NATIONAL RENEWABLE ENERGY LABORATORY

Prognostics and Health Management of Wind Turbines: Current Status and Future Opportunities

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Outline

- Introduction
- Current status
- Challenges and opportunities

Photo by Lee Jay Fingersh, *NREL 17245*

Introduction: Global Wind Energy

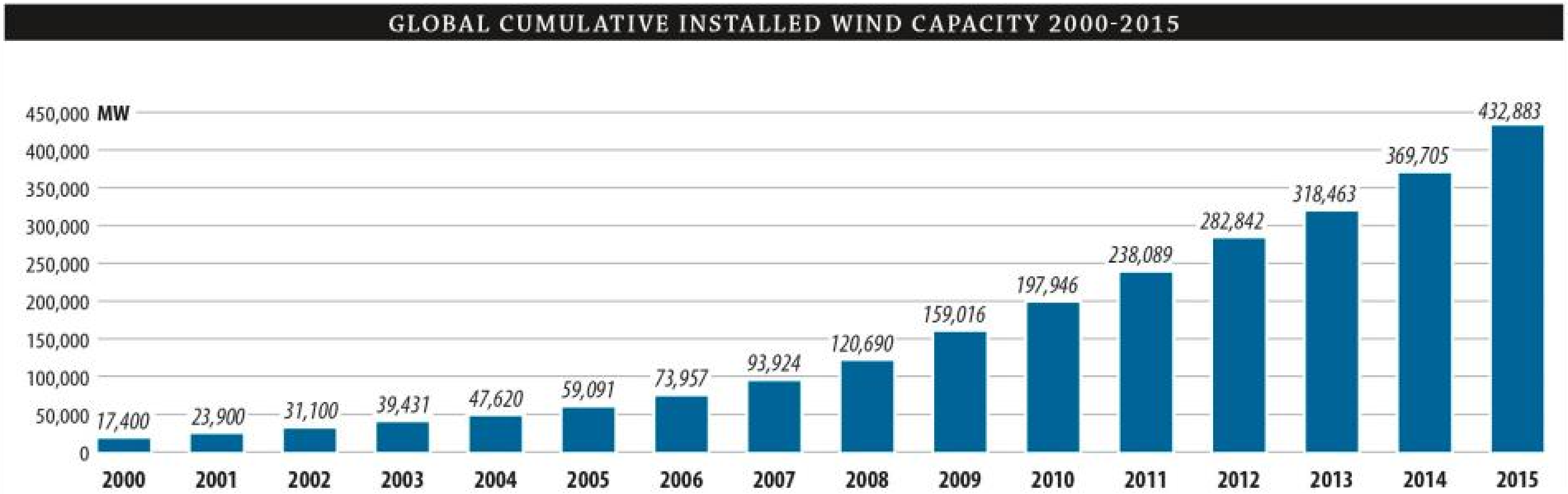


Figure from [1]

