Fibre Optic Sensing Technology and Applications in Wind Energy

Sandia Blade Workshop 2008
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Phil Rhead

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Presentation Contents

- Introduction to Insensys Limted
- Insensys Technology
- System Overview and Key Components
- Verification and Reliability
- Application 1 - Test and Measurement
- Application 2 - Individual Pitch Control
- Application 3 - Rotor Condition Monitoring
- Summary

Introduction to Insensys

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Insensys Introduction
- Company Overview

- Founded in 2002
- 40 staff across 3 offices located in the UK
- Focussed on 2 key market areas
  - Wind Energy
  - Aerospace
- Oil and Gas division sold to Schlumberger in 2007
- World class engineering skills
  - Fibre optics
  - Composite design
  - Composite manufacture

Insensys Introduction
- Wind Energy Applications & Market Status

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Focus

Supply advanced load measurement technology to the Wind Turbine Industry enabling improved Wind Turbine performance and reliability

Key Application Areas

1) Individual Pitch Control (IPC)
2) Rotor Condition Monitoring
3) Test and Measurement Applications

Market Experience

- Insensys system is designed into production turbines between 1.5 and 6 MW with multiple turbine manufacturers
- Systems are currently being supplied in series quantities
- System is currently under test in 14 different turbine platforms
- Deployed in blades from 27m to 60m

Insensys Technology
Time Division Multiplexed (TDM) Sensor Interrogation

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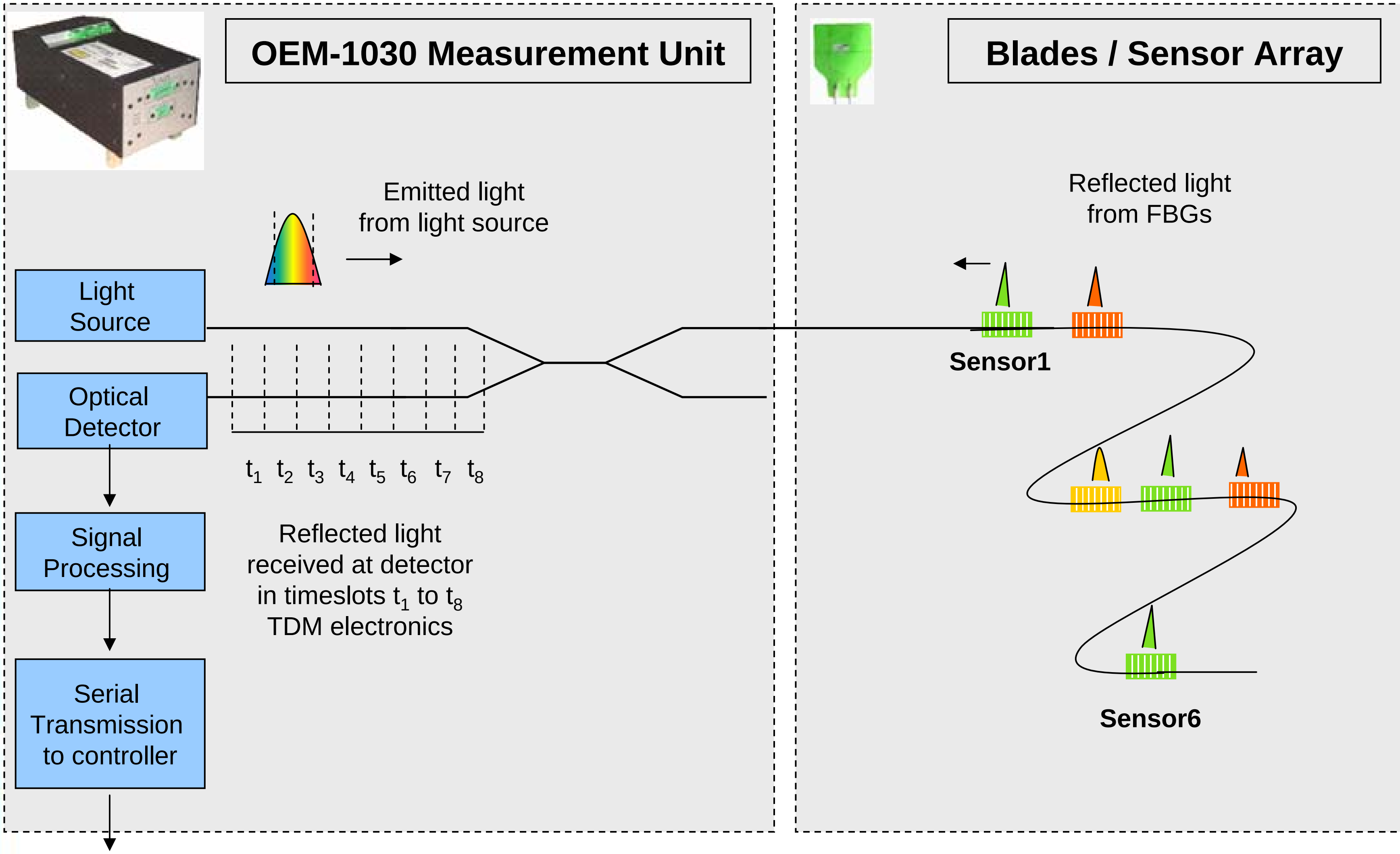
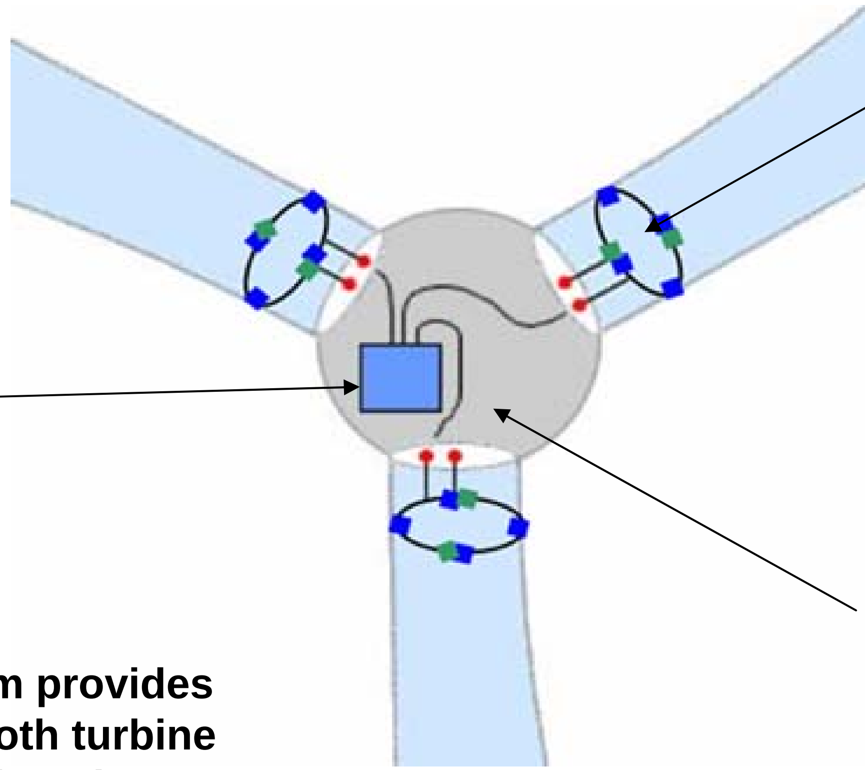
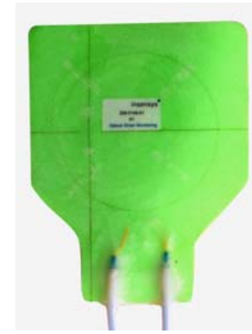
Insensys Technology
- Time Division Multiplexing Schematic



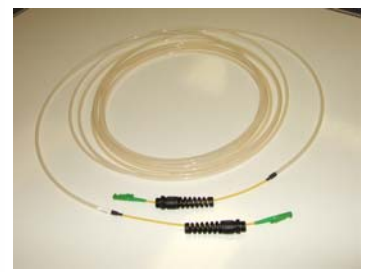
Insensys Technology
- Typical System Configuration

OEM-1030
Measurement unit
located in turbine hub





Sensor Arrays
installed in the blade
(4 per blade)

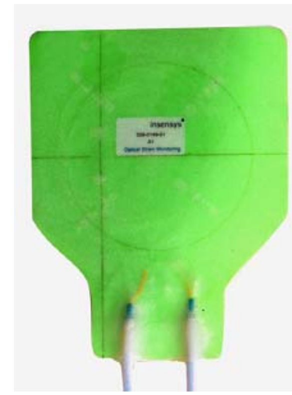


Optical
Interconnection
Cables (3 per turbine)

