NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Wind Turbine Gearbox Reliability Database, Condition Monitoring, and Operation and Maintenance Research Update


Photo by Dennis Schroeder, NREL 21883

Shuangwen (Shawn) Sheng

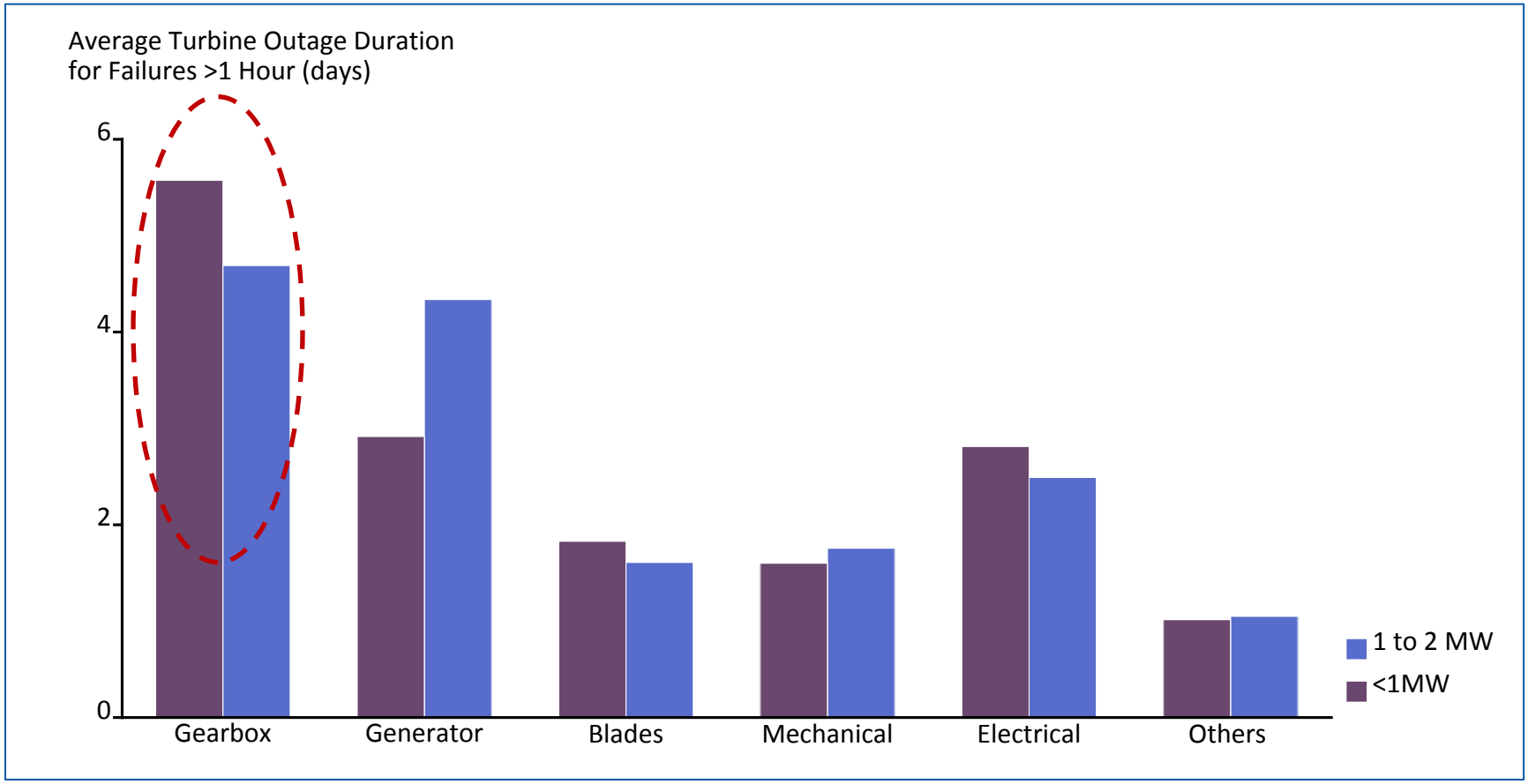
Drivetrain Reliability Collaborative Workshop

February 16–17, 2016
Golden, Colorado

NREL/PR-5000-66028

Gearbox Reliability Challenge

- Globally: Premature component failures, led by gearbox, increase Operation & Maintenance (O&M) costs, downtime, and Cost of Energy

