Wind Turbine Drivetrain Reliability Assessment and Remaining Useful Life Prediction

Yi Guo, Lindy Williams, and Shawn Sheng
National Renewable Energy Laboratory

Nathan Post
WindESCo, Inc.

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Outline

- Background and Objectives
- Testing Site and Data
- Methodology
- Results
- Summary


Photo by Dennis Schroeder, NREL 21882

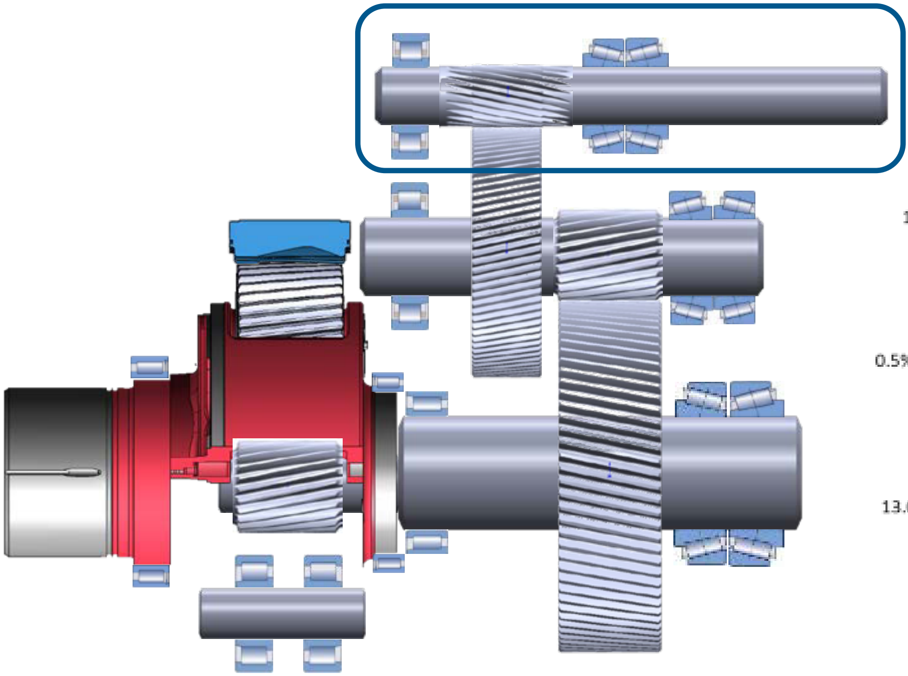
Background

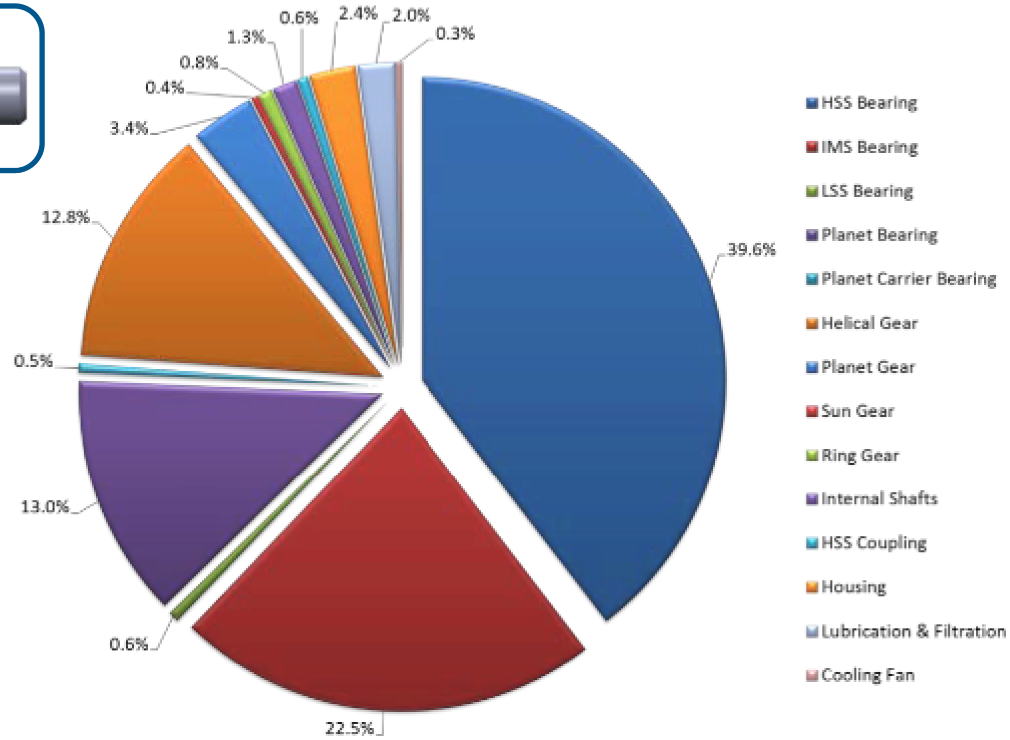
- High operations and maintenance cost for wind energy, an even bigger challenge for offshore
- Accurate remaining useful life (RUL) prediction and understanding of operations and design effects on component failures essential [1]
- Top failure mode in megawatt-scale gearboxes, i.e., bearing axial cracking, not accounted for in design life
- NREL developed a physics-based methodology for gearbox reliability assessment and prediction [2]

Project Objectives

- Validate the developed NREL technology [2]
- Apply the methodology to a commercial wind plant

High-Speed Stage Bearing Failures (39.6%)





Testing Site and Data

- 10 turbines commercially operated for 10 years
- SCADA time series, event log, design drawings, failure records, and lubricant properties
- Tapered roller bearings (TRB) failed by axial cracking
  - New roller slip model for the TRBs needed

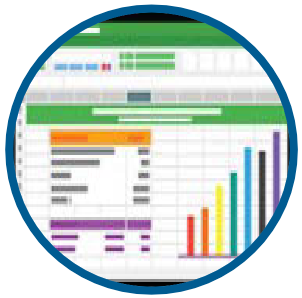
Photo by Dennis Schroeder, NREL 50712

Methodology: Major Steps [2]

Guo, Yi, et al. 2020. *Renewable and Sustainable Energy Reviews* 127: 109888. https://doi.org/10.1016/j.rser.2020.109888.

