

# Fault Detection and Drive Train Condition Monitoring

## *SUPERGEN Wind 2011 General Assembly*

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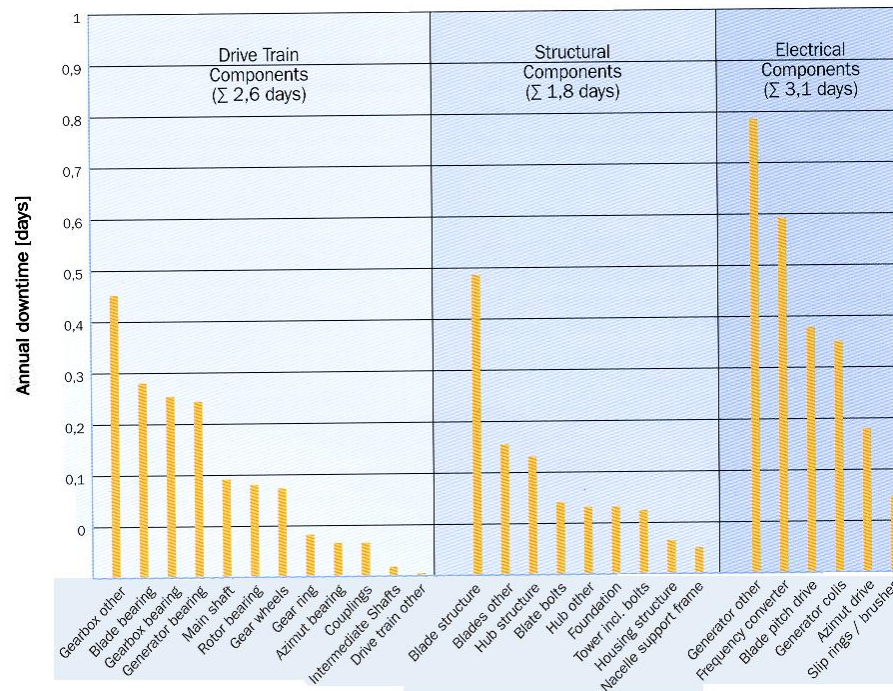
**Manchester University**

