A Survey of Wind Turbine Condition Monitoring Experience in Europe

Peter Tavner

"I have only one eye; I have a right to be blind sometimes... I really do not see the signal!"

Rear-Admiral Horatio Lord Nelson at the battle of Copenhagen

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Overview

- Supergen Wind
- SCADA, monitoring and data
- Why we need condition monitoring
- Wind power cost of energy, availability and reliability
- Wind turbine availability onshore and offshore
- Conclusions-detection, diagnosis, prognosis & prediction
- Future challenges

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Supergen Wind Research Consortium

- ***To undertake research to achieve an integrated, cost-effective, reliable & available Offshore Wind Power Station***
- http://www.supergen-wind.org.uk/
- Funded by UK EPSRC
- Phase 1: 2006-2010, £2.55M
- Phase 2: 2010-2014, £5.83M
- Seven Research Institutions
- 19 Industrial Partners
- Four Research Themes:
  - The Turbine
  - The Farm
  - The Connection
  - The Offshore Wind Farm as a Power Station

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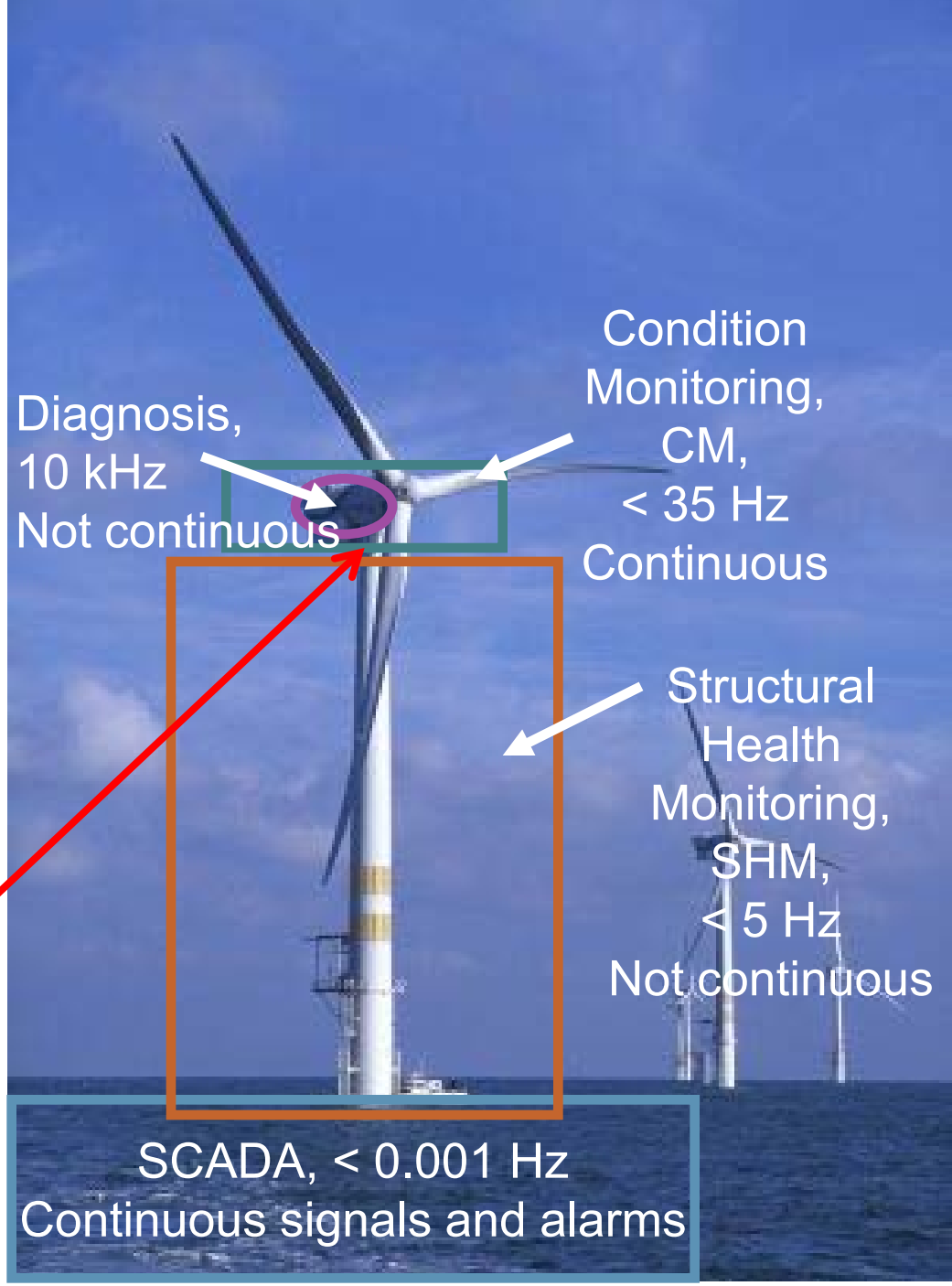
SCADA and condition monitoring in context

Modern WTs ≥ 2MW have up to 500 Input/Output data pieces, signals and alarms every 10 mins.
Coming from WT Controller



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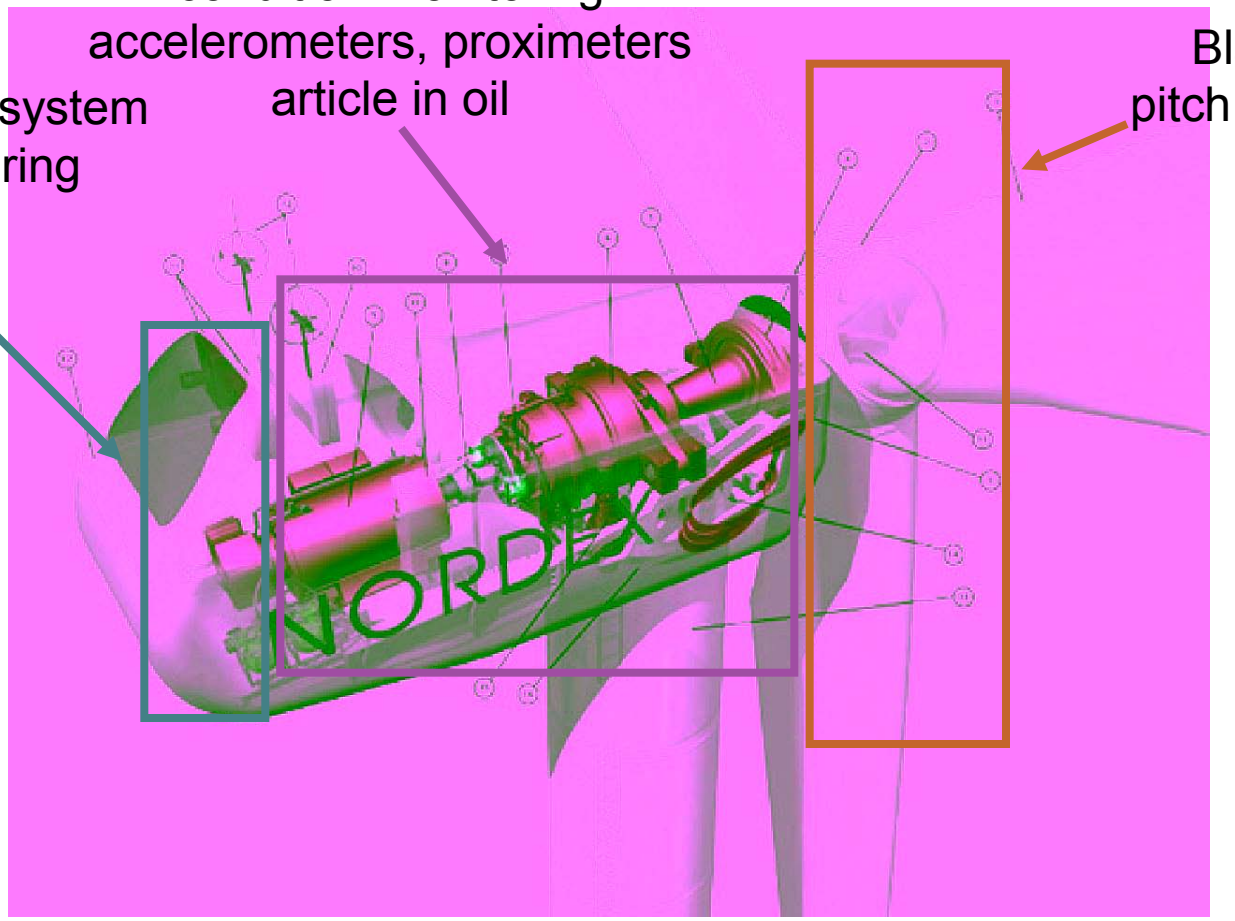
Condition Monitoring in Context

Conventional rotating machine condition monitoring
accelerometers, proximeters
article in oil