4 SCADA

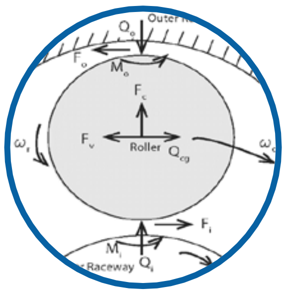
5 Failure Records



1

Roller Slip,

$\Delta V, \mu$



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2

Roller Load,

N

=

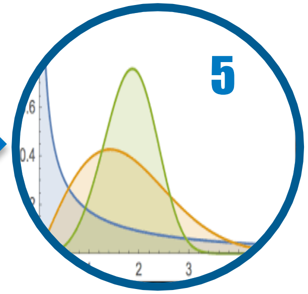
3

Frictional Energy,

E

Wind Plant,

E



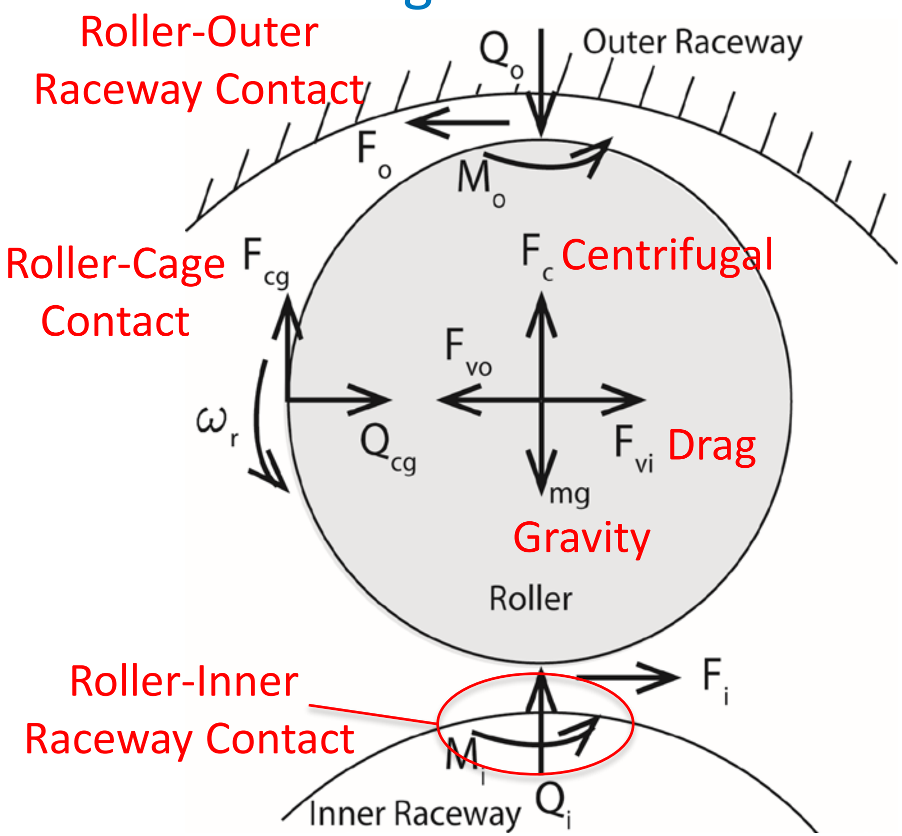
Probability of Failure, *PoF*

Developed TRB Slip Model

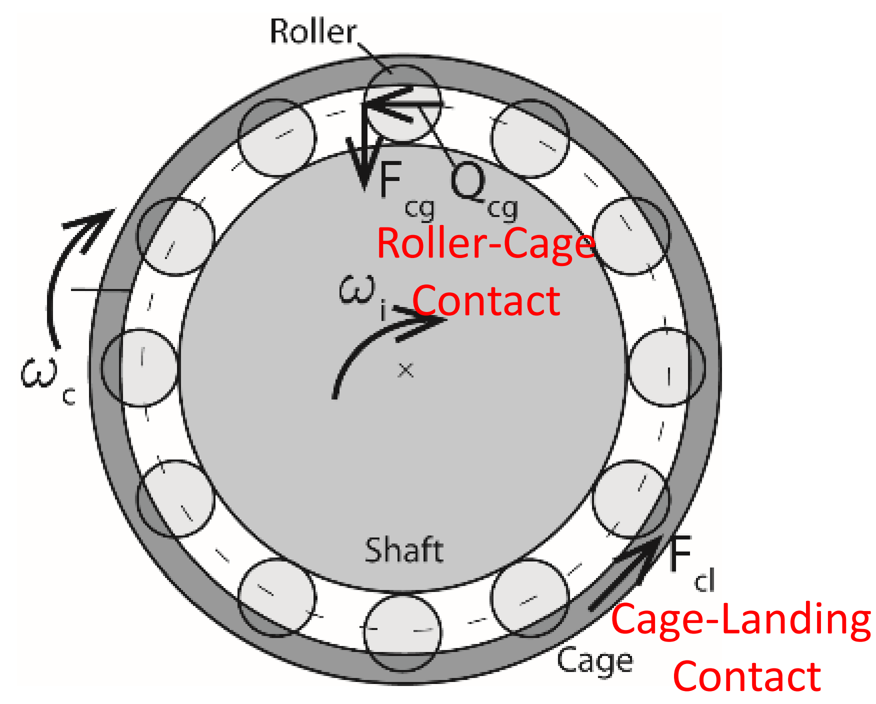
Updated Damage Threshold

Methodology #1: Roller Slip Modeling [3]