**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

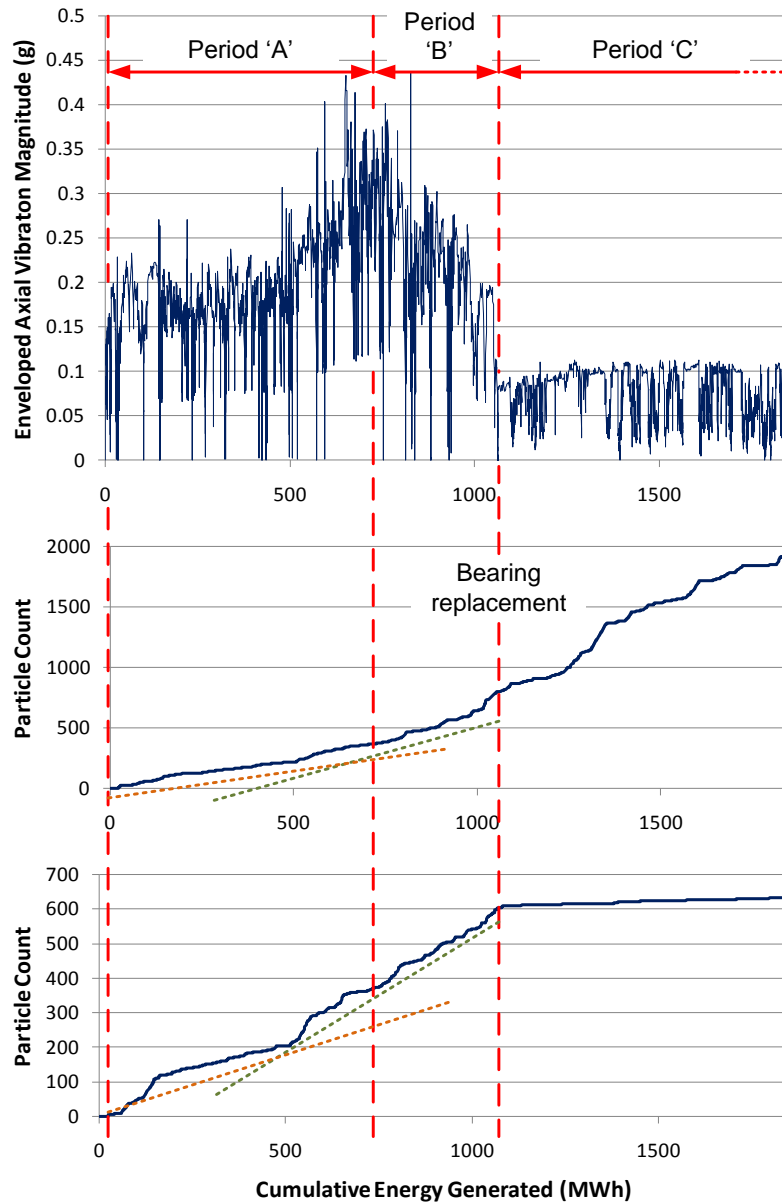


## Gearbox bearing replacement - Industrial Data

*Intermediate shaft bearing fault on a two-speed induction generator*

*Fault signals: vibration / oil debris*

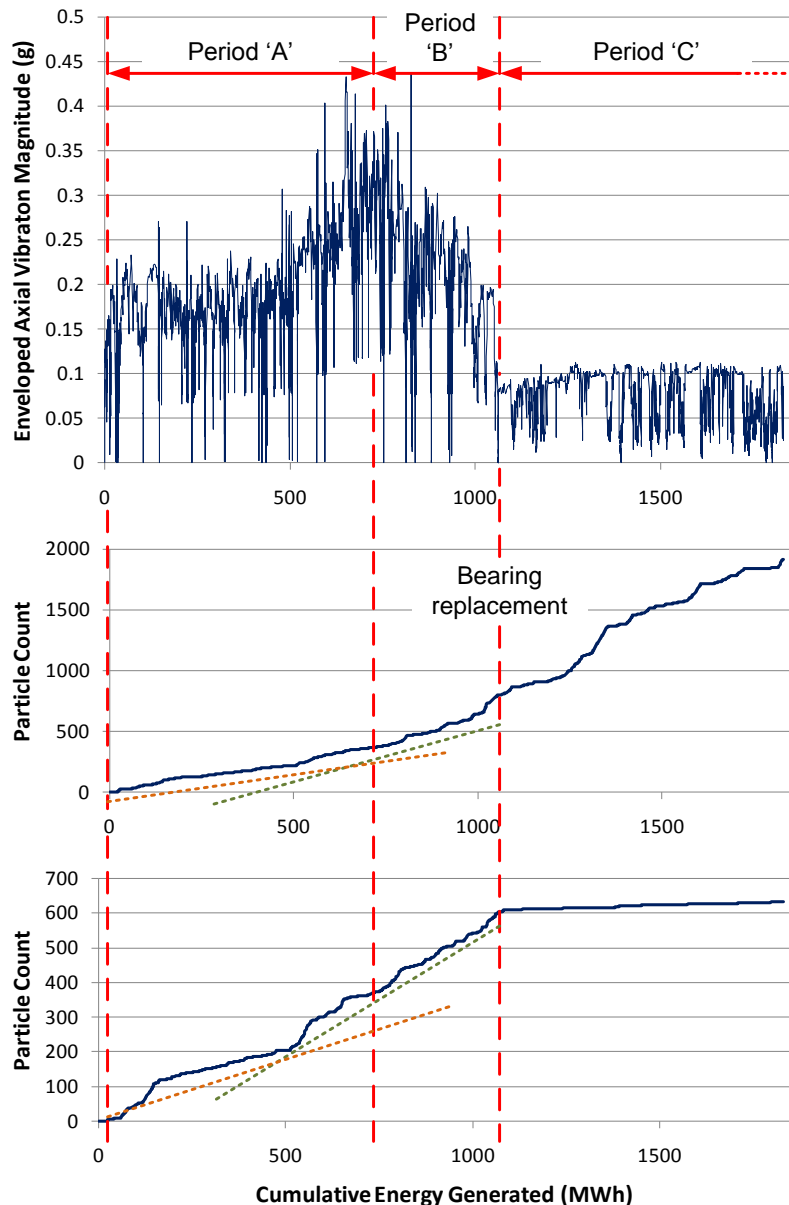
- Time domain is not suitable for trending data from vibration and gearbox oil debris signals
  - Cumulative energy generated is more valid
  - Takes account of periods of high and low load and the turbine operating conditions