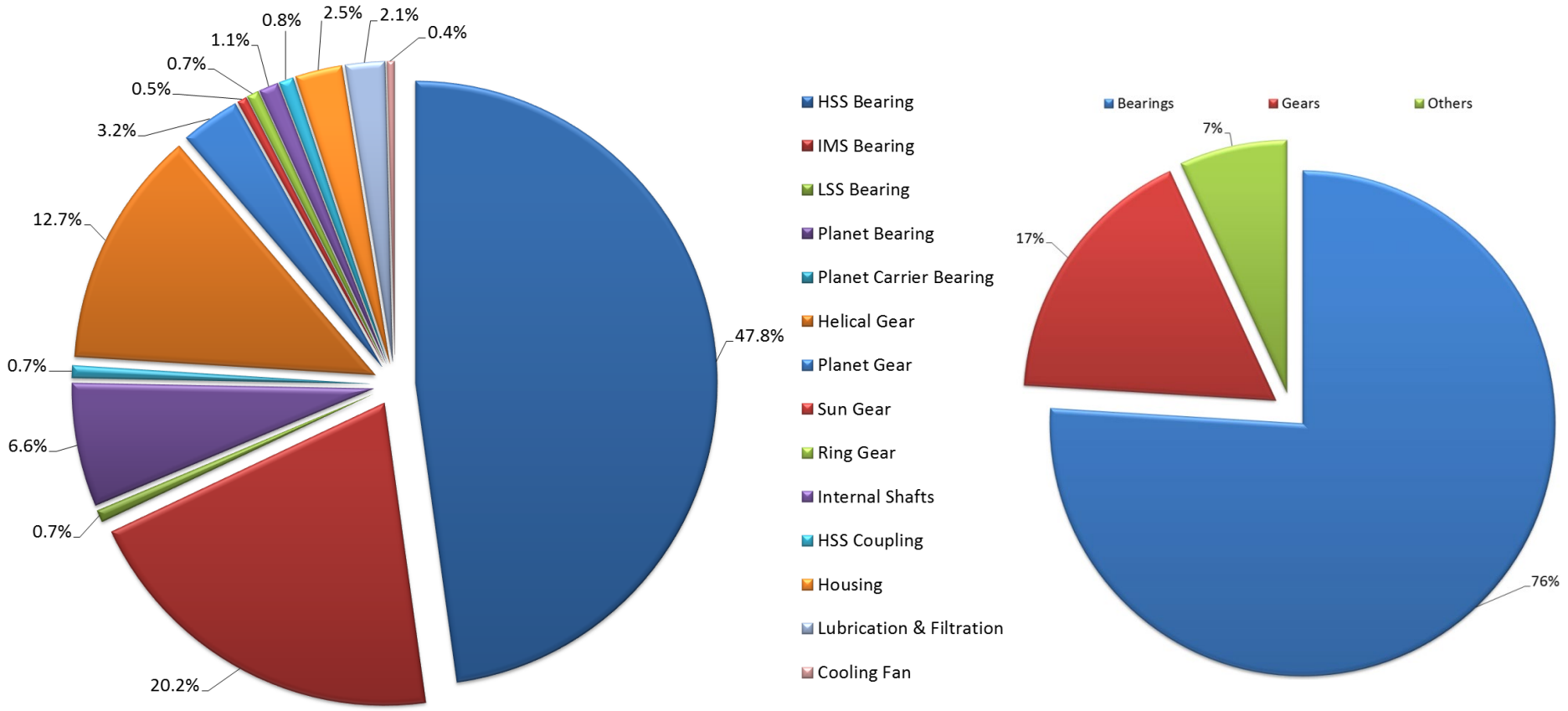


Plot Source: Wind Energy Update and Sciemus, 2015

Reliability Database: Status

- Background: http://www.nrel.gov/docs/fy15osti/63106.pdf
- Partners:
  - Close to 25 partners, including turbine and gearbox original equipment manufacturers (OEMs), wind plant owner/operators, gearbox rebuild shops, and consulting companies
  - Assets represented by owner/operator partners are ~40% of U.S. end-of-2014 installed capacity
  - Not all partners actively submit data to NREL.
- Data Records:
  - Increased to ~2,750 data entries
    - 67% gearboxes and 33% generators
  - Confirmable gearbox damage records ~1,210
    - Different partners follow different terminologies and data collection practices; the industry needs to standardize reliability data collection efforts.

Reliability Database: Damage Distribution



The charts were released by 09/30/2015 and are based on ~750 damage records:

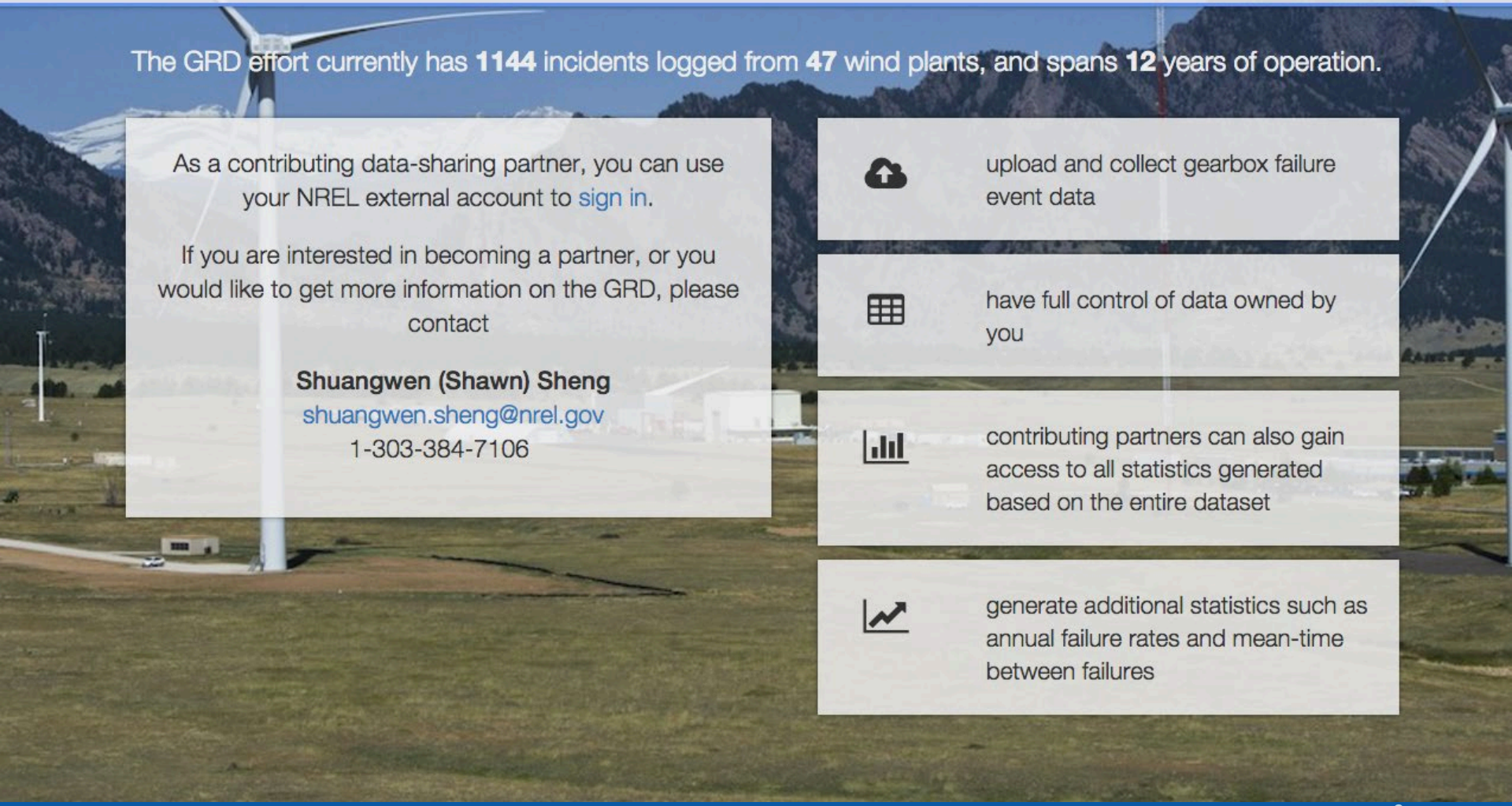
- Bearings: 76%, dominated by HSS and IMS bearings
- Gears: 17%, dominated by Helical gears
- Others: 7%, dominated by housing and lubrication & filtration system
- Both bearing and gear faults are concentrated in the parallel section.

