Wind Turbine Reliability Assessments for Efficient Operations

Reliability Projections Valuable for Reducing O&M Costs

Wind Power Industry

Global wind power capacity reached 622 gigawatts in early 2020, with 30 gigawatts of that offshore. Global wind capacity is expected to surpass 1.3 terawatts by the end of 2030, with more than 200 GW offshore. Reduction in wind turbine capital expenses (CapEx) per megawatt and greater productivity per megawatt have contributed to reduced cost of energy of about 5% annually. From 2014-2019, CapEx per megawatt decreased 15% globally [1] and is projected to be on a similar 3-5% reduction per year into the mid-2020s. However, operational expenses (OpEx) have been increasing mainly due to increased O&M costs with fleet age.

Turbine Reliability–Industry Needs

Currently, global onshore wind turbine operations and maintenance (O&M) spend is around $15 billion annually. Since about 75% of global wind power capacity has been installed in the last 10 years, there is little data about the reliability over the next decade. Along with changing technology, that makes it very challenging for a single owner/operator to build statistically significant cost models. O&M cost increases with age, but how can operators forecast this cost specific to their fleet and wind farm? Figure 1 shows the possible increase in onshore wind turbine average O&M costs with operational years. In a fleet sense, O&M costs are expected to increase by 7% annually in the next eight years due to unplanned failures and unscheduled maintenance, which account for around 50% ($7.5 billion) of total O&M costs. This unplanned maintenance cost is highly variable depending on major component reliability, which can differ by a factor of more than two. Almost universally, an increase in major component failure rates (including blades, pitch bearings, main bearings, gearbox, and generator) drives the O&M cost increase with usage.

For instance, the drivetrain, consisting of gearboxes, mainshaft assemblies, and generators are typically sourced from several suppliers with multiple sub-suppliers, resulting in a wide range of variability and quality. With the development of larger turbines and new technologies, new serial issues have initiated (such as mainshaft bearing failures, gear material quality related failures, and high speed and intermediate speed bearing race cracks), making drivetrain reliability a moving target.

Competitive forces in the marketplace previously put more pressure on CapEx, but educated buyers are now requiring wind turbine OEMs to take a harder look at long-term reliability. As more collaborative reliability data is compiled, developers and owners can more quantitatively incorporate long-term OpEx into their site planning and supplier selections.

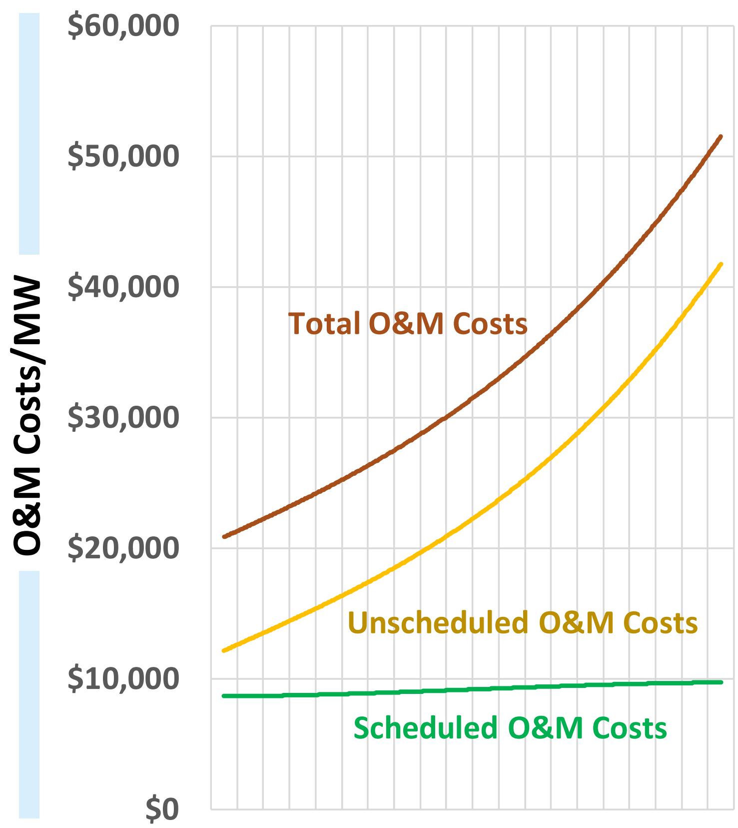

Figure 1: Onshore wind turbine average O&M costs with fleet age

1. *Future of wind: Deployment, investment, technology, grid integration and socio-economic aspects,* IRENA, 2019