- Gearbox high speed end axial vibration envelope magnitude

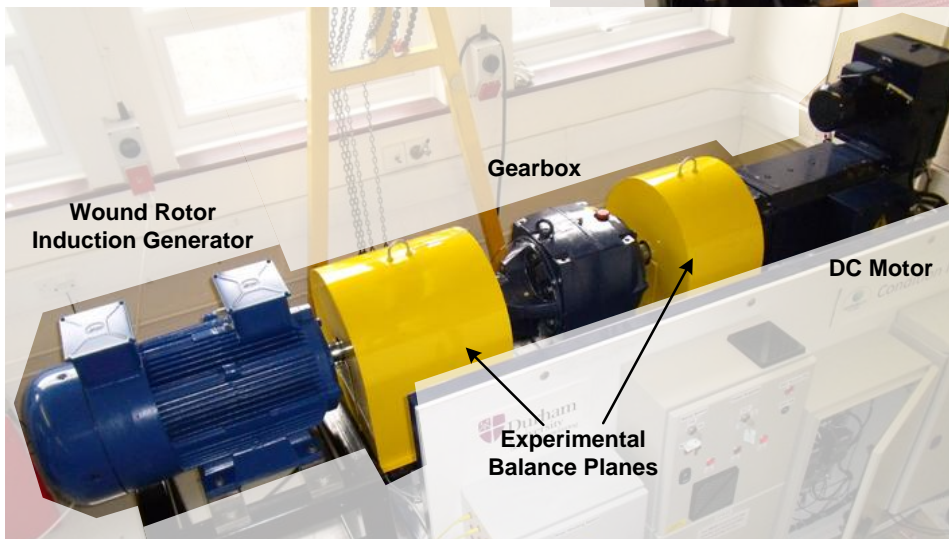
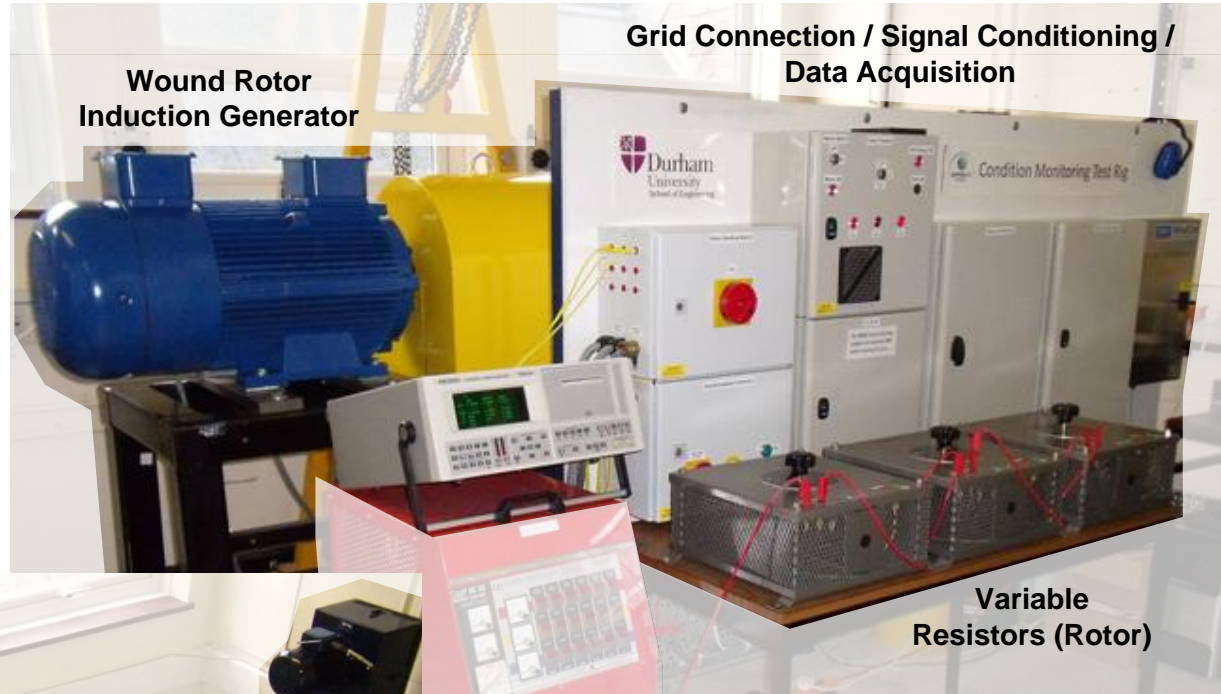
- Gearbox oil debris particle count: 50-100µm

- Gearbox oil debris particle count: 100-200µm



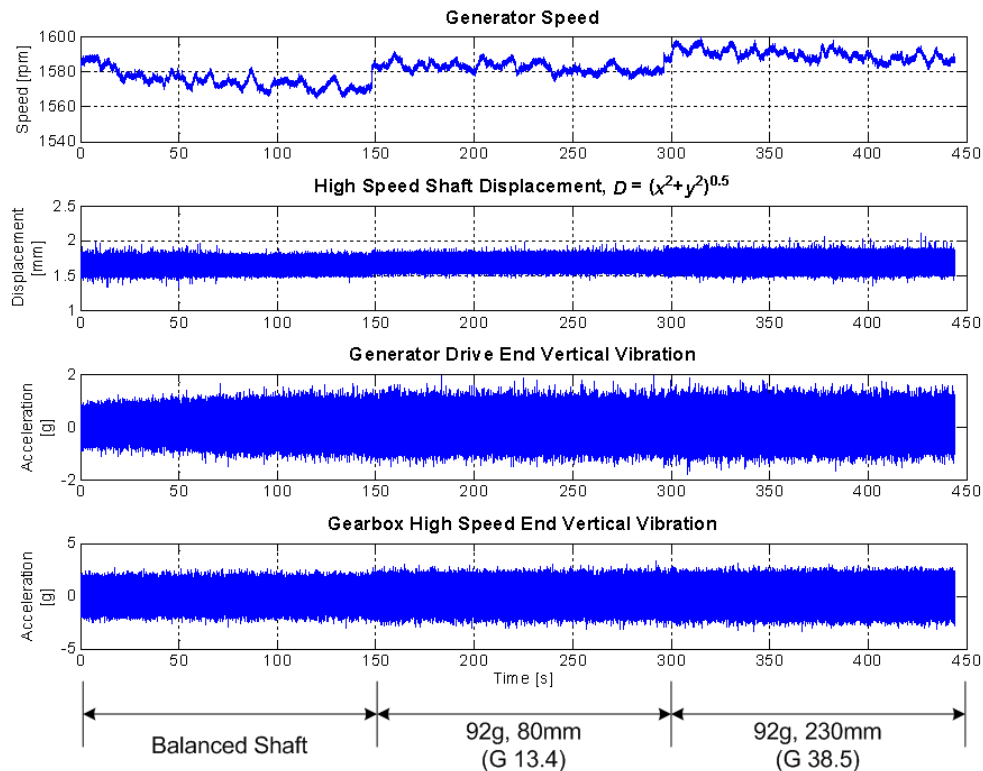
- **Period 'A'**
  - Bearing deterioration of unknown severity
  - Increasing vibration with steady particle count rate
  
