Risk and asset management for wind turbines
BINDT Workshop on NDT and SHM requirements for Wind Turbines

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Date: 13th February 2019
Total: 116,393 MW
Total Asset Management

Environmental and Safety compliance
- Environmental risk management and mitigation

Safety compliance
- Implementation of applicable Safety Rules and safe systems of work

Environmental compliance

Commercial administration
- Commercial and financial services for renewable projects including revenue and budget management

24/7 ControlCentre
- 24/7 Monitoring – based on real-time access to operational data, including site access, work control and grid services
  - 1200+ WTG monitored

ControlCentre
- High Voltage system management
- Management of high voltage (HV) site infrastructure both onsite and remotely, including OFTO services
  - 1500+ WTG monitored

High Voltage

Service and repair
- Minor corrective maintenance and routine servicing, including spare part procurement and management
  - 200+ MW servicing portfolio

Inspections
- Bespoke inspections at the commissioning and operational phases

Performance analytics
- Asset performance reporting and benchmarking informing predictive maintenance and optimisation

Site management
- Proactive management of contracts and stakeholders on behalf of our clients through a local onsite presence
  - 1.5GW+ under management

Commercial administration

Performance analytics
Understand the inspection problems faced by the manufacturers and operators of wind turbines;

Establish the requirements for improved NDT solutions for thick-section large composite structures, metallic components and systems

Consider the application of emerging inspection tools and technologies.
Dedicated on-site personnel with high degree of ownership of individual assets

Proactive approach to ensure the efficiency and longevity of assets

Health and safety – core to all operations

Continuous development towards implementation of lower cost solutions to routine maintenance issues

Effective governance and auditing procedures

Continuous process improvement and active innovation R&D

Schedule work during planned downtimes and low wind periods to reduce losses

Service and repair functions include:

Routine maintenance - main service and interim service provided annually and including:

Cleaning, painting and lubricating of key components

Visual inspections and parts replacement

Oil and filter changes

Brake checks

Battery checks
Advanced performance engineering

- Initial health check requirements
- Benchmark on annual basis
- In-house Analytics team
- Vibration analysis and Condition Monitor System – CMS/SCADA
- Dedicated Inspection and HV teams

Communications and reporting

- 24/7 Control centre
- Collaborative approach across Natural Power and Stakeholder teams
- Defined point of contact for client communications
- Near real time reporting accessible through Natural Power Portal
Our services are intended to compliment each other and provide an overlap in order to fully understand and provide insight into the health status of the turbine.

➡ Physical Inspections
- Commissioning Inspections
- Snagging Inspections
- Endoscopic Gear Box Inspections
- Endoscopic Main Bearing Inspections
- End of Warranty Inspections
- HD Blade Inspections – onshore / offshore
- Onsite Assembly
- Due Diligence Inspections
- Component Inspections during fabrication / assembly
- Thermographic Studies

➡ Advanced Performance Engineering
- Review of SCADA / CMS data

➡ Post Warranty Health Assessments
State of the art endoscopic images of the internal individual components of the drivetrain can be captured.

Gear and Bearing features are classified according to ISO standards.

ISO 10825/ISO 15243

Bearings and Gears demonstrating normal wear are pictured here.
Main Bearing Inspections
Visual inspection of main bearing

- State of the art endoscopic images of the internal individual components of the main bearing can be captured;
  The challenge lies in cleaning the inspection area of all grease prior to endoscopy

- Bearing features are classified according to ISO standards.
  ISO 10825
SCADA review is entirely dependant on what on board sensors are available and what information is stored in the turbine’s CPU. Previous analysis has looked at:

- Capacity Factors and Wind Speed data analysis
- Tower oscillation analysis
- Particle Counter analysis, this is directly inline with any oil sample analysis
- Temperature analysis
  - Rotor bearing
  - Gearbox bearing
  - Generator bearing
  - Gearbox oil sump
  - Control cabinet temperature
    - Top box and bottom box
- Yaw and Pitch analysis
- Power Analysis, including power curve analysis
- Consistency check
- Peak Oscillation check
- RMS
- Ensure all levels are within limits set out by VDI and ISO standards for consistency
- This vibration monitoring is very low frequency

- Adoption of the vibration limits specified in VDI 3834, which specifies 60 mm/s RMS (0.1-10 Hz) as the warning alarm level for an on-shore wind turbine up to 3 MW
- Extract from VDI 3834:

<table>
<thead>
<tr>
<th>Component</th>
<th>Evaluation acceleration in m/s² rms</th>
<th>Evaluation velocity in mm/s rms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nacelle and tower</td>
<td>Frequency range ≤ 0.1 to 10 Hz</td>
<td>Frequency range ≤ 0.1 to 10 Hz</td>
</tr>
<tr>
<td></td>
<td>Band limit I/II</td>
<td>Band limit I/II</td>
</tr>
<tr>
<td></td>
<td>Band limit I/III</td>
<td>Band limit I/II</td>
</tr>
<tr>
<td></td>
<td>0.3</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>0.5</td>
<td>100</td>
</tr>
</tbody>
</table>
Trends in the data give an indication of which gearbox rates of count increases fastest.

Corroboration with oil sample analysis yields a good indication of an issue.

Increases in temperature also aid verification.

A gearbox inspection provides an excellent visual of potential damage and sources of increases in particle count.

ISO 4406

<table>
<thead>
<tr>
<th>Sample ID:</th>
<th>Wear</th>
<th>Contamination</th>
<th>Chemistry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2861719</td>
<td>3.00</td>
<td>2.00</td>
<td>1.00</td>
</tr>
<tr>
<td>taken on 08 June 2016</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Comment:

Oil sample results are presented in traffic light colours, green for acceptable and red indicating high levels of wear, contamination and/or chemistry.
A CMS review is a high frequency vibration analysis of the onboard accelerometers (vibration sensors).

