

DFIG modelling and winding fault analysis

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Research

- Doubly fed induction generator (DFIG) is the most commonly used type of generator in contemporary large variable speed wind turbines
- One of the most common induction machine faults are winding faults due to short-circuit or open-circuit or abnormal connection of phase windings
- Preferred fault diagnostic method is the steady state stator current spectral analysis (MCSA) - non invasive as windings are used as search coils
- Investigate the possibility of DFIG winding fault detection through monitoring stator line current frequency spectra

Work so far

- An analytical model for a DFIG has been developed to enable the dynamic behaviour of a generator operating with various healthy and faulty winding configurations to be simulated.
- A 30 kW DFIG test-rig has been built to explore DFIG steady-state operation under a range of winding and supply fault scenarios.
- The analytical model has been verified by comparison of model predictions with test-rig measurements in both time and frequency domain for a series of typical DFIG steady state operating points.
- DFIG operation with a range of typical winding faults and supply asymmetries has been explored.
- Changes in the stator current spectrum arising from each fault condition, have been identified.

DFIG modelling for condition monitoring purposes

- Based on coupled-circuit approach
- A circuit is defined as ‘any series connection of coils’
- Coupling inductances are calculated between circuits
- This approach makes it possible to analyze an arbitrarily connected n-phase machine while taking into account higher order field space harmonics

Model equations

- Machine voltage and flux equations (matrix form)