http://energy.gov/eere/wind/articles/statistics-show-bearing-problems-cause-majority-wind-turbine-gearbox-failures

Reliability Database: Web Interface

- A centralized place
  - Data collection and results reporting
  - IEC 61400-4 nomenclature followed to accommodate multiple gearbox configurations
  - General public: sanitized information
  - Data-sharing partners with contributed data gain more insights
    - In-depth statistics on own data and all data contained in the database by removing data owner and source information
    - Collect data and upload data files

The **Gearbox Reliability Database** (GRD) is a unified data platform for utility-scale wind plant owners, operators, and other stakeholders along the gearbox supply chain. This effort aims to categorize top wind turbine gearbox **failure modes**, identify possible **root causes**, and direct future wind turbine gearbox reliability **research and development** (R&D) activities. By the end of 2015, the assets represented by only owner/operator partners on this effort comprised approximately 35% of the U.S. installed capacity.



The GRD effort currently has **1144** incidents logged from **47** wind plants, and spans **12** years of operation.

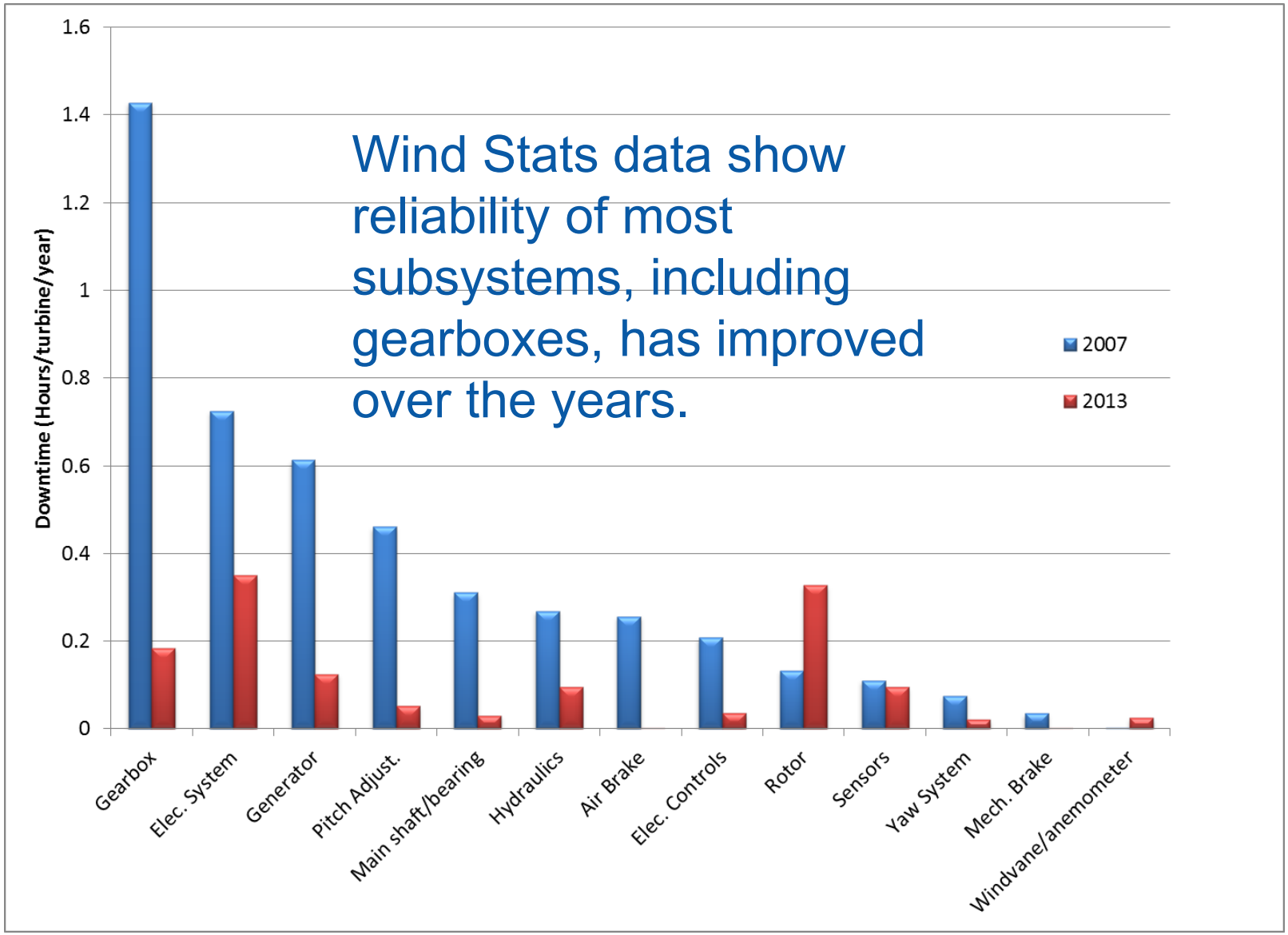
As a contributing data-sharing partner, you can use your NREL external account to sign in.

If you are interested in becoming a partner, or you would like to get more information on the GRD, please contact

Shuangwen (Shawn) Sheng
shuangwen.sheng@nrel.gov
1-303-384-7106

- upload and collect gearbox failure event data
- have full control of data owned by you
- contributing partners can also gain access to all statistics generated based on the entire dataset
- generate additional statistics such as annual failure rates and mean-time between failures

