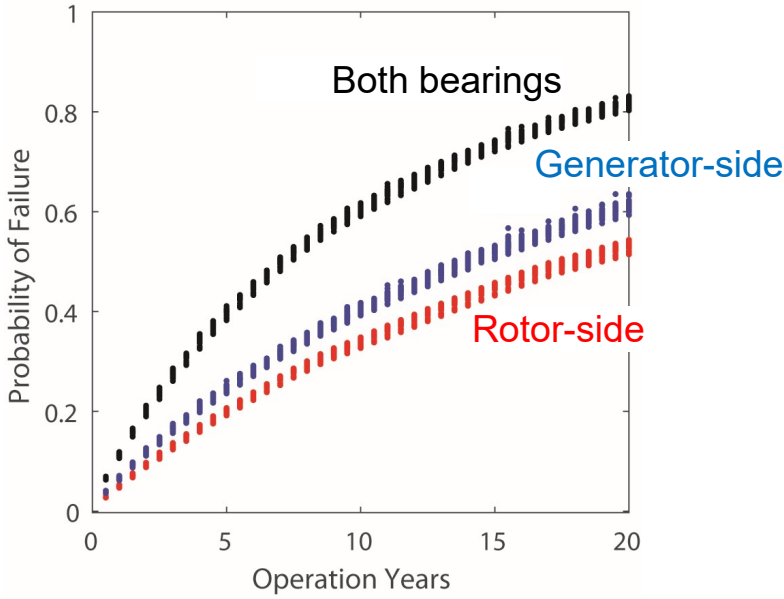
- **Determine designs and operations influencing WECs**
  - Bearing loads and roller slip are strong causal factors
  - Oil temperature, moisture, electrical current are contributors

Load and slip model validation and design study of changes in bearing type, clearance, temperature and lubricant

Probability of failure model validation with 10 years of wind plant operational data and failure records







Program Performance – Accomplishments & Progress

- **Investigation of main bearing wear and lubrication**
  - Characterization of applied axial loads
  - Detailed investigation of axial motion between bearing rings

Main Bearing Motion Instrumentation

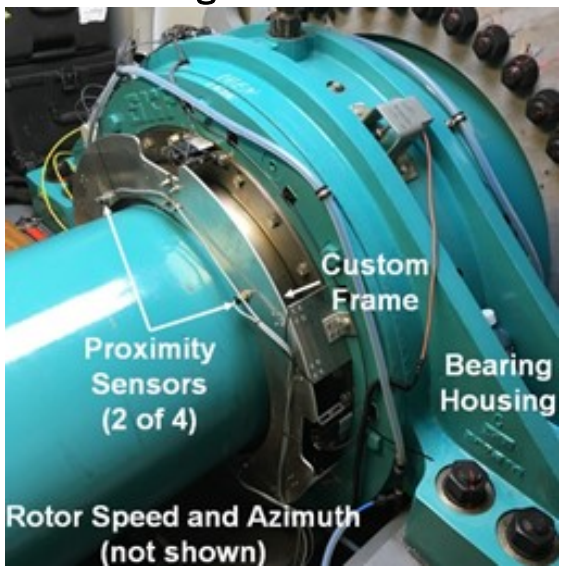
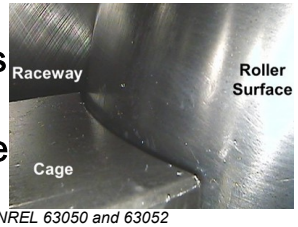