The single system provides information for both turbine control and health monitoring applications

Insensys Technology
- Key Advantages of Fibre Optic Sensing

Sensors

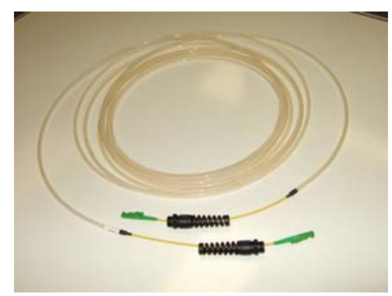


- Optical fibre Bragg grating sensors – non disruptive to the laminate
- Absolute strain measurement with no drift or de-bonding
- Immune to EMI and lightning effects in blade environment
- Installed during blade build or retrofitted to operational machines
- Sensor quantities, locations and spacing can be custom designed to suit exact turbine dimensions and sensing requirements

Measurement Unit

- Designed specifically for hub environment - No moving parts
- High speed & low measurement latency
- +/- 4500 microstrain measurement range
- Low power (3W typical) and low weight (< 3Kg)

Cable System



- IP65 cable system when connected
- All interconnection cables are replaceable by the field service team without the need to recalibration

System Verification & Reliability Testing

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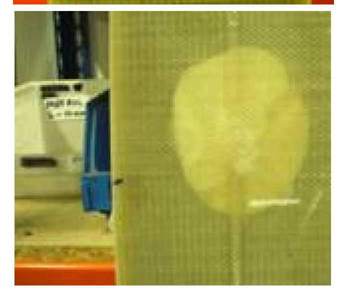
System Verification Testing

Sensors for control or SHM applications must be highly reliable!





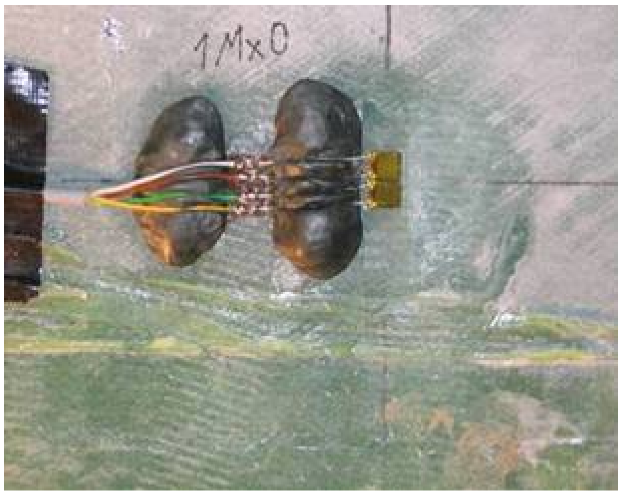

- **Performance Testing**
  - Sensor patch testing > 45 million cycles of 0 – 1000 microstrain
  - Dynamic coupon fatigue test > 2 million cycles +/- 5000 microstrain range
  - Active blade testing – 1 x 10^6 cycles during an active blade tests
  - Static blade test – sensors used for multiple GL certification tests
  - No sensor failures, degradation or de-bonding in any of these tests

- **Laboratory Testing**
  - Lightning strike tests, Impact tests
  - Environmentally tested to IEC standards - Shock, vibration, thermal cycling etc

- **Design Verification**
  - MTBF in excess of 20 years (from calculation and hours in service)

Product Reliability – In Field Testing

Long term comparisons have been carried our with conventional electrical strain gauges instrumented by DEWI GmbH, WindTest GmbH and Garrad Hassan!