- Requires access to the raw data, including the signal processing parameters.
  - Sampling parameters
- Key frequencies are shaft rotational frequencies, gear meshing frequencies, single tooth fault frequencies, planet passing frequencies and bearing fault frequencies
- Identifying these frequencies in the measured dataset can be used to identify sources of vibration (frequency domain analysis)
- Knowledge of the gearbox kinematics is also required
Standards exist for consistency.

Adoption of the vibration limits specified in VDI 3834, which specifies 3.5 mm/s RMS (10-1000 Hz) as the warning alarm level for an on-shore wind turbine up to 3 MW.

Extract from VDI 3834:

<table>
<thead>
<tr>
<th>Component</th>
<th>Band 1 – suitable for continuous operation</th>
<th>Band 2 – Not suitable for continuous operation without further inspection</th>
<th>Band 3 – Dangerous, machine not to be operated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nacelle and tower</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation acceleration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in m/s² rms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation velocity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in mm/s rms</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range ≤ 0.1 to 10 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band limit I/II</td>
<td>0.3</td>
<td>0.5</td>
<td>60</td>
</tr>
<tr>
<td>Band limit II/III</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Frequency range 10 Hz to 1000 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band limit I/II</td>
<td>0.3</td>
<td>0.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Band limit II/III</td>
<td></td>
<td></td>
<td>3.2</td>
</tr>
<tr>
<td>Rotor with roller bearing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gearbox</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range ≤ 0.1 to 10 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band limit I/II</td>
<td>0.3</td>
<td>0.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Band limit II/III</td>
<td></td>
<td></td>
<td>5.6</td>
</tr>
<tr>
<td>Gearbox</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frequency range 10 Hz to 2000 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band limit I/II</td>
<td>7.5</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>Frequency range 10 Hz to 5000 Hz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Band limit I/II</td>
<td>10</td>
<td>16</td>
<td>5.0</td>
</tr>
<tr>
<td>Band limit II/III</td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>
Natural Power Engineers complete a visual inspection of the turbine, including:

- Tower (internally and externally)
- Electrical cabinets and transformer
- Nacelle
- Hub

Any damage, defects or anomalies are documented and reported.

On behalf of the client Natural Power can produce a snagging list of defects that the turbine manufacturer must address.

These defects will be reviewed once resolved.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Significant Defect Requiring Immediate Repair</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>Indication of Potential Long Term Issue</td>
<td>6</td>
</tr>
<tr>
<td>C</td>
<td>Defect Requiring Rectification</td>
<td>19</td>
</tr>
<tr>
<td>D</td>
<td>Information</td>
<td>2</td>
</tr>
</tbody>
</table>

Total: 25
Thermographic Inspections
Visual assessment of the electrical components

What are we looking for?
- Physical damage within a single cell
- Faulty connections
- Defective bypass diodes
- Electrical interconnection problems
- Cracks in cells
- Manufacturing defects

Advantages of thermography for turbine maintenance:
- Prevents costly downtime
- Accident prevention
- Quick and efficient scanning of large objects
- Allows repair/replace components before failure occurs

Using state of the art thermographic technology, thermal imagery of turbine components can be collected and analysed
What we don’t wish to happen

Visual damage to the drivetrain components

- Gear and Bearing damage is always classified according to ISO standards.
  ISO 10825/ISO 15243
- Bearing and Gear defects seen here are classed as catastrophic failures
- Modern turbines have a vast range of innovative technologies on board to allow defects to be picked up and monitored before failures such as these occur
- These types of images can be prevented
When failure occurs

Natural Power support and oversight

- Gearbox and Main Bearing Exchanges
- In-situ Bearing Replacements
- Seal Replacements
- Lubrication System installs and repairs

Review:
- Processes
- Equipment
- Procedures

Offer recommendations:
- Based on on-site observations
- Knowledge of standards
- Health and safety practices
## Cost of Replacement

<table>
<thead>
<tr>
<th>Component</th>
<th>Estimated Cost (USD)</th>
<th>£k</th>
<th>€k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bearings</td>
<td>8-14 k</td>
<td>5.5-10</td>
<td>6.5-11.5</td>
</tr>
<tr>
<td>Gears</td>
<td>20-25 k</td>
<td>15-20</td>
<td>16-20</td>
</tr>
<tr>
<td>Lubrication System</td>
<td>2-10 k</td>
<td>1.5-5</td>
<td>1.5-8</td>
</tr>
<tr>
<td>Crane Costs</td>
<td>Excess of 15 k for mobilisation and 5 k/day</td>
<td>10 k mobilisation and 3.5 k/day</td>
<td>12 k mobilisation and 4 k/day</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Up-tower</th>
<th>Down-tower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated Crane Costs</td>
<td>GBP 7-14 k</td>
<td>GBP 170-340 k</td>
</tr>
</tbody>
</table>
Natural Power Engineers offer a range of services designed to help our client with predictive maintenance measures.

It is important to stress that these measures are most effective when combined:
- Visual damage to electrical cabinets can be supported by thermographic results.
- Rises in gearbox temperature can be explained by oil particle count and oil sample analysis.
- Increases in vibration level from the gearbox can be supported by endoscopic visual imagery of any damage that may be present.
- Any drops in capacity factor could be investigated by looking at aerodynamic issues, a potential source is blade defects.

Data does not always come in a signal form:
- Imagery is just as important.
- Discussions with industry leaders and collaborations regarding techniques we could employ are essential.

Natural Power adopt a Predictive Maintenance approach to Asset Management:
- Good monitoring combined with a good inspection and maintenance regime is essential.
- Combining every data type at our disposal is key.