Electrical system monitoring

Blade and pitch monitoring



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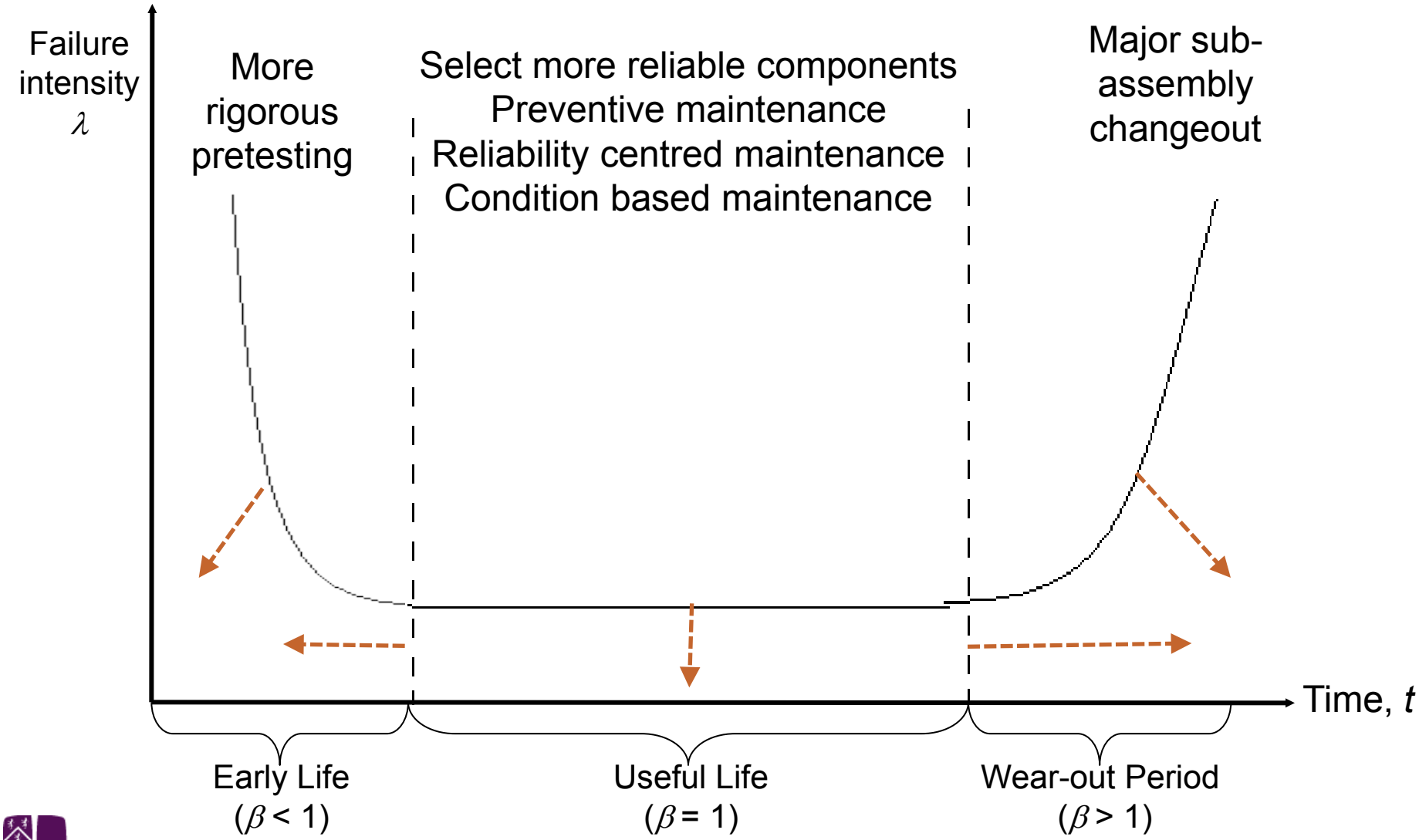
Bathtub Curve



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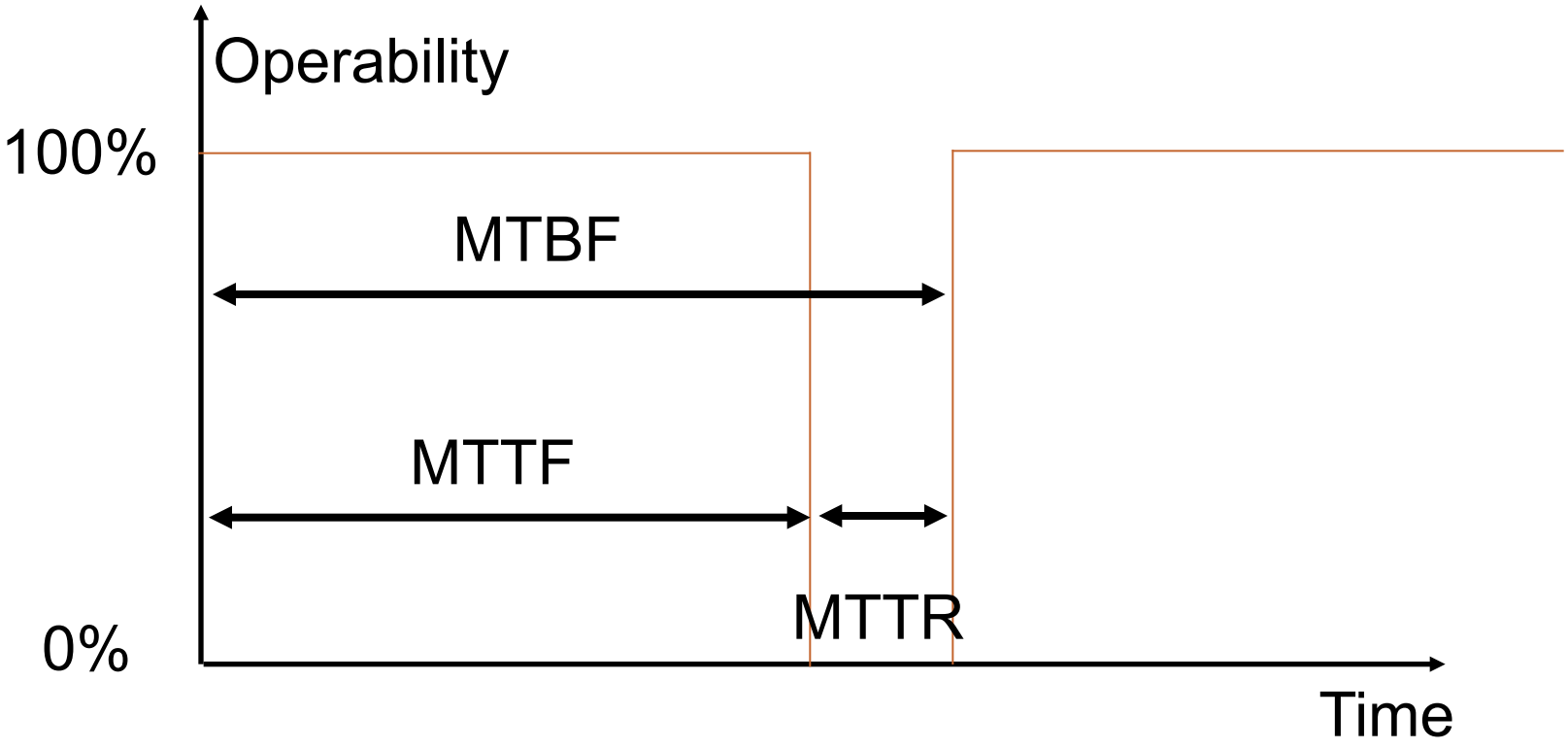
Availability, Inherent



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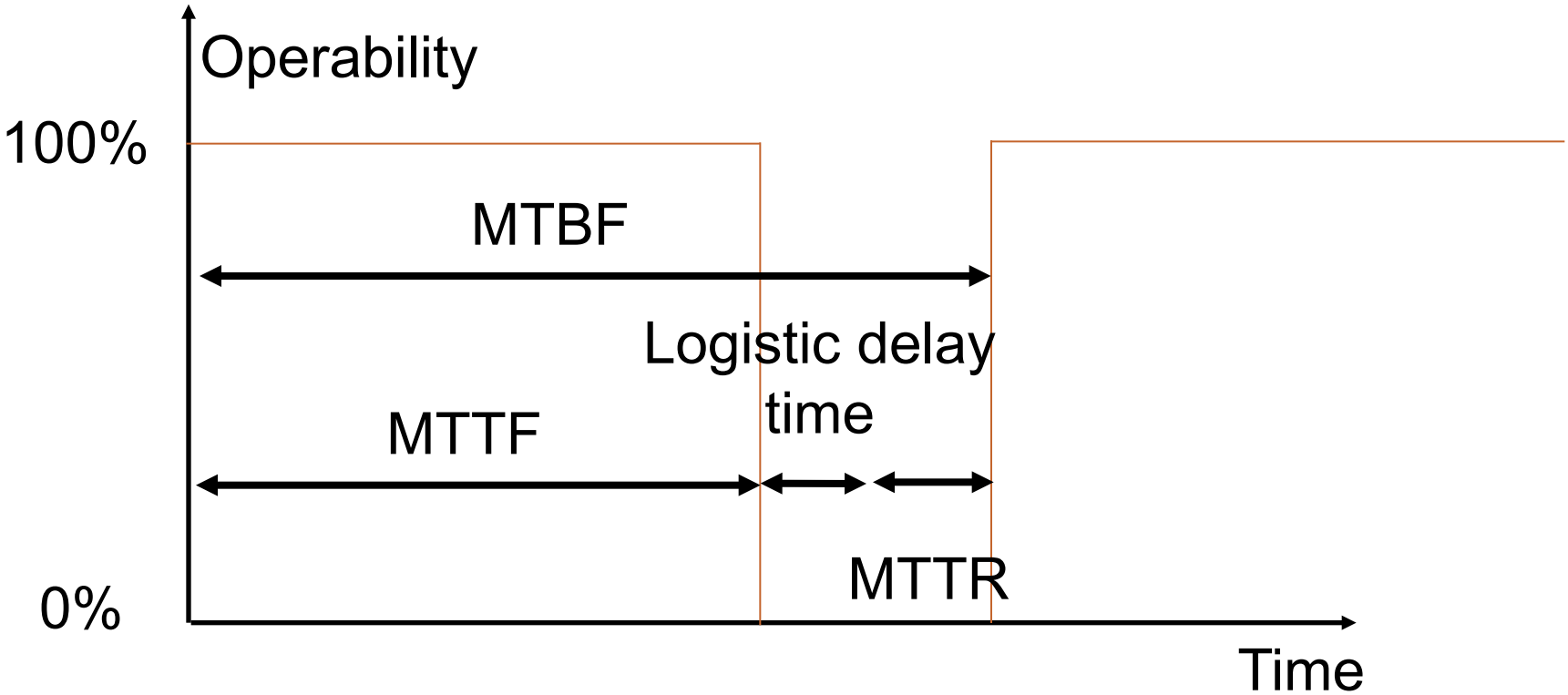
Availability, Operational



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Capacity Factor, Availability, Cost of Energy, *COE*

Energy generated in a year = C x Turbine rating x 8760

Capacity Factor, *C*

8760: number of hours in a year

Therefore *C* = *Energy generated in a year / Turbine rating x 8760*

C incorporates the Availability, *A*

Availability, $A=1-MTTR/MTBF$, where $MTBF=1/\lambda$ & $MTTR=\mu$

	Capacity Factor, C	Availability, A
Typical UK values		
Onshore	27.3%	97%
Early offshore	29.5%	80%
Typical EU values		
Vattenfall onshore target		98%
Offshore	36%	90%
Vattenfall offshore target		95%

