Risk and asset management for wind turbines

BINDT Workshop on NDT and SHM requirements for Wind Turbines

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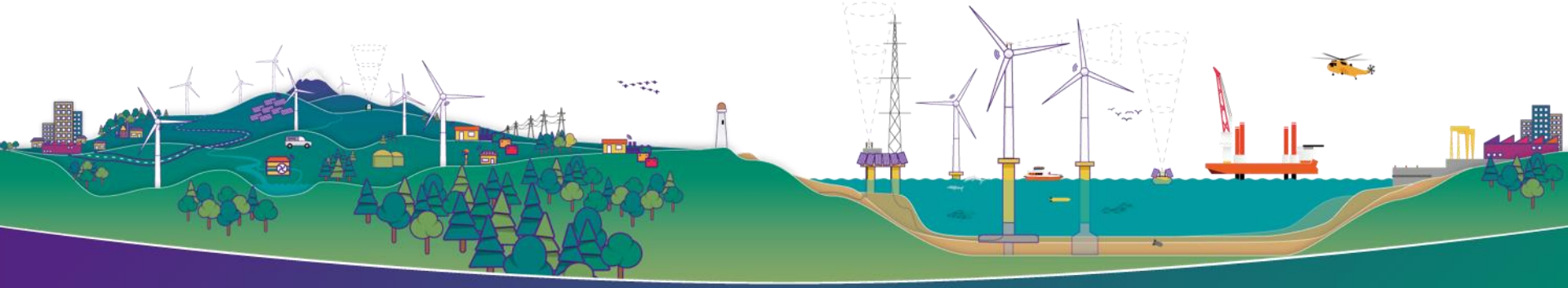