- **Period 'B'**
  - Increase in bearing health
  - Step change in overall particle rate and vibration at same point, especially larger particles
  - Vibration transmission path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

# Drive Train Test Rig



# Shaft Mass Unbalance

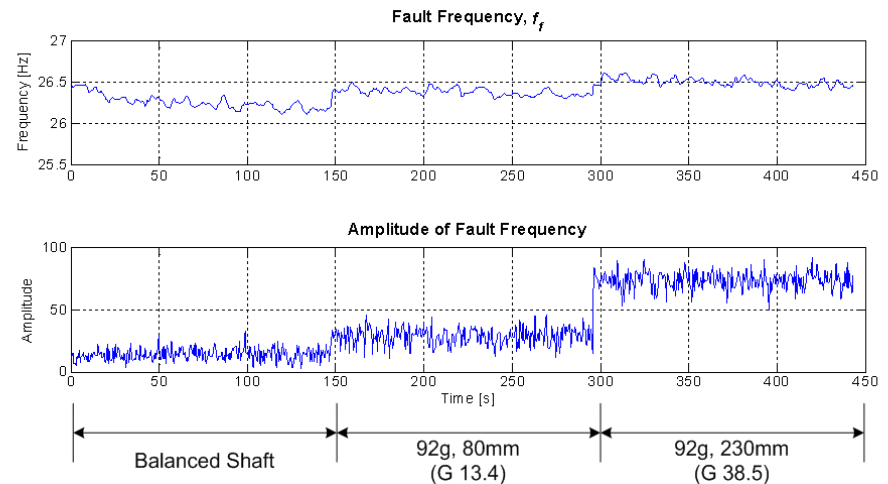
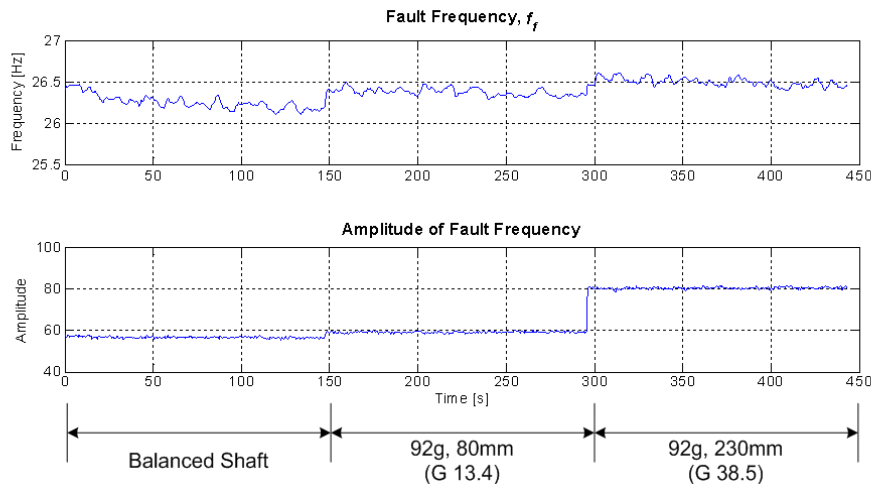
- High speed shaft mass unbalance
  - Mass applied near generator drive end