Photo by Iberdrola Renewables, Inc., *NREL 16706*

Photo by HC Sorensen, Middelgrunden Wind Turbine Cooperative, *NREL 17856*

Reliability of Turbine Subassemblies: Old Statistics

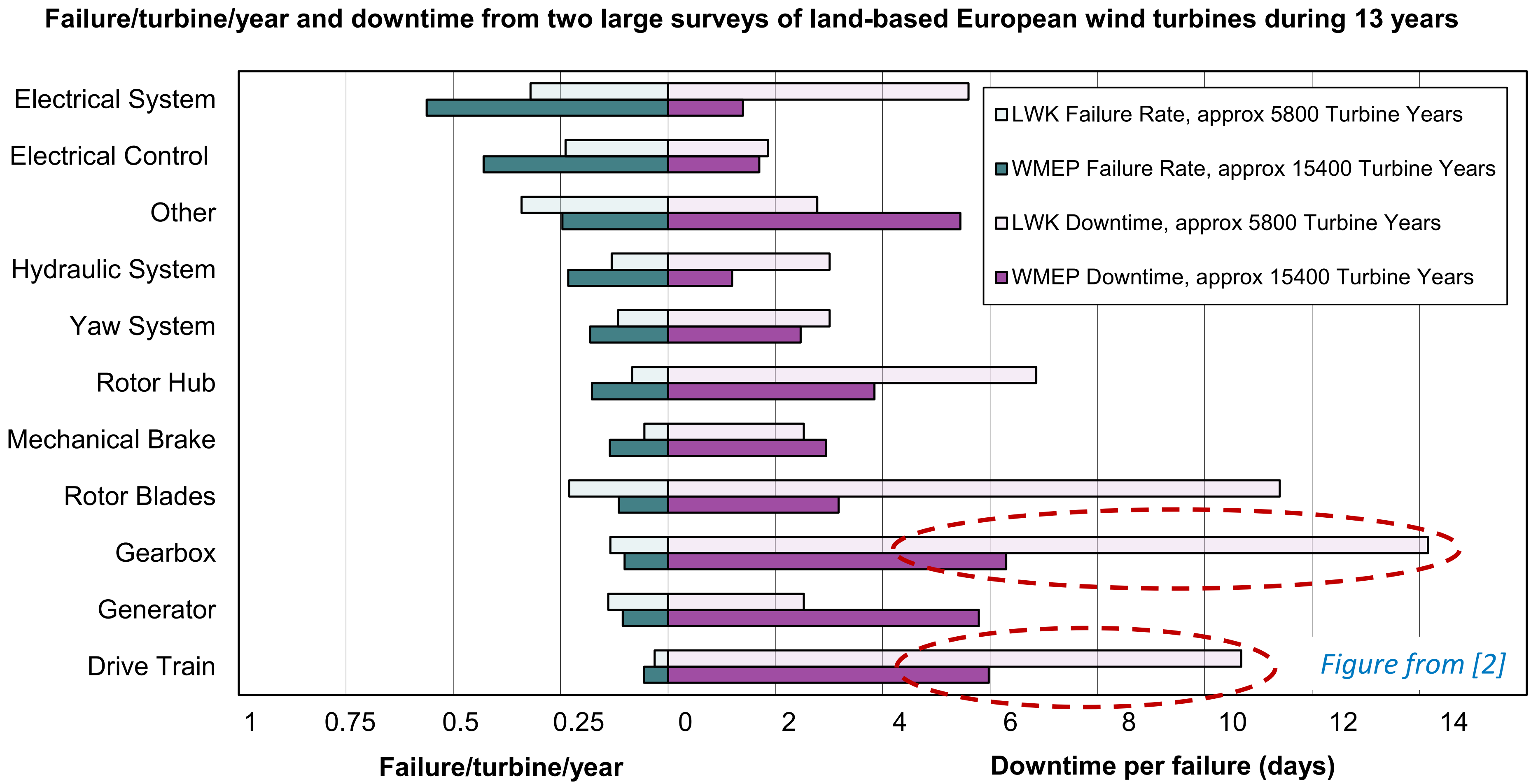
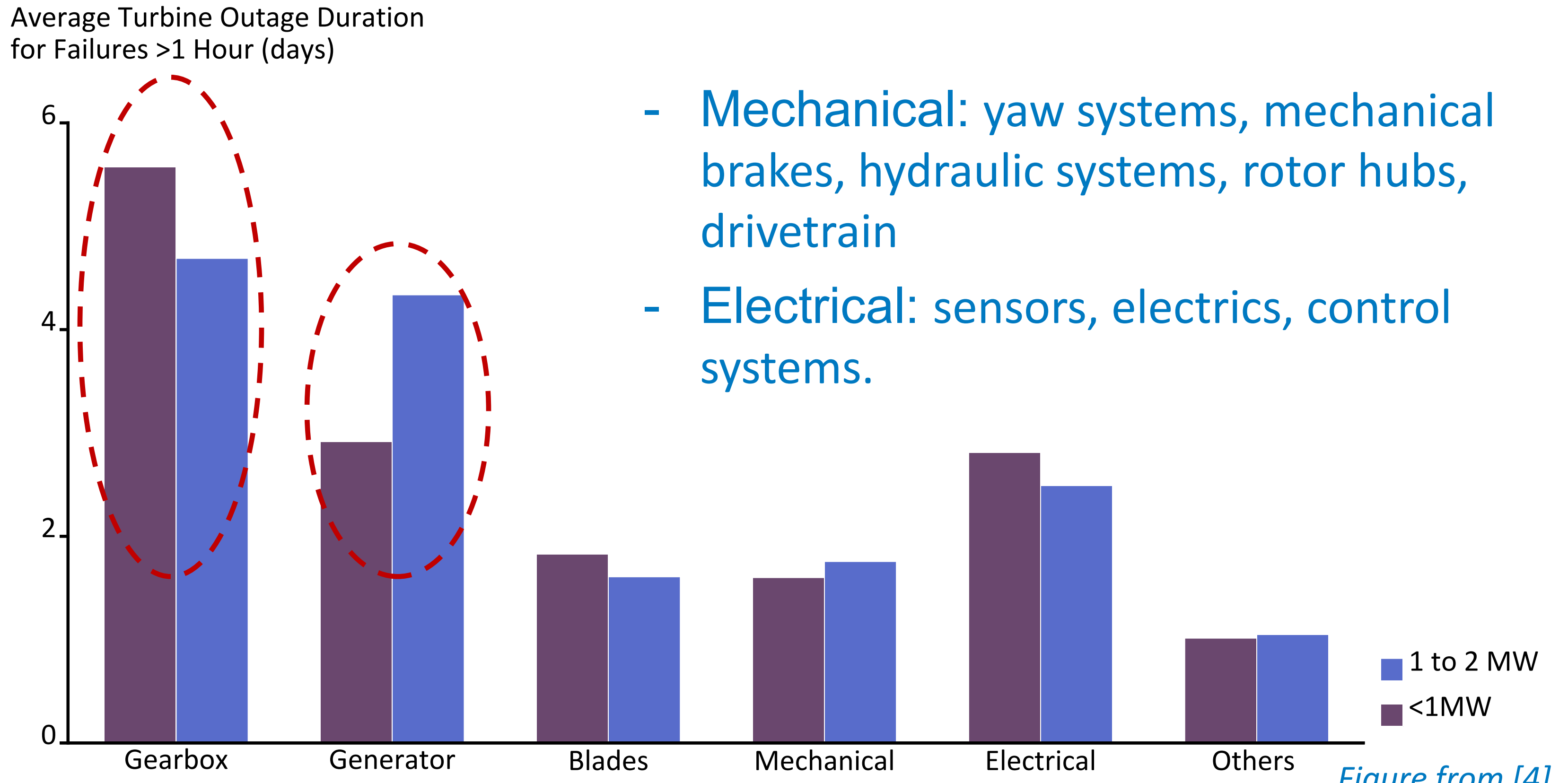