EPRI's Approach to Addressing Industry Needs

EPRI is conducting in-detail major component reliability analysis considering the impact of wind turbine design, manufacturing, quality, operating conditions, and other variables. This body of work includes:

- Evolution of wind turbine technology and its impact on reliability and O&M costs
- Guidelines for wind turbine key data collection and digitalization
- Reliability of wind turbines, suppliers, and sub-suppliers, and the key factors impacting critical parts
- Web-based reliability tools for benchmarking and industry-wide collaboration on O&M
- Physics-based machine learning (ML) models to capture major components damage in its early stages
- Optimum O&M actions for turbine life extension/improvement

The web-based reliability benchmarking tool is part of the newly launched Wind Innovators Network (WIN), a user group that EPRI chartered in 2020 to help owners, operators, maintainers, and other organizations balance trade-offs between energy production, affordability, reliability, and operational capabilities of large-scale wind power plants.

As of mid-2020, EPRI is collecting major component configuration and failure data spanning 15 years from over 3,000 turbines (over 6 gigawatts) at 80 sites for purposes of reliability analysis and developing transparent performance and health monitoring methods [2]-[4]. The database includes seven major OEMs (GE, Vestas, Siemens, Suzlon, Nordex, Mitsubishi & Gamesa), 22 turbine models ranging from 1.5MW – 3.45MW, 14 gearbox manufacturers (including Winergy, Moventas, Nanjing, ZF Bosch Rexroth, Eickhoff, GETS, and HANSEN) and six bearing manufacturers (SKF, FAG, INA, NSK, NTN and Timken).

Figure 2 shows gearbox annual failure percentage for various operational years. Most of this data was collected from wind farms installed since 2008. Early gearbox failures during the first four years of operation are mainly due to design, assembly, and manufacturing/serial defects. Annual failure rate for the first four years of operation is 0-1.2%, with an industry average of 0.9%. Overall, the gearbox annual failure rate increased between 5-10 years of operation mainly due to bearing failures (such as race cracks, pitting, spalling, and wear). There have also been limited gear-related failures due to tooth bending fatigue (tooth breakage/loss), tooth flank fracture, wear and contact fatigue (pitting and spalling).Annual failure rate between 5-10 years of age is 1.0-2.3%, with an industry

Figure 2: Wind turbine gearbox annual failure rate vs. operational years

2. *Wind Turbine Gearbox Reliability, Damage Prediction, & Recommendations for Life Improvement,* EPRI Report, 3002016434, 2019
3. *Wind Turbine Streaming Data Specifications: Sources, Sampling Rates, & What's Missing,* EPRI Report, 3002016450, 2020
4. *Wind Turbine Performance Monitoring Methods Development and Demonstration,* EPRI Report, 3002016451, 2019

average of 1.6%. The relatively high gearbox failure rate in the fifth year of operation is typically due to end-of-warranty proactive replacements.

Figure 3 shows a comparison of EPRI's predictions of fleet gearbox cumulative failure rate during 20 years of operation, ranging from 30% (best-case scenario) to 70% (worst-case scenario). Actual cumulative gearbox failure rate was categorized based on installation years 2008, 2010, 2012, and 2014. As shown in Figure 3, actual wind turbine gearbox cumulative failure rate percentage over operational years is within EPRI's predicted values.

EPRI's goal is to gather tens of gigawatts of additional reliability data for all major components to make improved projections based on smaller subsets of data, such as make/model, sub-suppliers, age, site conditions, and many more metrics based on industry input.

The lack of universal feedback between OEMs, suppliers, and owners/operators for smooth data transfer make tasks like digitalization and reliability tracking a complicated, yet critical industry gap that owners and operators are addressing with EPRI's support. Component reliability digitalization and wind energy component reliability database is just the beginning to address this industry gap.

