Real-time Rotor Icing and Imbalance Monitoring for Improved Operation and Maintenance

Insensys Wind Energy

IPC RMS TM insensys

Contents

- Why monitor the rotor and blades?
- What can be measured?
- Sample data and results
- What is the business case?
- What does the future hold?
- Summary

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Why Monitor the Rotor?

- Most of the loads on turbine components originate in the rotor:
  - The loads that generate power
  - The loads that damage the drive train
  - The loads that could generate power, but don't
- By measuring these loads, our hypothesis is that we can:
  - Change operational behaviour and increase energy generation
  - Change operational behaviour and improve turbine reliability/longevity
  - Validate (or not) design calculations and improve future turbine designs

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What Can Be Measured?

- Strains – Time Domain data
  - Measurement of strain at strategic locations enables calculation of edgewise and flapwise bending moments, in real time
  - Uses strain gauges (resistive or fibre optic)

- Resonances – Frequency Domain data
  - Enables calculations of blade resonances (fundamental and higher order)
  - Uses accelerometers, or strain gauges, plus Fourier Transform techniques

- Both techniques can be combined for extra sensitivity and error correction

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So What?

- As turbines become larger, imbalances, lost generating revenue and blade damage have become much more important O&M issues

- Blade bending moments, strains and resonances are related (by more or less complex numerical methods) to:
  - Blade mass (e.g. Ice accretion, blade mass imbalances, gross blade damage, hydraulic leaks etc.)
  - Blade torque (e.g. Pitch calibration error, stiffness imbalances, aerodynamic imbalances, leading edge wear)
  - Asymmetric loading (e.g. Yaw misalignment, Wind shear)
  - Time domain effects (e.g. Turbulent conditions)
  - Rotor Bending moment (transmitted to bearings and gearbox, causing secondary damage over time)

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Rotor Monitoring System - Overview

- RMS, from Insensys, provides cost-effective, real-time monitoring of the turbine rotor, providing relevant operational information to the turbine OEM / operator, including:
  - Blade ice detection and measurement
  - Rotor imbalance and Yaw misalignment
  - Blade damage detection
- System can be retrofitted, to existing operational turbines, in 1 or 2 days, without affecting any existing turbine components
- System measures the blade root strains at 20-100 Hz, and analyses the data in real time, in both time and frequency domains

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Rotor Monitoring System - Overview

- All measurements are based on the Insensys fibre optic load sensing technology – all solid state, immune to interference and lightning – 1000+ units installed since 2004
- Communicates with Turbine PLC or SCADA system, 3rd Party CM system (e.g. SKF WindCon) or direct to customer/Insensys via GSM
- This provides instant feedback on turbine operating parameters, anywhere in the world
- Only requirements from turbine infrastructure are mounting holes and 24V DC power in hub

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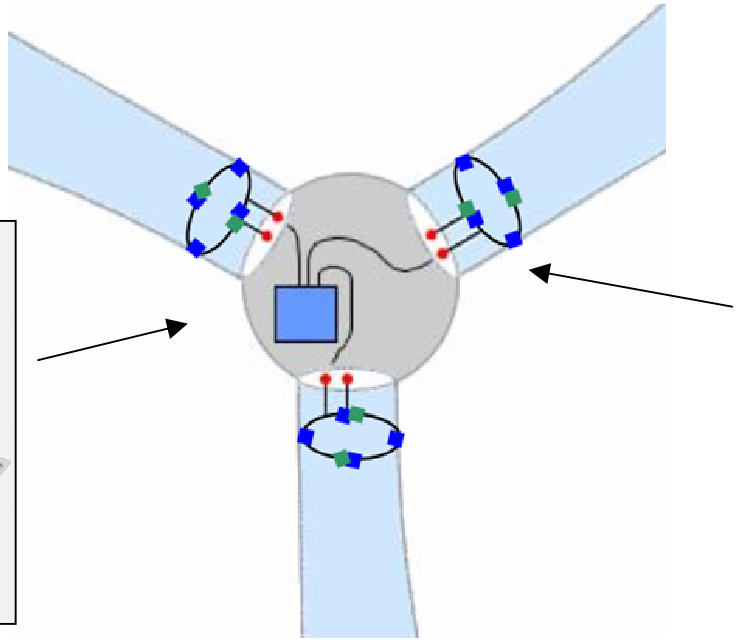
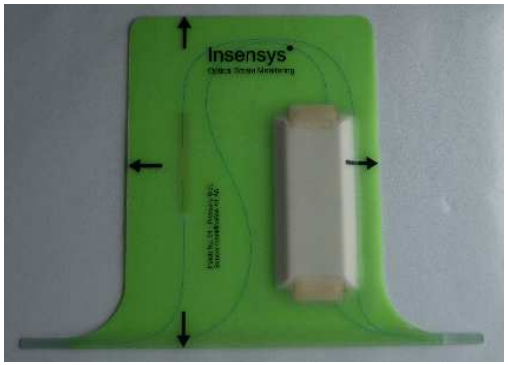
Typical RMS Load Measurement System