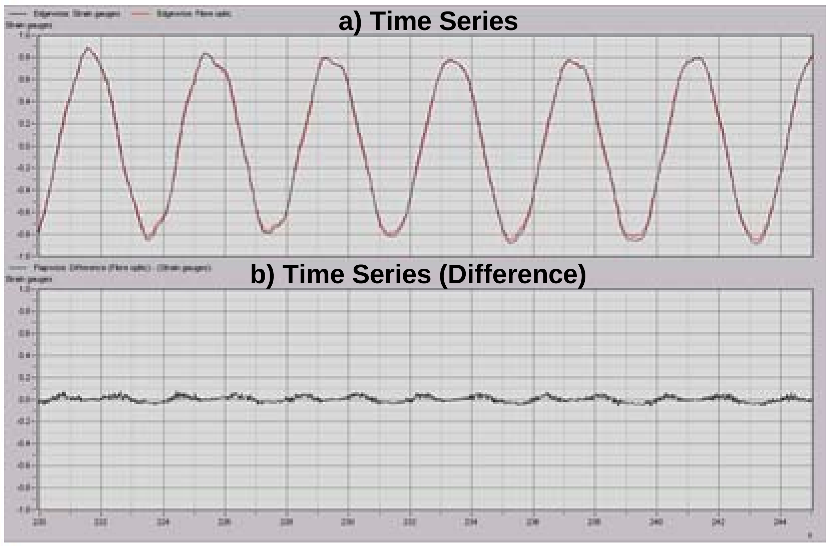


WindTest Grevenbroich DMS Sensor

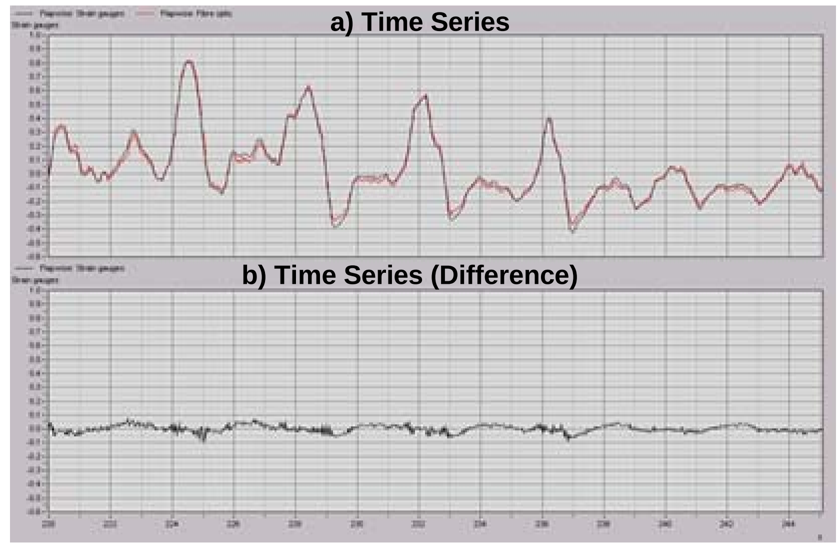
Insensys FBG Sensor Patch

In Field Testing
- Data Comparison

Edgewise Data Sample

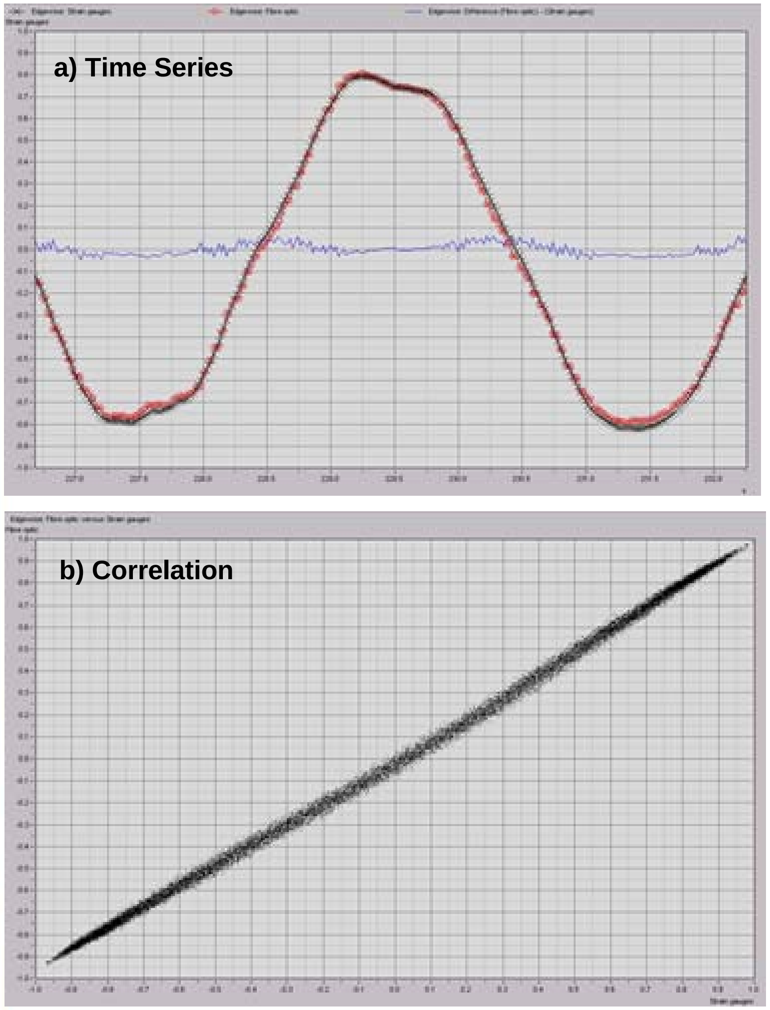


Flapwise Data Sample

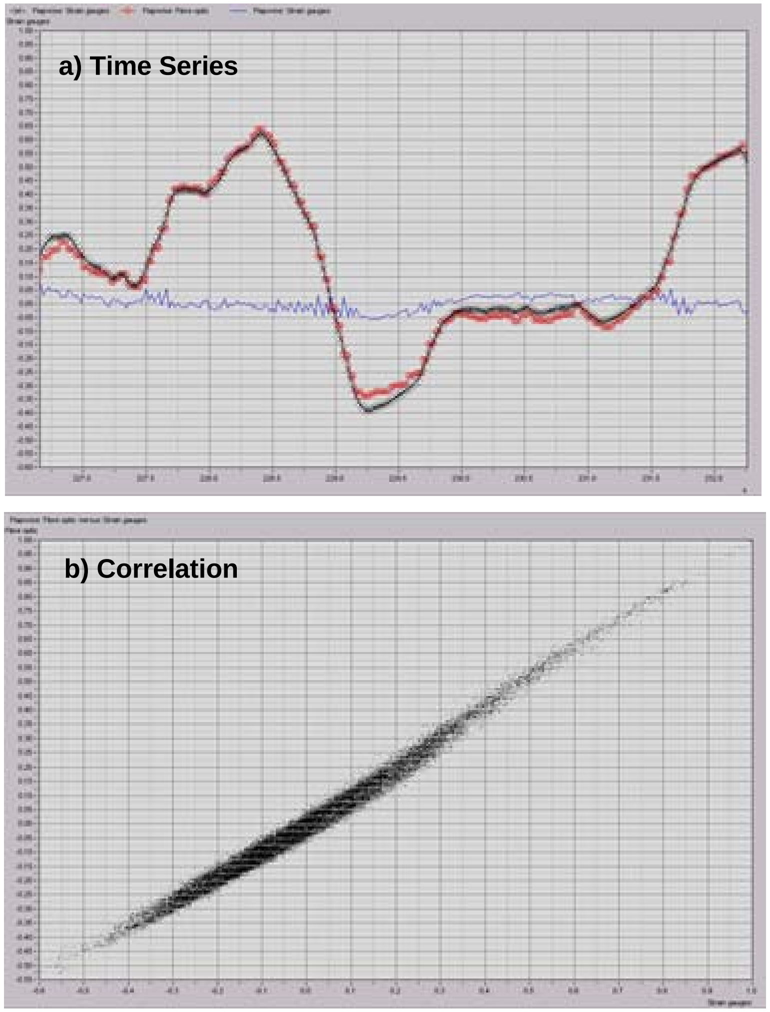


In Field Testing
- Data Comparison (zoom)

Edgewise Data



Flapwise Data



Fibre Optic Sensor Deployment Techniques

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Sensor Deployment Techniques - Overview

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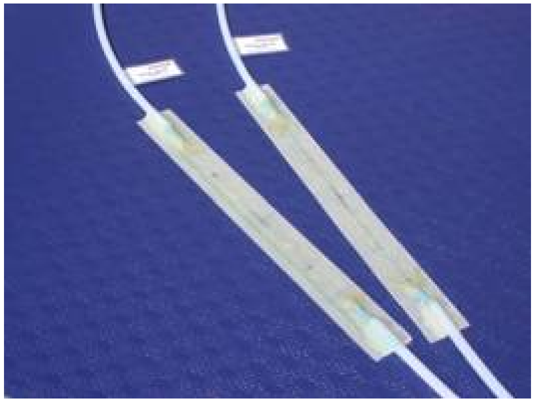
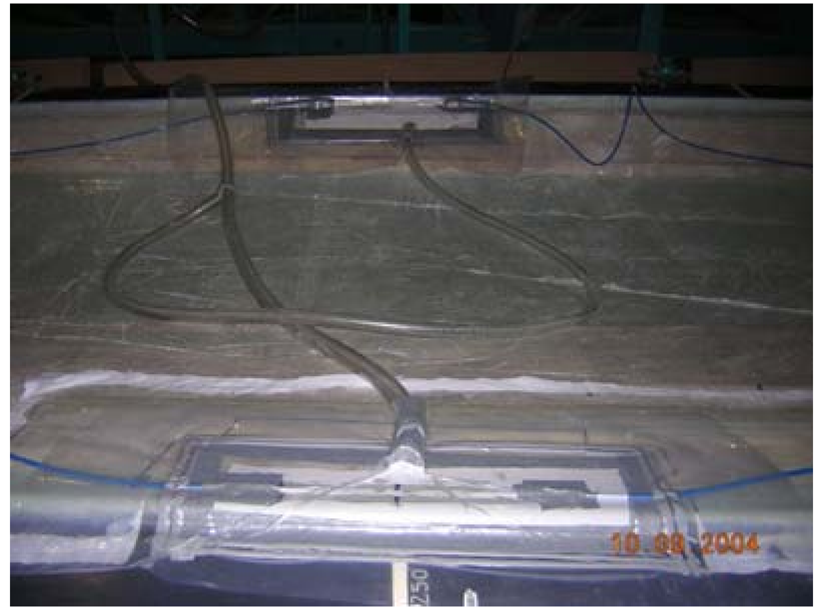
- **Many people have proven that bare fibre installation doesn't work!**
- Insensys have developed specific deployment techniques for Wind Energy to ensure: accuracy of installation, high yield, reliability and simplicity of installation
- Multiple sensor deployment techniques developed to suit different blade manufacturing processes, materials and applications
- Embedded during blade infusion
- Retrofit to completed blades or assemblies (in-factory / up-tower)
- Blade manufacturing process - Pre-preg (including ATL), infusion, hand layup
- Blade materials - GRP, CFRP, Hybrids
- All deployment processes
  - utilise standard materials and blade manufacturing processes
  - are designed to minimise intrusion into blade production process

Deployment Techniques
- Retrofit Sensor Installation



- Applied internally or externally
- Applied to shells, spars, webs & root sections
- Simple customisation of positions
- Standard arrays from stock or fully configurable
- Standard method for prototype test and measurement applications and blade testing
- Cost effective for series application in low labour rate countries

Deployment Techniques
- Retrofitted to Shells (Secondary Infusion)



- Sensor applied to blade LE and TE post shell manufacture
- Rapid / reliable / low cost installation technique for series production

Deployment Techniques
- Custom Sensor Application (deep install)





- Custom sensor patch designed for measurement deep inside laminate 30 mm
- 27m long, 13 sensors (tree effect)
- Installed in shells prior to central belt being installed

Deployment Techniques
- Bonding to Shells (Primary infusion)

- Applied during primary blade infusion
- Rapid deployment of multiple sensors – sensors treated as per any other layer
- Can be located near blade surface (deep) or near inner skin (shallow)
- Cost effective for series deployment in high labour rate countries
- Specific care must be taken when designing connection points!