$$[V_s] = [R_s][I_s] + \frac{d[\psi_s]}{dt}$$

$$[\psi_s] = [L_{ss}][I_s] + [L_{sr}][I_r]$$

$$[V_r] = [R_r][I_r] + \frac{d[\psi_r]}{dt}$$

$$[\psi_r] = [L_{rs}][I_s] + [L_{rr}][I_r]$$

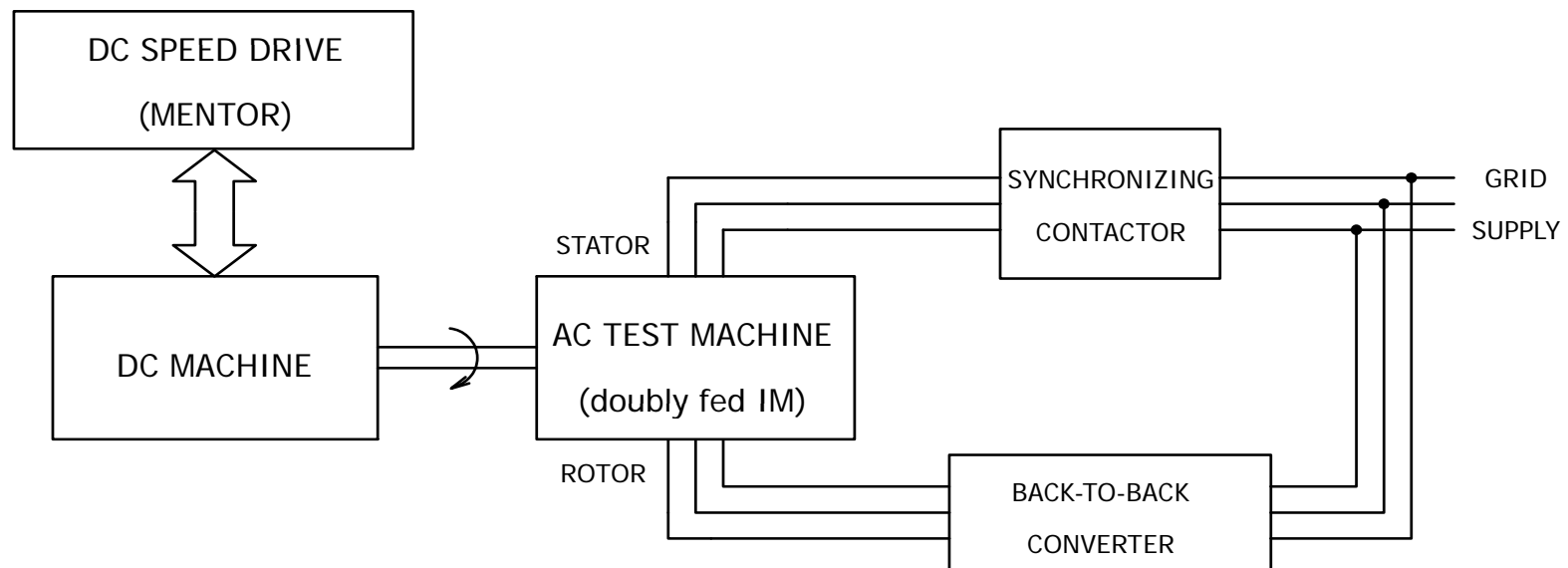
- Torque and speed equations

$$T_e - T_{LOAD} = J \frac{d\omega}{dt}$$

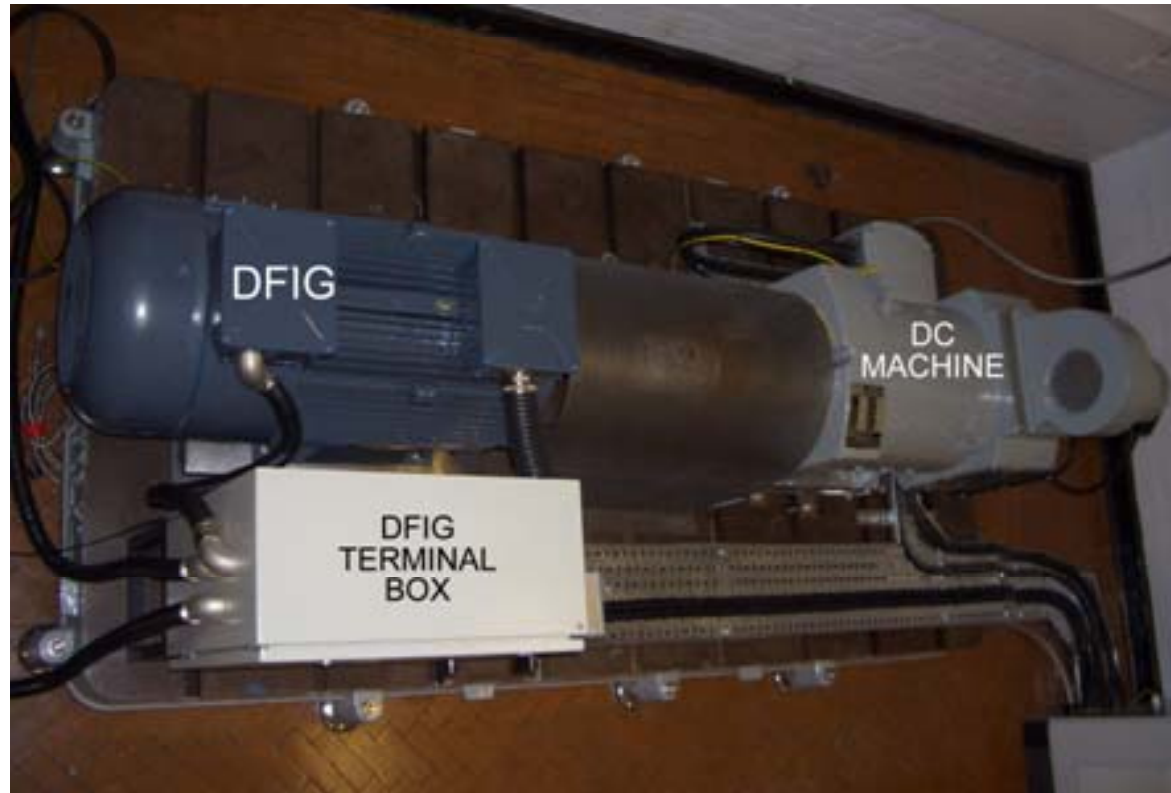
$$\frac{d\theta}{dt} = \omega$$

$$T_e = \frac{1}{2} [I]^T \frac{d[L]}{d\theta} [I]$$

DFIG test rig diagram



Test Rig Description



Laboratory test bed
(viewed from above)