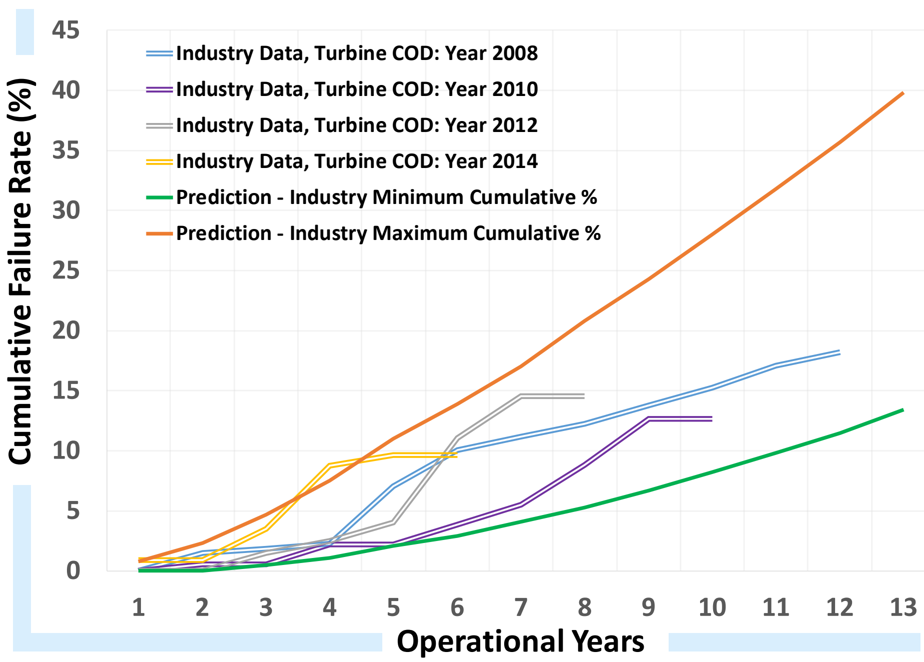

Figure 3: Wind turbine gearbox cumulative failure rate, predicted vs. actual

EPRI's reliability database and insights provides value to wind operators at multiple levels:

Fleet level

- O&M budgeting and forecasting
- Critical wind farms identification
- Inventory management
- Resource planning

Turbine level

- Critical turbines identification
- O&M optimization
- Preventive maintenance
- Turbine upgrades, life extension

System and sub-system level

- Critical systems identification
- Uptower repairs, replacements
- Supplier selection
- System upgrades

Component level

- Critical components identification
- Supplier selection
- Serial defect identification & rectifications
- Component upgrades

Further Information and Opportunities to Join EPRI's Wind Innovators Network

Additional objective and data-driven analysis and insights can be gained through active participation in EPRI's Wind Innovators Network (WIN). The key offerings of WIN include:

- **Workshop.** An annual workshop provides a multi-day meeting, with scheduled technical presentations and roundtable discussions, and opportunities for in-person exchanges. The focus is on operations and maintenance topics, resulting in a report summarizing findings.
- **Reliability Benchmarking.** WIN provides the opportunity for EPRI to intake, analyze, and integrate individual member data into the benchmarking database. This capability enables WIN members to visualize and compare the reliability of their own wind farms to the broader fleet of farms.
- **Website.** A website provides access to workshop proceedings and reports as well as a data portal for benchmarking the reliability of wind farms. A public-facing version allows very high-level information, and a members-only section allows access to more detailed benchmarking analysis.
- **Webcasts.** EPRI also conducts periodic webcasts for all WIN members on selected topics, and less formal meetings may be scheduled.
- **Published Materials.** Conference proceedings and slide decks are available from annual workshops and webcasts for all WIN members.

Joining WIN can provide many benefits, including the opportunity to share lessons learned with a continually expanding network of colleagues and experts. This opportunity means wind utilities/operators have access to objective, expert, and peer insights on operations and maintenance best practices, reducing lifetime costs, increasing energy production and reliability, and adding operational capabilities.

For more information about this analysis or how to join EPRI's Wind Innovators Network, please contact Brandon Fitchett (bfitchett@epri.com) Raja Pulikollu (rpulikollu@epri.com), or Ron Schoff (rschoff@epri.com)

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