Example Wind Energy Applications

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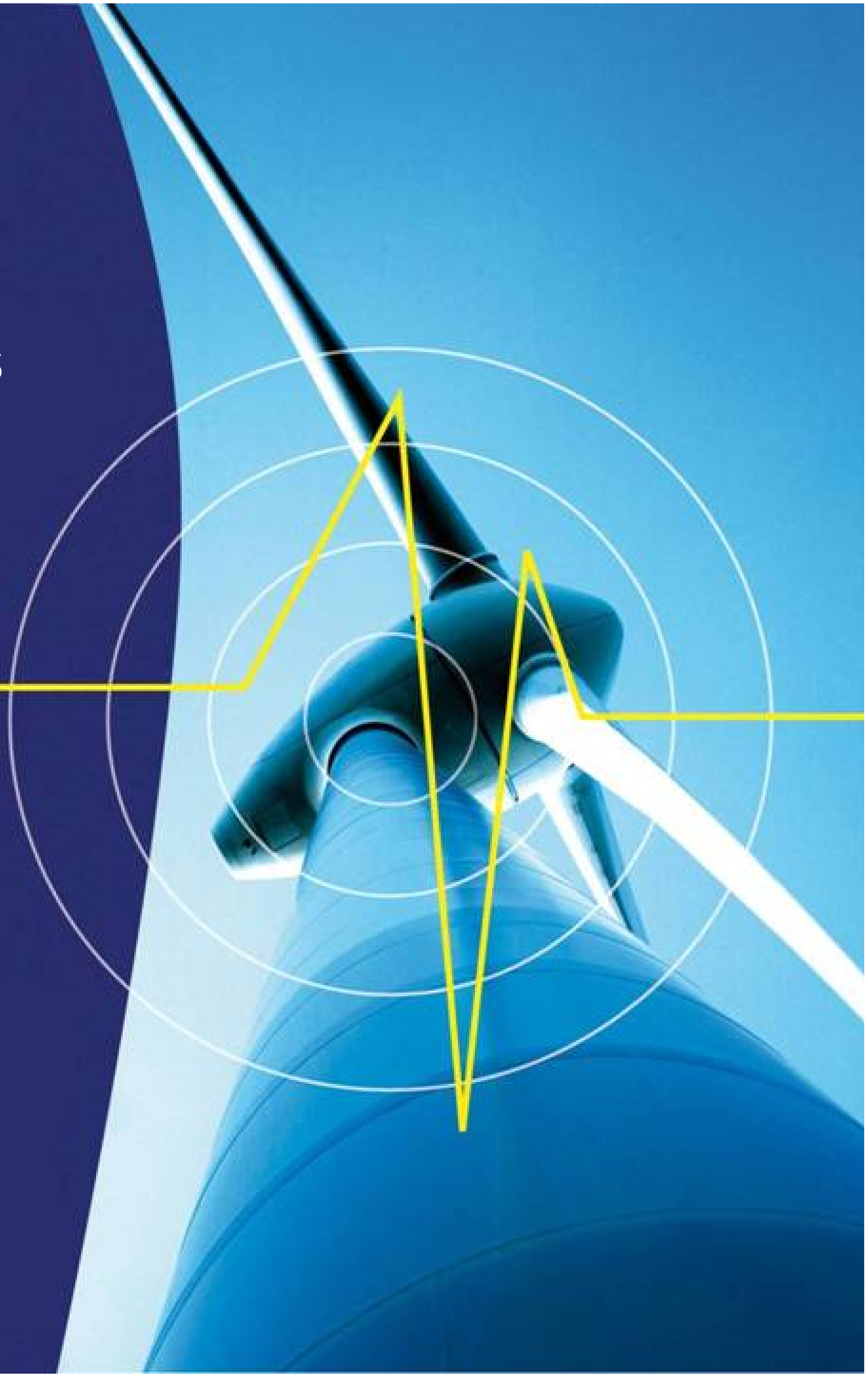

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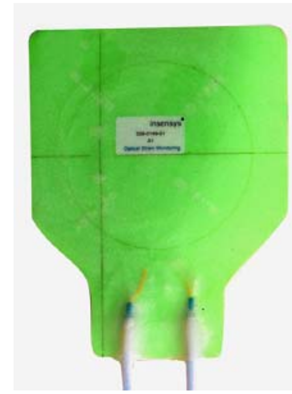
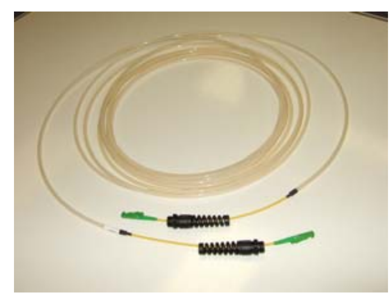
Applications Overview

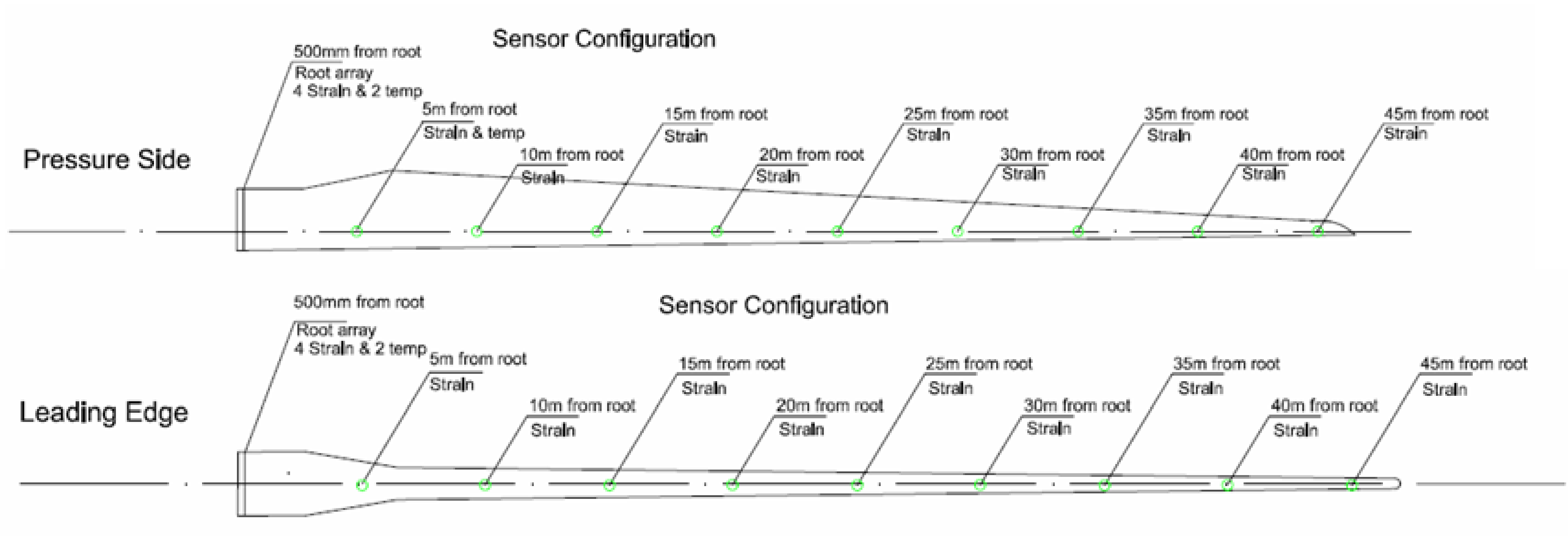
- **Prototype Turbine and Blade Measurement Campaigns**
- **Individual Pitch Control**
- **Structural Health Monitoring**

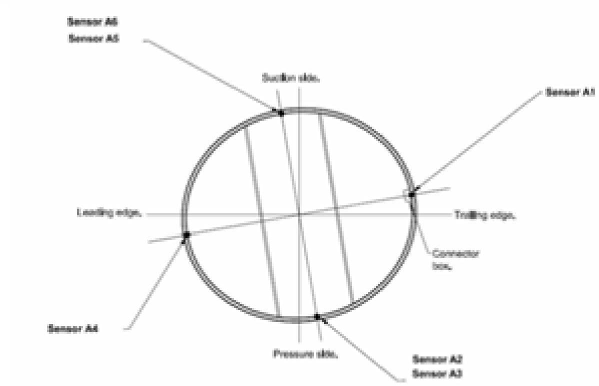
- System designed as modular platform with common architecture
- Enables dual functionality to be achieved





Insensys Technology
- Blade Installation Schemes





Application 1
Prototype Turbine and Blade Test

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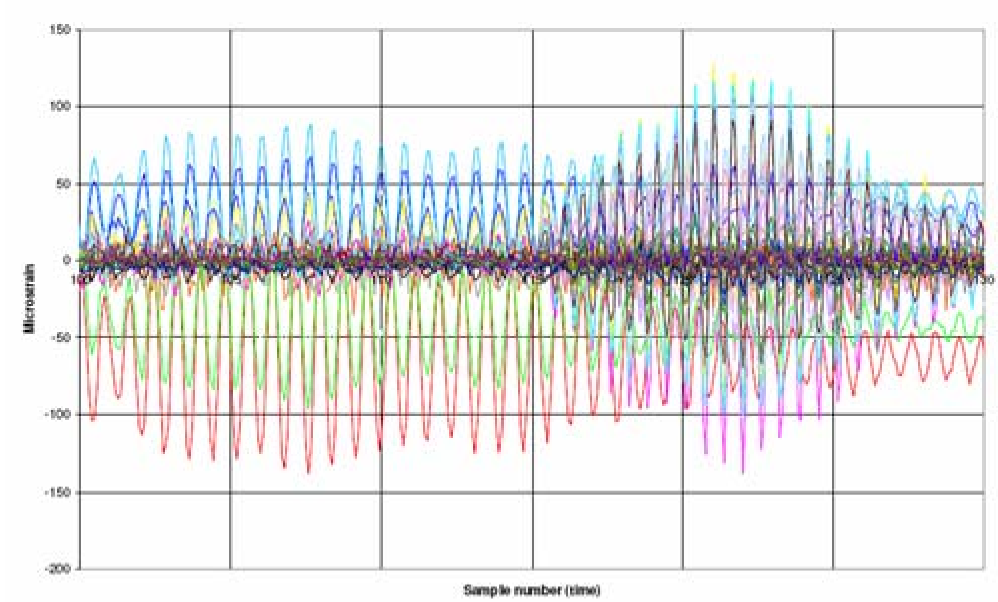
Test and Measurement
- Example Applications