COE:

Onshore £30-40/MWh
Offshore £69-120/MWh

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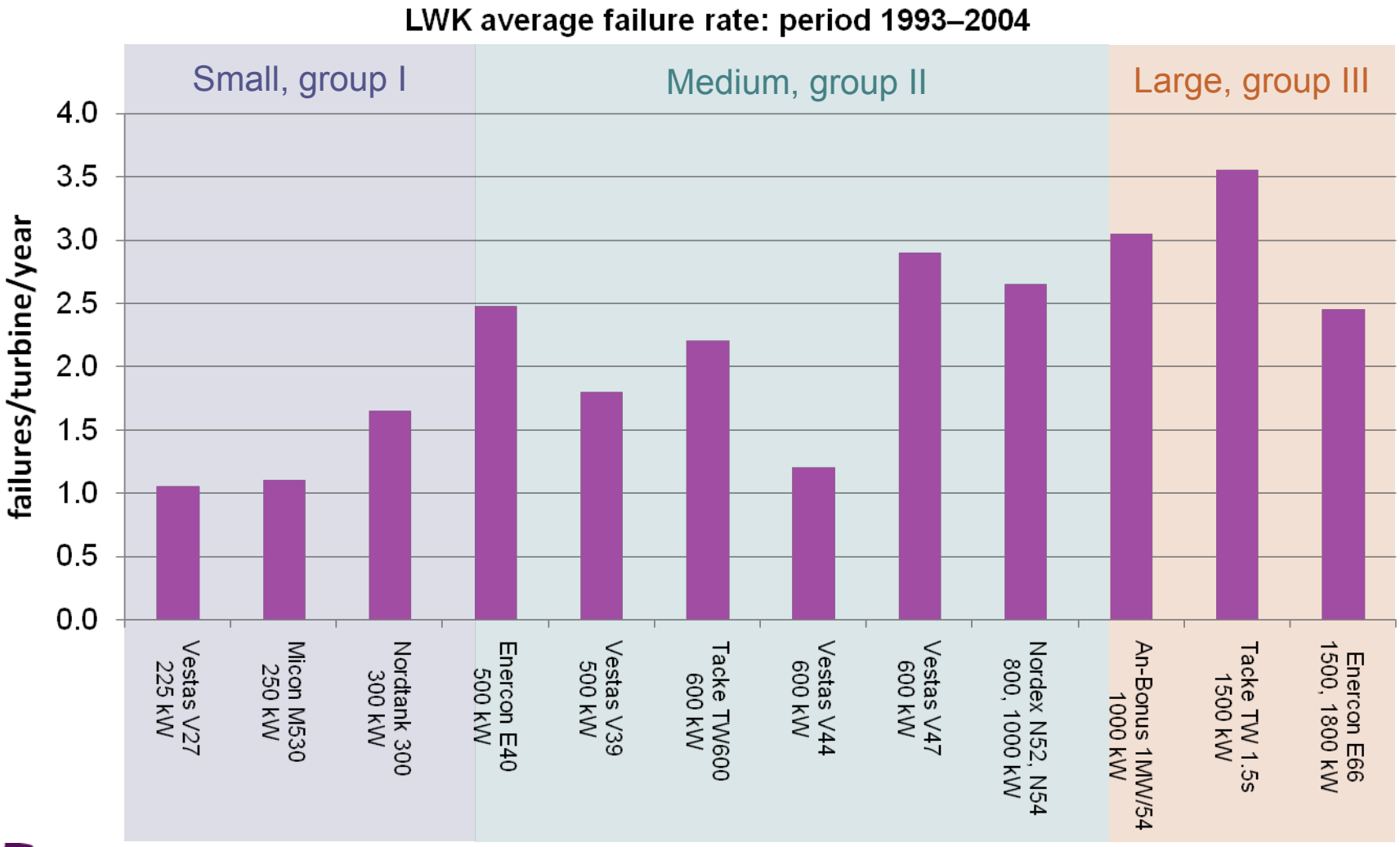
Reliability and Size, EU



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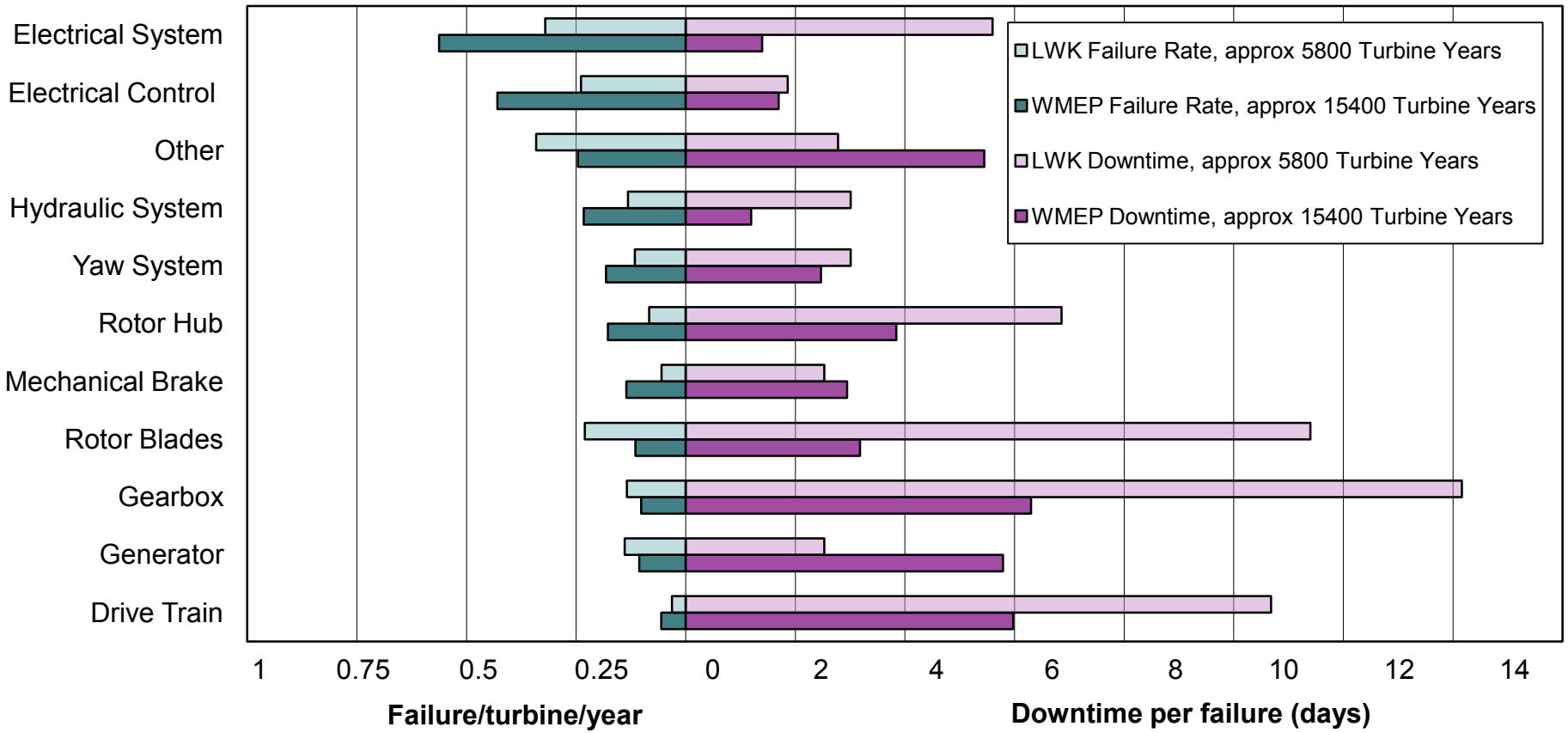
Reliability, Downtime and sub-assemblies, EU

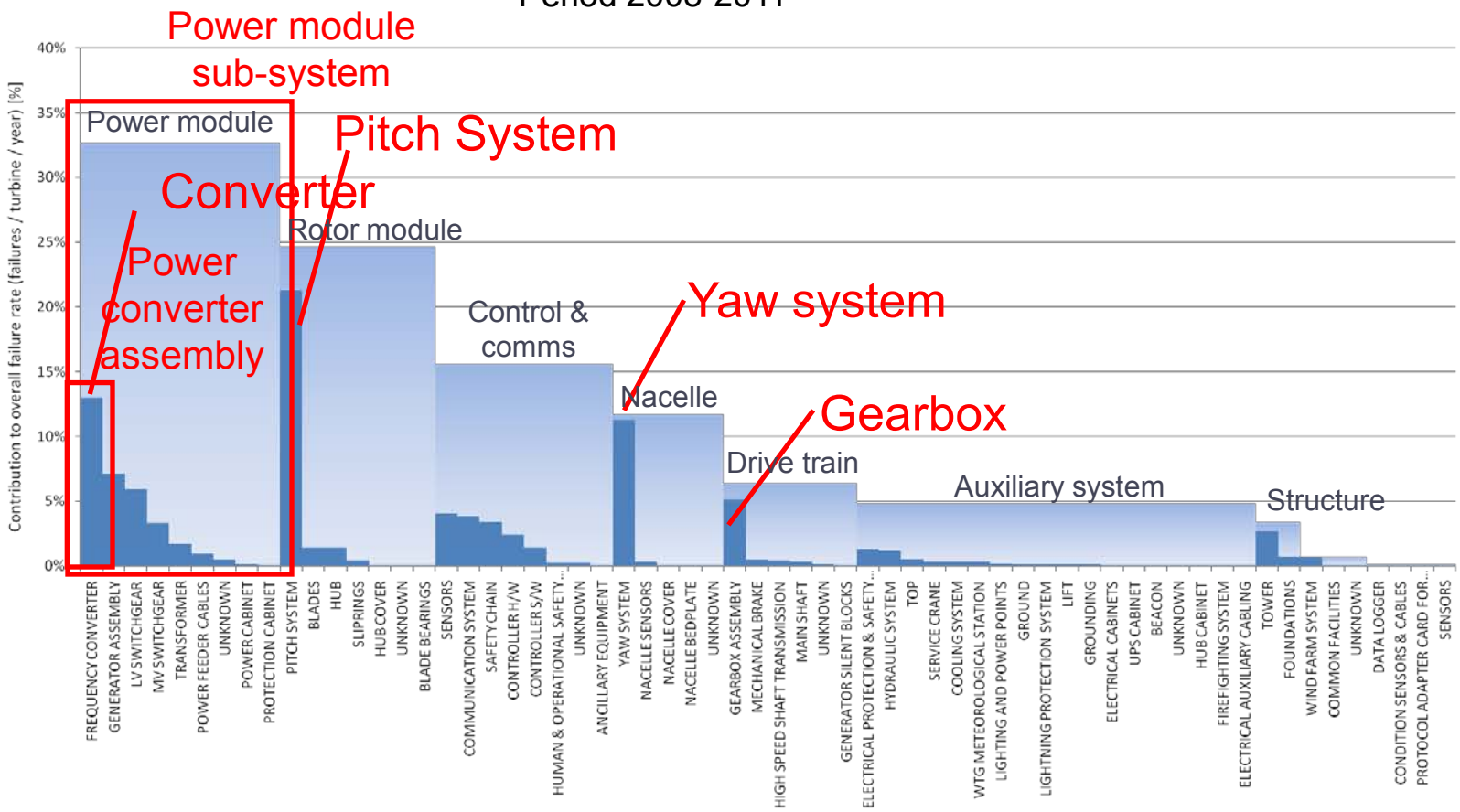
Failure/turbine/year and Downtime from 2 Large Surveys of onshore European Wind Turbines: period 1993-2006