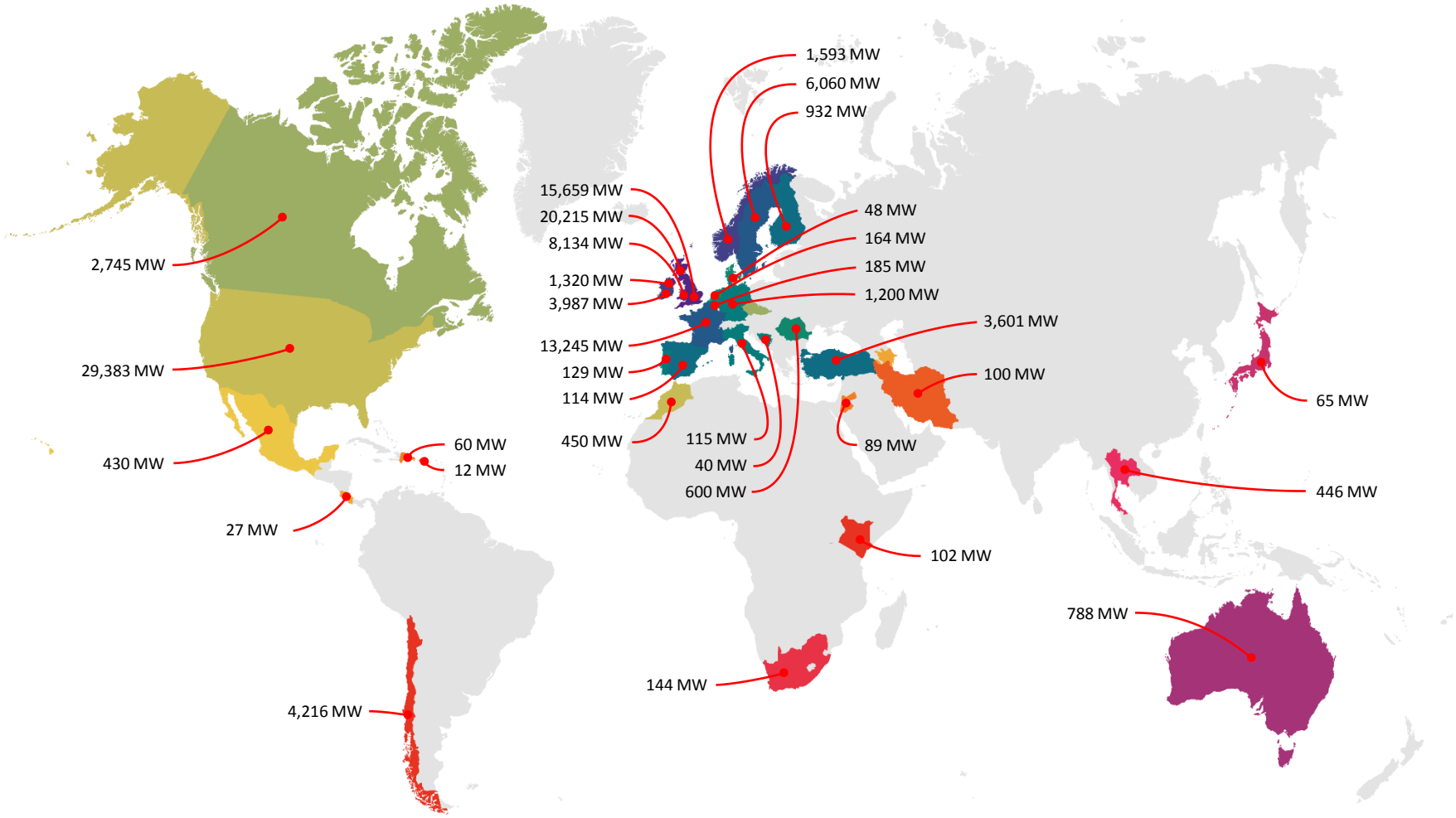
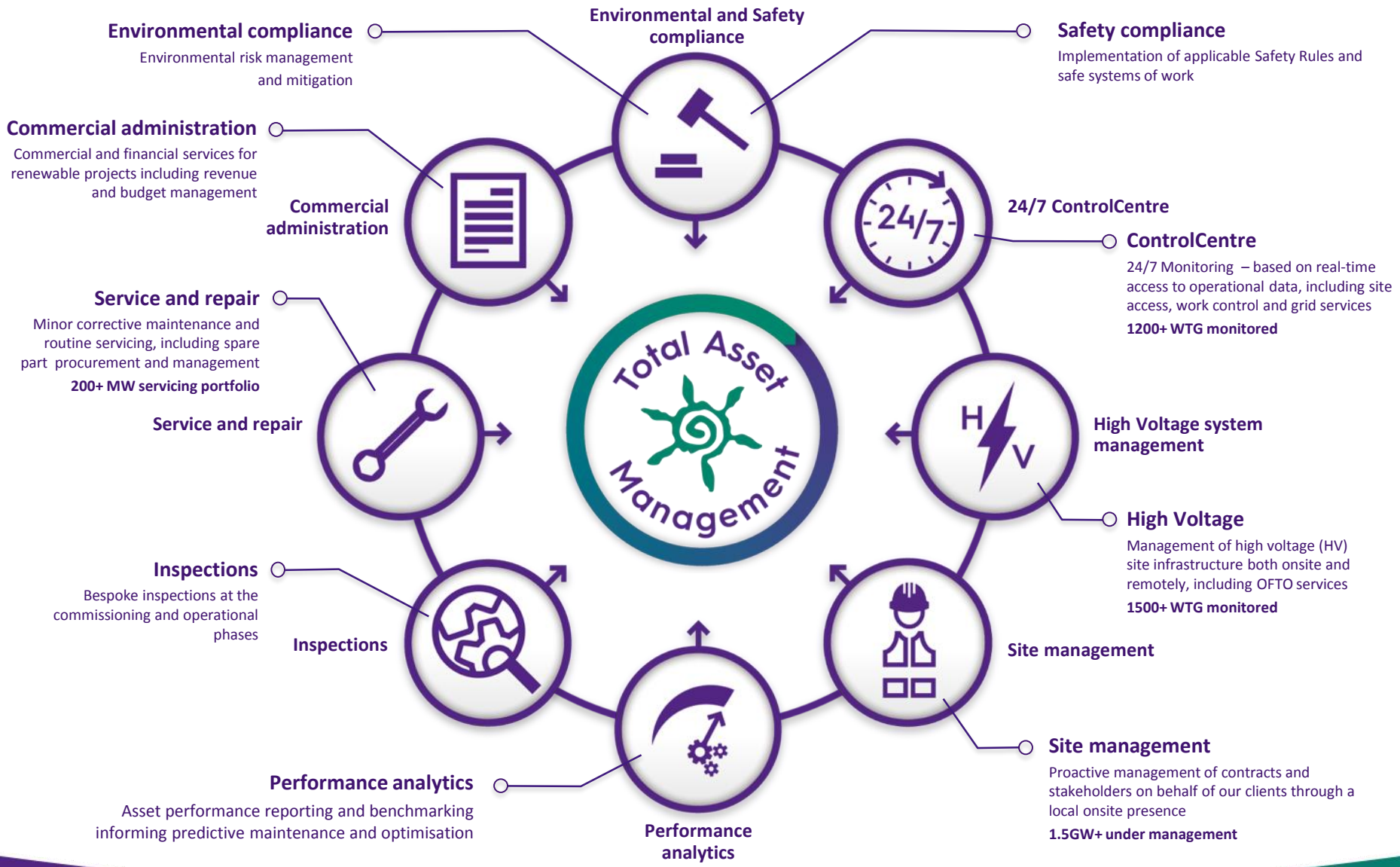


Global Experience

Total: **116,393 MW**



Total Asset Management



BINDT Workshop Aims

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.

