

Fault Detection and Drive Train Condition Monitoring

SUPERGEN Wind 2011 General Assembly

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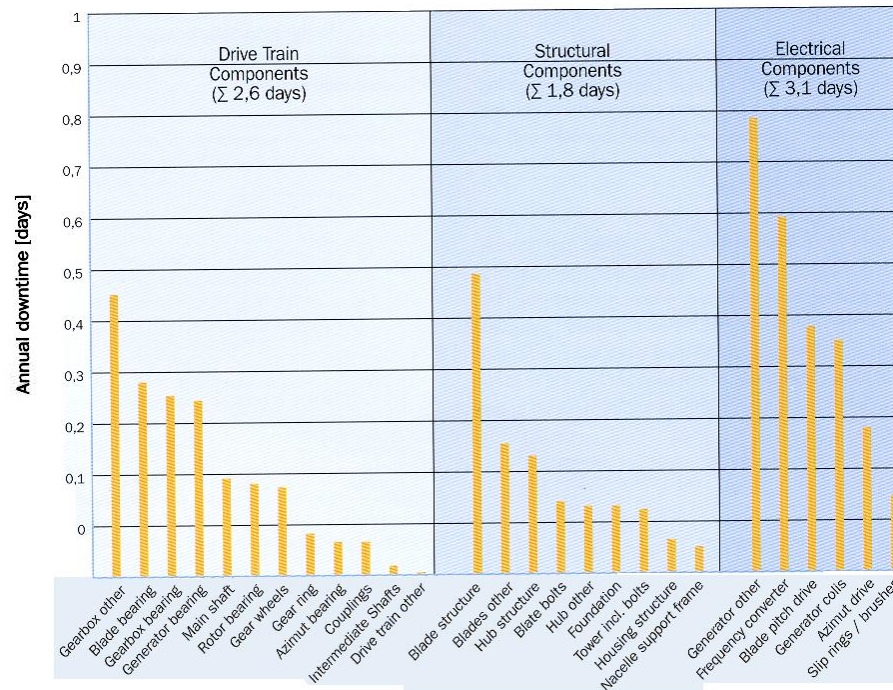
Manchester University

Durham University

Why?



- Generator and gearbox failures contribute significantly to wind turbine downtime
- Generators and gearboxes have very high replacement costs
- Spectral analysis of vibration signals commonly used in commercial condition monitoring systems for fault detection
- Spectral analysis of line current common in other fields for detection of motor/generator faults



Aims



- Fundamental understanding of potential failure mechanisms and resulting fault signals in generators and drive train
- Develop practical methods of tracking fault signals under normal operating conditions
- Extend to all generator types and associated electrical supply converters
- Mixed signal sources: current, power, vibration, temperature etc