Test Rig Description

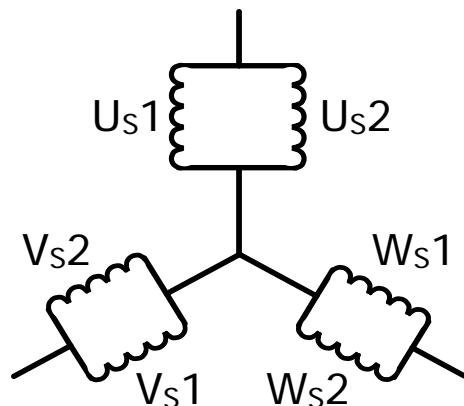


DFIG Terminal box

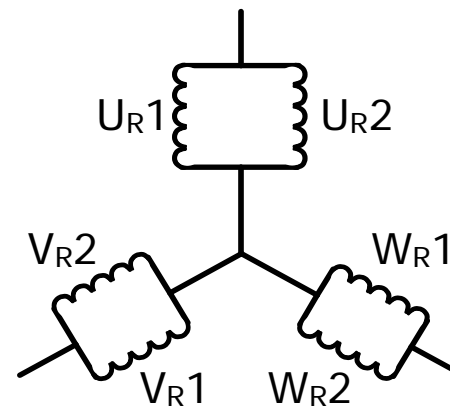


Rotor back-to-back converter

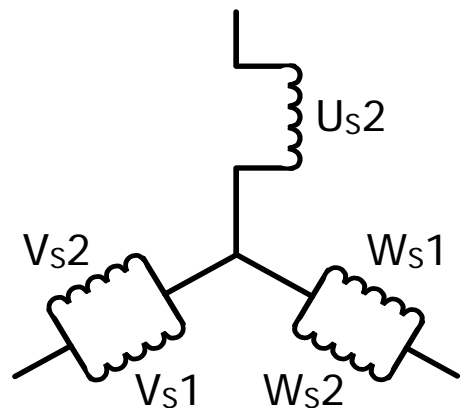
Healthy and faulty DFIG winding configurations used in this presentation