Figure from [2]

- The Wissenschaftliches Mess-und Evaluierungsprogramm (WMEP) database was accomplished from 1989 to 2006 and contains failure statistics from 1,500 wind turbines [3].
- Failure statistics published by Landwirtschaftskammer Schleswig-Holstein (LWK) from 1993 to 2006 contain failure data from more than 650 wind turbines [3].

Outage Duration for Different Subsystems: New Statistics

- Downtime caused by premature component/subsystem failures, led by gearboxes, challenges the wind industry and results in an increased cost of energy for wind power.



- Mechanical: yaw systems, mechanical brakes, hydraulic systems, rotor hubs, drivetrain
- Electrical: sensors, electrics, control systems.

Figure from [4]

Wind Power Plant Operation and Maintenance

- Operation and maintenance (O&M) research needs:
  - The majority of the wind turbines (~430 GW) installed worldwide are out of warranty.
  - A 1% performance improvement would equal an approximate $1.4 billion in additional revenue (assumed: 30% capacity factor, $120/MWh electricity rate).
  - The cost to replace most subsystems is extremely high [5].
- O&M cost reduction and business opportunities:
  - The life-cycle cost is approximately 21% for offshore plants and for 11% for land-based plants [6].
  - Further reductions are achievable by improved O&M practices.
  - The global O&M market will likely reach $20.6 billion by 2023 [7].
- Actions to improve performance, reliability, and availability are more critical for offshore wind.

Current Status: Focuses

- Subsystems on drivetrain: main shaft bearing, gearbox, and generator
- Layers 1 to 4: sensing, signal processing, fault detection, and diagnostics.