75% of faults cause 5% of downtime
25% of faults cause 95% of downtime

Reliability, Downtime and sub-assemblies, EU Onshore

- ~35,000 Downtime Events
- ~1400 Turbine Years
- Onshore turbines 1-6 years old, all large & pitch-regulated
- Period 2008-2011



Percentage contribution to overall failure rate

Data source: turbines from multiple manufacturers

Summary of ReliaWind WP1 Data: Critical sub-assemblies

Sub-system / Assembly	Total Failure Rate %	Medium Time Lost %
Pitch System	16%	20%
Frequency Converter	12%	13%
Yaw System	12%	10%
Control System	14%	9%
Generator Assembly	6%	11%
Gearbox Assembly	5%	4%

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Offshore Capacity Factor & Availability

UK Round 1: Scroby Sands, North Hoyle, Kentish Flats, Barrow; USA: Brazos; Netherlands: Egmond aan Zee

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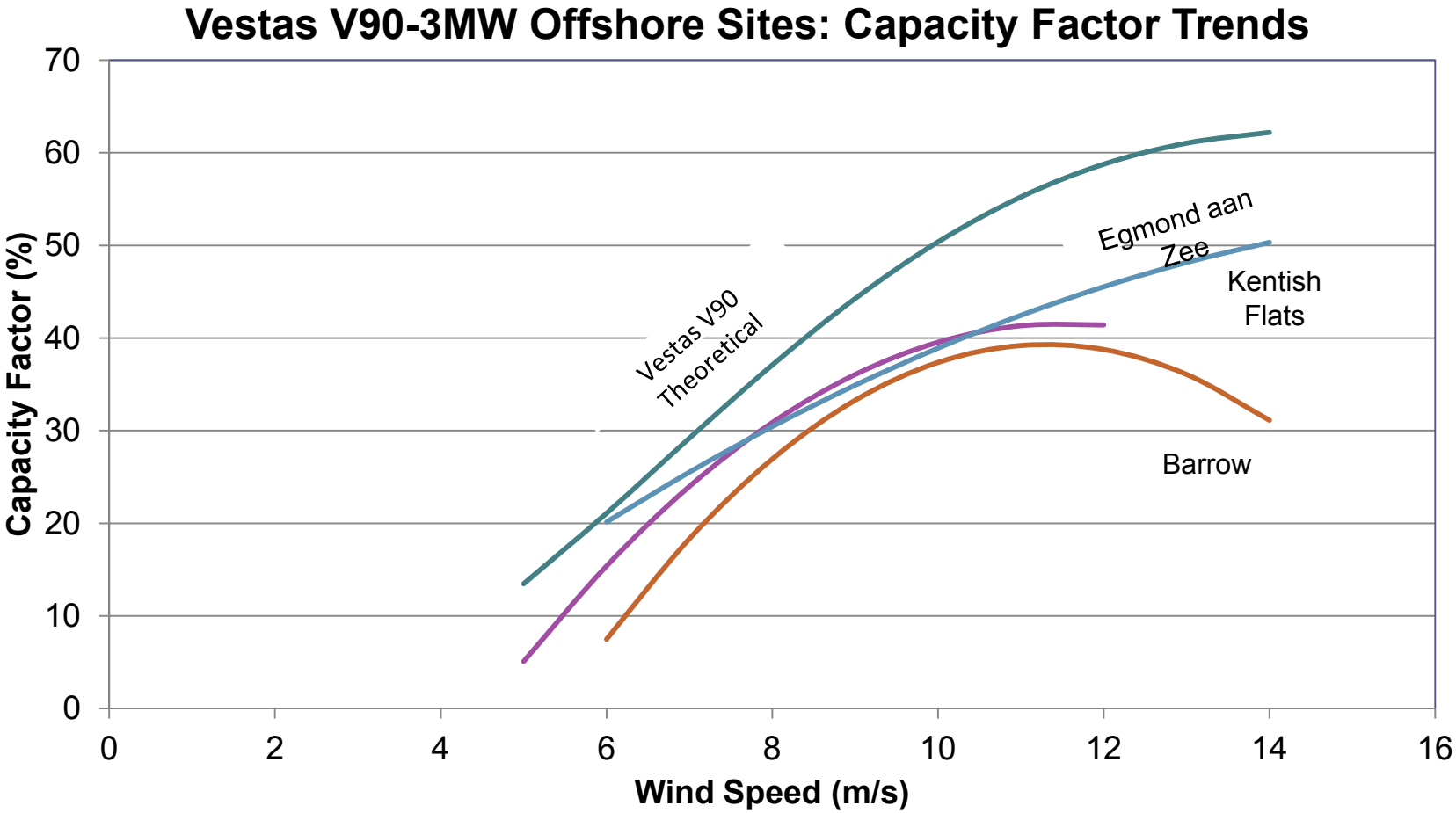
Offshore Capacity Factor and Wind Speed, UK



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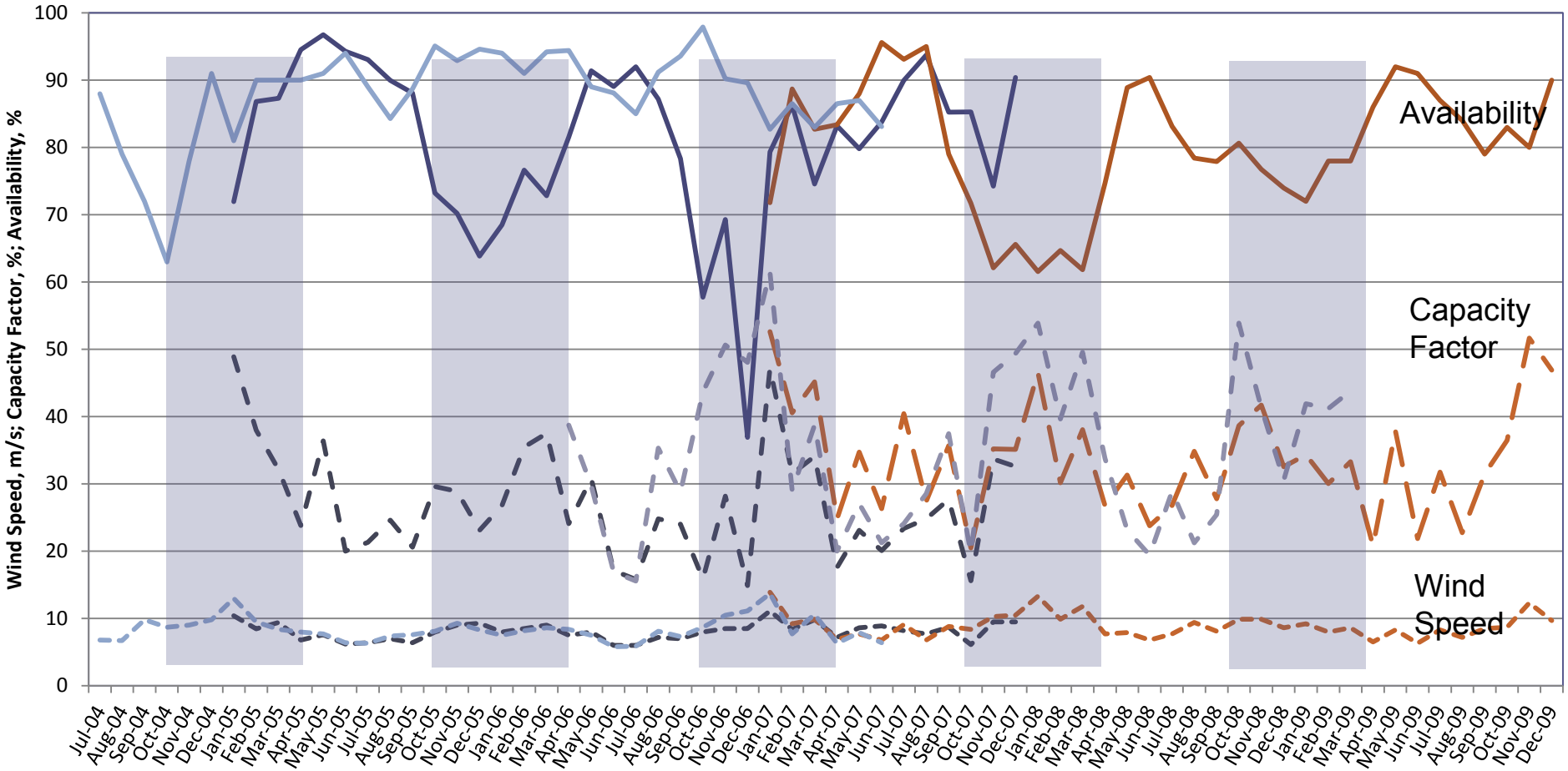
North European Offshore Wind Farm Performance