# Shaft Mass Unbalance

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

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

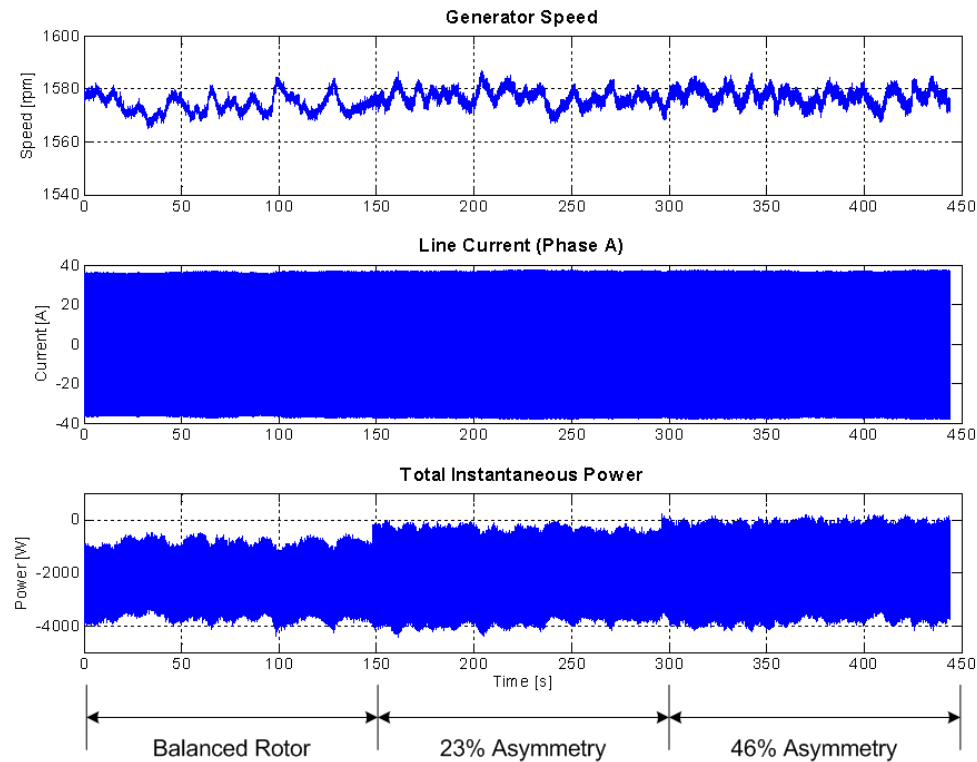


- Fourier-based frequency tracking

# Generator



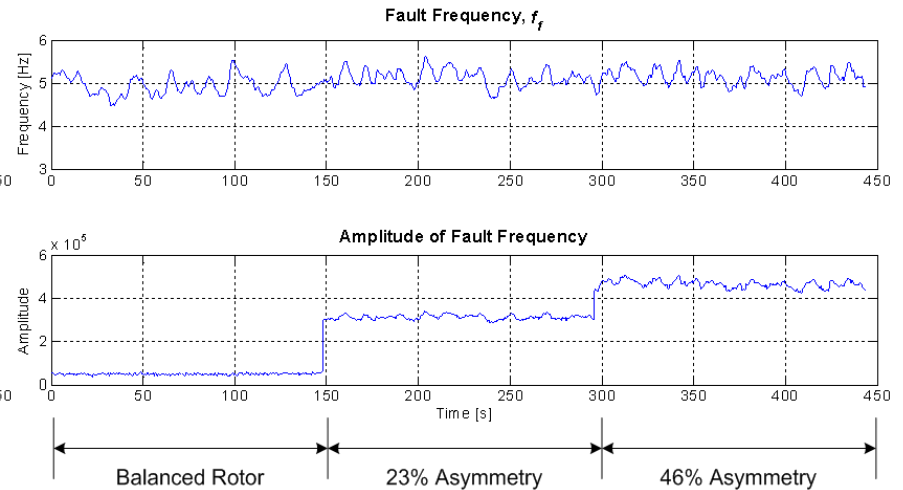
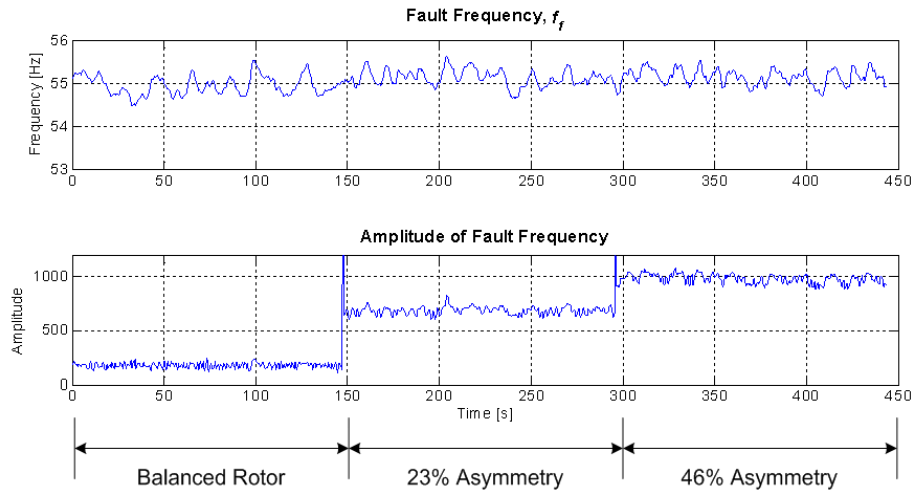
- **Wound rotor induction generator rotor electrical asymmetry**
  - eg slip-ring/brush gear fault/unbalance