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Drive Train

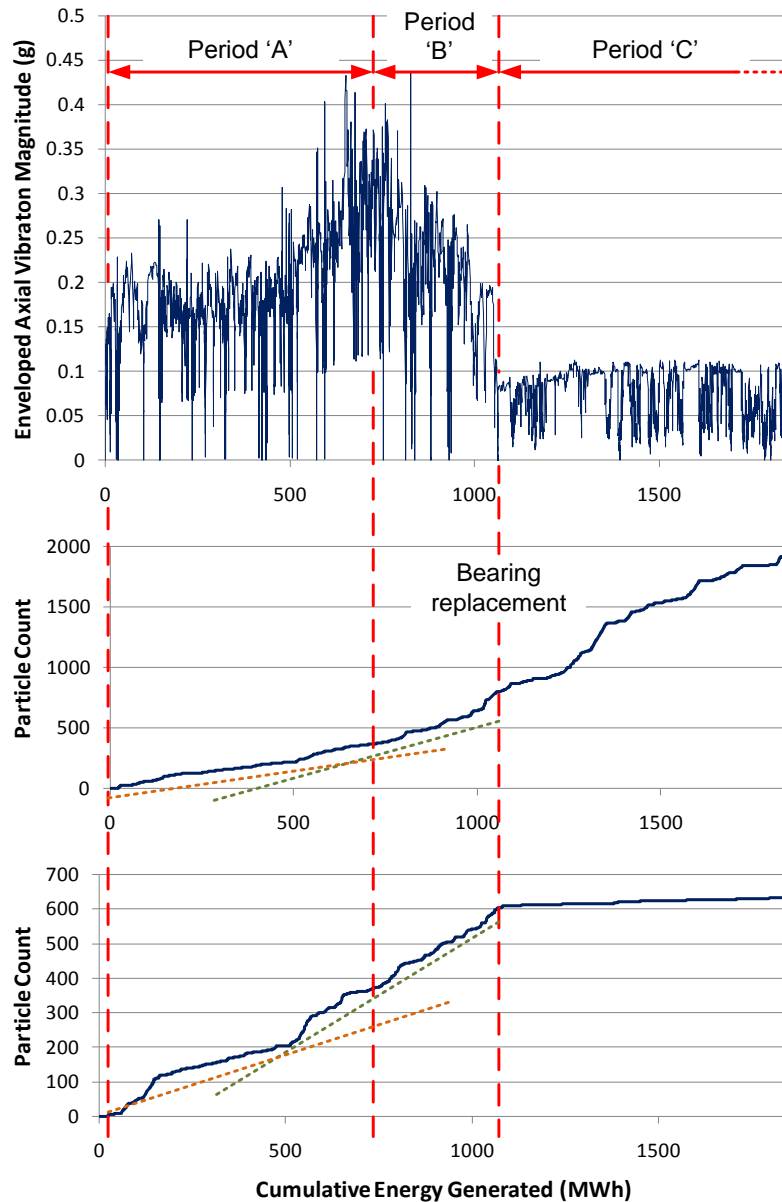


Gearbox bearing replacement - Industrial Data

Intermediate shaft bearing fault on a two-speed induction generator

Fault signals: vibration / oil debris

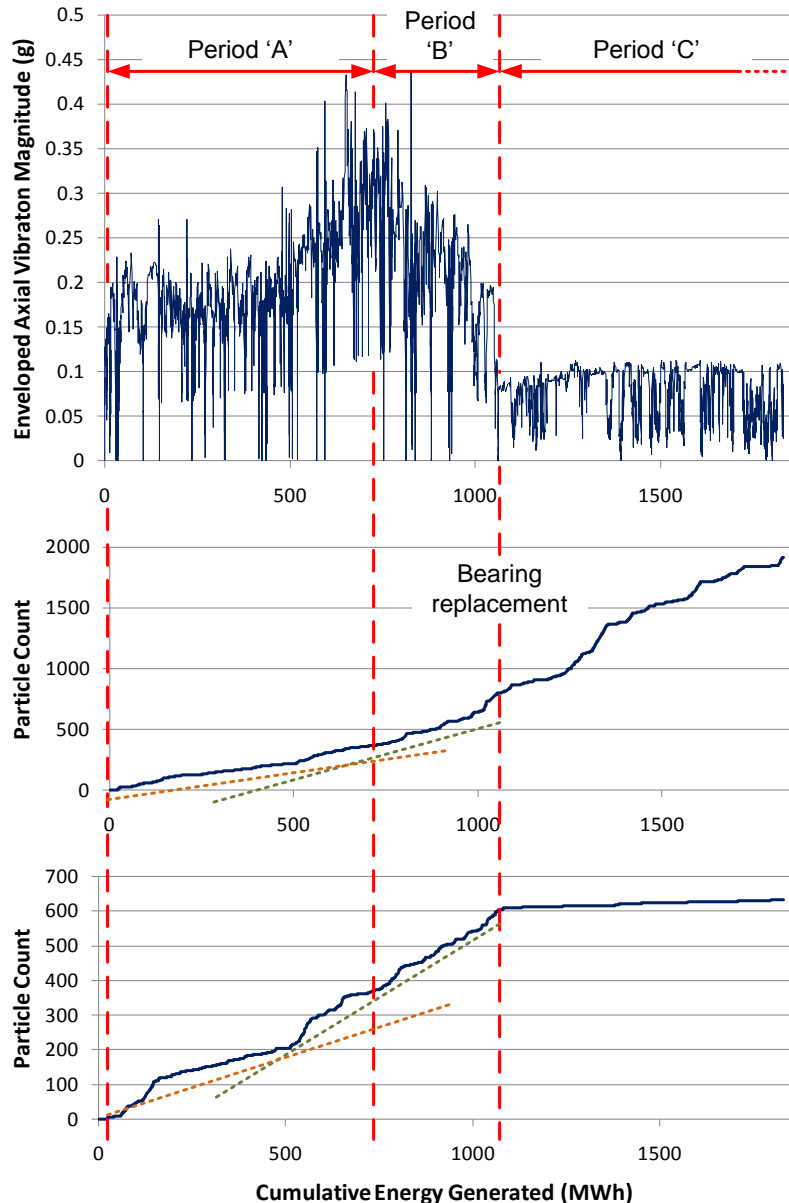
- Time domain is not suitable for trending data from vibration and gearbox oil debris signals
 - Cumulative energy generated is more valid
 - Takes account of periods of high and low load and the turbine operating conditions