- **Used for in place of a conventional electrical strain gauge**
  - Simple installation and connectivity
  - Immunity to lightning and EMI
  - Highly reliable – no de-bonding or sensor fatigue
  - Data use for design validation and correlation of loads with FEA models during the turbine design phase

- **Blade measurements**
  - On turbine data collection – multiple points per blade
  - Static proof test
  - Dynamic blade test
  - Blade subsection / panel test

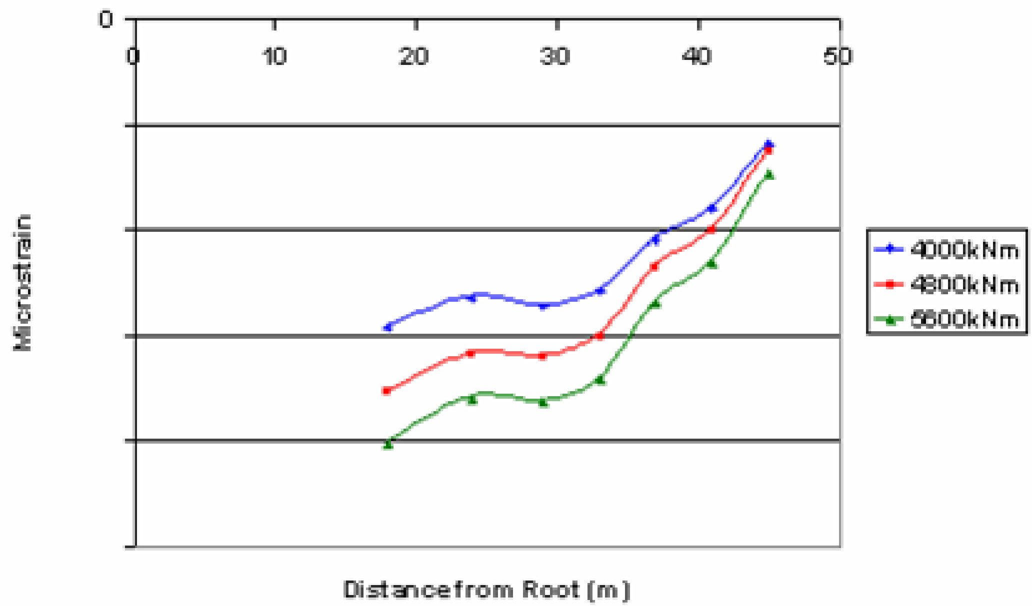
- **Structural component measurements**
  - Low speed shaft (bending and torsion)
  - Tower (bending and torsion)
  - Hub casing (strain)
  - Gearbox and bedplate (strain)

Test and Measurement
- Dynamic Fatigue Test (Time Series Data)



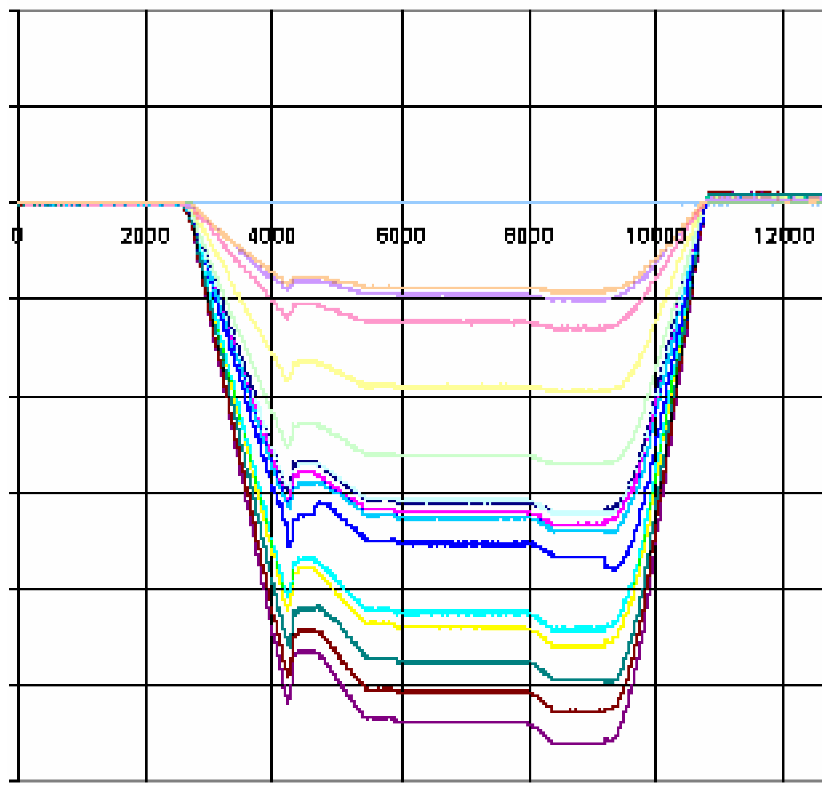
- •Time series data (24 sensors dynamic fatigue test)
- •Generating data is the easy part!
- •Analysis and reporting needs effort and software tools!

Test and Measurement
- Dynamic Fatigue Test (Time Series Analysis)



Measured strain profile along a blade at 7 sensor locations and under 3 different load conditions

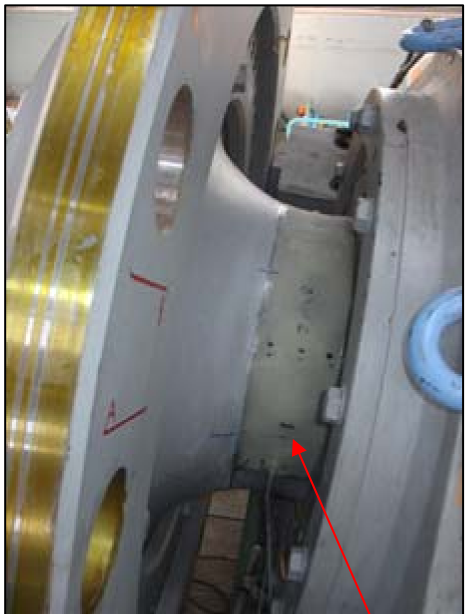
Test and Measurement
- Ultimate Load Test

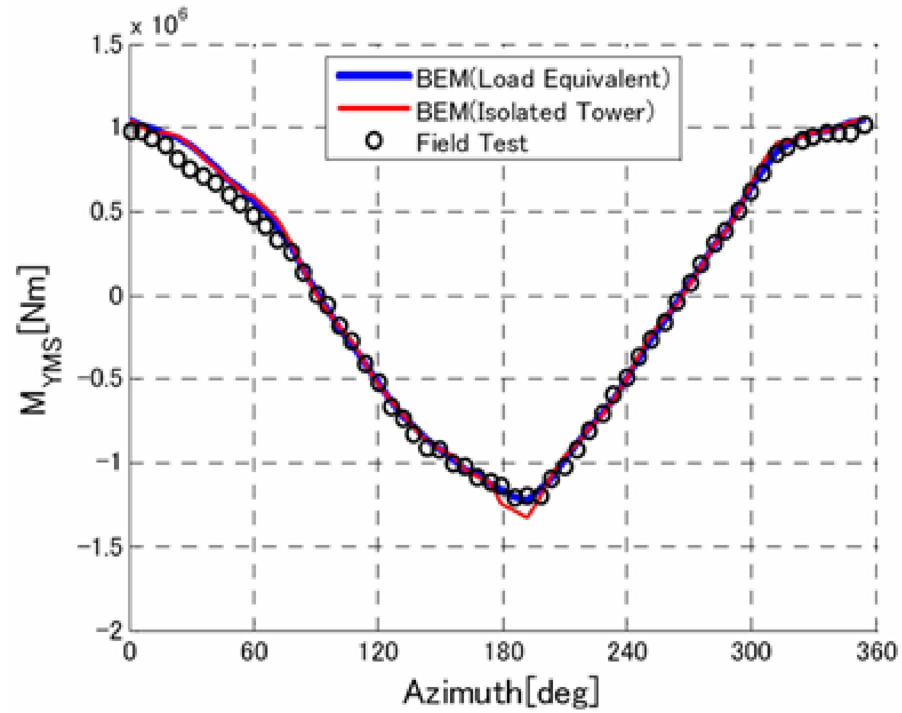


Measured strain profile along a blade at 15 sensor locations during a static fatigue test