Gearbox Reliability Has Been Improved



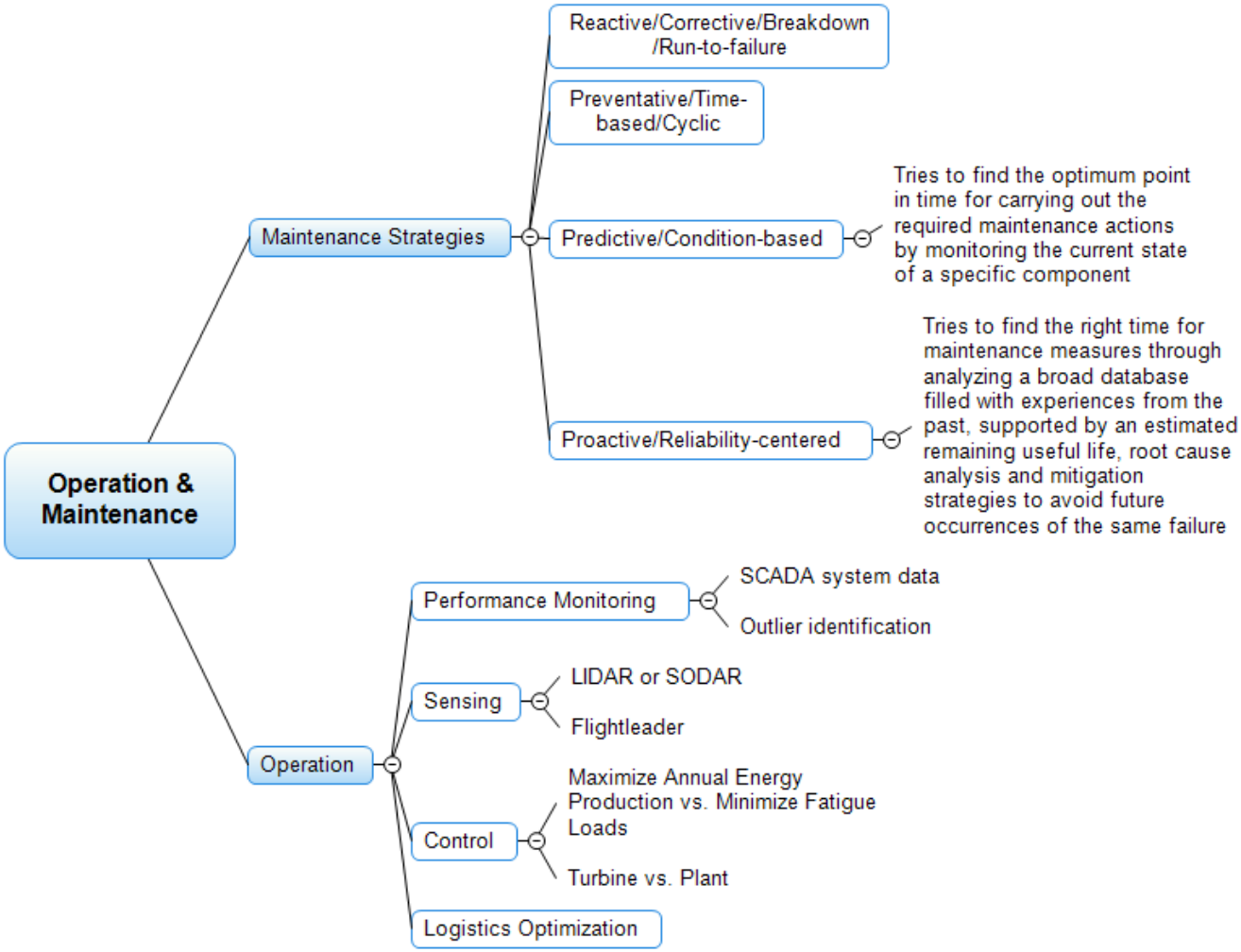
Data Source: Wind Stats Newsletter

Future Plans

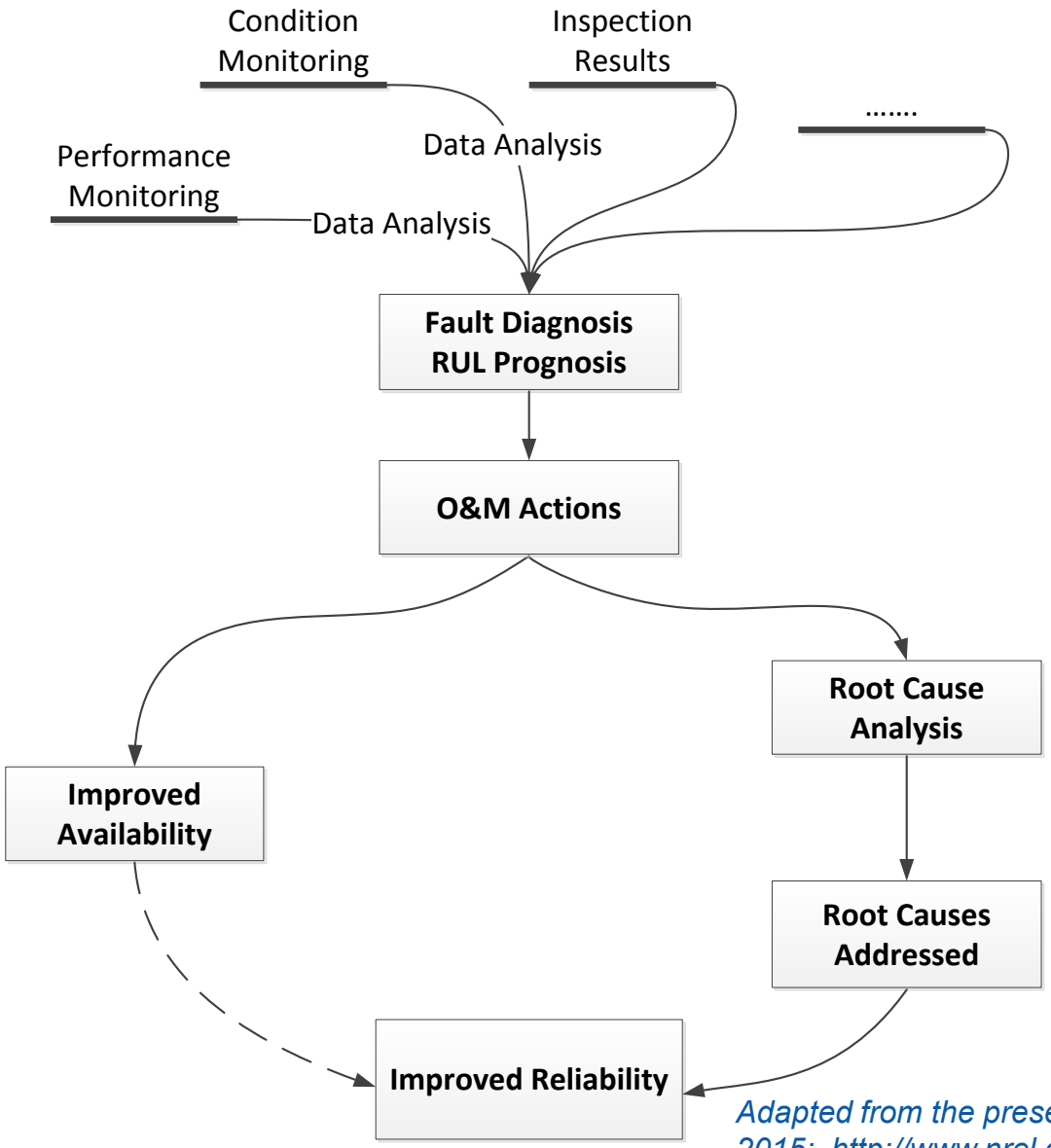
- Near-term:
  - Release Web Interface by end of June 2016
  - Focus on data collection and analysis
  - Target one dominant failure mode and release statistics based on the collected data
- Discussions:
  - Is this a valuable effort to your company?
  - If you are a data-sharing partner, what data fields would you like to add? What additional results would you like to see?
  - Is this an effort appropriate for DOE/NREL to continue?