Typical instrumentation scheme for Rotor Monitoring Applications

Solid state interrogator located in hub, with GSM interface

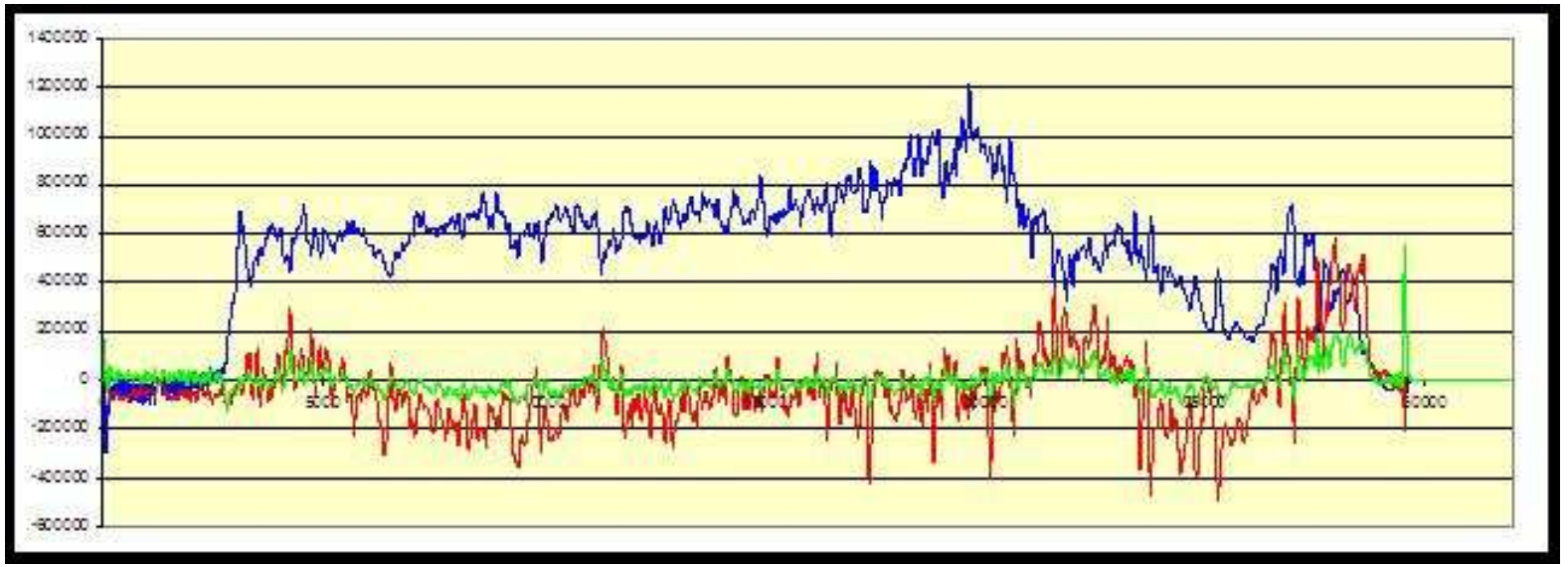




Insensys strain sensors at 4 locations around blade root

Example Data – Moments and Torque