Prototype Turbine Measurement
- Low Speed Shaft Design Validation

- Used during design phase to validate FEA models / design of low speed shaft





Sensor Patch Located on Main Shaft

Application 2
Individual Pitch Control

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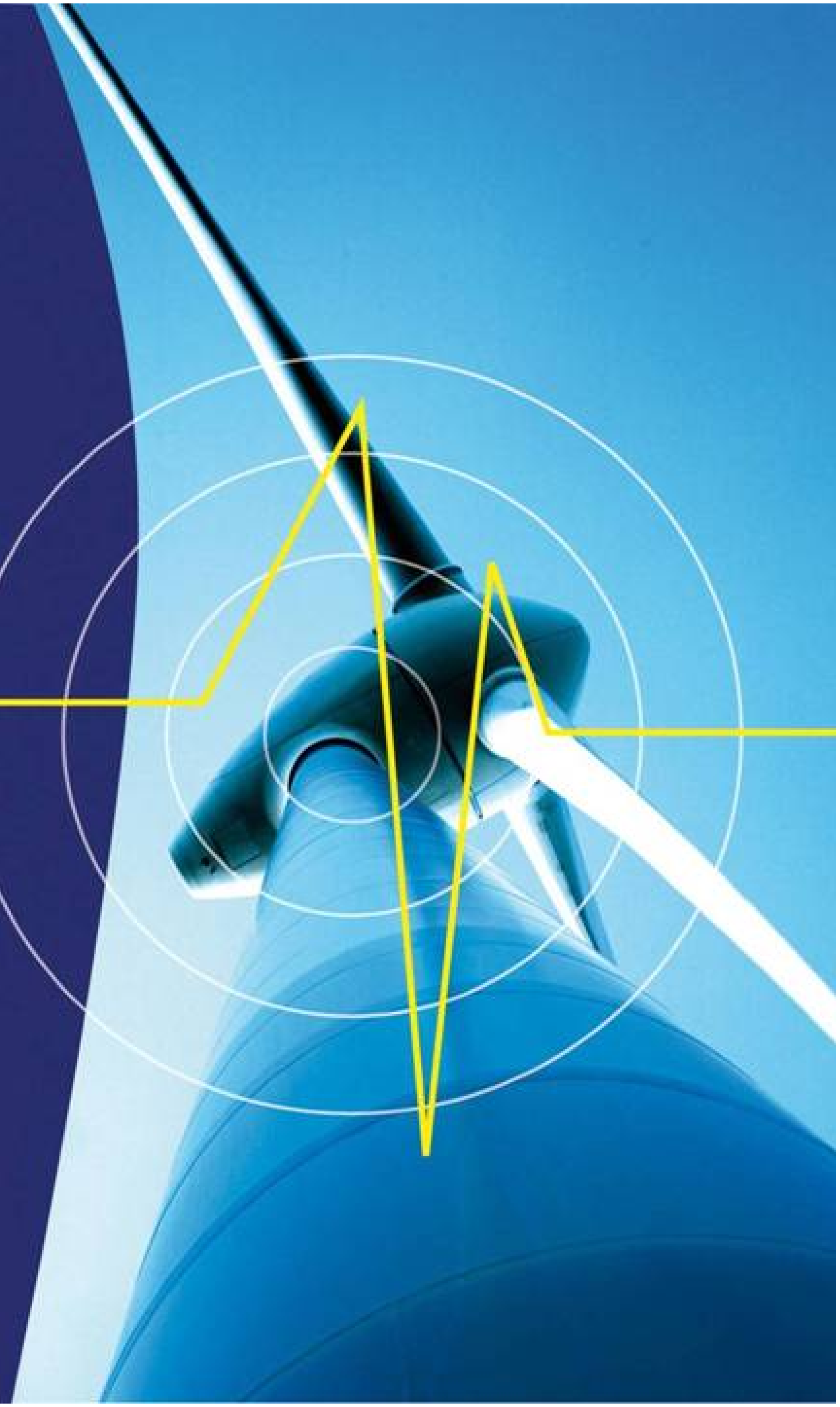

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Individual Pitch Control
- Current Status of the Market

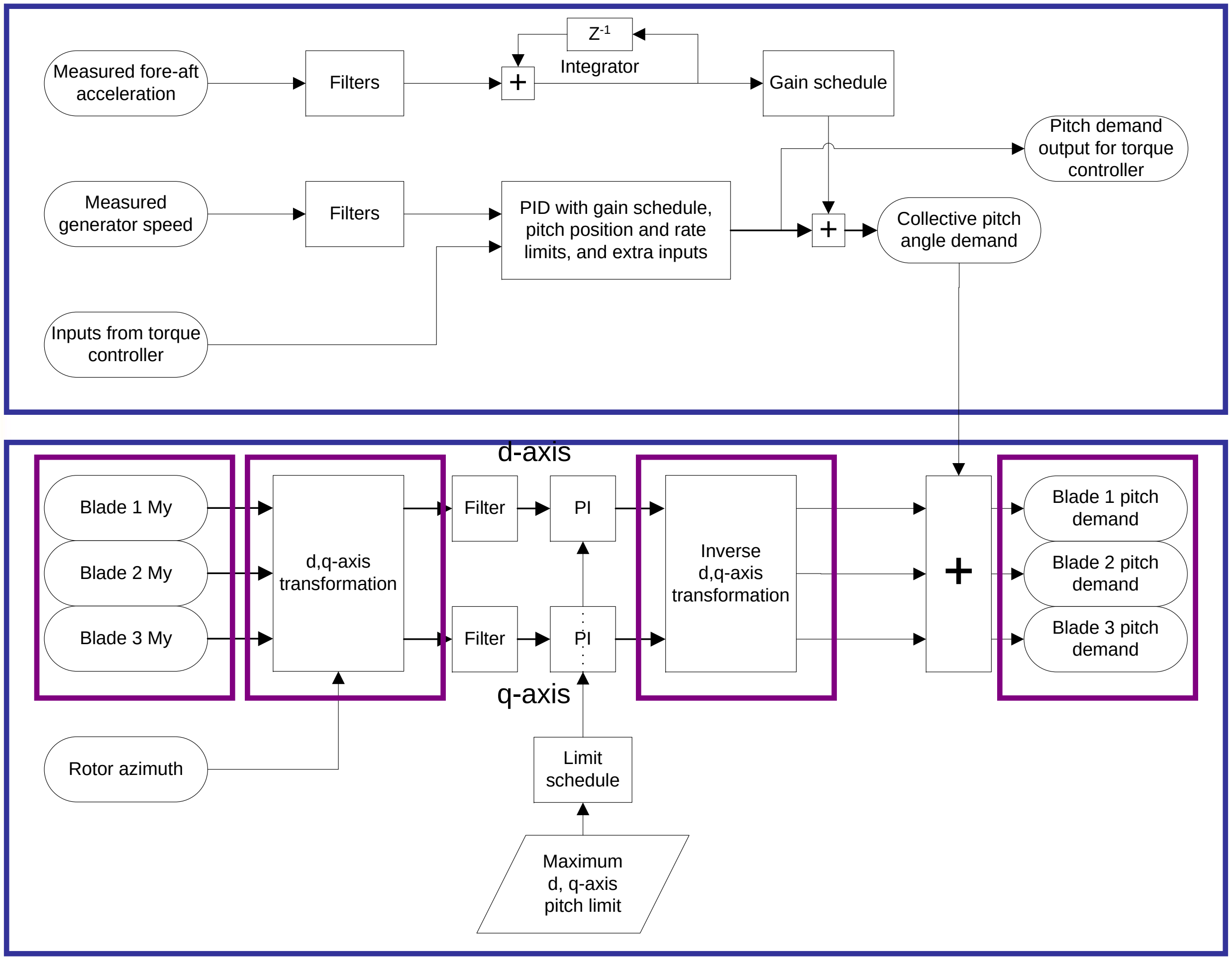
- Turbines rotors are increasing in size and are being installed on more complex terrains. This is leading to:
  - Increased asymmetric loading across the rotor
  - Increased yaw and tilt moments
  - Due to wind speed and spatial variations - (stochastic process)