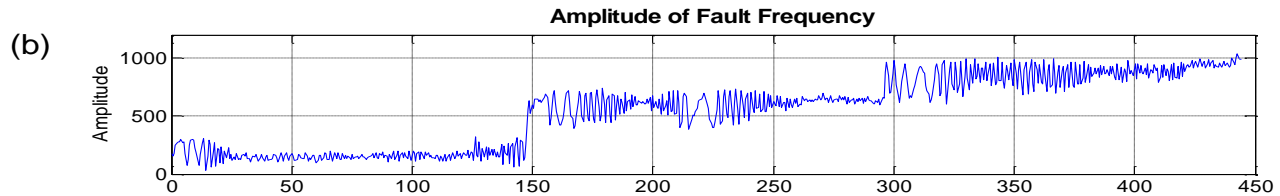
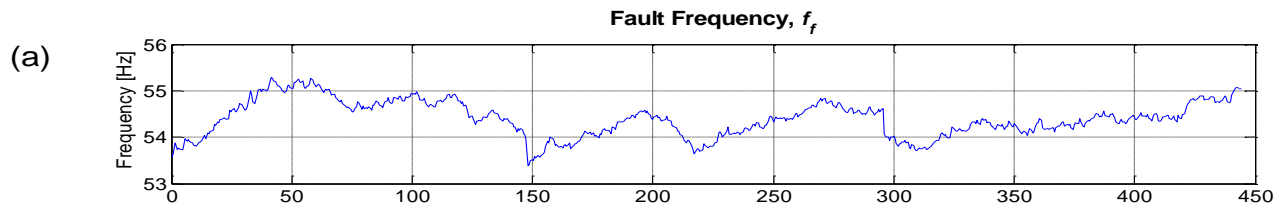
# Electrical Signals

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

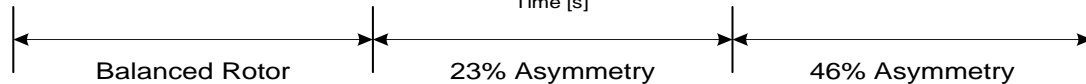
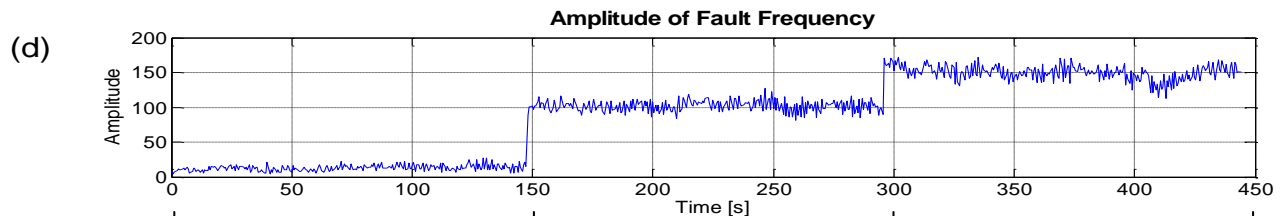
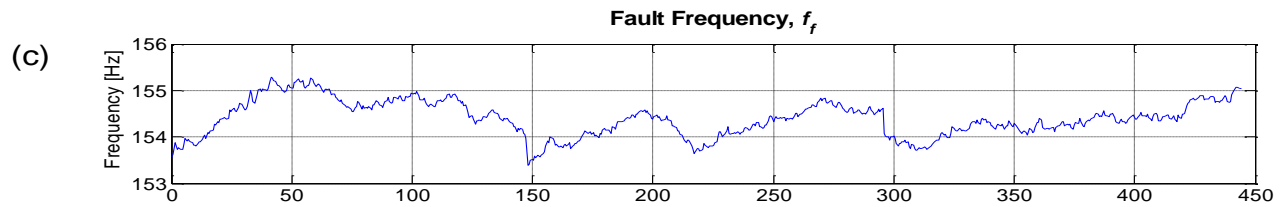
- Total power analysis
  - $2sf_{se}$