- Gearbox high speed end axial vibration envelope magnitude

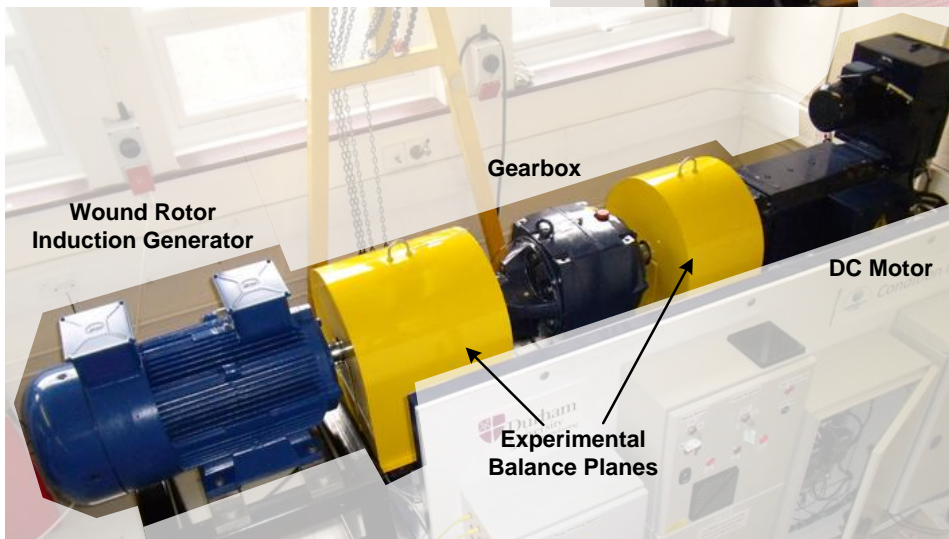
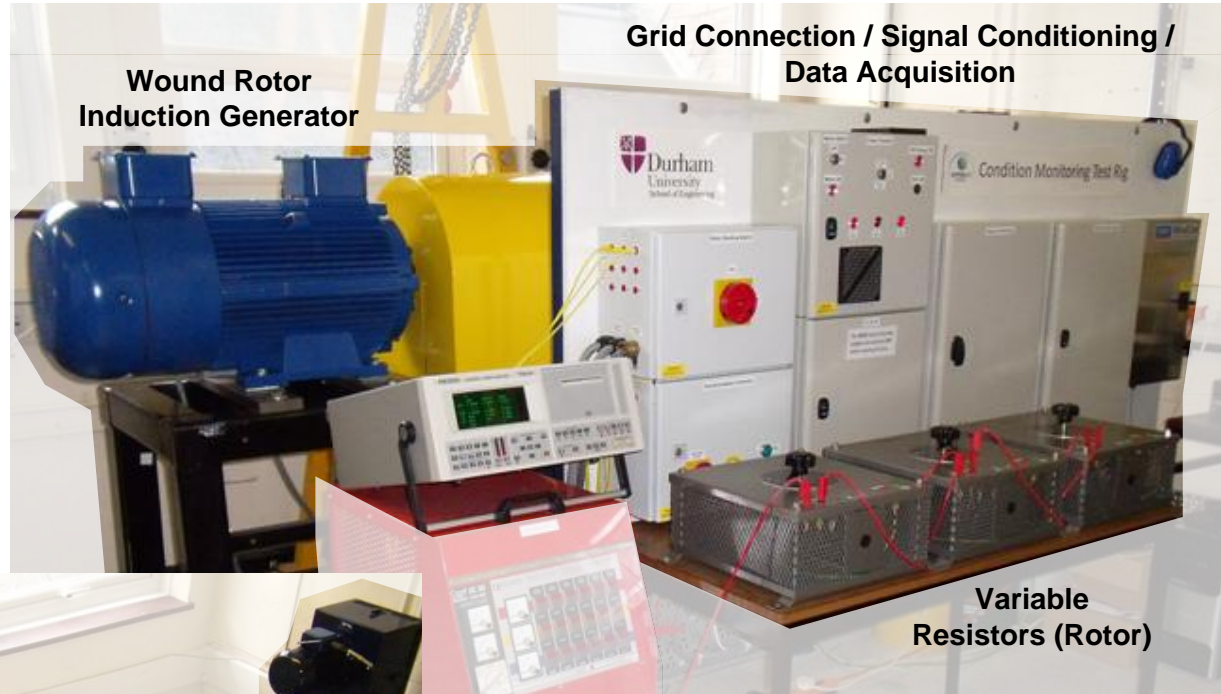
- Gearbox oil debris particle count: 50-100µm

- Gearbox oil debris particle count: 100-200µm



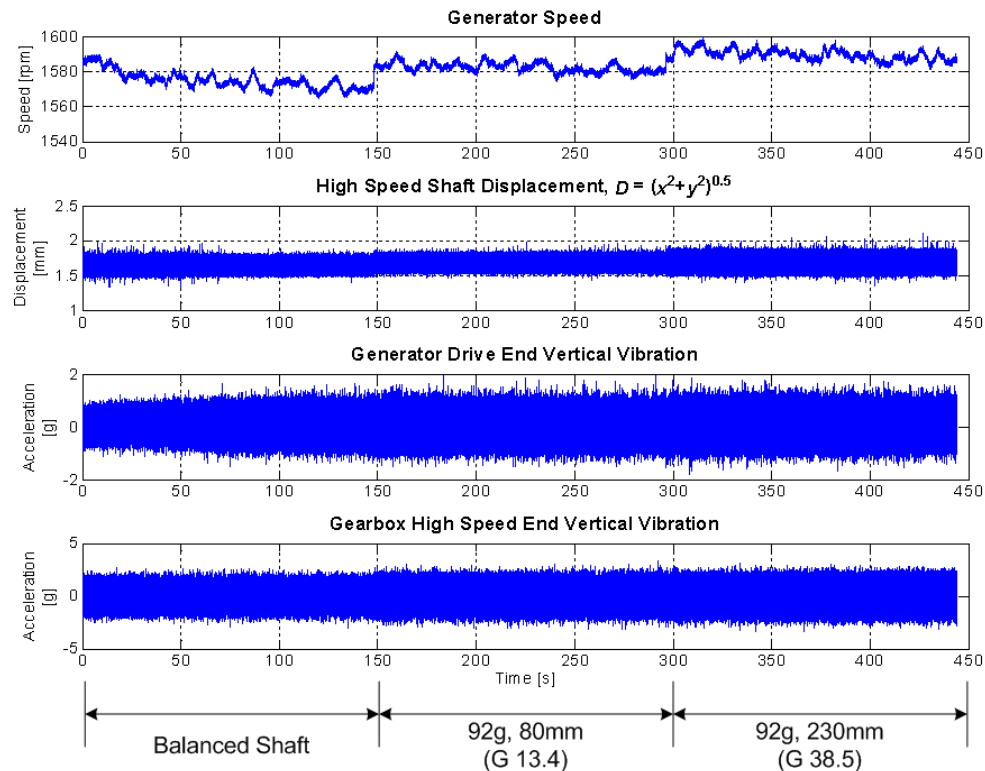
- **Period 'A'**
 - Bearing deterioration of unknown severity
 - Increasing vibration with steady particle count rate
- **Period 'B'**
 - Increase in bearing health
 - Step change in overall particle rate and vibration at same point, especially larger particles
 - Vibration transmission path affected by level of bearing deterioration, reducing vibration signal
- **Period 'C'**
 - Levels reduced following bearing replacement