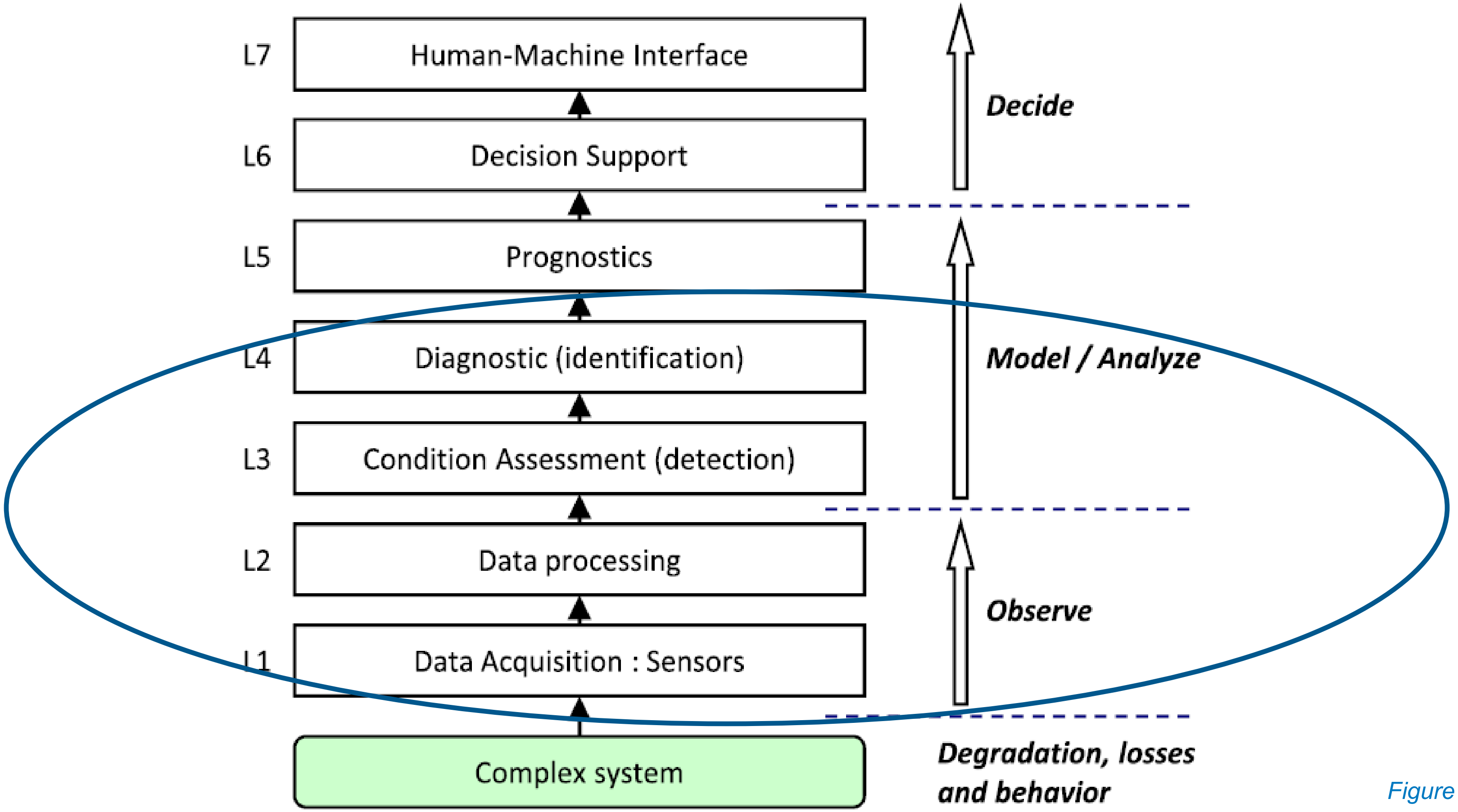
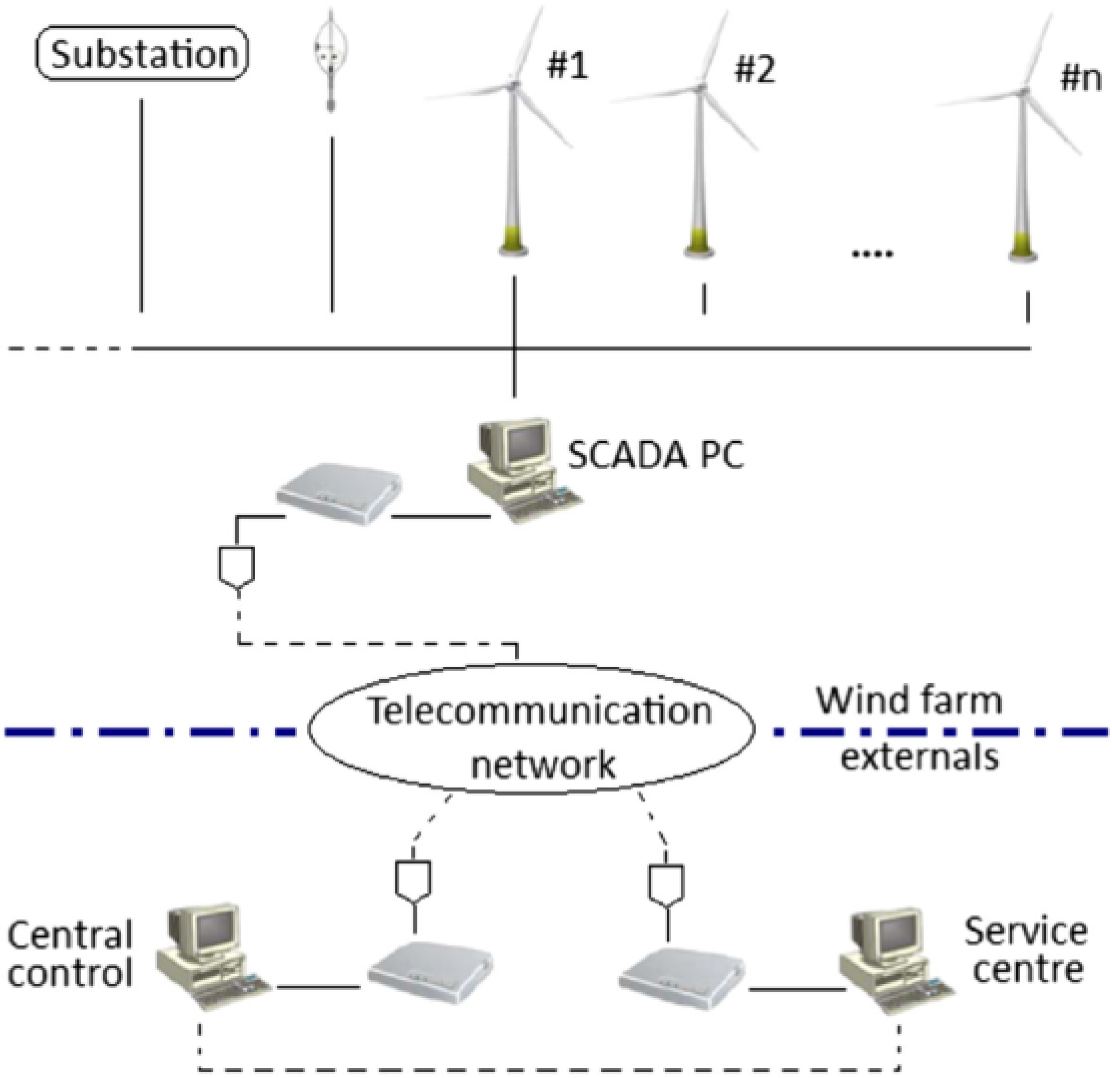