Force Diagram of a Roller



Force Diagram of the Cage

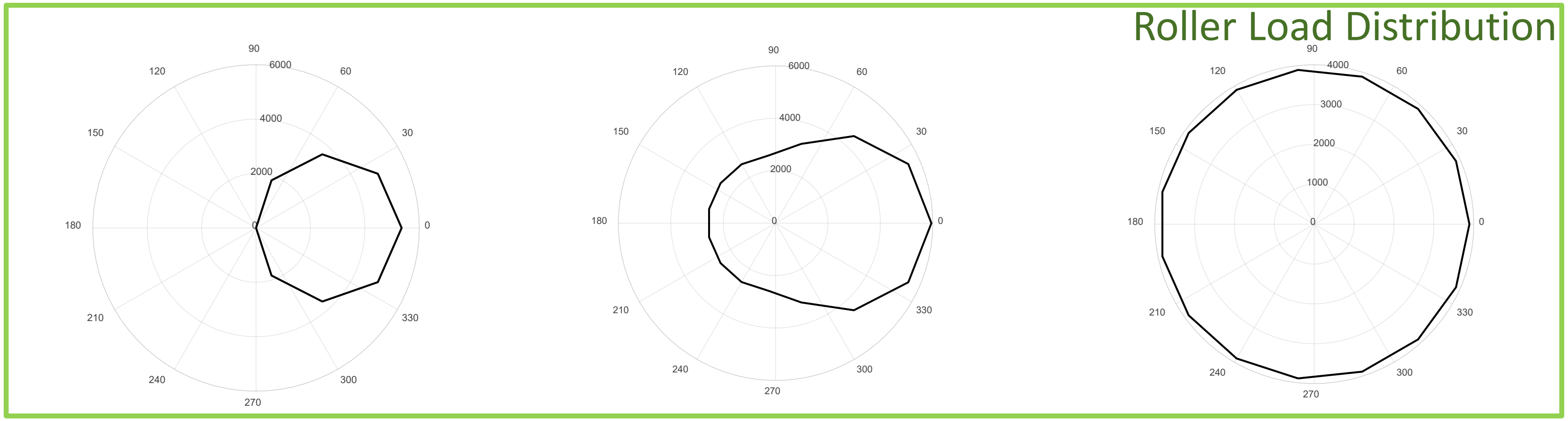


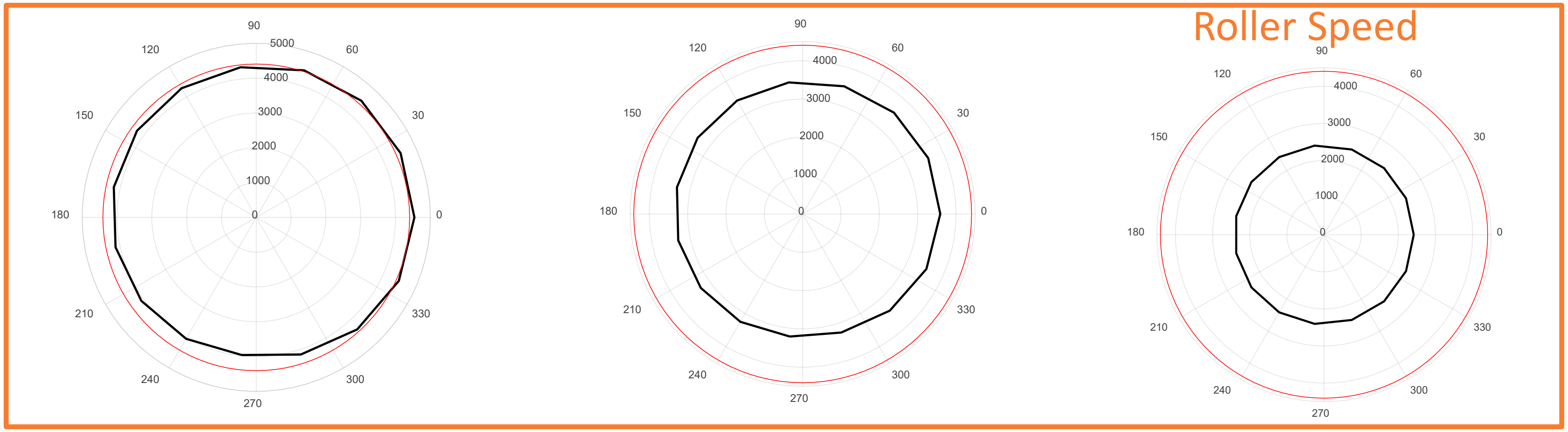
- Quasi-static slip model considers:
  - Contact between roller-raceway, roller-cage, and cage-landing
  - Bearing-lubricant interactions
  - Axial load, gravity, centrifugal forces, and gyroscopic moments