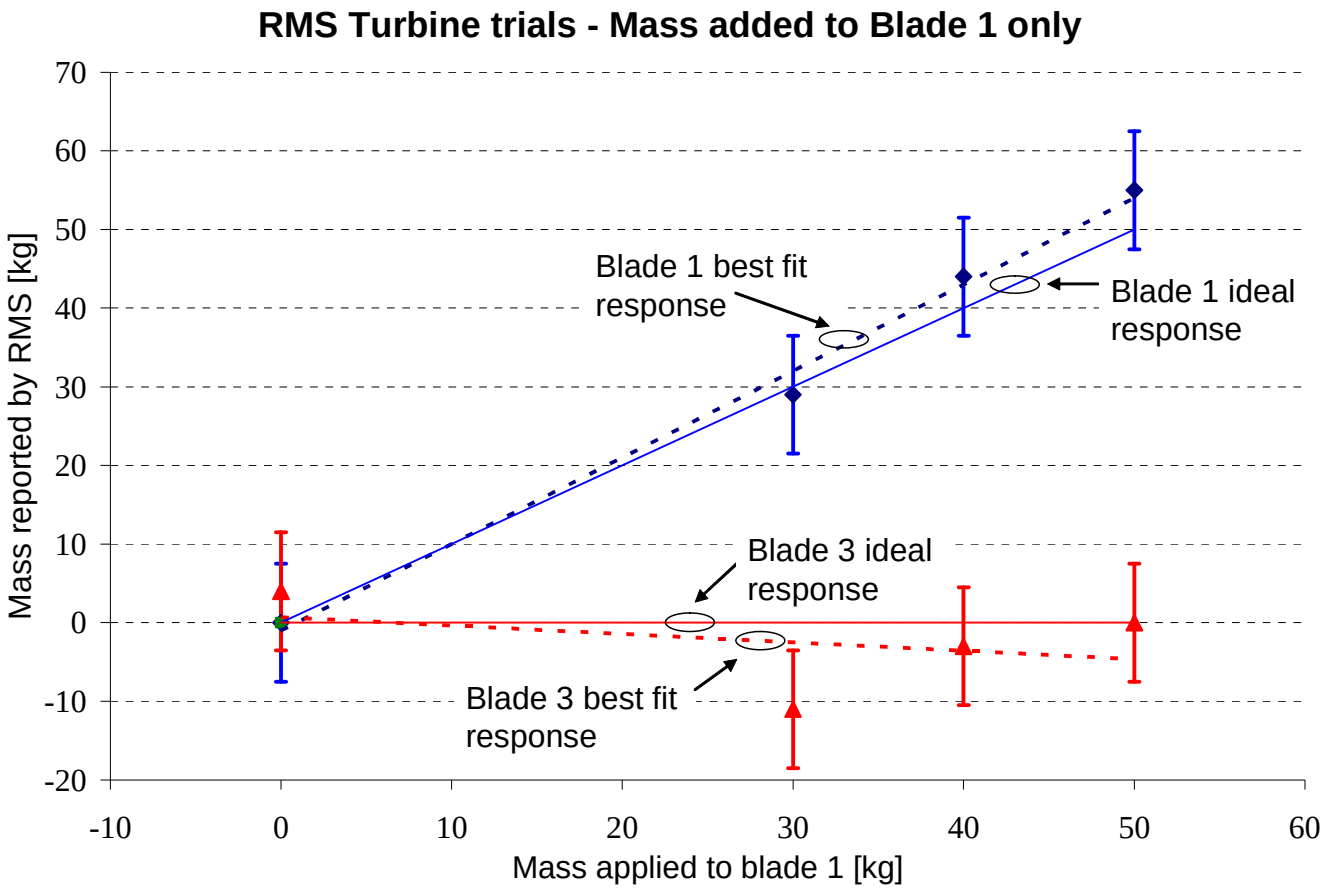
- Processed data – calculation of total rotor torque, vertical and horizontal shaft bending moment
- Demonstrates out of balance loads on rotor and drive train
- Data courtesy of BP Alternative Energy