Figure from [8]

Typical Practices: Performance Monitoring



SCADA: supervisory control and data acquisition

Figure from [5]

Performance Monitoring

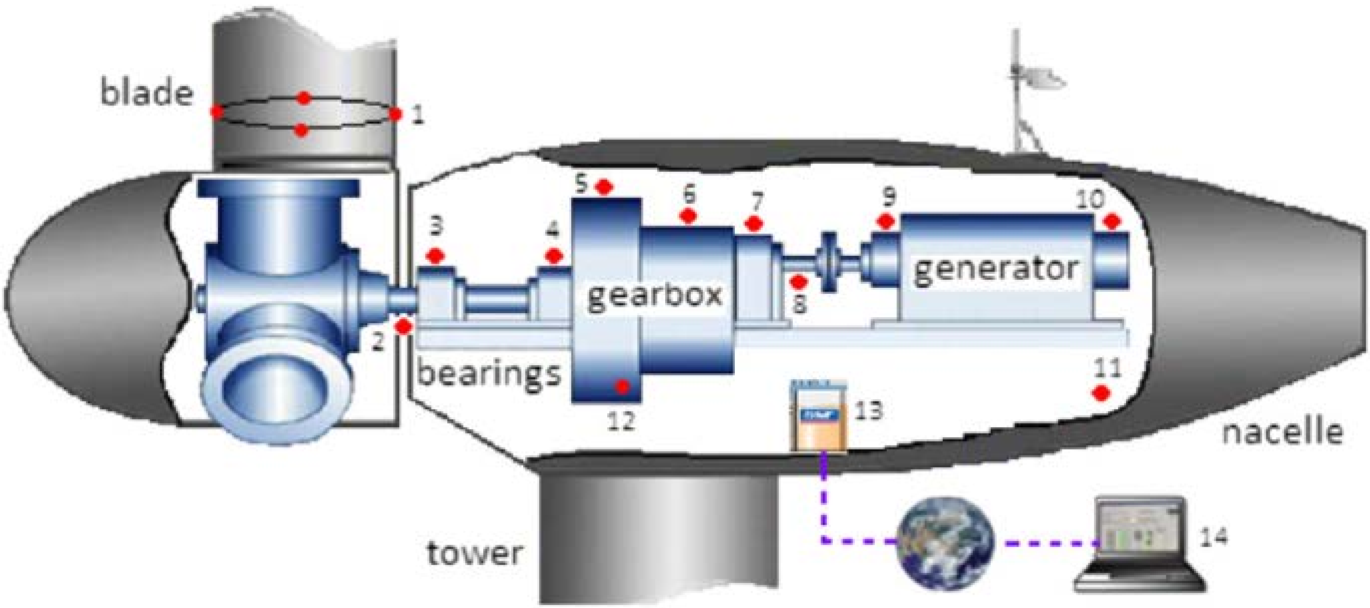
- Classification of measured parameters:
    - Wind parameters: e.g., speed, deviation
    - Performance parameters: e.g., power output, rotor speed, blade pitch angle
    - Vibration parameters: e.g., tower acceleration, drivetrain acceleration
    - Temperature parameters: e.g., bearing and gearbox temperature [9].
- Grouping of control system status report:
    - Status codes: e.g., error, warning
    - Operating states: e.g., brake, start, yaw, pitch [10].
- Analysis:
    - Correlate different groups of parameters (e.g., power and wind), develop models for normal operational states, and use these models to identify abnormal scenarios.
    - Conduct statistical analysis of events (e.g., status codes) experienced by turbines at a wind power plant.

Performance Monitoring

- Benefits [11]:
  - Readily available and no need for investments in dedicated condition monitoring instrumentation
  - Helpful for identifying outliers that may need further inspection by looking at key performance parameters or status codes.

- Drawbacks [11,5]:
  - May not be straightforward for pinpointing exact damaged subsystems/components (e.g., bearings or gears inside gearboxes)
  - Many false alarms caused by varying loads experienced by turbines
  - Does not meet full turbine condition monitoring needs, such as fault diagnosis.

Typical Practices: Condition Monitoring



1 --- fibre optic transducers; 2, 8 --- speed transducers; 3, 4, 5, 6, 7, 9, 10, 11 --- accelerometers; 12 --- oil debris counter; 13 --- online CMS; 14 --- PC at control center.

- Typical techniques [12]:
  - Acoustic emission (e.g., stress wave) or vibration analysis
  - Oil.

- Real-time continuous or offline periodic
- One or a combination of a few.

Figure from [5]

Condition Monitoring with the Drivetrain as a Focus

- Raw signal examples:
  - Accelerations, acoustic emissions
  - Oil debris counts, oil cleanliness measurements.
- Feature (condition indicator) examples:
  - Preprocessing: filtering
  - Time-domain statistical parameters: peak, root mean square
  - Frequency domain: gear meshing frequencies and sidebands, bearing fault frequencies, and their statistical values.
- Typical diagnosis:
  - Trending or rate of changes of features or condition indicators
  - Appearance of frequency components corresponding to certain faults or abnormal modulation of signal spectra
  - Violating thresholds set for certain features.