Drive Train Test Rig



Shaft Mass Unbalance

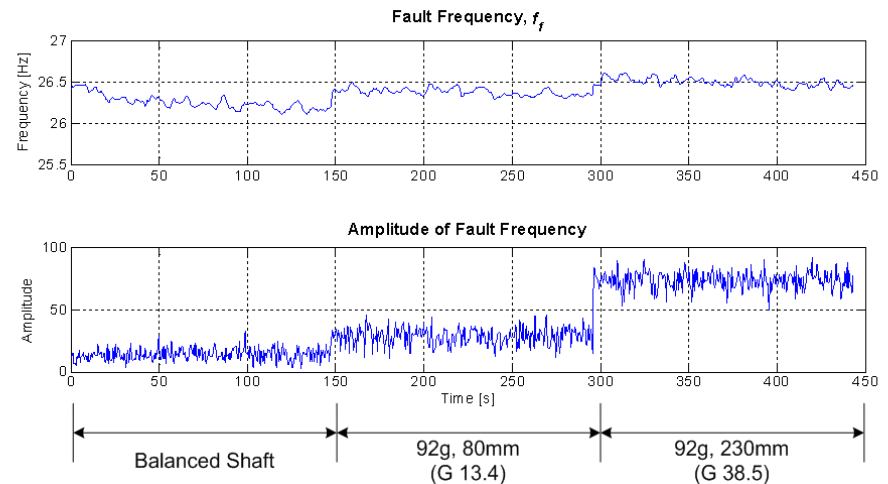
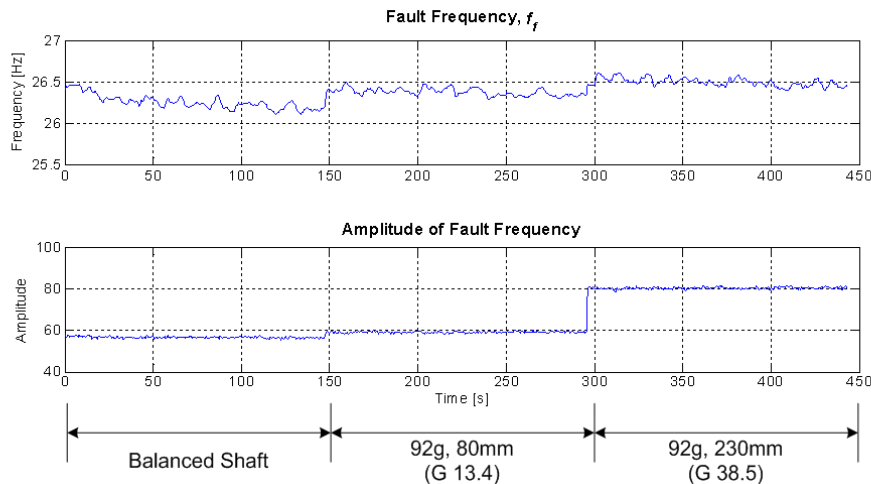
- High speed shaft mass unbalance
 - Mass applied near generator drive end