Guo, Yi & Jonathan Keller. 2020. *Tribology International* 148: 106347.

Slip Model Results: Roller Speed and Loads

Case 1: Radial Load only | Case 2: Combined Radial/Axial | Case 3: Axial Load only

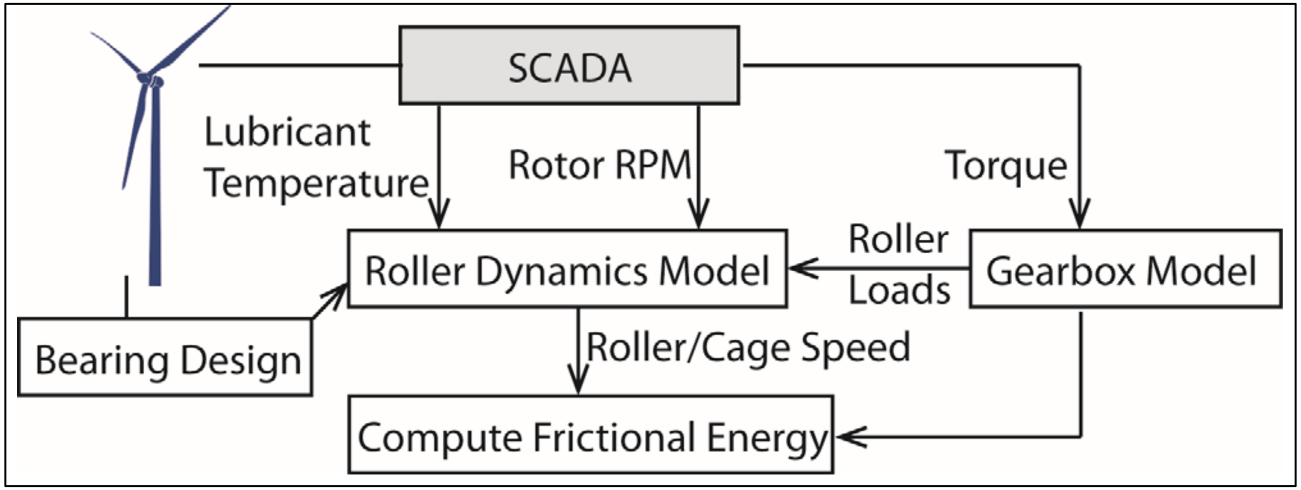




- Validation data needed

Red: Pure Rolling
Black: Model