Condition Monitoring and O&M

- Background on Condition Monitoring (CM): http://www.nrel.gov/docs/fy12osti/52748.pdf



Component Reliability Improvement through Performance and Condition Monitoring



- Performance and condition monitoring data analyses are two tools to achieve fault diagnosis and remaining useful life (RUL) prognosis
- Immediate impacts on O&M actions leading to improved turbine availability, an indirect measure of reliability
- Root cause analysis, if conducted and addressed, can lead to direct improvement in component reliability

Adapted from the presentation given at wind power monthly data forum 2015: http://www.nrel.gov/docs/fy15osti/64027.pdf

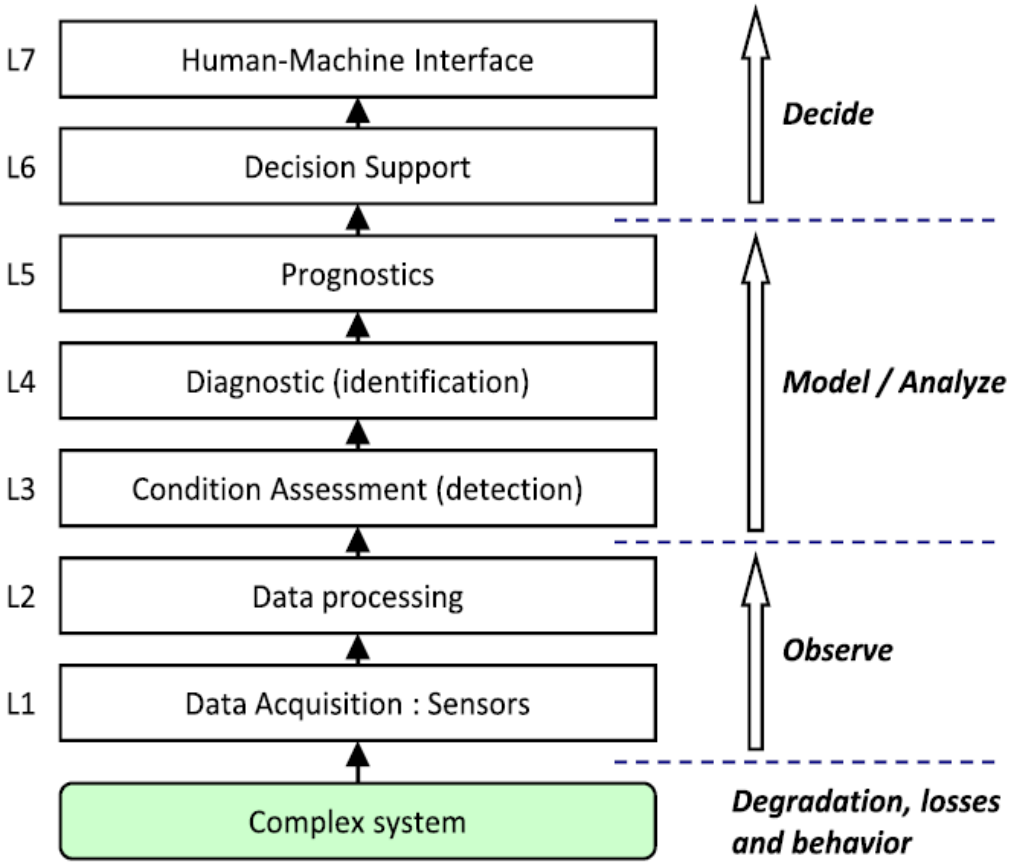
Maintenance for Mission-Critical Subsystems

Reactive Maintenance

Condition-Based Maintenance

Proactive Maintenance

Prognostics and Health Management (PHM): an approach to system life cycle support that seeks to reduce or eliminate inspections and time-based maintenance through accurate monitoring, incipient fault detection, and prediction of impending faults.



Source: M. Jouin et. al. (2013) International Journal of Hydrogen Energy

O&M R&D: Big Picture

- O&M research needs:
  - Majority of wind turbines (~370 gigawatts [GW]) installed worldwide are out of warranty
  - A 1% performance improvement: ~$1.2 billion additional revenue (assumed: 30% capacity factor, $120/megawatt-hour [MWh] electricity rate)
  - Extremely high replacement costs for most subsystems.[1]
- O&M cost reduction and business opportunities:
  - ~21% of life cycle cost for offshore plants and ~11% for land-based plants[2]
  - Further reductions achievable by improved O&M practices
  - Global O&M market likely to reach $20.6 billion by 2023.[3]

[1]W. Than et. al. Wind Energy, 2014.
[2]R. Meadows, Condition Monitoring Workshop, 2011.
[3]Offshore Wind Biz, Business Inside, 2015.

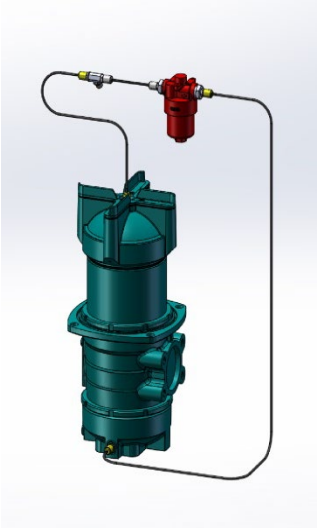
Actions to improve performance, reliability, and availability are more critical for offshore wind.