Shaft Mass Unbalance

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

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

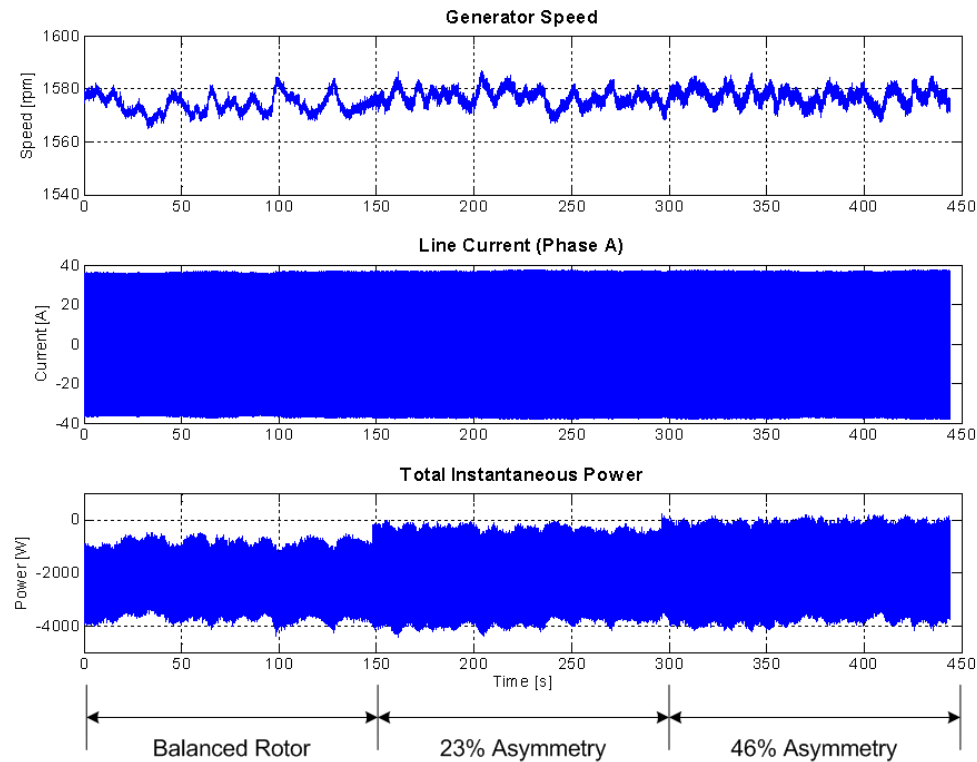


- Fourier-based frequency tracking

Generator



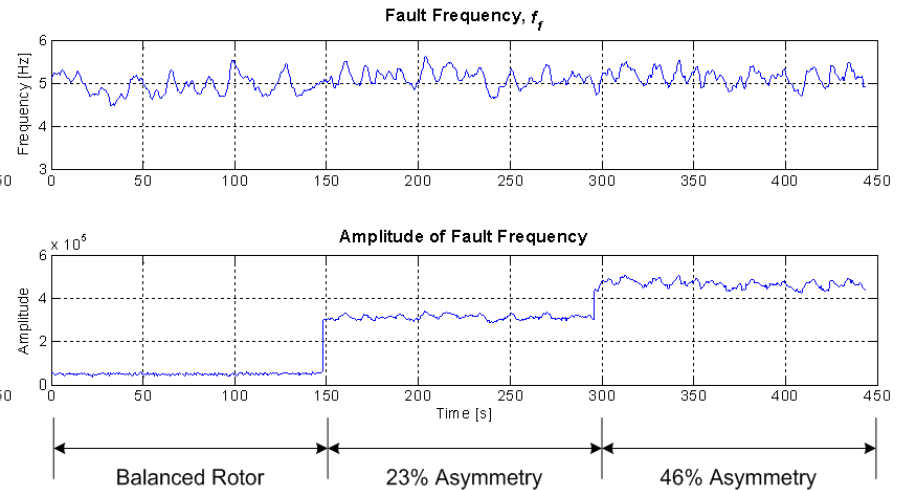
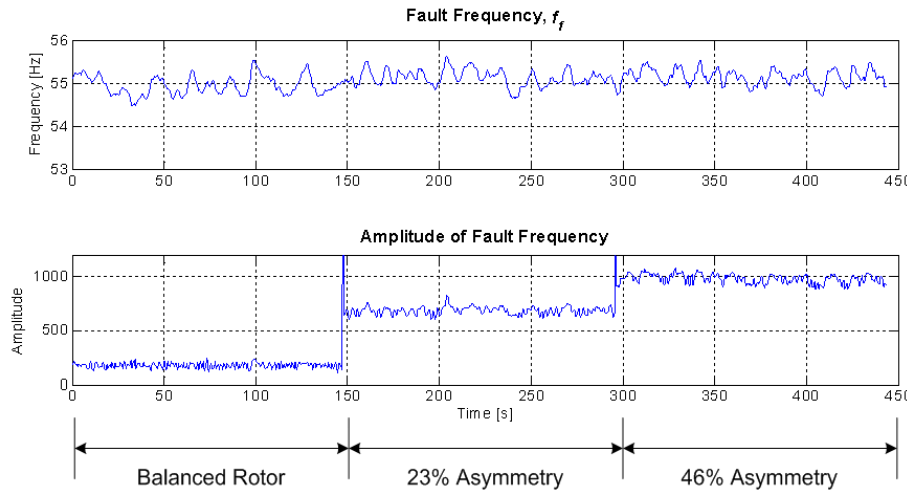
- **Wound rotor induction generator rotor electrical asymmetry**
 - eg slip-ring/brush gear fault/unbalance