Service Team Overview

- 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

Value Added Approach

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

Inspection Services Overview

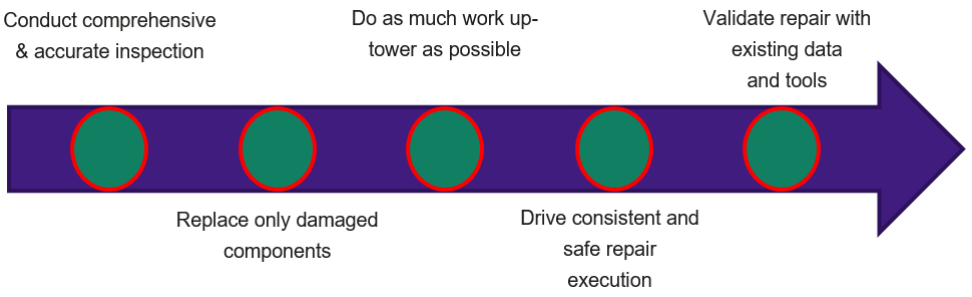
Our services are intended to compliment each other and provide an overlap in order to fully understand and provide insight into the health status of the turbine.

➜ 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



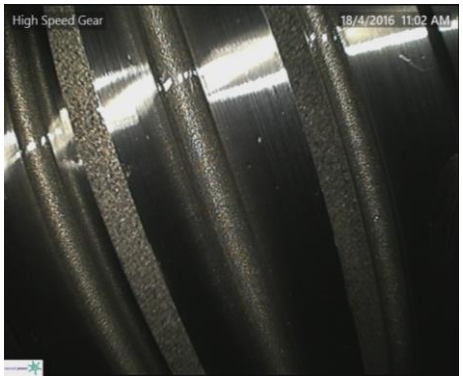
➜ Post Warranty Health Assessments

Gearbox Inspections

Visual inspection of gearbox components

- 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.

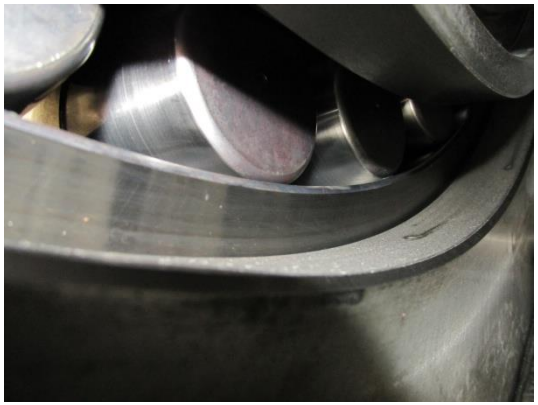
  ISO 10825/ISO 15243
- Bearings and Gears demonstrating normal wear are pictured here