Status Update

- Vibration benchmarking datasets inquiries around the globe
- Compact filter field testing with first six units installed
- O&M research agreement with two universities and an owner/operator executed
- Publications:
  - Turbo expo 2015 integration of condition monitoring with gearbox design
  - WindTech International article on main shaft bearings
  - Journal article on oil and wear debris analysis—accepted
  - Journal article on main shaft bearing dynamics analysis—under review.
- Presentations:
  - Wind Power Monthly 2015 data forum presentation on improving component reliability through performance and condition monitoring
  - Wind Power 2015 on main shaft bearing dynamics in three-point suspension
  - Wind O&M Congress 2015 on compact filter analysis
  - Tribology Frontiers 2015 wind workshop on lubrication and monitoring.

Compact Filter Field Testing and Analysis

- Partners: Hydac, SGS Herguth, and an owner/operator
- Six sets were installed at a wind farm in Texas along with portable vibration inspections provided by FAG
- First set of samples was extracted and sent for analysis
- Looking for another partner to test four remaining compact filters.



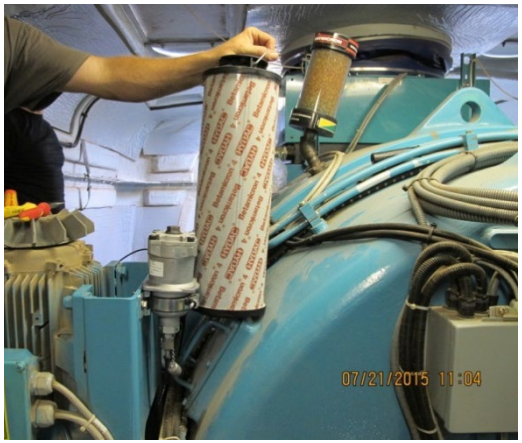


Photo and Illustration Source: Don Roberts

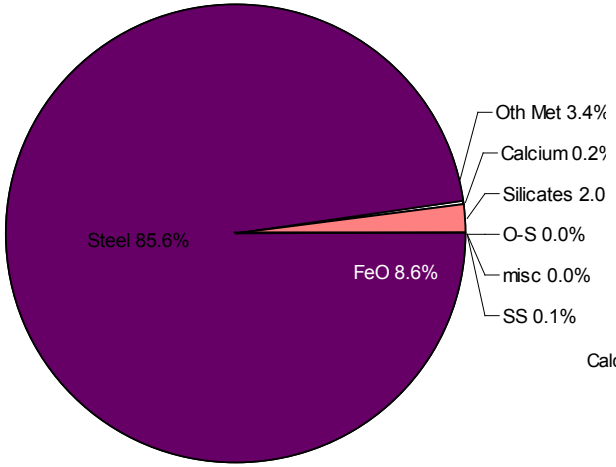
First Pair Analysis Results

Polymer layer of large filter

Glass layer of large filter

Steel mesh of small filter

- Majority of particles from both the large and small filters are steel
- Cutting the steel wire mesh of the small filter may have contributed to the stainless-steel content



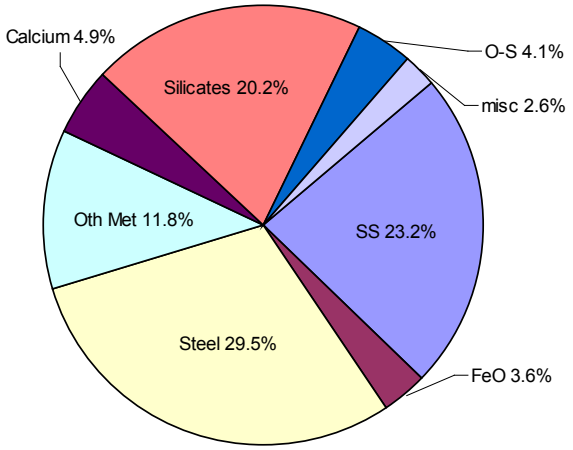


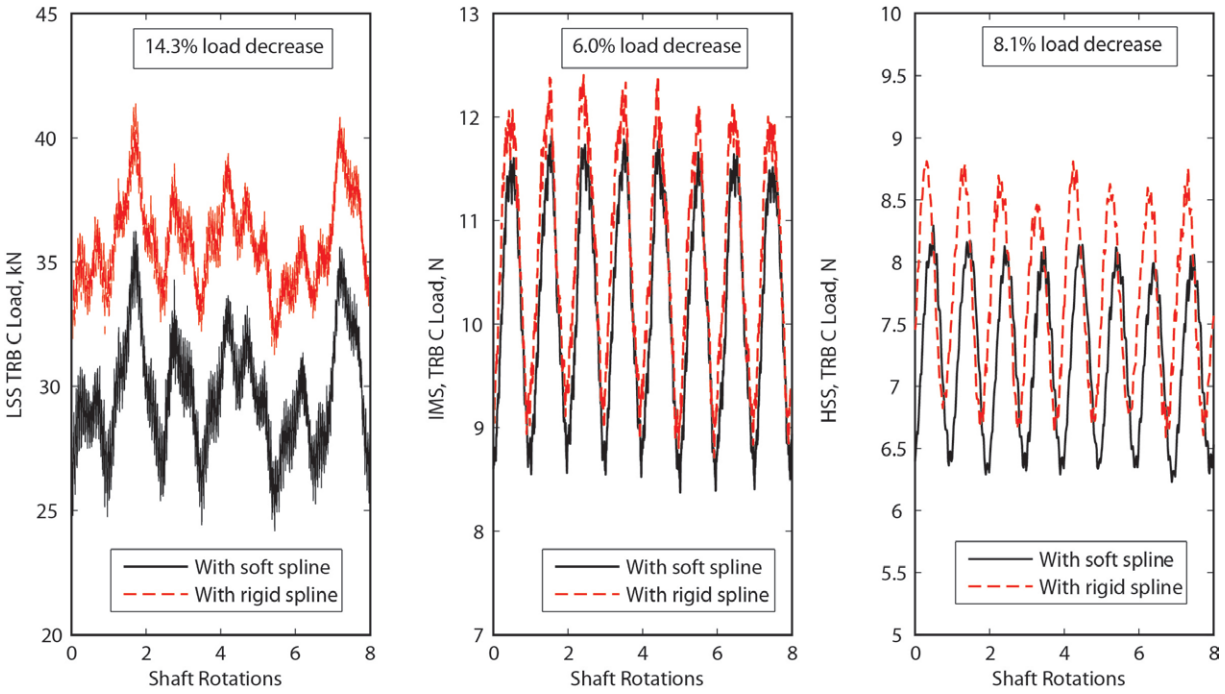
Photo and Illustration Source: SGS Herguth