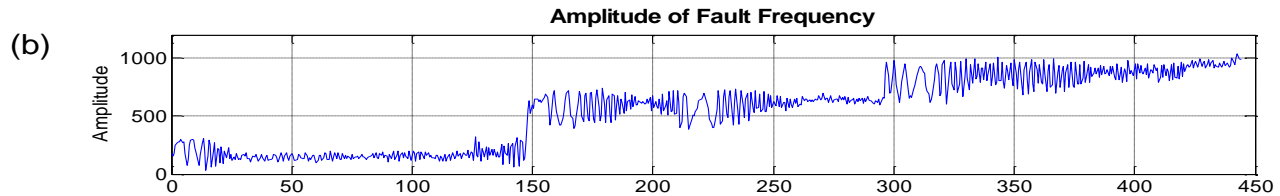
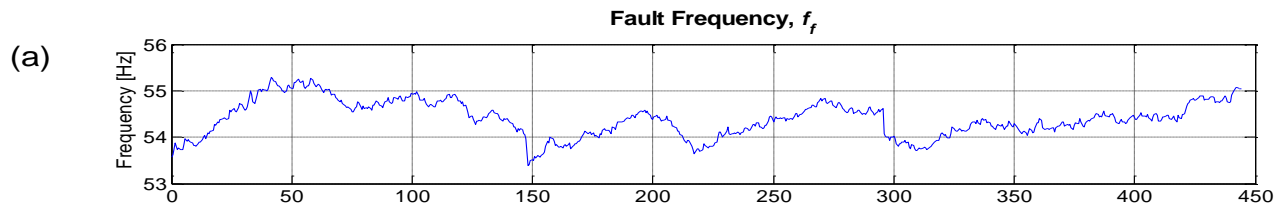
Electrical Signals

- Line current analysis
 - $(1-2s)f_{se}$

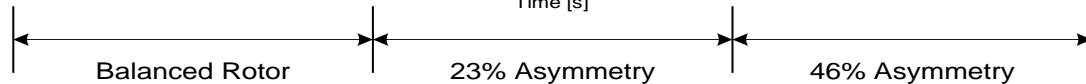
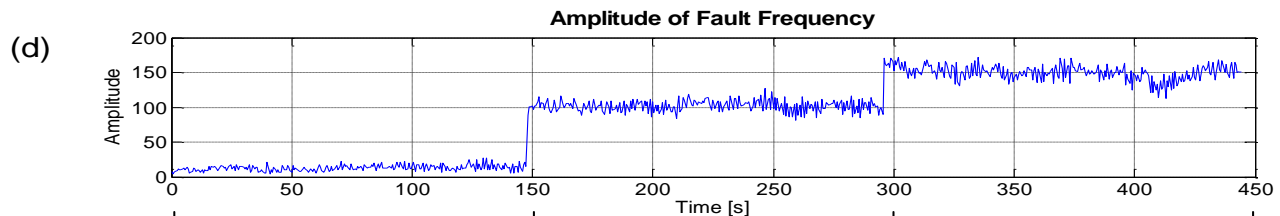
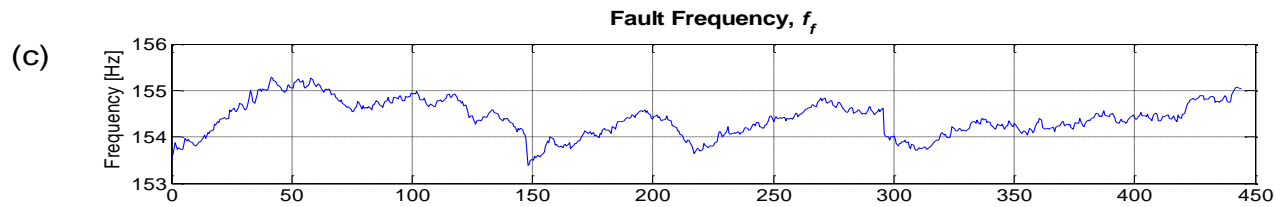
- Total power analysis
 - $2sf_{se}$



(1-2s)f

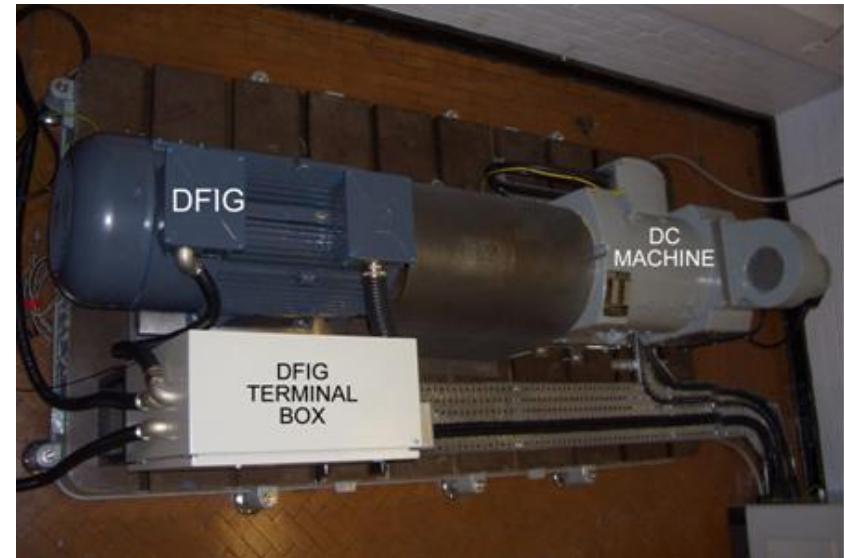
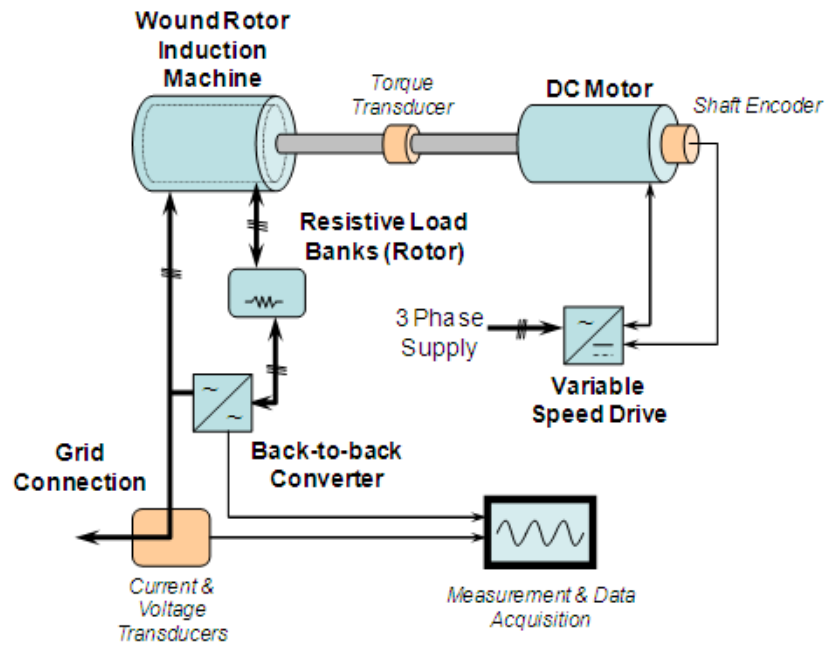