Y axis – Moment/torque in Nm
X axis – time (5 hours total)
Blue – Rotor torque, Red – Horizontal BM, Green – Vertical BM

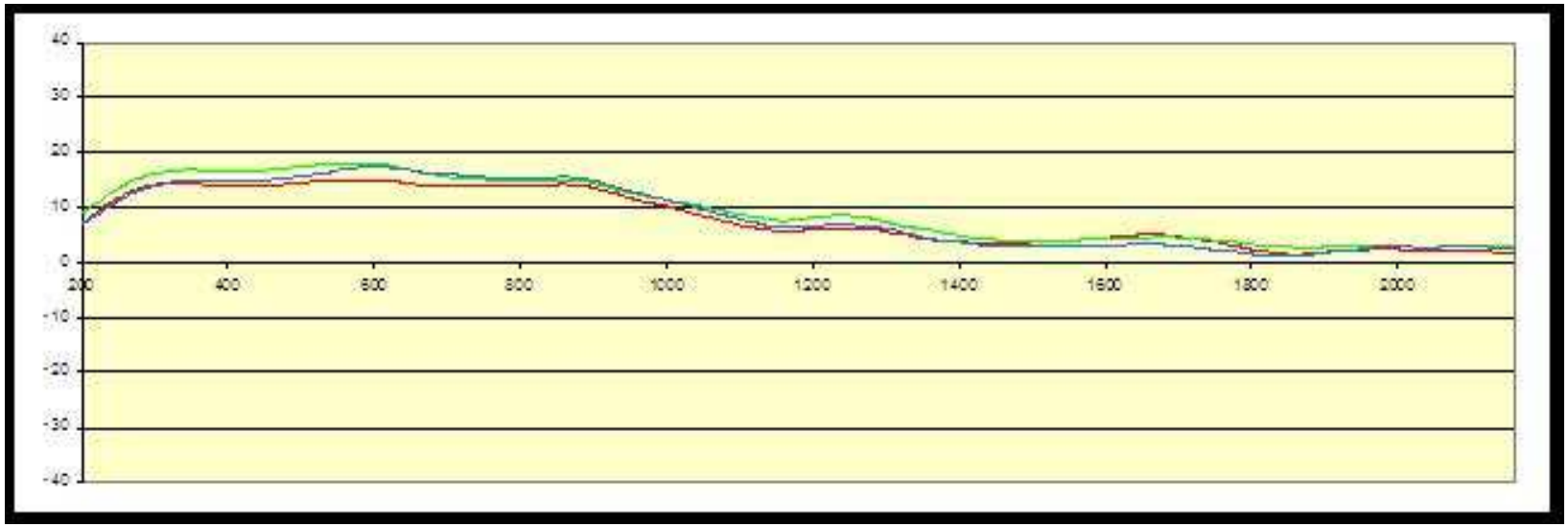
Example Data – Ice Detection

- Simulation of Ice build up on one blade only, by adding known masses to the blade and comparing masses of blades 1 and 3
- Performed in high winds, turbulent location – worst case
- Data source – undisclosed OEM