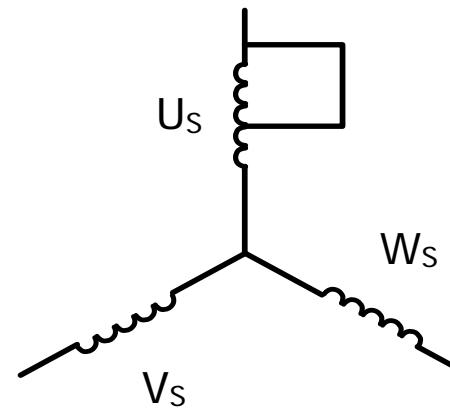
a) Stator healthy



b) Rotor healthy

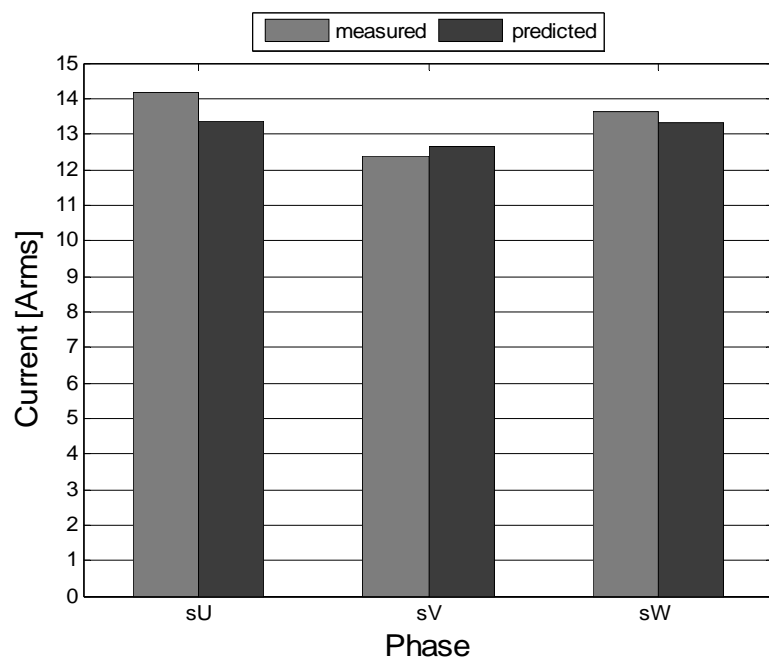


c) Stator open-circuit fault

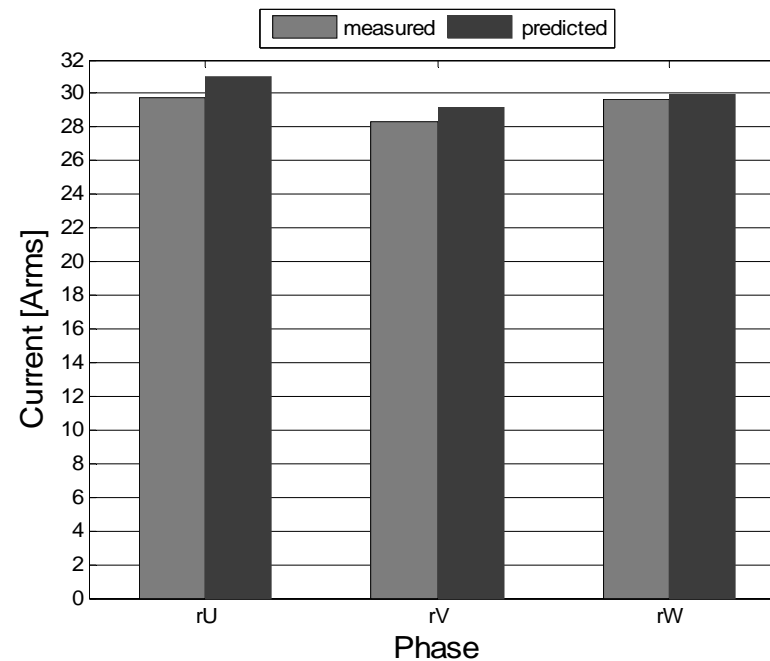


d) Stator short-circuit fault

Predicted and measured DFIG current rms values for a typical operating point and a healthy DFIG