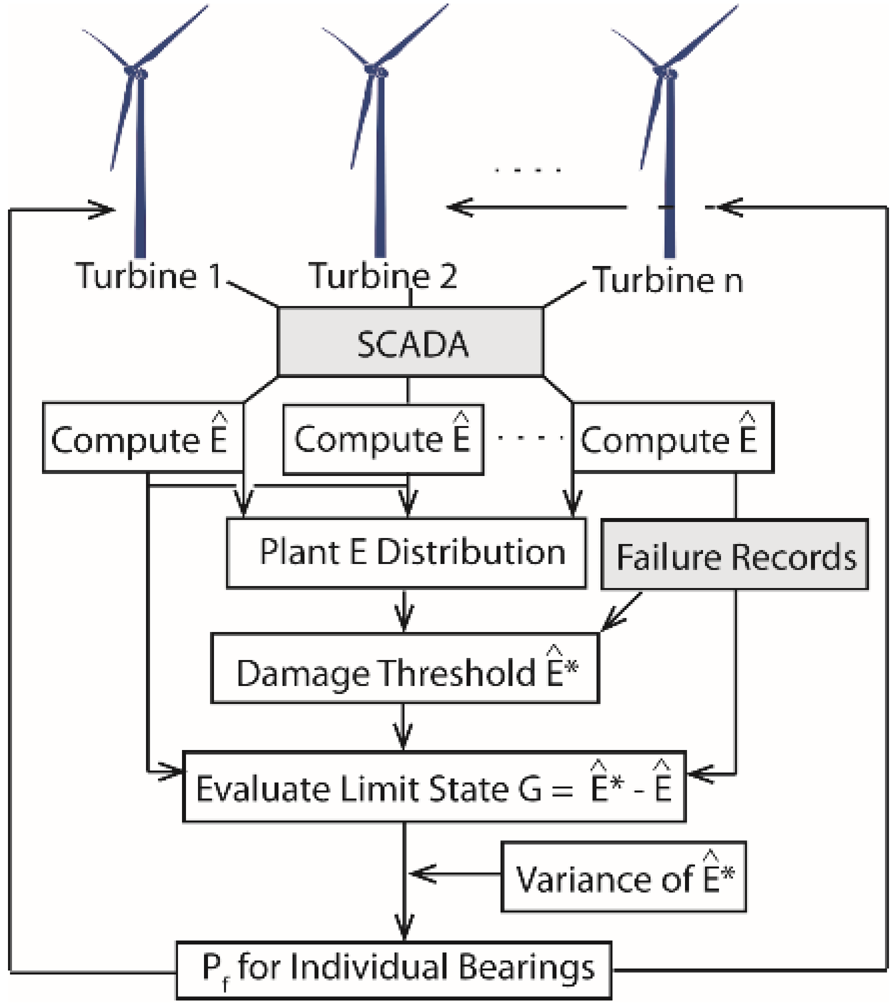
Methodology #4: Plant Frictional Energy [2]



Calculate frictional energy of individual bearings

Guo, Yi, et al. 2020. *Renewable and Sustainable Energy Reviews* 127: 109888. https://doi.org/10.1016/j.rser.2020.109888.

Methodology #5: Probability of Failure [2]