Example Data – Ice Detection

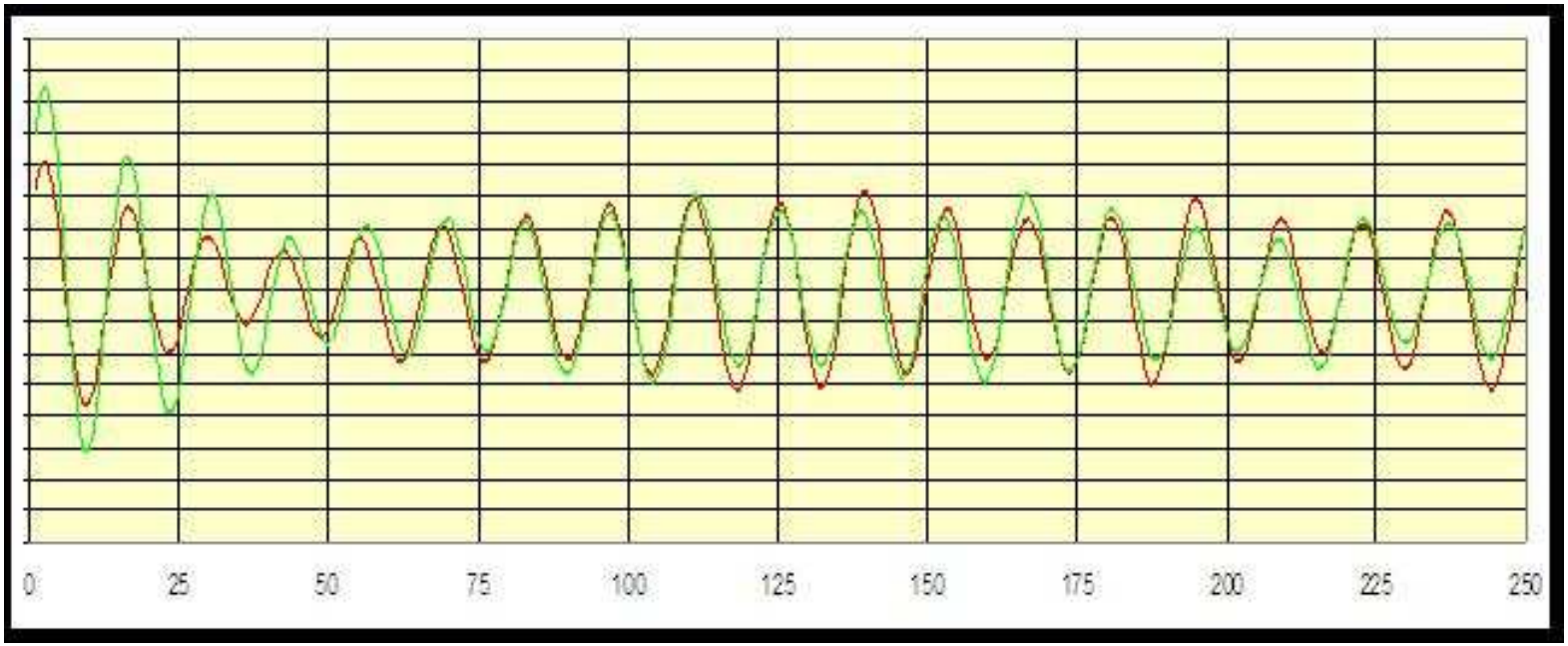
- Data downloaded remotely via GSM modem, showing mass variation of each blade
- Demonstrates good blade to blade correlation and ~20 kg noise on signal over many hours of continuous monitoring
- 40 kg of ice over the blade leading edge is around 2 mm thick…
- Data courtesy of Allianz