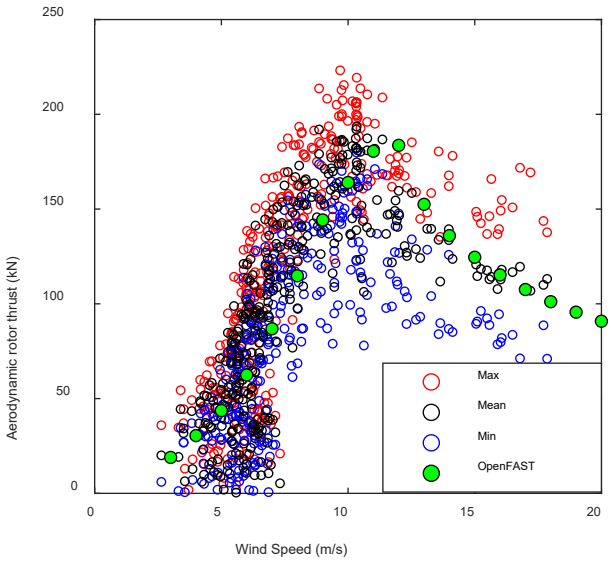
Photo by Jerry Hur, NREL 49959

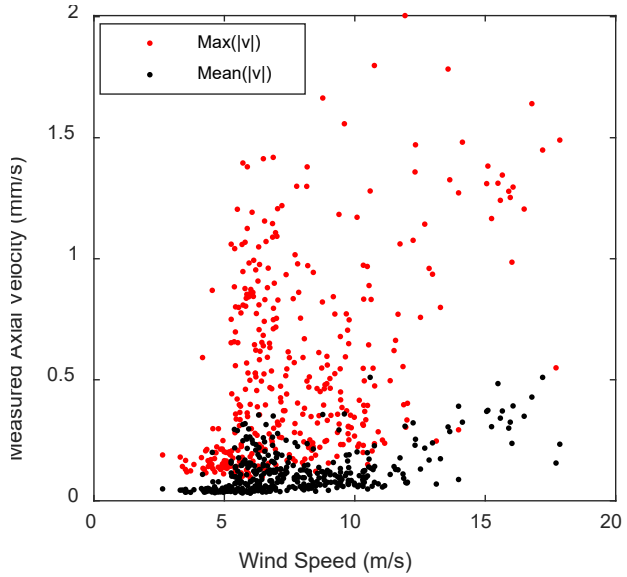
Rollers and Grease



Photos by Mark Dunn, SKF USA Inc., NREL 63050 and 63052

Aerodynamic rotor thrust causes relative axial motion and velocity between the main bearing rings, but compared to the speed of rolling it is not sufficient to disturb lubricant film formation





Project Performance - Upcoming Activities

- **WEC investigation and RUL estimation (FY21 and FY22)**
  - Complete WEC risk assessment method with TU Denmark
  - Install Winergy torque sensor in DOE1.5 for RUL
- **Main bearing wear (FY21 and beyond, subject to merit review)**
  - Roller load and acoustic emission DOE1.5 data analysis
- **Pitch bearing reliability (FY21 and beyond, subject to merit review)**
  - Specification of pitch bearing for 15 MW reference turbine
  - Rating life analysis and improvement
- **O&M research (FY21 and beyond, subject to merit review)**
  - Prognostics and O&M optimization via physics domain modeling, artificial intelligence, and machine learning
- **Support advanced lubricant TCF (FY22 and FY23)**

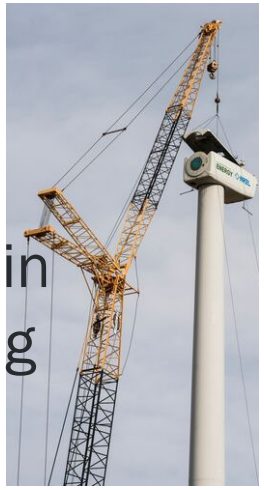


Photo by Dennis Schroeder, NREL 49401

Stakeholder Engagement & Information Sharing

- **Collaborative meetings and workshops**
  - Attended by 150+ people, 75% industry
- **Cooperative Research and Development Agreements**
  - WEC: Winergy, SKF, and Technical Univ. of Denmark
  - Main bearing: SKF
  - O&M and failure statistics: Vrije Univ. Brussel and others
- **Publications and Data Release**
  - 7 journal articles, 4 conference paper and presentations
  - 2 related, ongoing TCF projects and 4 software records
  - Uptower gearbox and main bearing test report and data (https://nrel.box.com/s/fx1wu3pkvgbeu5ikv7ghn61pjg1oao20)
  - Gearbox failure statistics (https://grd.nrel.gov/)

Key Takeaways and Closing Remarks

- **Uncharacterized failure modes are predominant**
  - A feature, not a coincidence!
- **Each project will continue to evolve from understanding root causes to identifying and validating:**
  - mitigation methods (materials, coatings, and components) and control changes;
  - remaining useful life with physics- and model-based methods with “big data”.

Photo by Dennis Schroeder, NREL 49520

- **Reliability and O&M are essential considerations in new drivetrain technology development**
  - Large-diameter gearboxes and bearings, integrated drivetrains, superconducting generators.