(1-2s)f

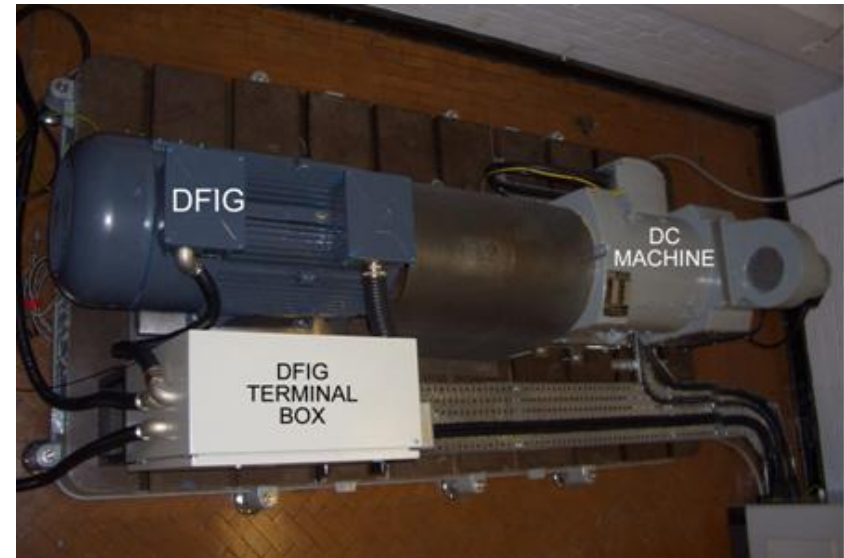
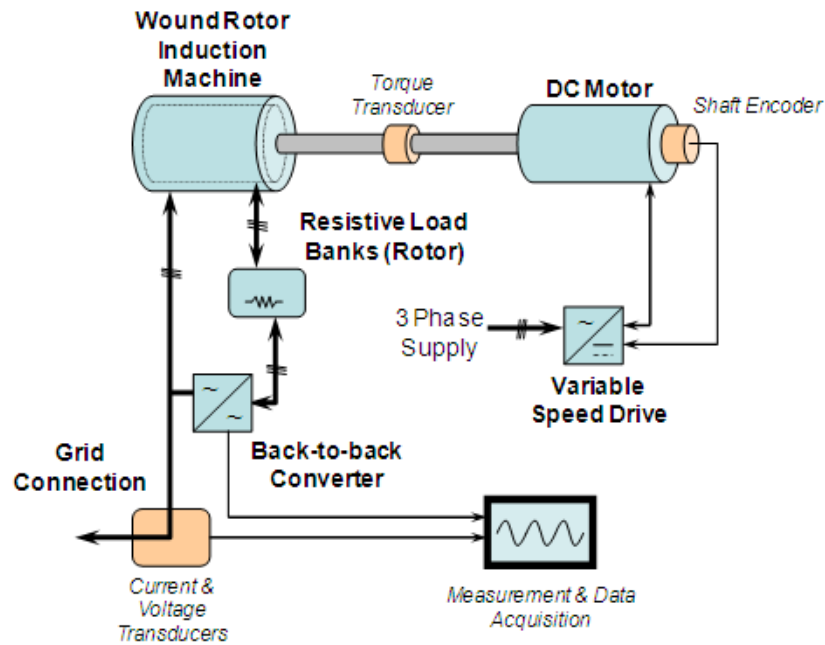


(3-2s)f

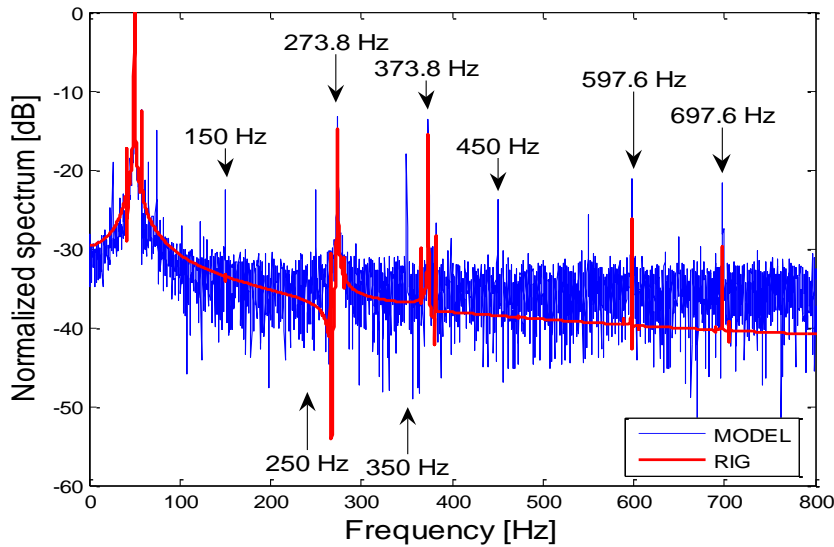
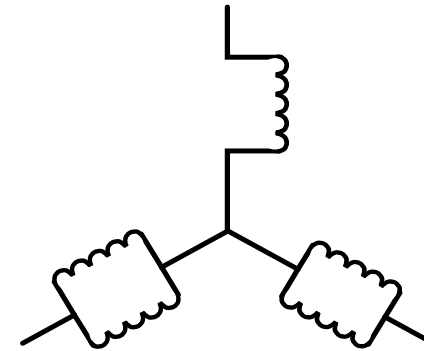
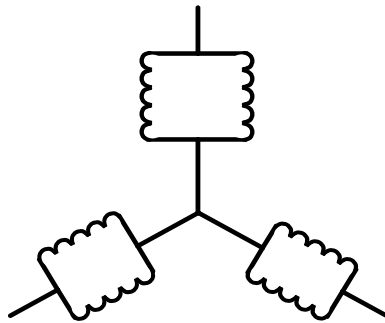