Y Axis –blade mass change in kg
X Axis – time

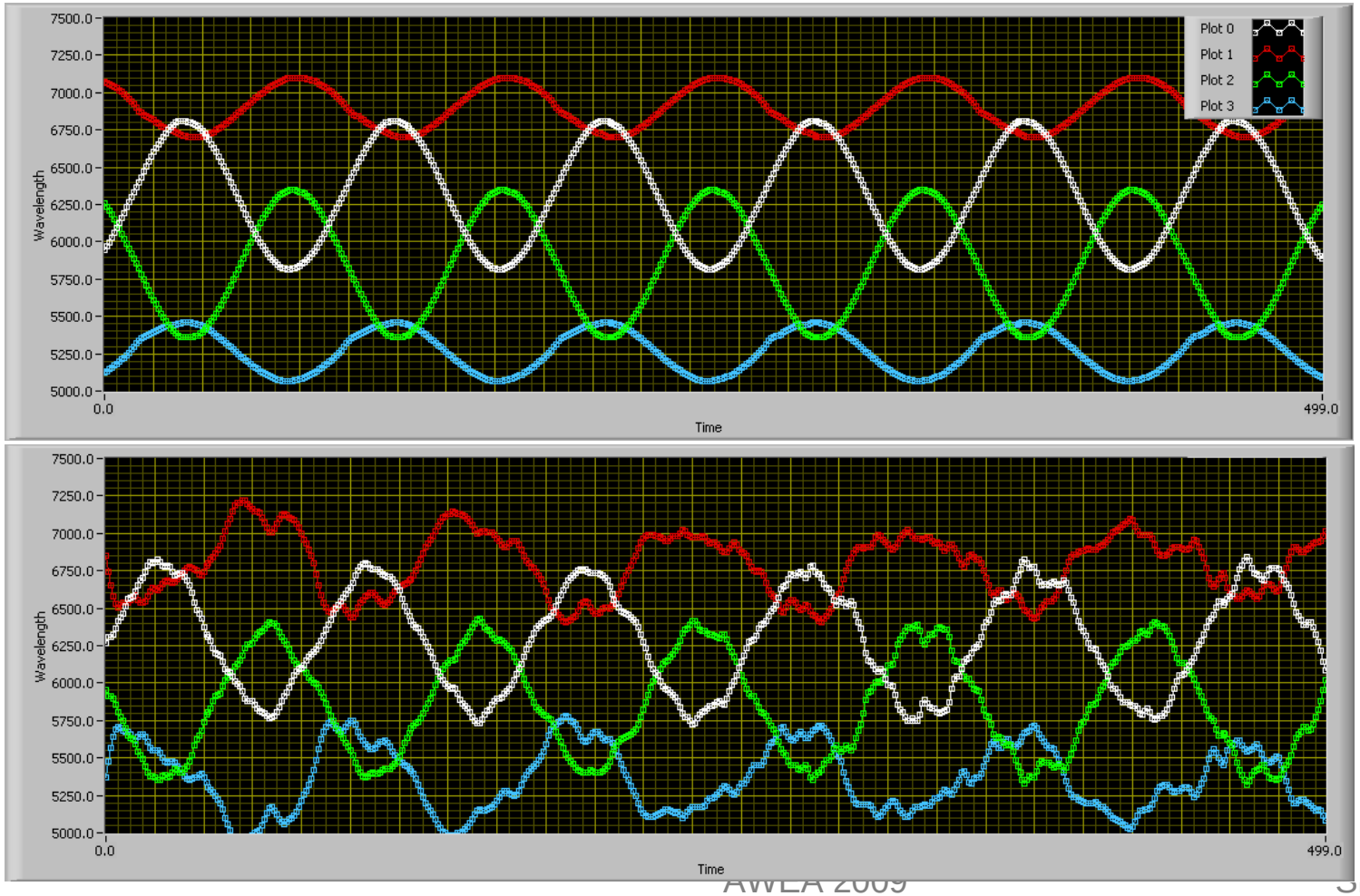
Example Data – Blade Resonance

- Turbine rotational frequency filtered out
- Destructive blade vibrations at 50-60 kNm could materially shorten blade and bearing life - need to take action
- Data source – undisclosed OEM



Example Data – Turbulence

- Clear increase in noise on raw data caused by turbulent wind (bottom)
- Higher frequency components could shorten fatigue life
- Data courtesy of Garrad Hassan Limited



So how can I benefit and how can my customers benefit?