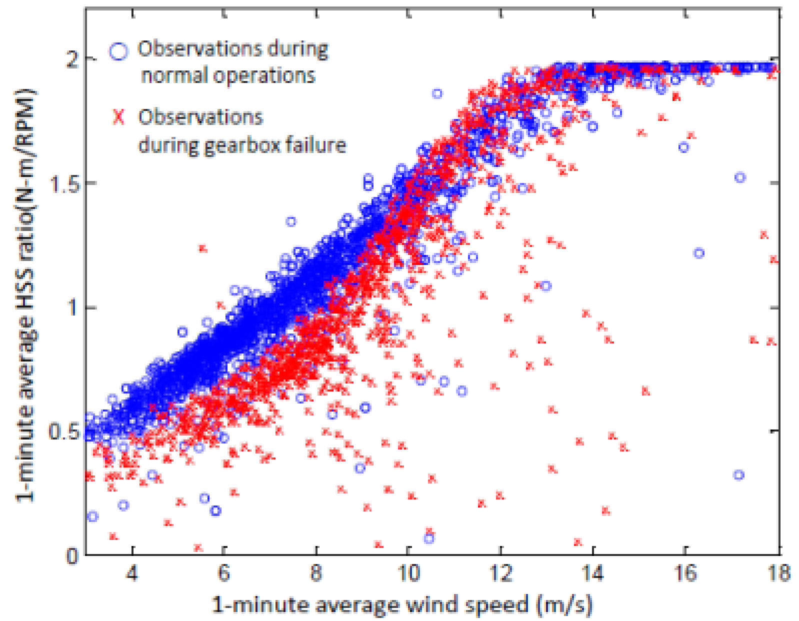
Condition Monitoring

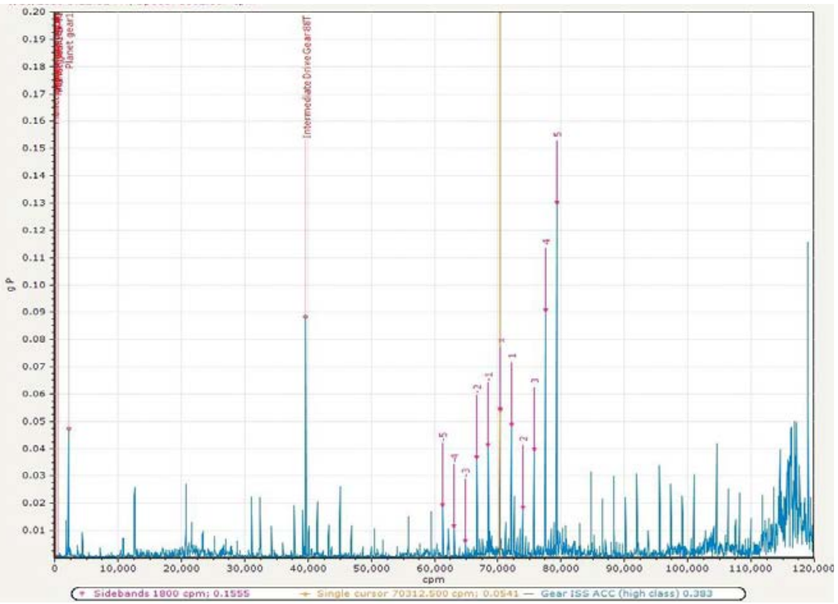
- Benefits:
  - Capturing high-frequency dynamics normally not achievable with a typical SCADA system
  - Identifying more failure modes occurred to turbine subsystems or components
  - Pinpointing exact damaged locations/components
  - Enabling condition or reliability-based maintenance, prognostics, and health management.

- Drawbacks:
  - Additional investment required for instrumentation and monitoring service
  - Dedicated resources on data analysis and interpreting results.

Summary

- SCADA data mining is picked up gradually.
- Deployment level of dedicated condition monitoring systems increases.
  - Most have one condition monitoring technology: e.g., vibration analysis, oil debris monitoring.
  - Regular oil sample analysis is typical.
  - Borescope inspections are conducted regularly or triggered by events.





Challenges

- The revenue margin is thin for the wind industry, and any prognostics and health management (PHM) solutions that are expected to be widely adopted need to be cost-effective.
- Variable and harsh operating conditions limit turbine accessibility for conducting maintenance.
- There are different types of turbines, each with a large number of components that can fail in dramatically different ways—e.g., axial cracks.
- There is not enough mining of SCADA data for O&M practice improvements.
- Vibration analysis may have challenges with low-speed-stage subsystems/components.
- Oil sample analysis may suffer from sample variations, and different lubricants may require different sets of tests or procedures.
- Offshore adds additional complexities due to the need to consider foundations and undersea transmission lines, saltwater and wave influences on turbines, and weather forecasts.

Opportunities

- PHM in the wind industry has been focusing on the first four layers, and gaps among the other layers need to be filled to maximize the benefits of PHM to wind.