Potential Benefits from CM to Design

- Soft sun spline led to 61.3% reduction in sideband index (SI) values for IMS gear set, indicating reduced sidebands or modulation levels

- A soft spline can lead to reduced bearing loads and help extend their lives

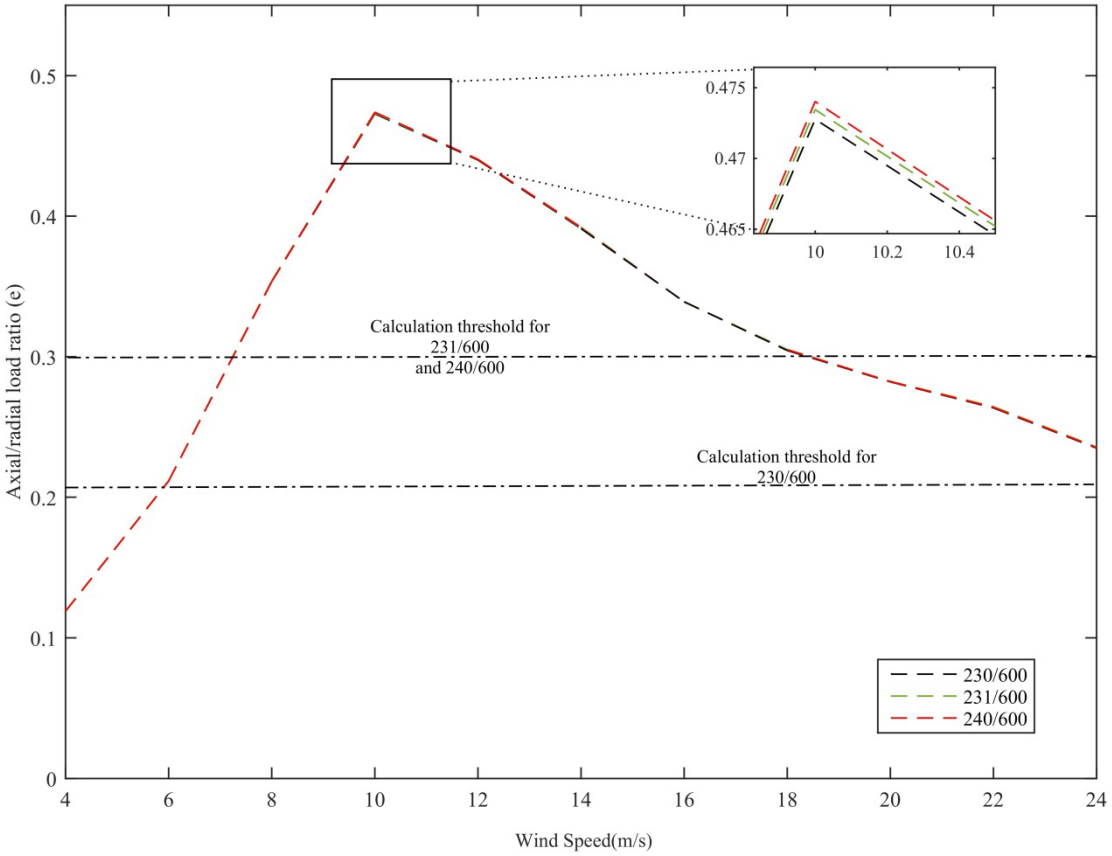
Gear Set	Sun Spline	SI Values (m/s^2)	Percent Difference (%)
IMS	Rigid	0.00733	61.3
	Soft	0.00284	
HSS	Rigid	0.06209	0.1
	Soft	0.06205	



Bearing loads on the IMS and HSS stages

Paper accepted by ASME Turbo Expo 2015: doi:10.1115/GT2015-43888

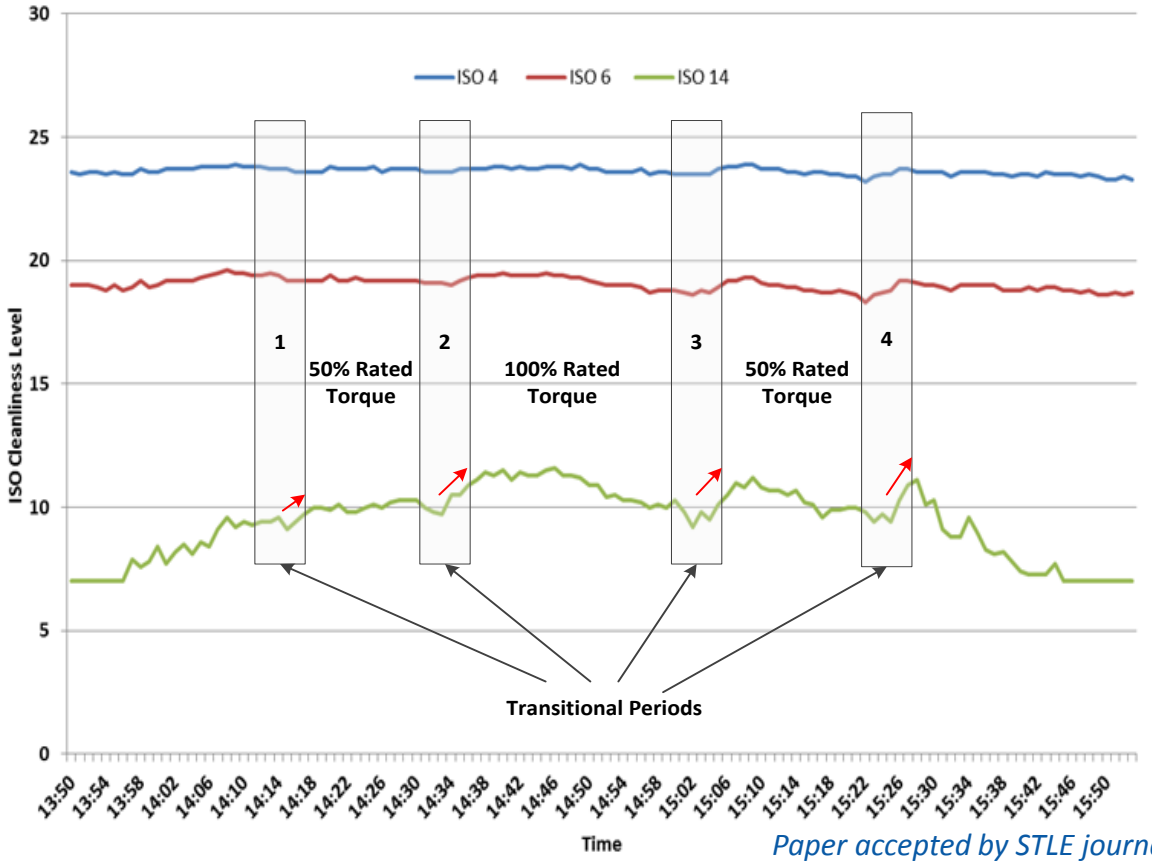
Three-Point Suspension Main Bearing Dynamics