Three North European Offshore Wind Farms

- Scroby Sands
- Noth Hoyle
- Egmond aan Zee

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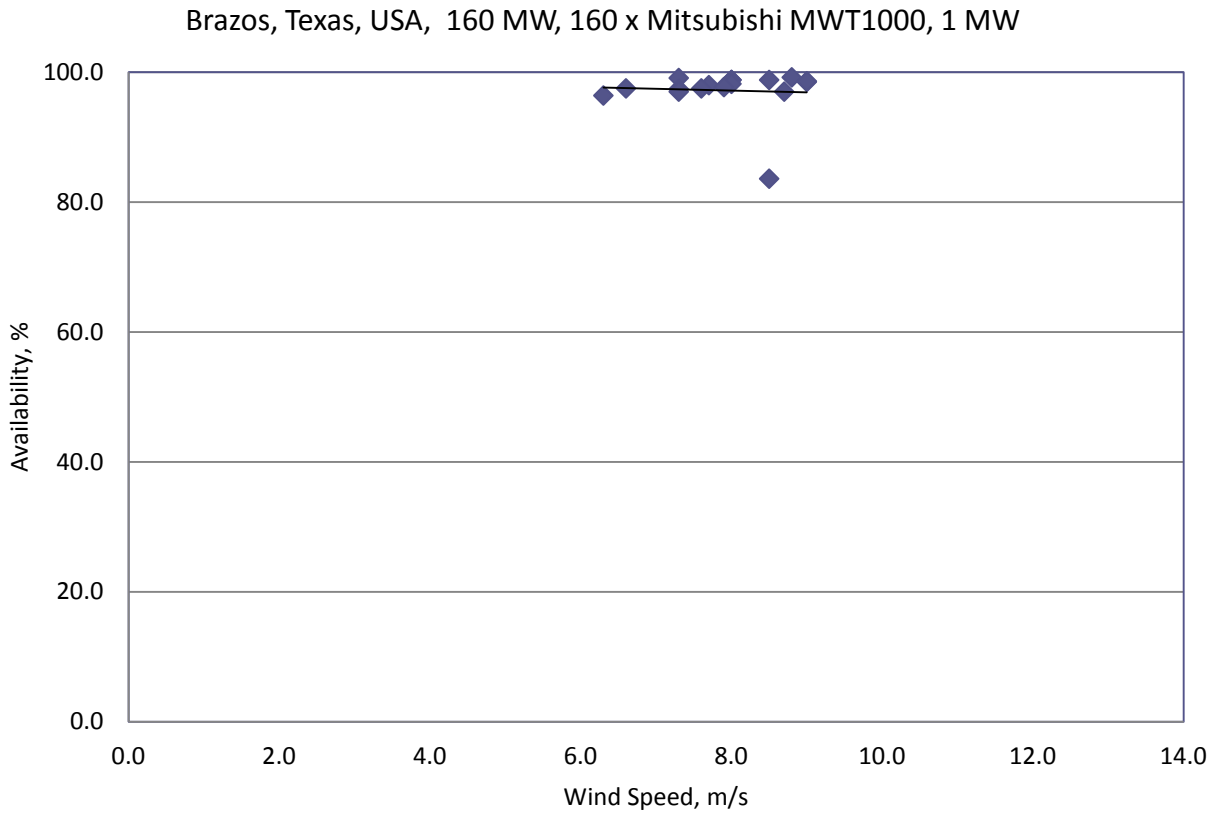
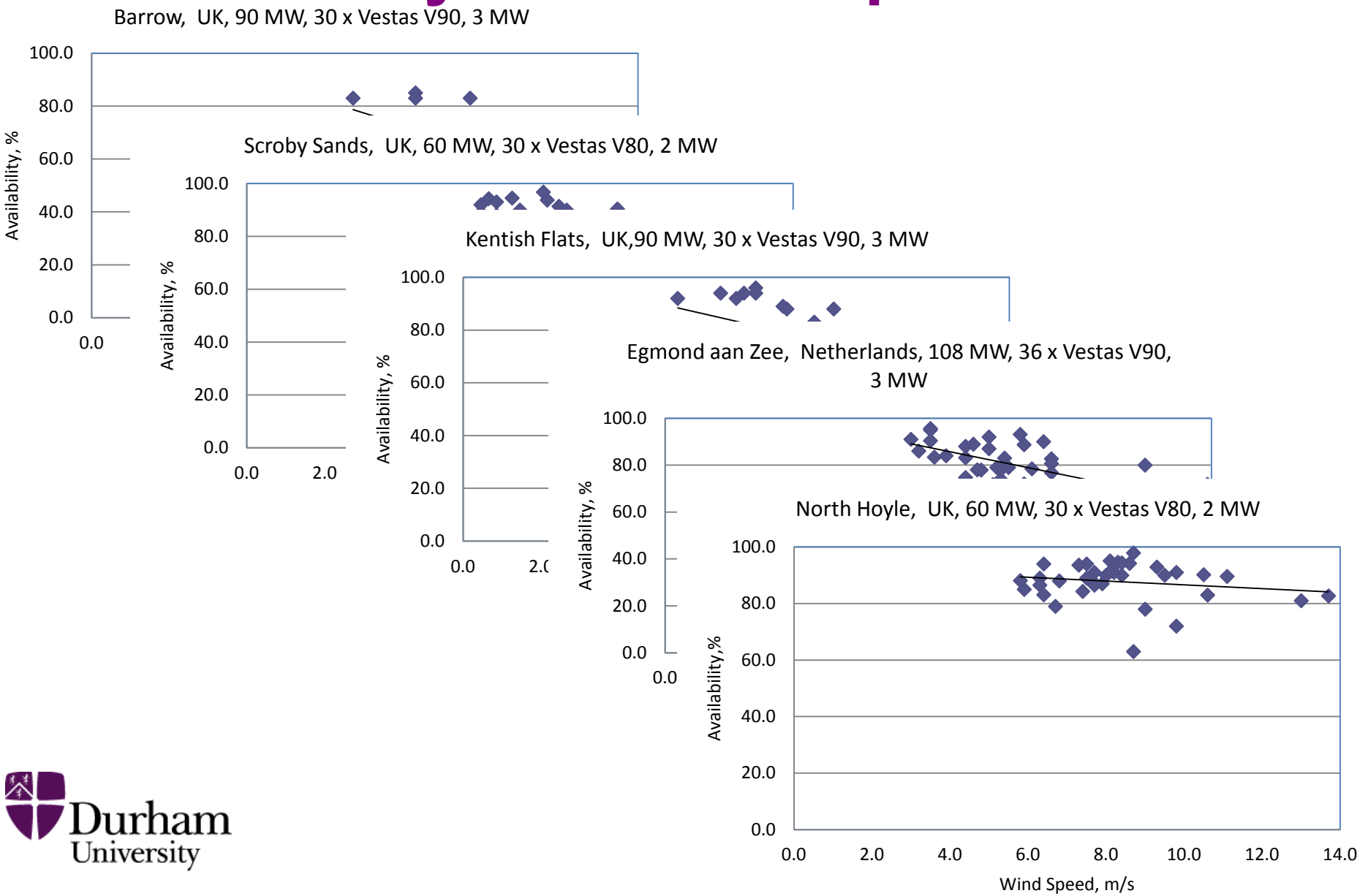
Onshore
Availability and Wind Speed



Offshore Availability and Wind Speed



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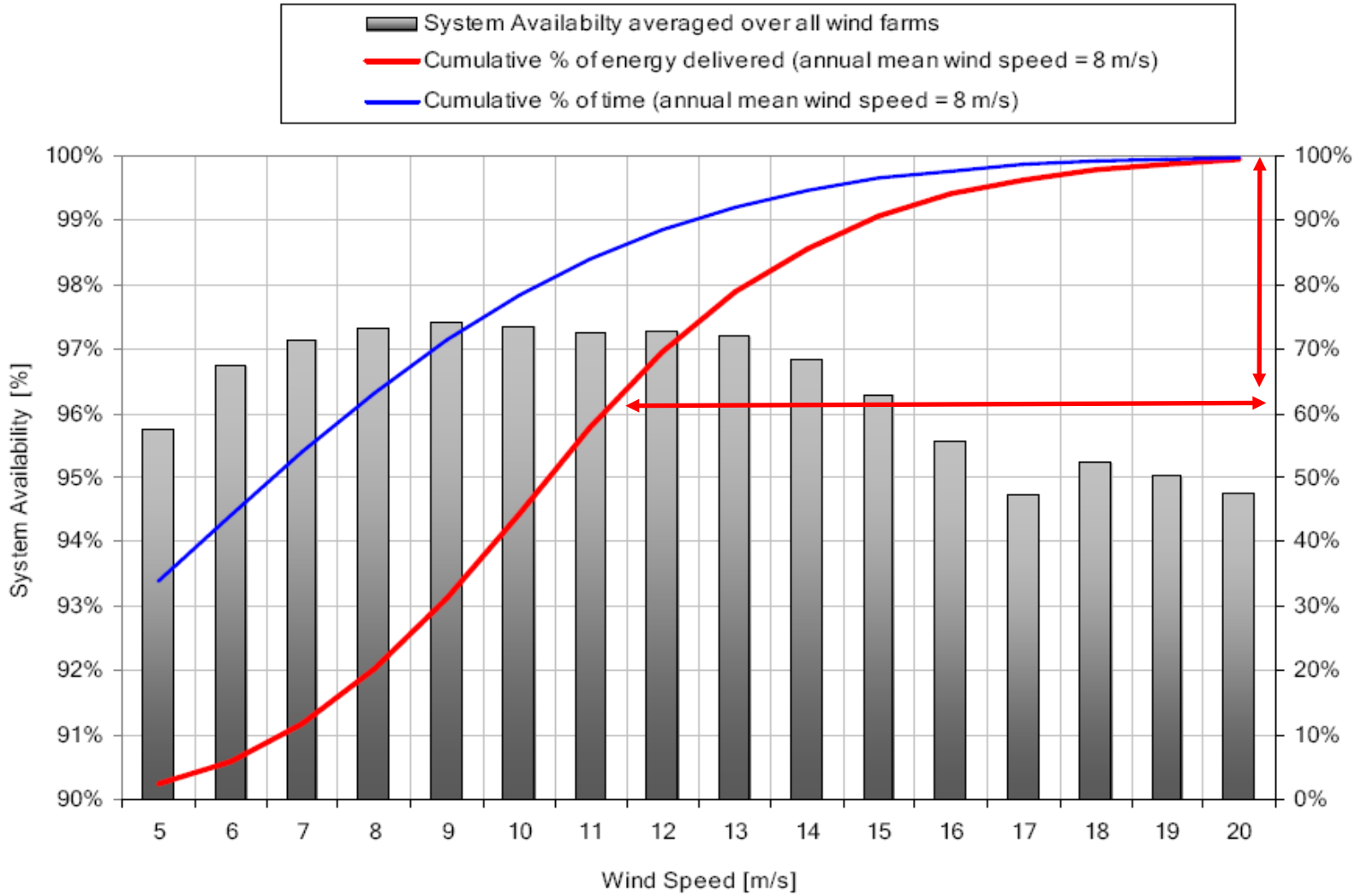
Onshore Availability and Wind Speed, World