## Fault frequency tracking under wind conditions

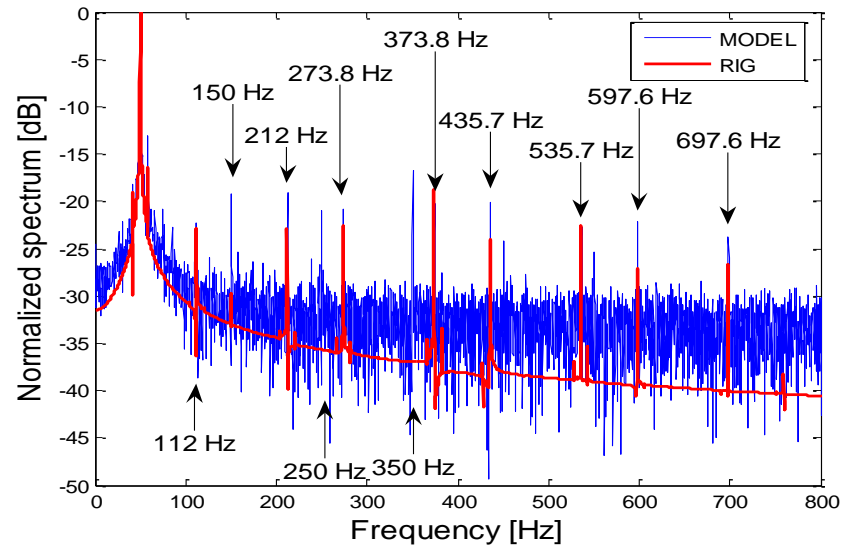
# DFIG Generator Test Rig



# DFIG Fault Frequency Spectrum



a) Healthy DFIG



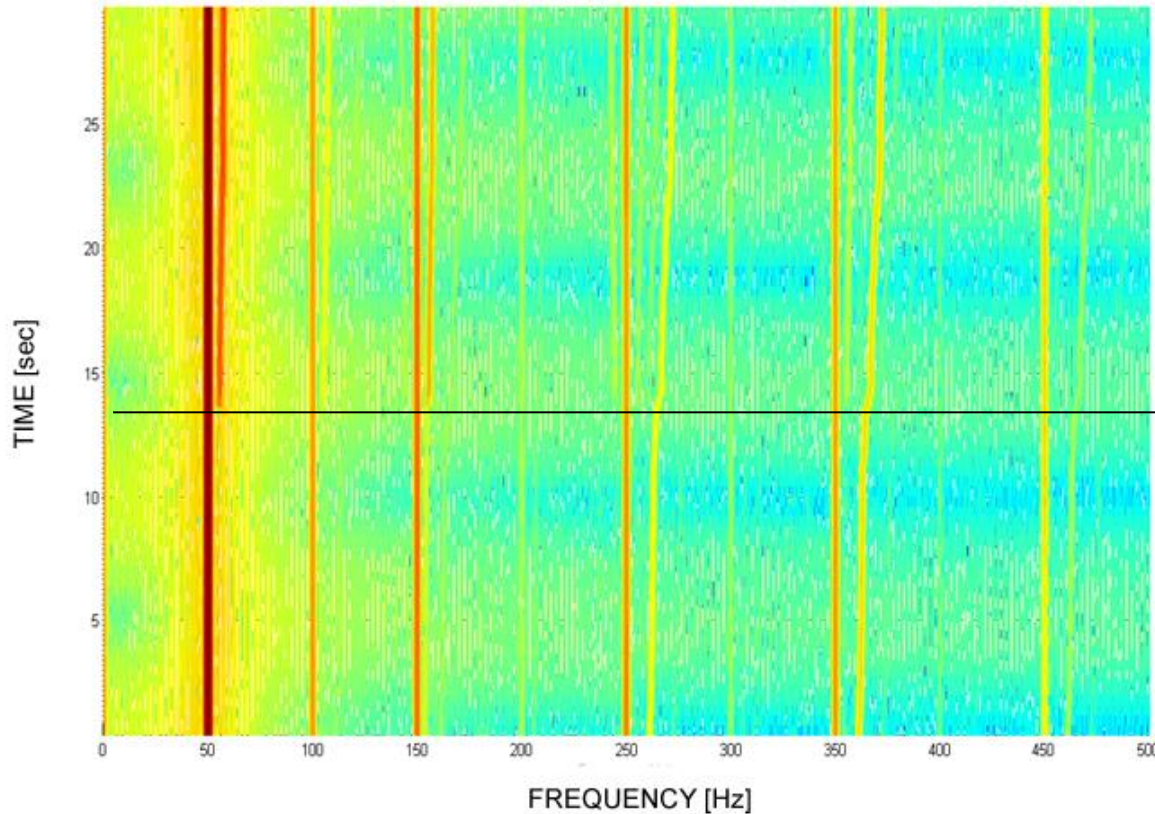
b) Stator winding fault

# 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



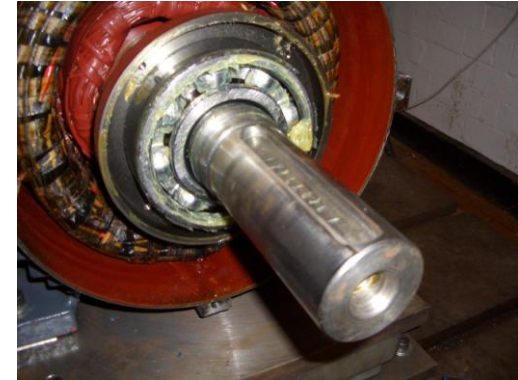
$t > 14 \text{ sec}$   
rotor winding unbalance

$t < 14 \text{ sec}$   
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.**