- Presentation given at Wind Power 2015: *http://www.nrel.gov/docs/fy15osti/64311.pdf*
- Article by Windtech International: *http://www.windtech-international.com/editorial-features/features/articles/mitigation-of-micropitting-in-wind-turbine-main-shaft-bearings*
- Manuscript submitted to the journal of *Wind Energy*—currently under review.

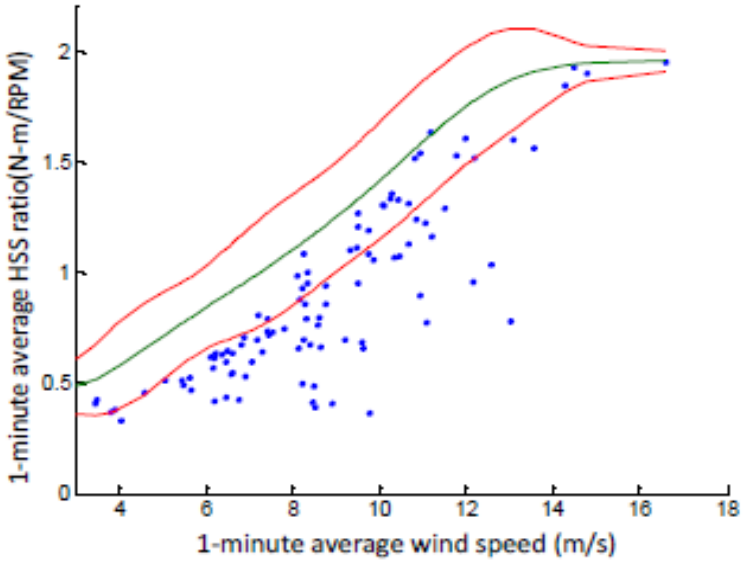
Oil and Debris Analysis: Impact of Transient Events

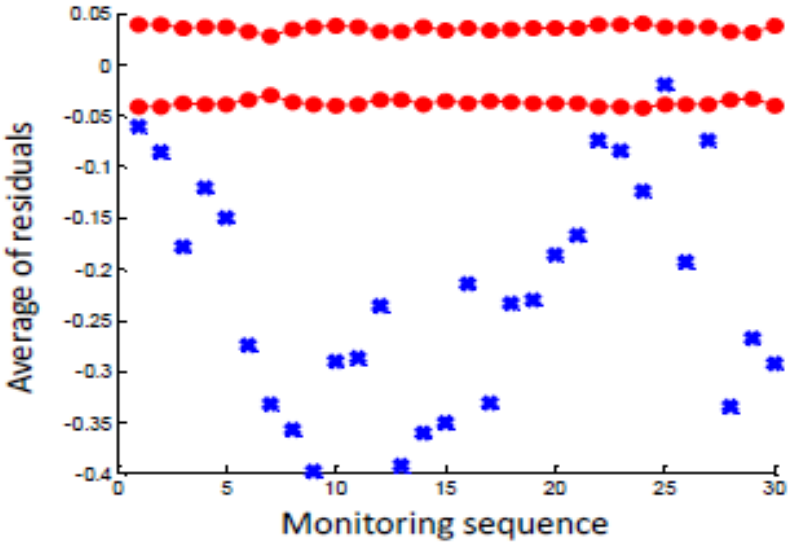
- Challenges:
  - Inconsistent oil-sampling practices
  - Huge variations in laboratory analysis results
  - Inconsistent terminologies used by different communities



Paper accepted by STLE journal of Tribology Transactions,
Doi: 10.1080/10402004.2015.1055621

Gear Failure Detection Based on SCADA Data





- High-speed shaft (HSS) ratio: HSS torque to HSS rpm
- Model developed based on normal operation
- Thresholds established based on a certain allowable false alarm rate
- Two angles: response and residual
- Abnormal: outside of established thresholds

New focus: RUL based on SCADA and other data streams

Paper published by IEEE Transactions on Energy Conversion, 29(2): 288-299.

Future Plans

- Near-term:
  - **SCADA and condition monitoring data analysis and modeling by considering big data techniques**
  - Continue compact filter testing and report results
  - Continue investigation of promising condition-monitoring techniques.
- Long-term:
  - Identify gaps in PHM for wind and conduct needed research to make it more beneficial to the industry
- Discussions:
  - What do you see is needed in condition monitoring and O&M (or PHM) research for wind industry, including land-based and offshore applications?
  - How can DOE/NREL or other governmental agencies better help you or the entire industry?

Thank You!

Special thanks go to the U.S. Department of Energy, compact filter testing, reliability database and condition monitoring research partners!

NREL's contributions to this presentation were funded by the Wind and Water Power Program, Office of Energy Efficiency and Renewable Energy, the U.S. Department of Energy under contract No. DE-AC36-08GO28308. The authors are solely responsible for any omissions or errors contained herein.

Photo by HC Sorensen, Middelgrunden Wind Turbine Cooperative, NREL 17855

shuangwen.sheng@nrel.gov
303-384-7106