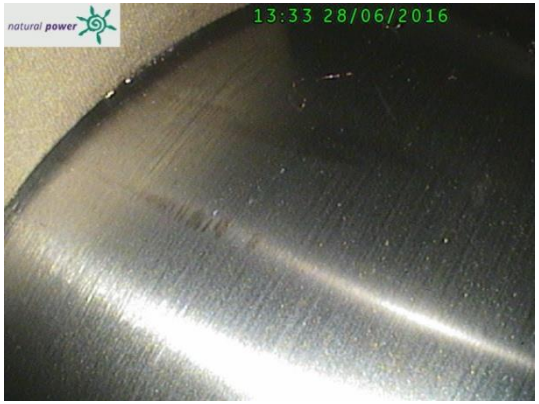


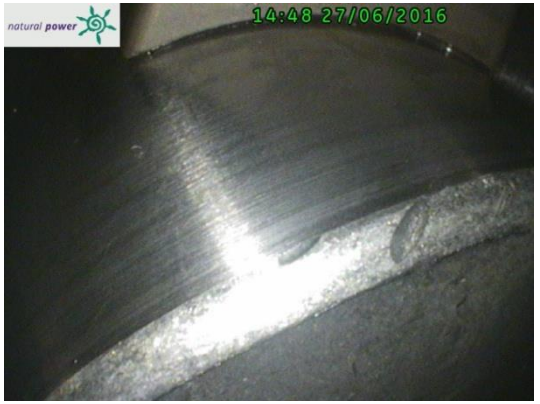
Main Bearing Inspections

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



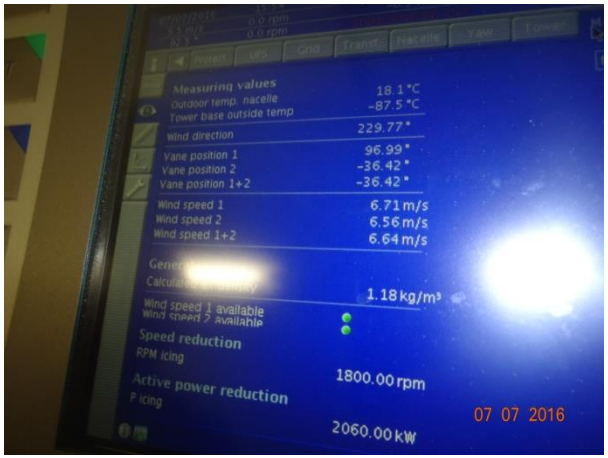




Review of SCADA data

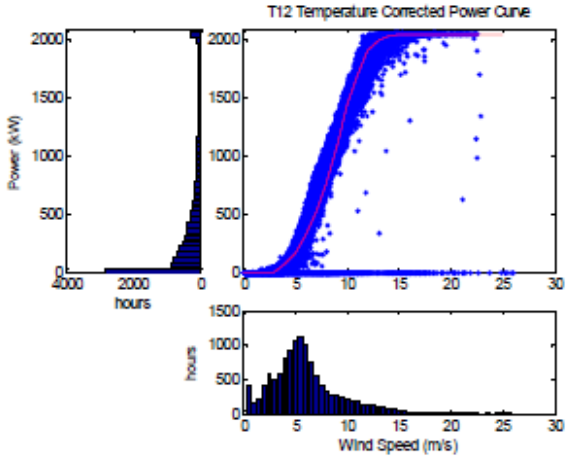
Providing an excellent indication of the turbine health

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

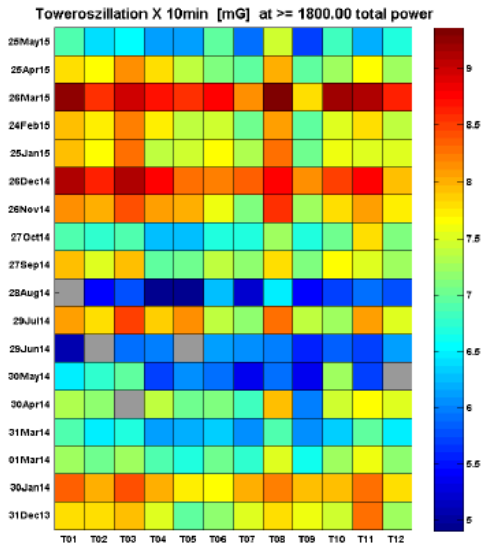
    Top box and bottom box
  - Yaw and Pitch analysis
  - Power Analysis, including power curve analysis