40% energy produced at wind speeds >11m/s

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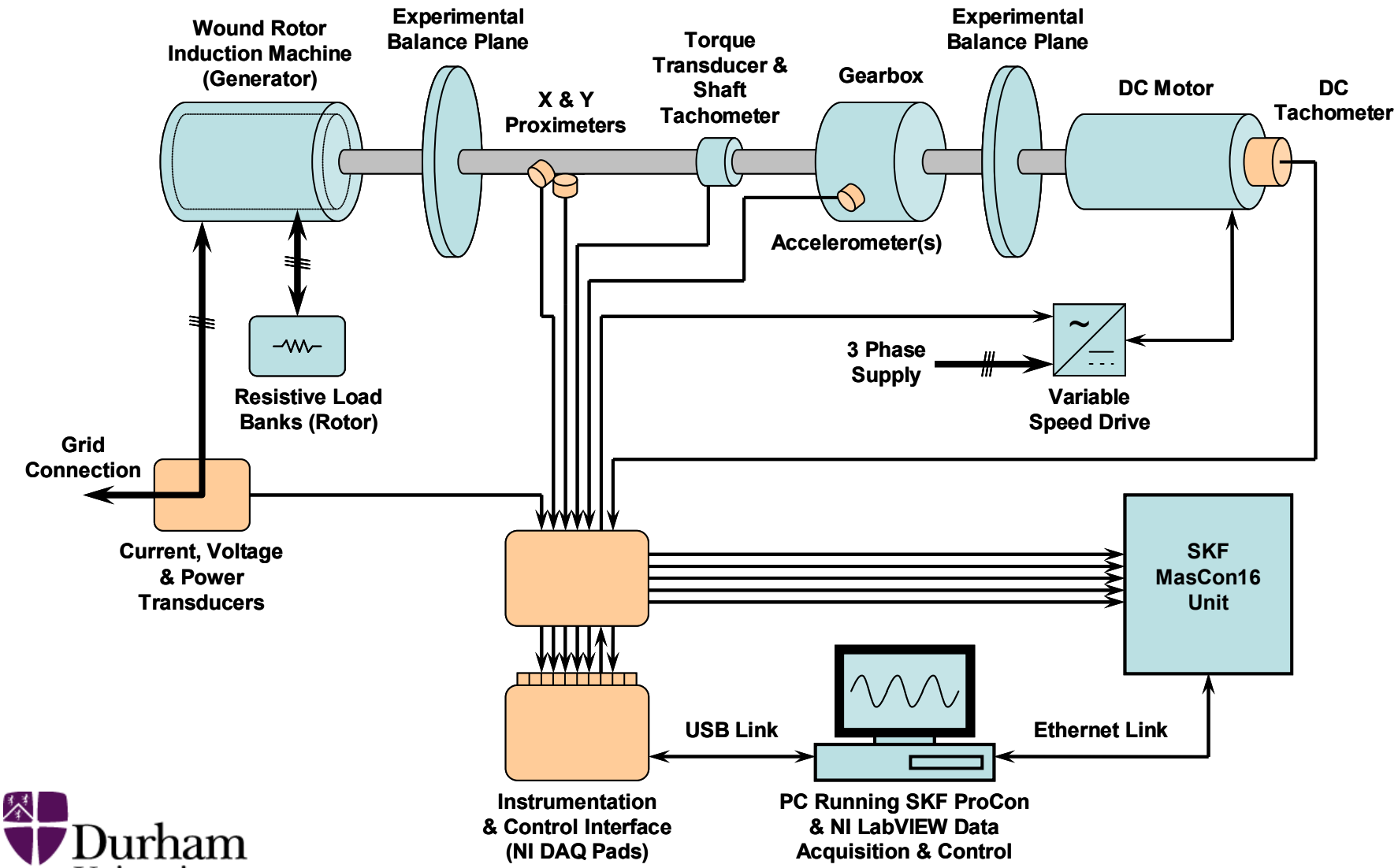
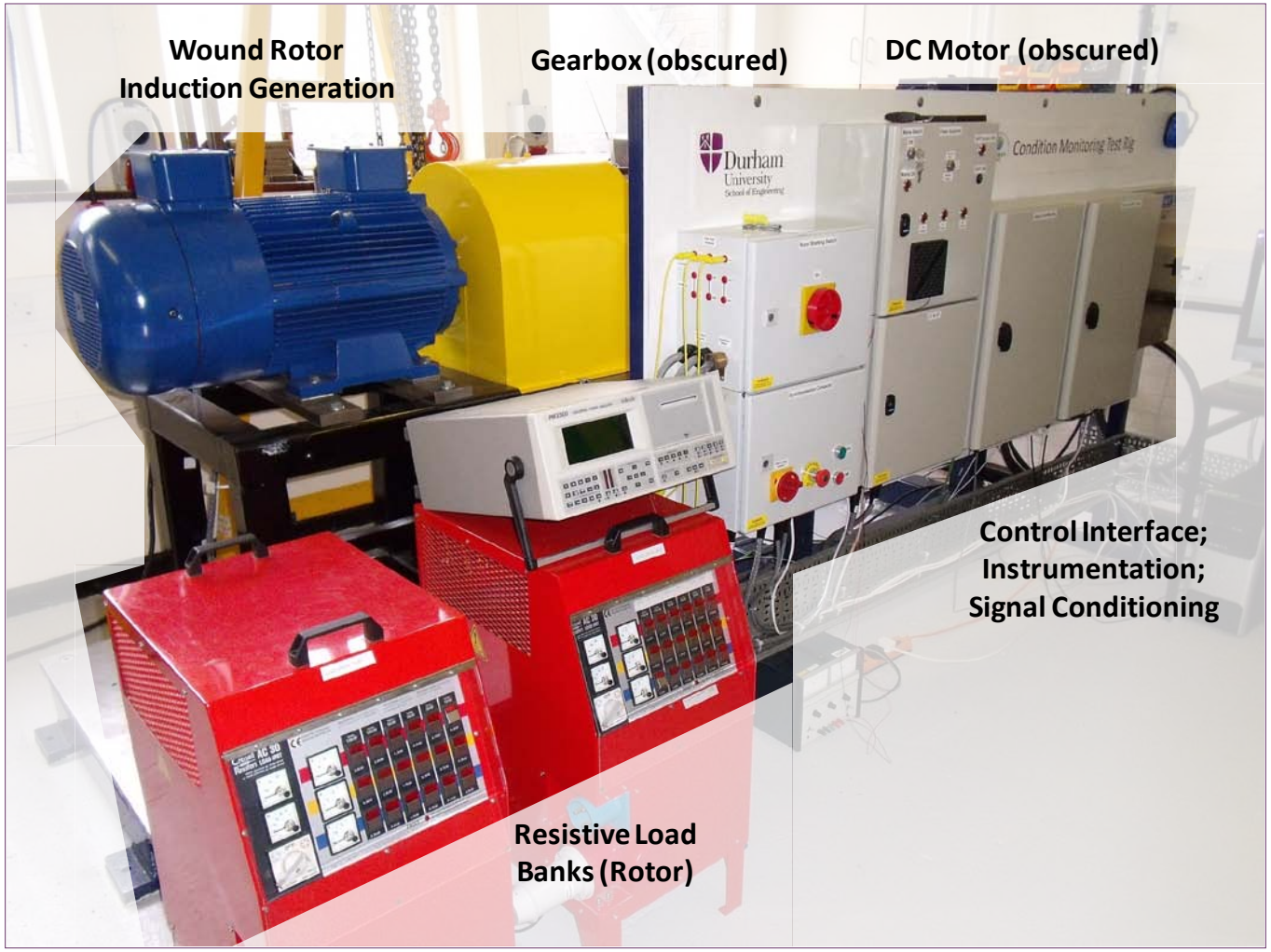
WT Condition Monitoring Test Rig I