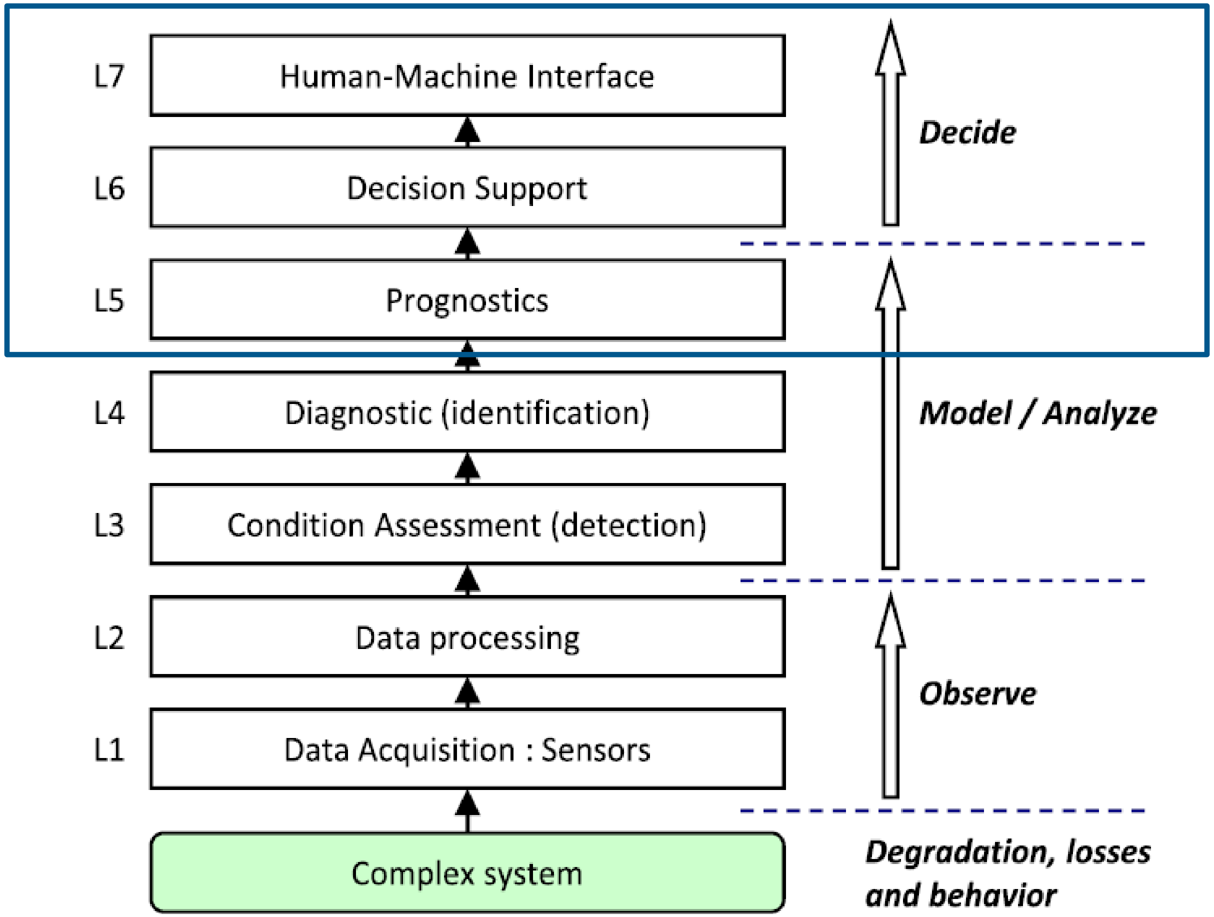


Image from [9]

Opportunities

- **Research improved use of SCADA data.**
- Study effective and reliable sensing for low-speed-stage components.
- Improve accuracy and reliability of diagnostic decisions, including level-of-severity evaluation.
- Develop reliable and accurate prognostic techniques to enable remaining useful life estimation of turbine components/subsystems.
- Target new technologies for next critical subsystem/component in wind turbines.
- Research plant-level or fleet-wide condition monitoring and asset management technologies .

Opportunities

- Fuse various data streams to optimize O&M practices, reduce loads, and extend life of turbine subsystems/components.
- Automate data interpretation to deliver actionable maintenance recommendations.
- Make use of emerging technologies, such as cloud storage, big data analytics, and the Internet of Things.
- Conduct PHM for offshore wind turbines and balance-of-plants.
- Perform field application feasibility study and cost-effectiveness analysis for PHM solutions.
- Standardize PHM practices.

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Thank you!

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