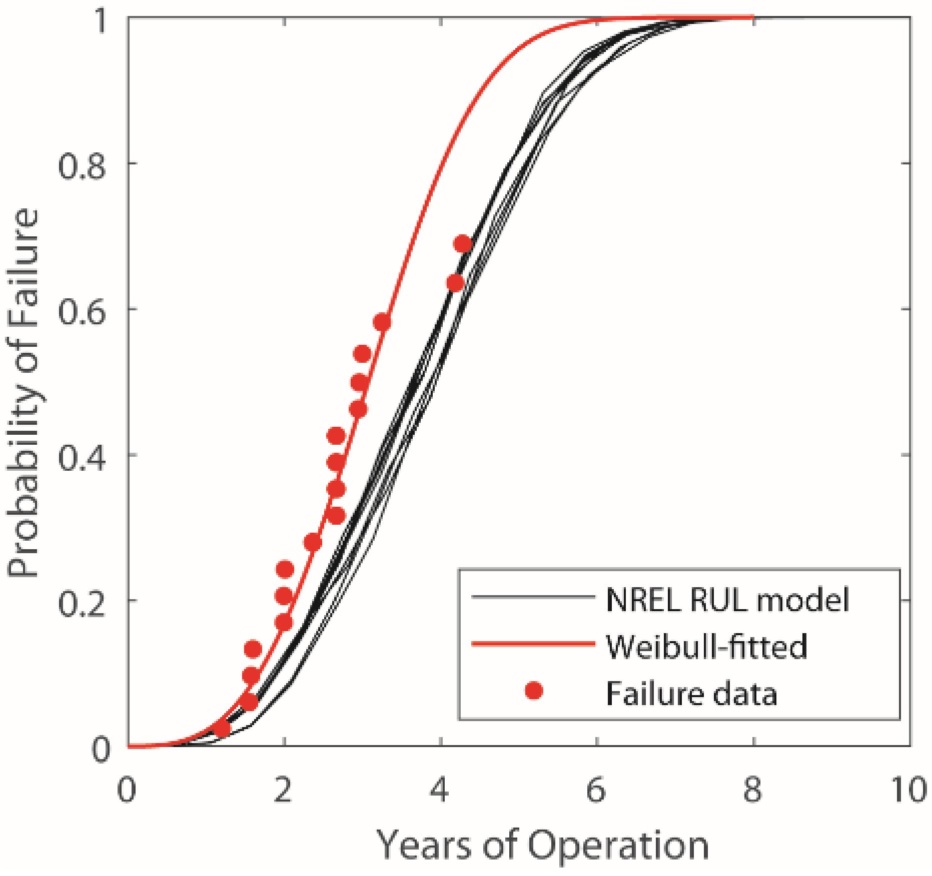


Calculate the probability of failure (P_f) of individual bearings

Guo, Yi, et al. 2020. *Renewable and Sustainable Energy Reviews* 127: 109888. https://doi.org/10.1016/j.rser.2020.109888.

Remaining Useful Life Comparison

- Failure data
  - Multiple failures at most turbines
- Results match actual failures
  - Transient events not considered
- Pof different for each turbine
  - Identify high-risk turbines
  - Operators can act proactively
- Evaluates impact of lubricant or bearing design on service life



Summary

- Parameter-based methodology enables assessment and prognosis of individual parts in each turbine
- Good agreements between predicted PoF and actual failures
- It evaluates the impact of lubricant or bearing design on bearing service life
- New TRB slip model extended NREL's bearing reliability assessment methodology for CRBs to TRBs
- New failure modes can be incorporated and validated through joint partnerships
- Future work
  - Expand to other components
  - Evaluate system performance and reliability

Photo by Dennis Schroeder, NREL 40389

References

1. Sheng, Shuangwen, and Yi Guo. 2019. “A Prognostics and Health Management Framework for Wind.” GT2019-91533. *Proceedings of ASME Turbo Expo 2019: Turbomachinery Technical Conference and Exposition.* Phoenix, AZ. New York: American Society of Mechanical Engineers (ASME). https://doi.org/10.1115/GT2019-91533.
2. Guo, Yi, Shuangwen Sheng, Caleb Phillips, Jonathan Keller, Paul Veers, and Lindy Williams. 2020. “A methodology for reliability assessment and prognosis of bearing axial cracking in wind turbine gearboxes.” *Renewable and Sustainable Energy Reviews* 127: 109888. https://doi.org/10.1016/j.rser.2020.109888.
3. Guo, Yi, and Jonathan Keller. 2020. “Validation of combined analytical methods to predict slip in cylindrical roller bearings.” *Tribology International* 148: 106347. https://doi.org/10.1016/j.triboint.2020.106347.

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yi.guo@nrel.gov shawn.sheng@nrel.gov

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