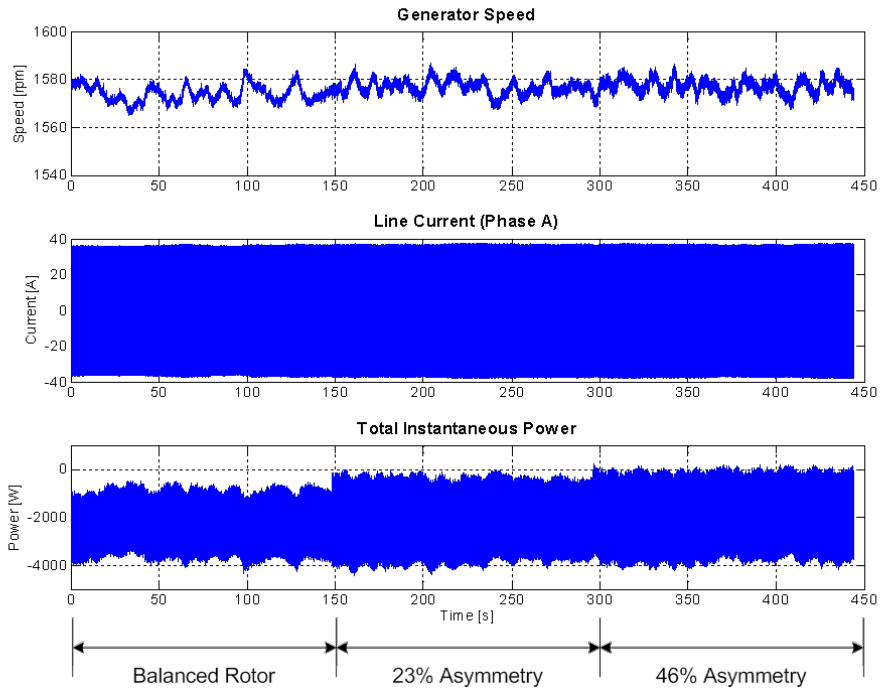


WT Condition Monitoring Test Rig II



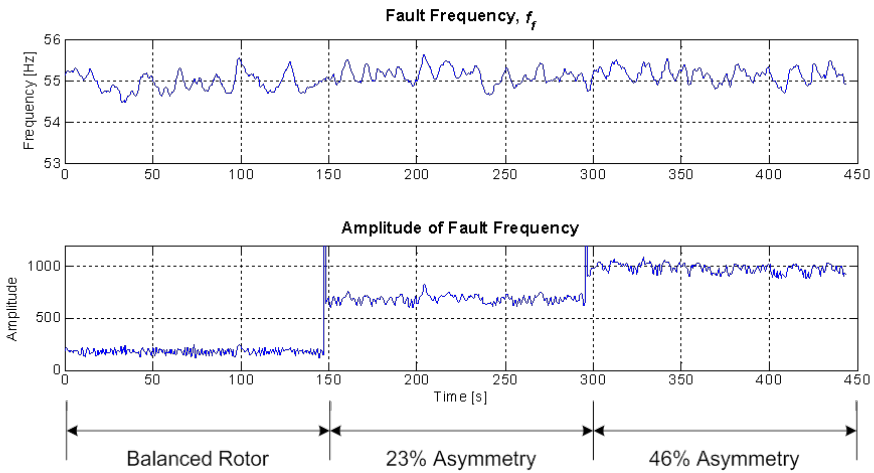
Test Rig Results – Electrical Asymmetry

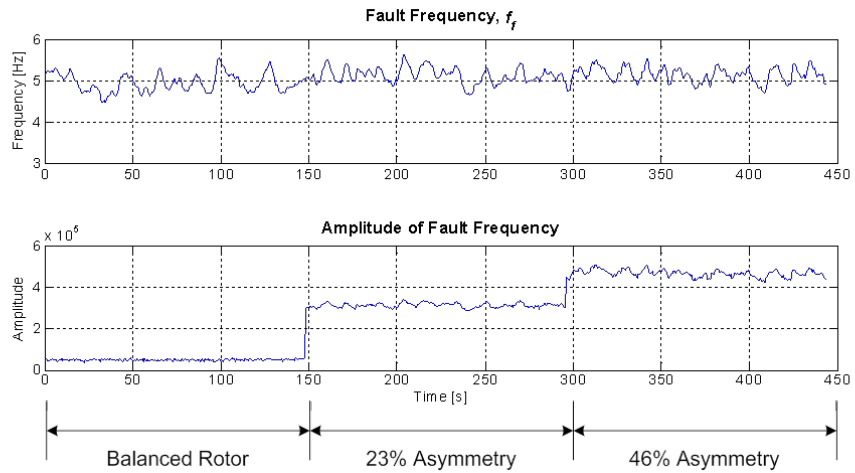
- Wound rotor induction generator rotor electrical asymmetry
- For example, brush gear fault/unbalance



Test Rig Results – Electrical Asymmetry

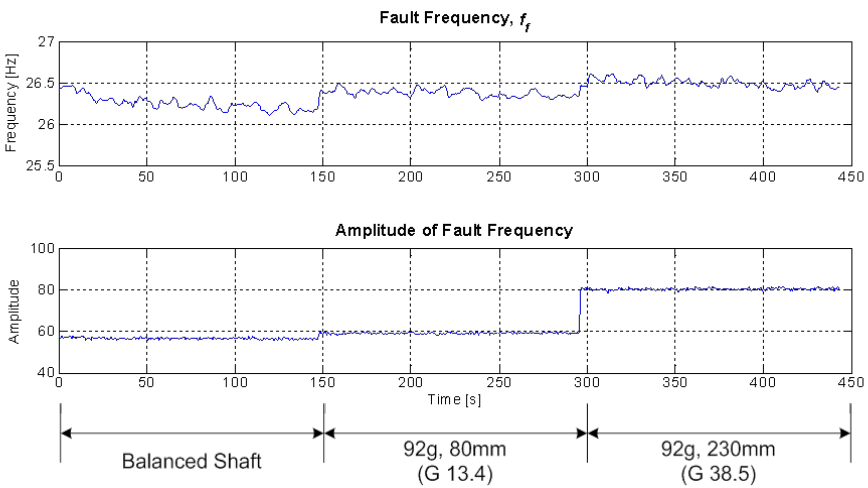
- Line current analysis
  - $(1\text{-}2s)f_{se}$
- Total power analysis
  - $2sf_{se}$



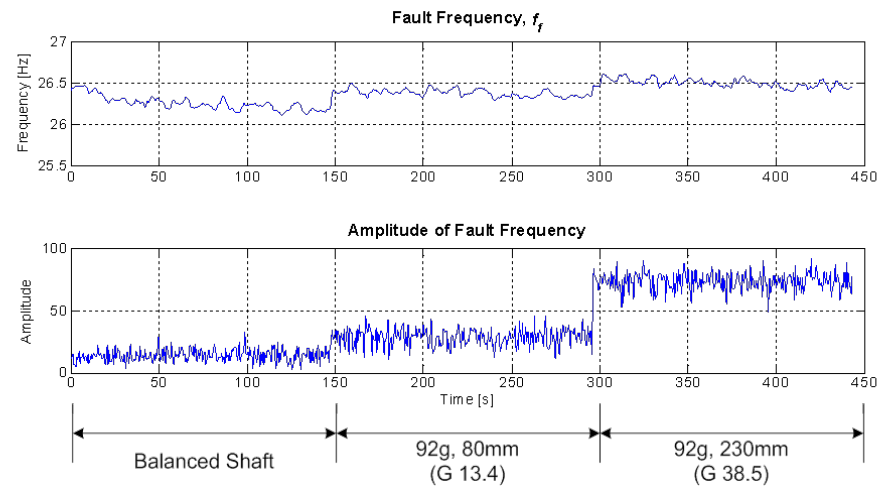


Test Rig Results –Mass Unbalance

- High speed shaft displacement analysis
  - f_{rm} , machine rotational speed



- Gearbox high speed end accelerometer analysis
  - f_{rm} , machine rotational speed



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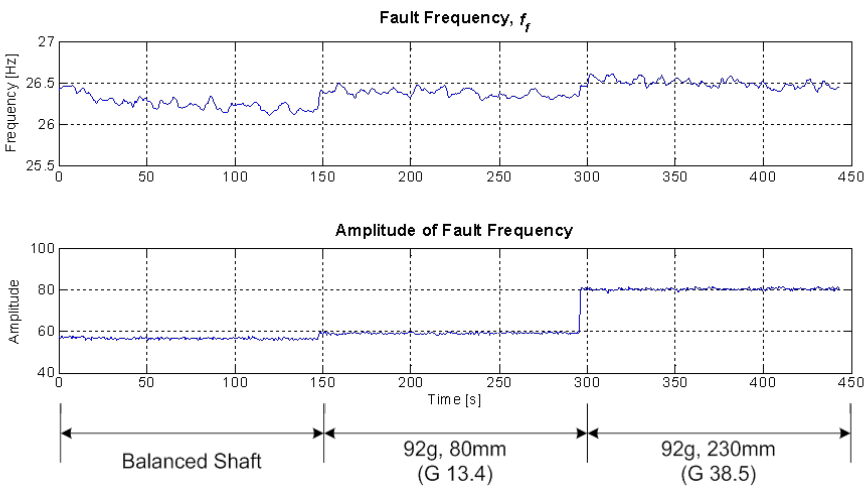

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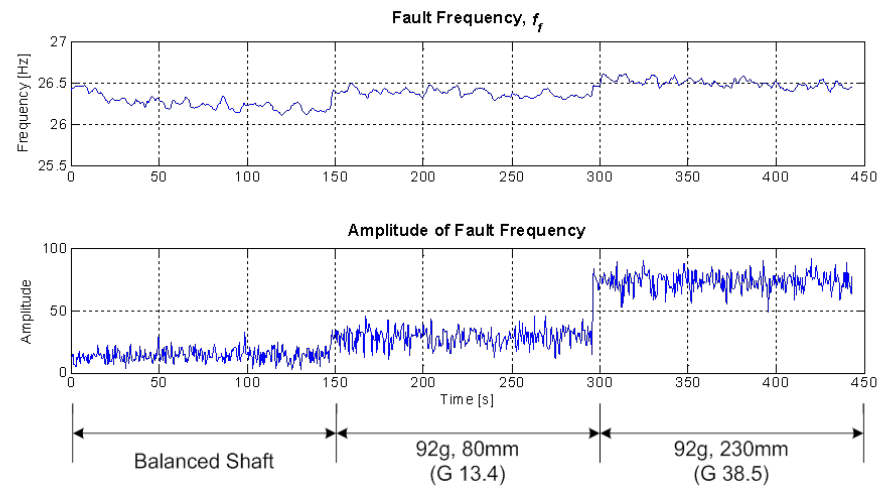
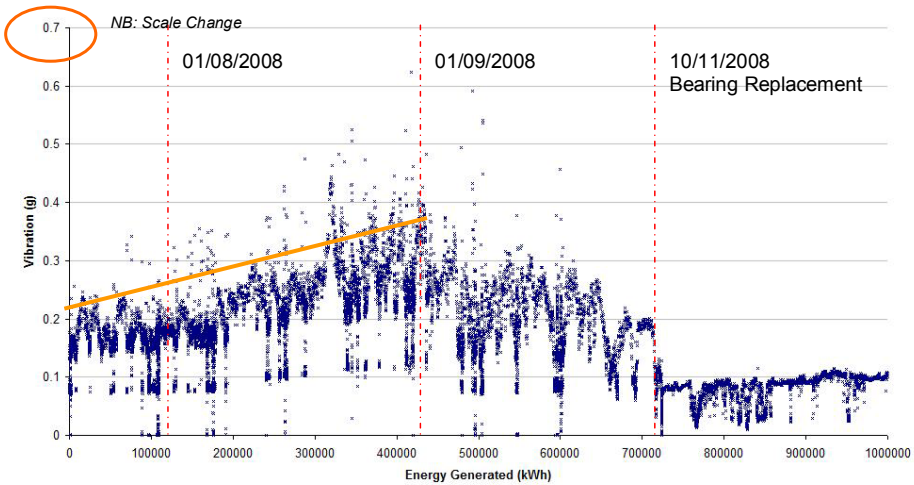