- Multiple load reduction strategies have been proposed
  - Any successful load reduction strategy must be based on measurements

- Individual Pitch Control can reduce loads significantly!
  - Blade loads typically reduced by 10 – 20%
  - Main shaft loads typically reduced by 20 – 30%
  - Reduced tower and yaw bearing loads, particularly with 2P based -IPC

- IPC is already being deployed in series production

Individual Pitch Control
- Process Requirements



Collective Pitch Control Loop

Individual Pitch Control Loop

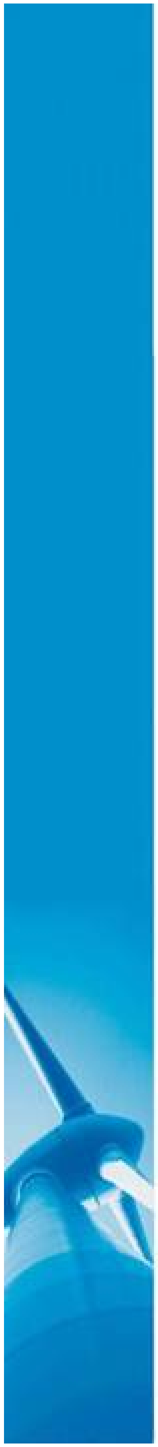
Edgewise and flapwise moment input data

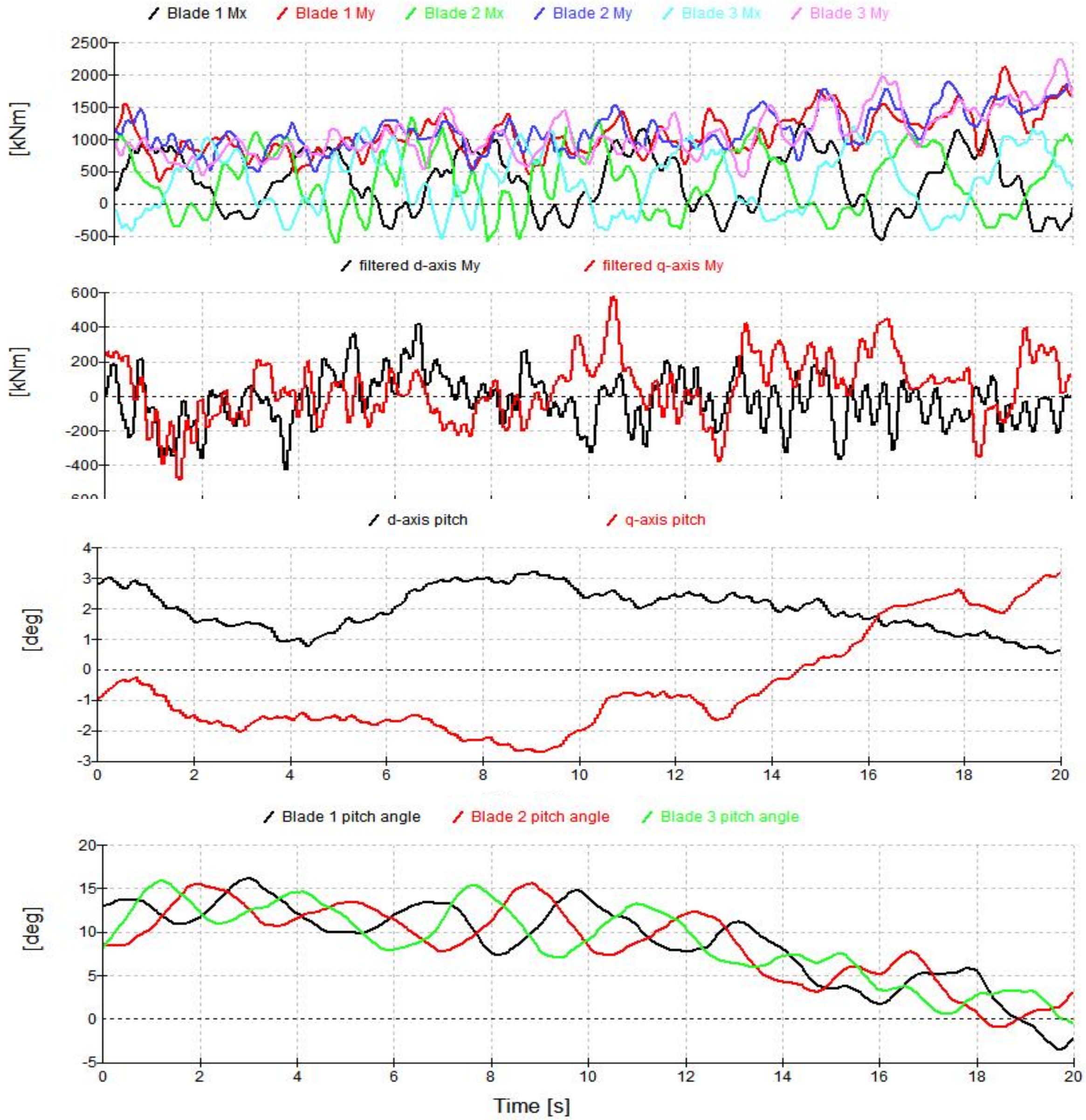
Out of plane moments transformed to non-rotating d-q axes

Non-rotating d-q axis pitch demands

Final pitch demands

Individual Blade Pitch Control - Example Data





Edgewise and flapwise moment input data

Pitch angles, rotor azimuth, filtering

Out of plane Moments transformed to non-rotating d-q axes

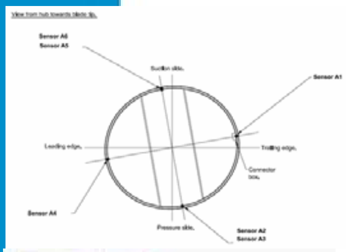
PI control

Non-rotating d-q axis pitch demands

Rotor azimuth, Collective pitch demand

Final pitch demands

Individual Pitch Control
- Hardware Implementation



1) Fibre optic sensors installed in the blade root

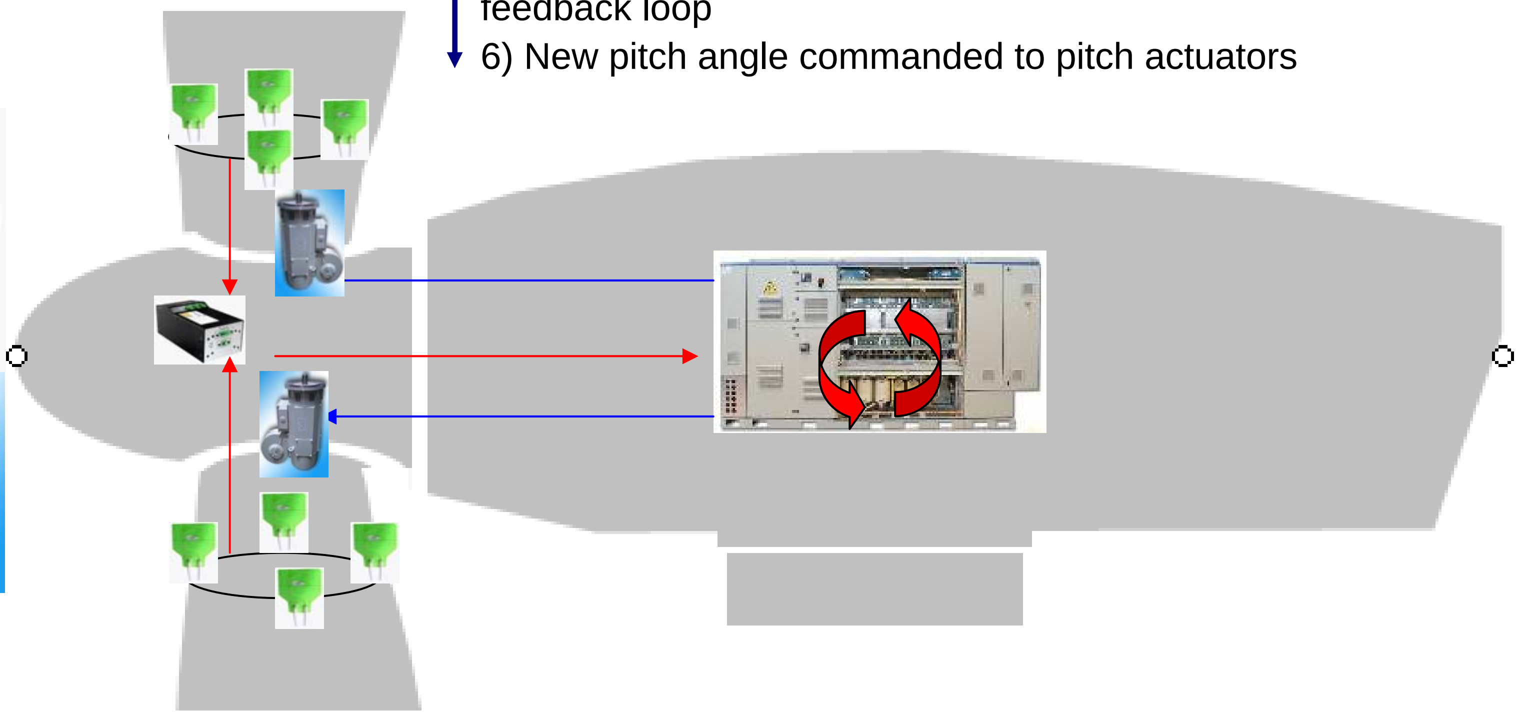
2) Measurement unit installed in the turbine hub