- Data only valuable if converted to information that is used to modify operational strategy
- No change in turbine/O&M strategy=NO BENEFIT=NO PAYBACK
- Most of these features result in direct changes to turbine control or O&M strategy, and hence, immediate savings
- Other, harder to quantify, benefits include R&D design validation and performance comparisons across windfarm
- Most operators look for payback of CM systems in 5 years or less

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Business Case – Ice Detection

- Current O&M strategy
  - Stop turbine either when ‘icing conditions’ are detected (too early) or when ice loads are so great that turbine can no longer generate (too late)
  - Only restart when manual inspection of turbine confirms loss of ice (much too late, especially in rural settings)
- Insensys suggested O&M strategy
  - Only shuts down when blade ice mass threshold exceeded
  - Restarts generation as soon as ice no longer present
- Operator benefit example
  - Wind farm in Northern Germany
  - Operator estimates reduced revenue due to early shut down and late restart to be $10,000 per turbine in 2008 alone
  - Payback in 1-2 years

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Business Case - Yaw Misalignment

Current O&M Actions

- None – not detected, due to inaccuracy of wind vane data – typically +/- 10°
- A 10° yaw misalignment reduces the effective rotor swept area and reduces power by ~5% when running below rated power (Source: CENER)

O&M Response with Insensys System

- Insensys RMS provides instant feedback on yaw misalignment, which can be fed into control system if desired

Estimated Benefit

- 10° misalignment for 20% of the time results in aro und $15,000 lost revenue, per 2.5 MW turbine, per year (assuming generation below rated power for 70% of the time)
- Payback in around 1 year

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Business Case - Aero / Mass imbalance

- Approx. 20% of turbines have a significant mass or aerodynamic imbalance[1]
- Even a pitch calibration error of +/- 1° causes 1-3% reduction in output power
- If not corrected, imbalances can also cause catastrophic damage
- Many more turbines have significant leading edge erosion– can cause up to 10% reduction in output power
- BUT, rarely correctly diagnosed as it happens so slowly:
  - Often, the correlation between wind speed and power output is not closely monitored from year to year
  - 'Must be deterioration of the bearings/gearbox/generator'
  - 'It doesn't seem to be as windy this year as it was last'

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1. Source – Windguard GmbH. 'Significant' means pitch error of 1° or more

Business Case - Aero / Mass imbalance

Current O&M Actions

- None, as imbalance not detected until nacelle vibrations become severe

O&M Response with Insensys system

- Almost all imbalances can quickly and easily be corrected
  - Corrections of pitch calibration errors takes minutes
  - Adding mass to balancing chambers in blades
  - Repairs to leading edge

Estimated Benefit

- 1% increase in output in of 2.5 MW turbine is worth ~ $15,000 per year, per turbine, assuming generating below rated power 70% of the time
- Payback in around 1 year

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Business Case – Other Applications

- Turbulence
  - Stop turbine in highly turbulent conditions to prevent reduction in blade life etc.
  - If turbulence caused by wake effects, shut down every other turbine when wind direction dictates
- Resonances
  - Adjust pitch angle, power output and/or yaw angle to move blades away from resonance and prevent deterioration in residual fatigue life

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What is the Future of Rotor Monitoring?

- Several applications show promise – key is to demonstrate compelling business cases
- Economic climate demands maximising energy output from turbines
- Since the hardware is the same, the business case grows rapidly for each new application
- Several other capabilities under development:
  - Blade damage detection and residual life prediction
  - Lightning detection and measurement
  - Combining Independent Pitch Control, Yaw control and RMS to automatically correct pitch imbalances, yaw misalignment and torque imbalance
- Ultimate goal is that demand drives OEM's to fit Rotor Monitoring as standard on all machines

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RMS Summary

- Launched in Sept 2008, but huge interest already (over 300 systems sold)
- Strongest value propositions seem to be:
  - Ice detection (early restart → Increased generating revenue)
  - Yaw misalignment (detection and correction → Increased generating revenue)
  - Mass and pitch imbalances (detection and correction → Increased generating revenue and improved reliability)
- Multiple installations completed in Q1 2009 with major customers – many more in Q2 (> 30 systems)
- Further testing ongoing with multiple customers to validate business case
- Expect GL certification to be completed within 2 months

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Thank you!

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