(3-2s)f

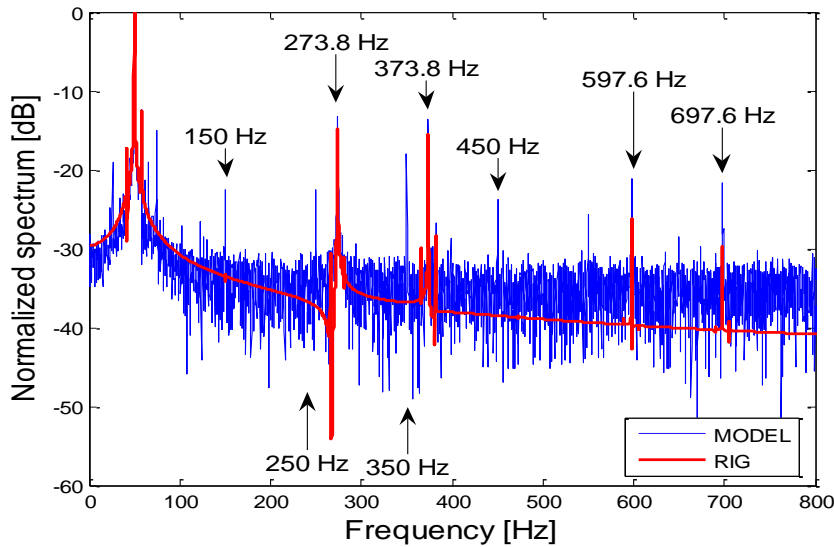
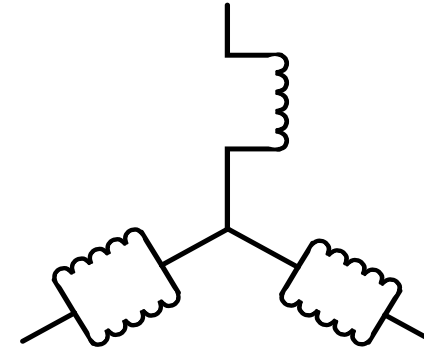
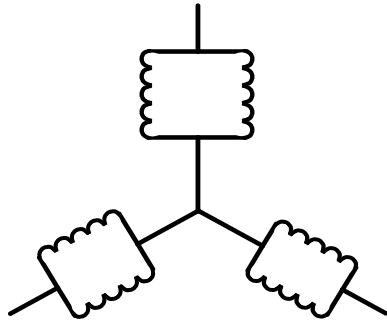