3) Data communicated to PLC cabinet

4) IPC calculations completed in PLC

5) Turbine blades pitch and load signal changes completing feedback loop

6) New pitch angle commanded to pitch actuators



Individual Blade Pitch Control
- Options for a Turbine Manufacturer

The load reductions from IPC can be leveraged in multiple ways by a turbine manufacturer;

1) Cost Optimisation

- Turbine's structural components can be designed for lower loads
- Lighter, cheaper parts, reduced transportation and installation cost

2) Modified Wind Class or Installation Conditions

- Increase rotor diameter for higher energy yield
- Installation in more turbulent locations i.e. more densely packed on a wind farm

3) Improved Turbine Reliability

- Utilise improved rotor balancing from IPC
- Reduced loads on blades, bearings, gearbox and drive-train
- Increase MTBF

All options can improve the turbine performance!

Application 3
Structural Health Monitoring

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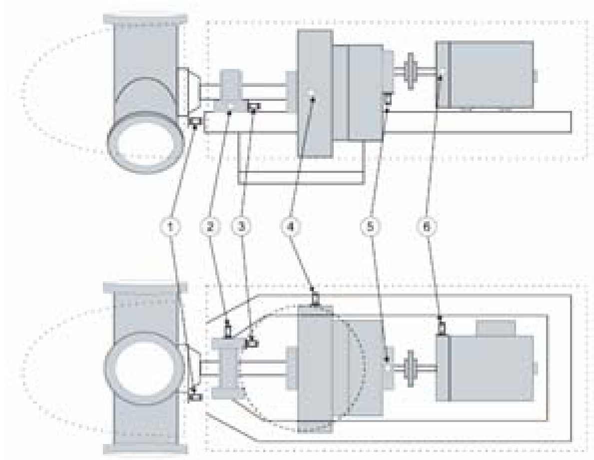
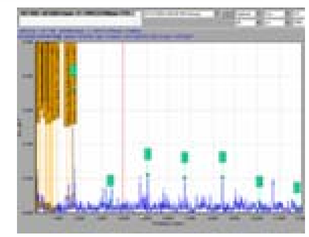
Structural Health Monitoring
- As it is today!

- A large number of parameters are monitored on modern wind turbines
  - Drive train vibrations
  - Generator oil condition
  - Pitch motor torques / pressures
  - Wind and machine parameters

- Very little if anything is monitoring on the blades or rotor

- Rotor is subjected to:
  - Instantaneous load variations
  - Fluctuating load pattern
  - Frequent peak loads
  - Rotor torque and axial thrust forces
  - Extreme environmental conditions
  - Acts of God!





Images courtesy of SKF, ISET, Gram and Juhl

Rotor Condition Monitoring
- Utilising Blade Load Data

- Measuring information from the blades can reveal a great deal of additional information about the performance of the turbine that can not be gained from conventional SHM techniques

- Insensys has developed algorithms to provide additional condition monitoring from blade load information that is complimentary to existing information

- Blade strain data can be processed in many different ways to real information about the turbine and blade performance

- Data can be issued to PLC, linked to an existing Condition Monitoring System enabling direct correlation between cause and effect or logged for latter analysis

Structural Health Monitoring - Overview

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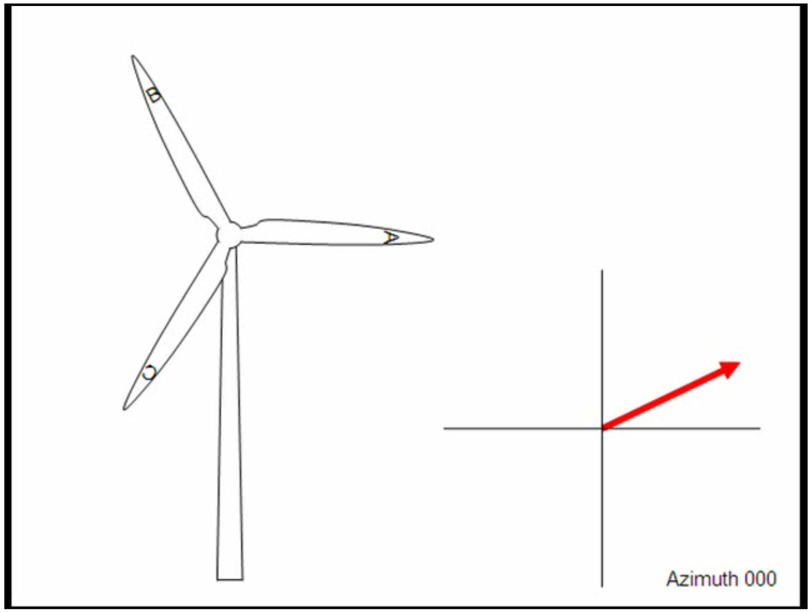
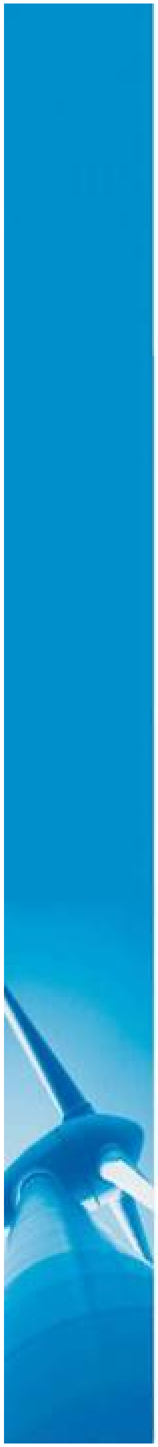
- Blade performance data
  - Strain and bending moments
  - Load histories and extreme loads
- Rotor performance data
  - Imbalance / offset load
  - Tilt moments / Yaw moments
  - Mass / Aerodynamic
  - L/D rations
- Performance history and defect detection
  - Accumulative fatigue and residual lifetime
  - Material Loss
  - Debond / delamination identification
- Lightning Strike Detection
- Blade Icing

(click image below to play video)





Structural Health Monitoring
- Lightning Detection and Measurement

- Insensys has developed a fibre-optic lightning detection and measurement system, based on existing architecture
- Measures every lightning strike, on each blade, in real time, providing several key intensity parameters Increases generating revenue by avoiding waiting for un-necessary inspections, and scheduling required inspections
- Allows decision to be taken whether protection system, or blades, likely to have been damaged in strike

Structural Health Monitoring
- Ice Detection and Measurement

- Insensys is developing an ice detection and measurement system, based on existing fibre-optic system architecture

- Key benefits:
  - Enabling safe shutdown, preventing ice throwing
  - Safe, automatic restart
  - Minimising generation loss
  - Avoiding rotor imbalance caused by icing
  - Compliance with latest EU legislation on ice detection

Summary

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Summary

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- Insensys fibre optic instrumentation is a proven, reliable technology for blade strain & load measurement in Wind Turbines
- The benefits of using blade loads sensors for turbine control applications are already well understood
- A number of turbine manufacturers today include IPC in their designs and many others will shortly be following suit.
- Significant additional benefit can be achieved by monitoring the blades loads and correlating the data with the data from the drivetrain monitoring system
- Àdvanced technologies and data processing techniques are being developed toprovide manufacturers and operators with further functionality

What Next?

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- Whatever you guys throw at us next……….
  - Multipart blades
  - Blades with adaptive flaps / actuators
  - Load shedding blades
  - Next generation IPC

- The sensors are ready!!!!!!

Thanks for listening!

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