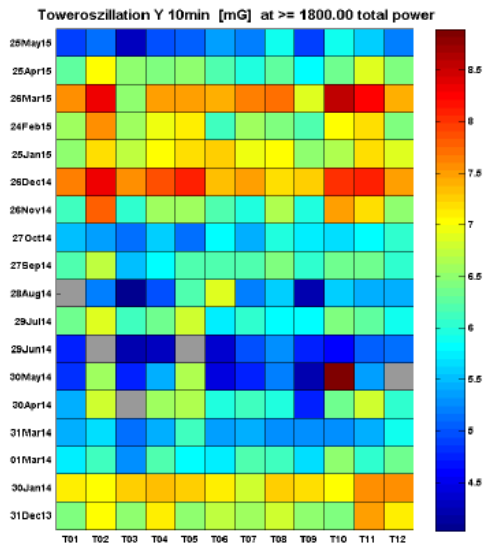


Tower Oscillation

Recorded in two directions

- 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





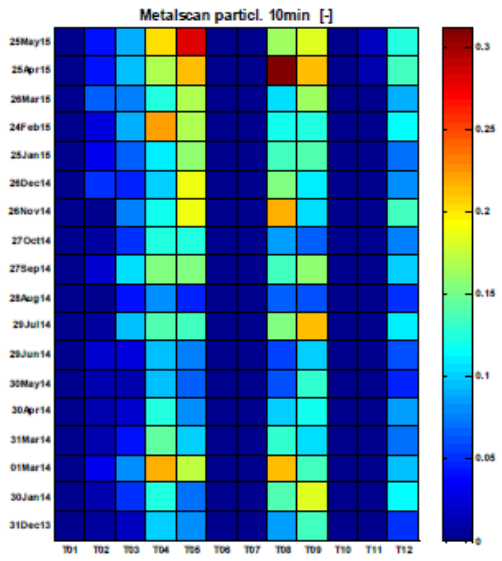
- Adoption of the vibration limits specified in VDI 3834, which specifies 60 mm/s RMS (0.1-10 Hz) as the warning alarm level for an on-shore wind turbine up to 3 MW
- Extract from VDI 3834:

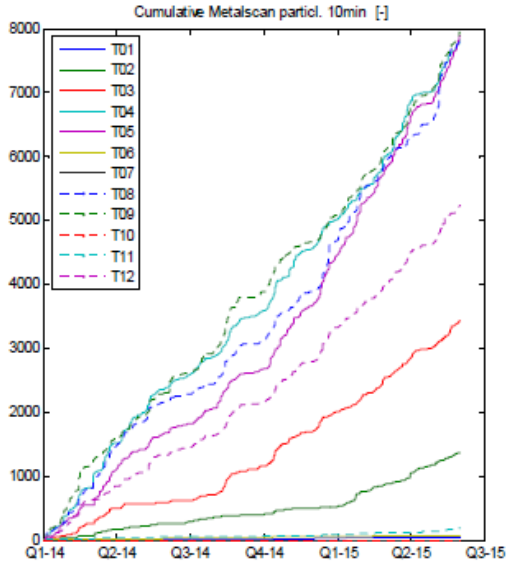
Component	Evaluation acceleration in m/s^2 rms		Evaluation velocity in mm/s rms	
Nacelle and tower	Frequency range ≤0,1 to 10 Hz		Frequency range ≤0,1 to 10 Hz	
	Band limit I/II	Band limit II/III	Band limit I/II	Band limit II/III
	0,3	0,5	60	100

Particle Count and Oil Sample Analysis

Recorded in two directions

- 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





Sample ID:	Wear	Contamination	Chemistry
2861719			
taken on 08 June 2016	3.00	2.00	1.00

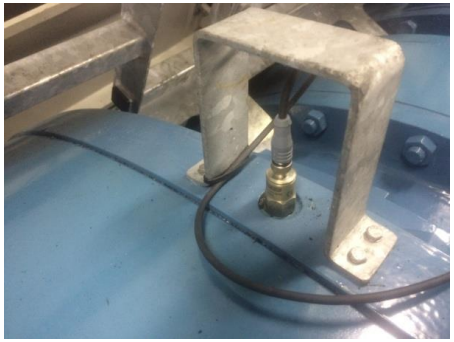
Comment :

Oil sample results are presented in traffic light colours, green for acceptable and red indicating high levels of wear, contamination and/or chemistry.

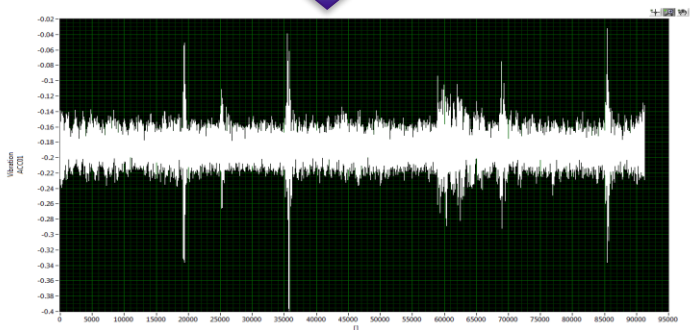
CMS Review

An Excellent indication of drivetrain health

- 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



RAW TIME SERIES DATA



SPECTRAL METHODS

FAULT DETECTION

VDI and ISO Vibration Standards

ISO and DIN

- Standards exists 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:

Component	**Evaluation acceleration** in m/s^2 rms		**Evaluation velocity** in mm/s rms	
Nacelle and tower	Frequency range ≤0,1 to 10 Hz		Frequency range ≤0,1 to 10 Hz	
	Band limit I/II	Band limit II/III	Band limit I/II	Band limit II/III
	0,3	0,5	60	100
Rotor with roller bearing	Frequency range ≤0.1 to 10 Hz		Frequency range 10 Hz to 1000 Hz	
	Band limit I/II	Band limit II/III	Band limit I/II	Band limit II/III
	0,3	0,5	2,0	3,2
Gearbox	Frequency range ≤0.1 to 10 Hz		Frequency range 10 Hz to 1000 Hz	
	Band limit I/II	Band limit II/III	Band limit I/II	Band limit II/III
	0,3	0,5	3,5	5,6
	Frequency range 10 Hz to 2000 Hz			
	7,5	12,0		
Generator with roller bearing	Frequency range 10 Hz to 5000 Hz		Frequency range 10 Hz to 1000 Hz	
	Band limit I/II	Band limit II/III	Band limit I/II	Band limit II/III
	10	16	6,0	10

Band 1 – suitable for continuous operation

Band 2 – Not suitable for continuous operation without further inspection

Band 3 – Dangerous, machine not to be operated

Turbine Inspections

Visual assessment of the condition of the turbine

- 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

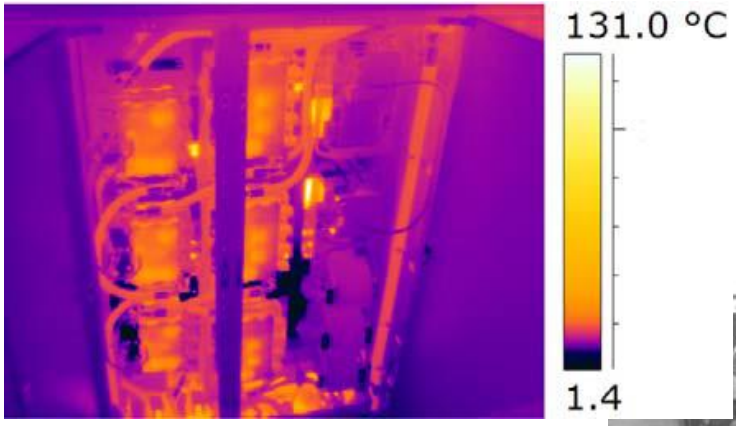
Category	
A – Significant Defect Requiring Immediate Repair	0
B – Indication of Potential Long Term Issue	6
C – Defect Requiring Rectification	19
D – Information	2
Total	25

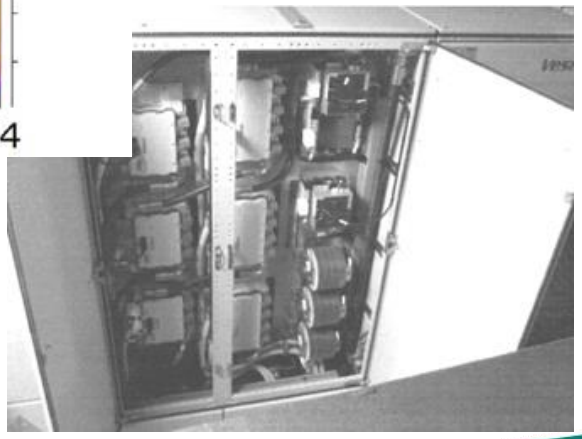
Thermographic Inspections

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



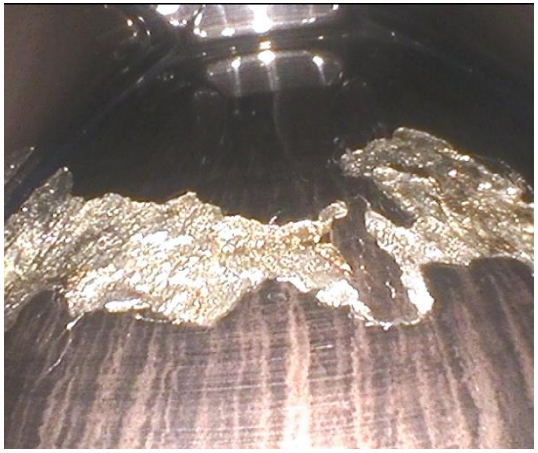


What we don’t wish to happen

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

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

	Up-tower	Down-tower
Estimated Crane Costs	GBP 7-14 k	GBP 170-340 k

Summary

- 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