SKF Field Results –Bearing Failure

- Gearbox intermediate shaft bearing fault
  - Inspection confirmed damage and bearing was replaced

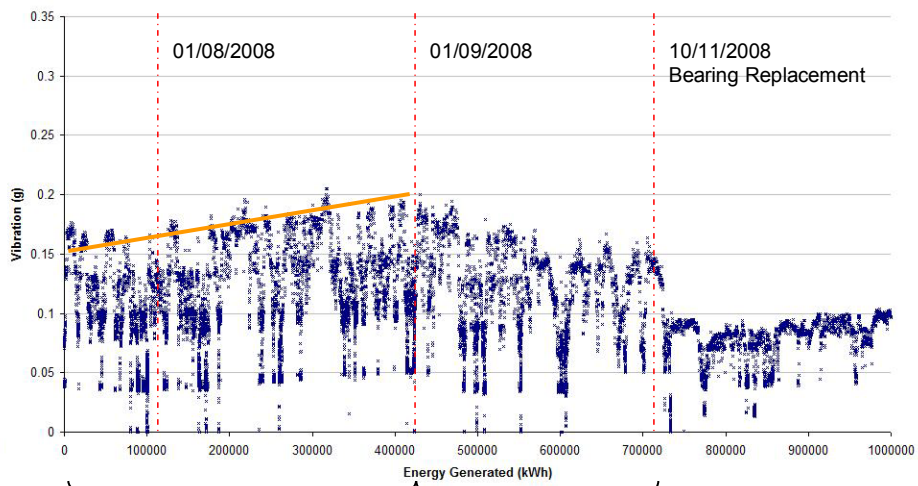
Gearbox High Speed Shaft Axial Vibration Envelope (g) against Cumulative Energy Generated (kWh)



Initial damage causing increased vibration

Severe bearing deterioration possibly causing reduction in vibration transmission path

Gearbox High Speed Shaft Transverse Vibration Envelope (g) against Cumulative Energy Generated (kWh)



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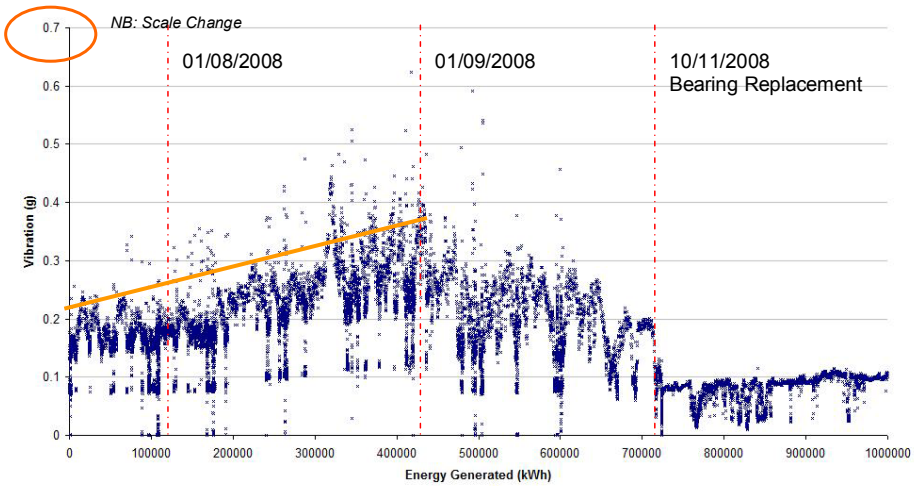
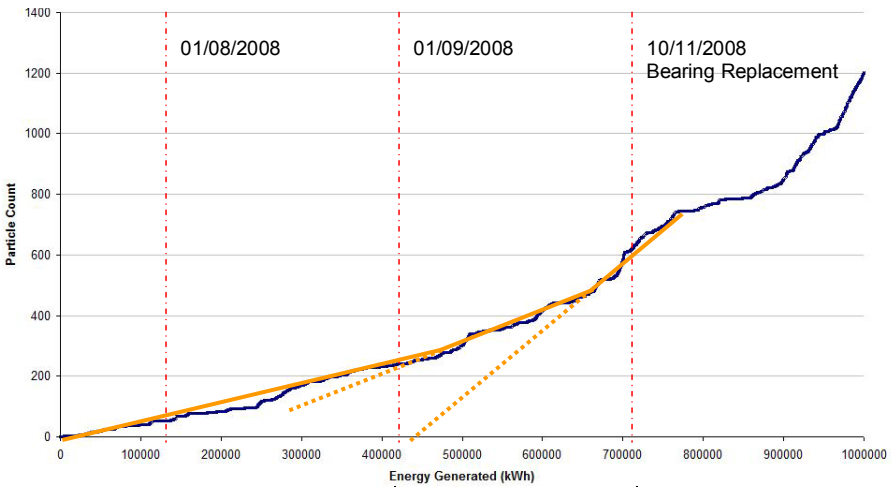


Initial damage causing increased vibration

Severe bearing deterioration possibly causing reduction in vibration transmission path

Cumulative Ferrous 50 µm Bin Count against Cumulative Energy Generated (kWh)



Increased particle count rate coinciding with change in vibration trend

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The Problem: Offshore Rounds 2 & 3

Wind Farms of 100-500 WTs

400 I/O per WT

20000 WT I/O per Wind Farm, excluding substation, cables & connection

Total Wind Farm I/O > 30000

Onshore 75% of faults cause 5 % of downtime

Offshore this 75% of small faults will be critical

With the alarm rates encountered onshore **Operations will be overloaded**

Because they will consume O&M time & money

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The Solution:
A Wind Farm Knowledge Management System

Integrate SCADA & CMS

Control Wind Farm I/O

Classify faults per WT

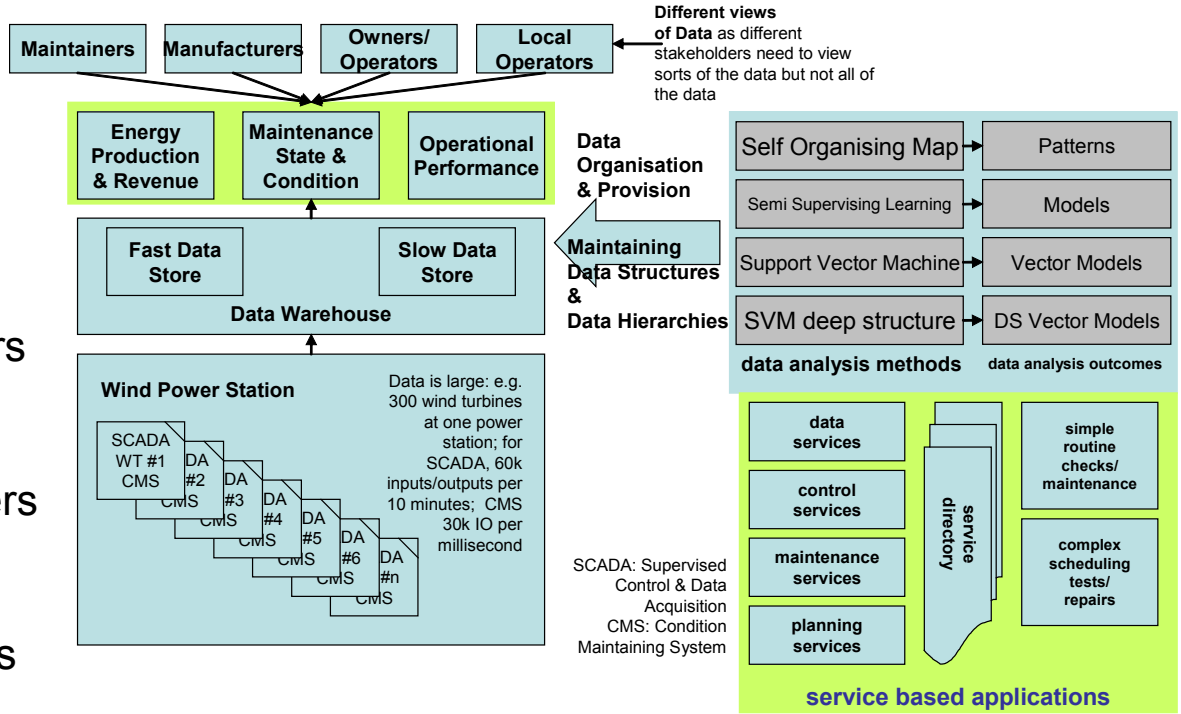
Automatic Alarm Handling

Clear GUI for Operational Managers showing key faults

Clear GUI for Maintenance Managers classifying key faults

Drill down from GUI for Maintainers to diagnose and prognose faults

Lengthen prognostic horizon



Conclusions

- WT reliability is improving;
- WT concepts have different reliabilities but failure rates are constant;
- sub-assemblies with high failure rates are consistent;
- Downtime or *MTTR* and cost are also important;
- Condition monitoring targeted at those sub-assemblies is effective & cost-effective;
- We must combine SCADA & CMS;
- We must consider multiple signals;
- We need to detect, diagnose, prognose & predict;
- We need automation.

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Thank you

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