Fault frequency tracking under wind conditions

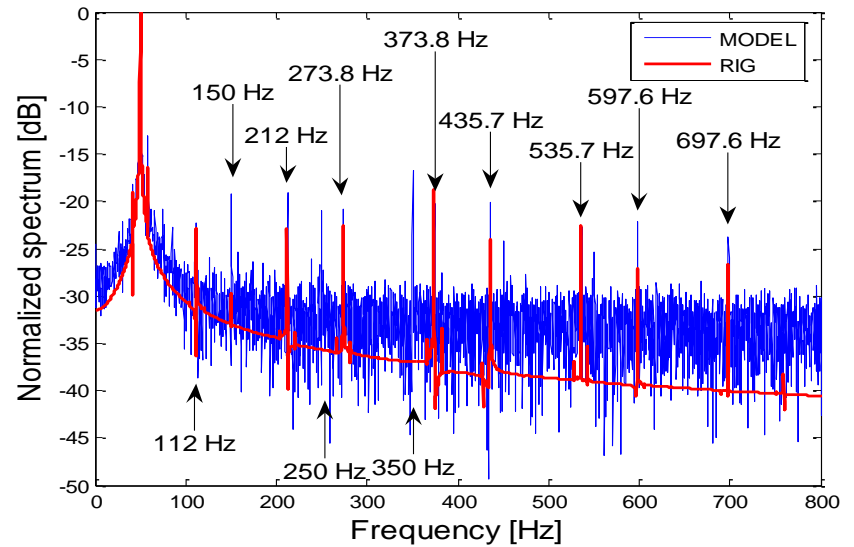
DFIG Generator Test Rig



DFIG Fault Frequency Spectrum



a) Healthy DFIG



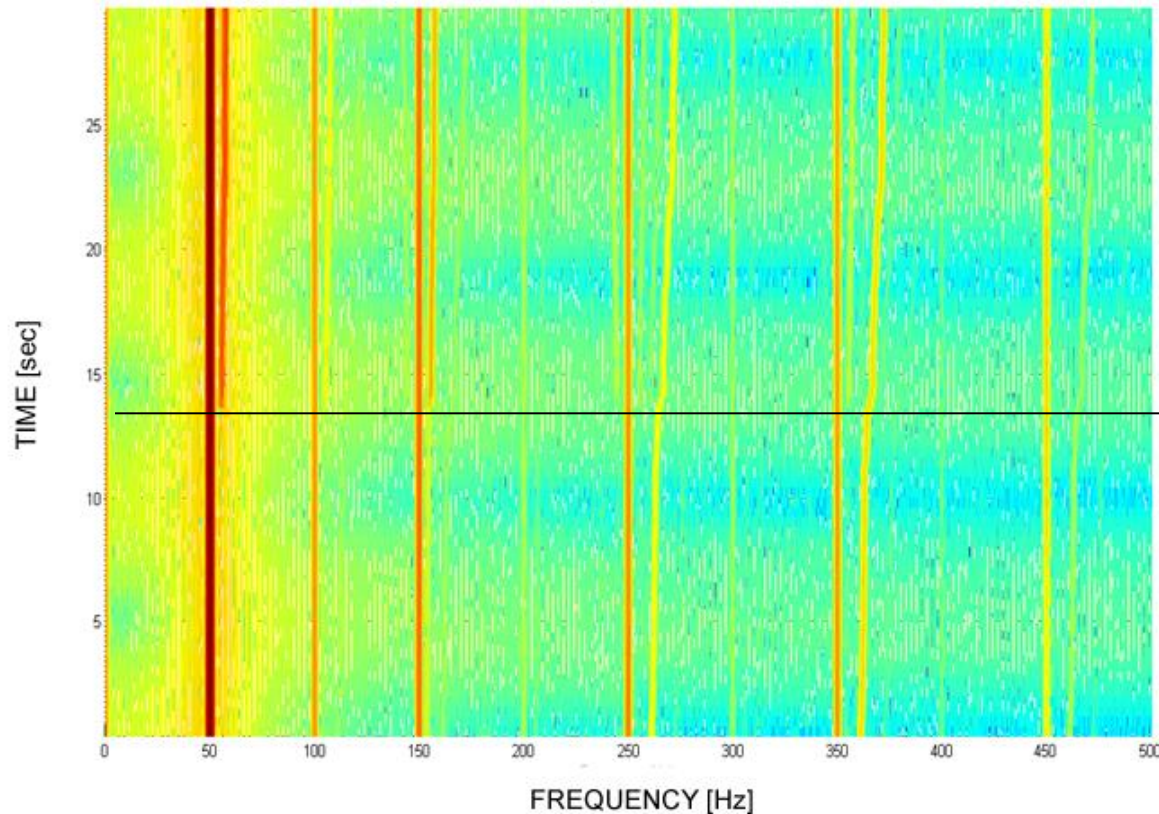
b) Stator winding fault

DFIG frequency spectral components

WINDINGS		SUPPLY		INDUCED DFIG STATOR CURRENT FREQUENCIES
STATOR	ROTOR	STATOR	ROTOR	
BALANCED	BALANCED	BALANCED	BALANCED	$f_{ind}^k = 6k(1-s) \pm 1 f$
BALANCED	BALANCED	BALANCED	UNBALANCED	$f_{ind}^k = 6k(1-s) \pm 1 f$ $f_{ind}^k = 6k(1-s) \pm (1-2s) f$
BALANCED	UNBALANCED	BALANCED	BALANCED	$f_{ind}^k = \left \frac{2k}{p}(1-s) \pm \left[s + \frac{1-s}{p} \right] \right f$
BALANCED	BALANCED	UNBALANCED	BALANCED	$f_{ind}^k = 6k(1-s) \pm 1 f$
UNBALANCED	BALANCED	BALANCED	BALANCED	$f_{ind}^k = \left \frac{2k}{p}(1-s) \pm 1 \right f$

$$k=0,1,2,3\dots$$

Real-time Frequency Tracking



$t > 14 \text{ sec}$
rotor winding unbalance

$t < 14 \text{ sec}$
windings balanced

Line current spectrogram

What next?

- Bearing faults in DFIG's
- Detection of converter faults
- Embed/Test fault algorithms in SKF-WindCon
- Develop link from condition monitoring to maintenance
- Electrical fault models for other generator types (eg direct-drive/hybrid pm generators)





Thank you.