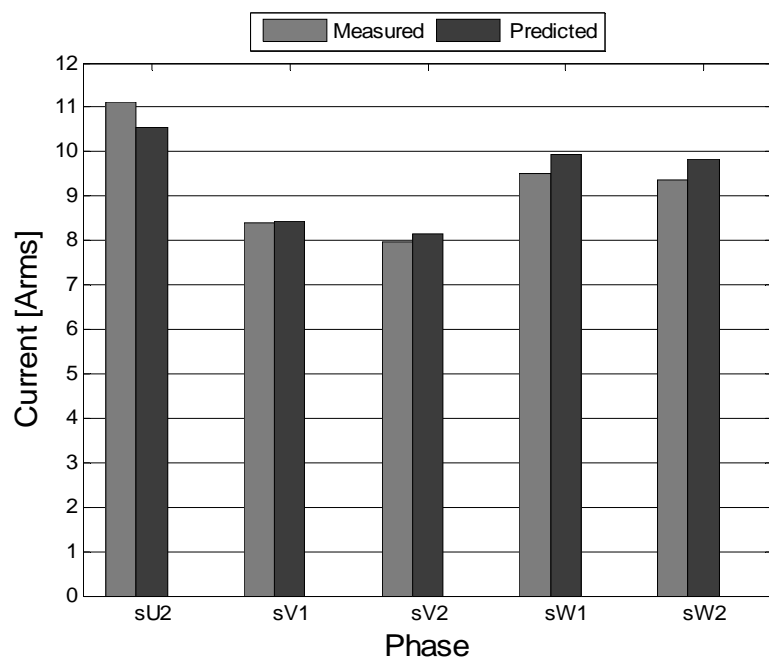
a) Stator line currents



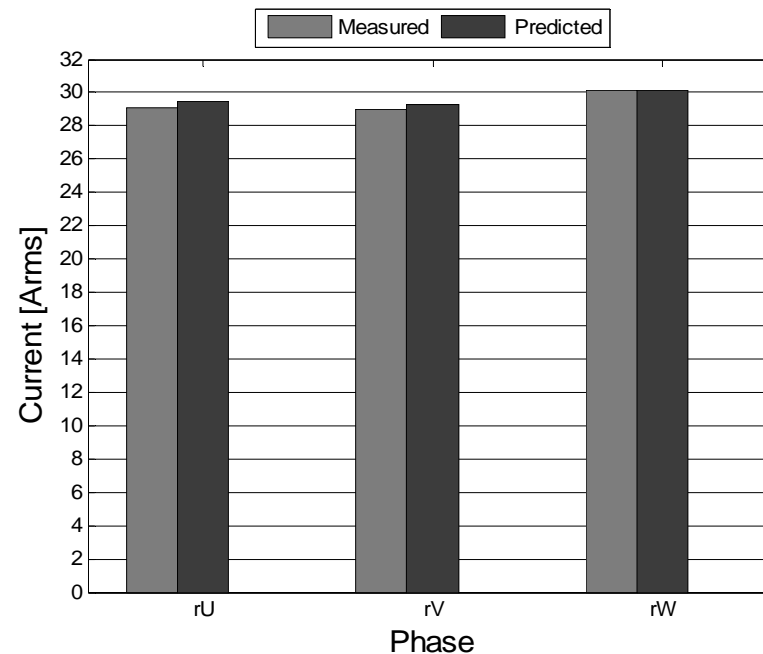
b) Rotor line currents

$$\omega_R = 1684 \text{rpm}$$

Predicted and measured DFIG current rms values for a stator open-circuit fault



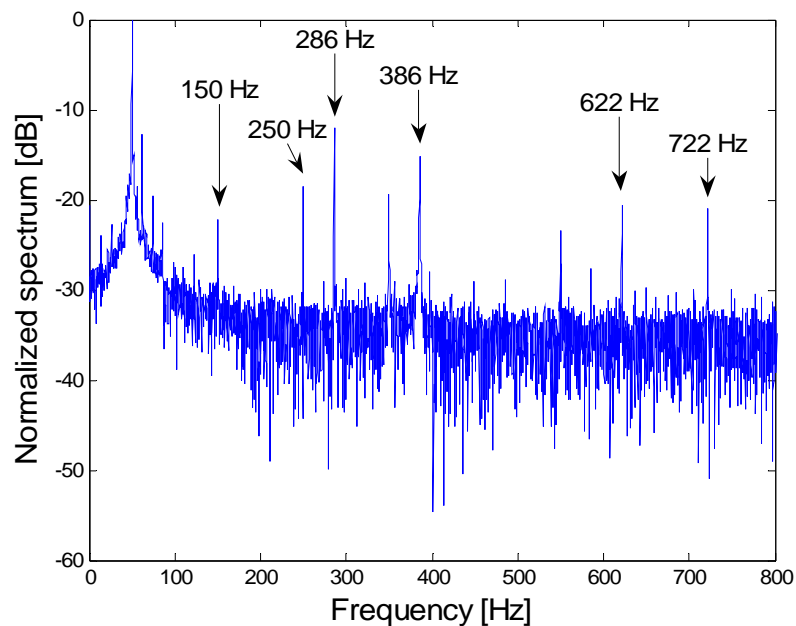
a) Stator winding group currents



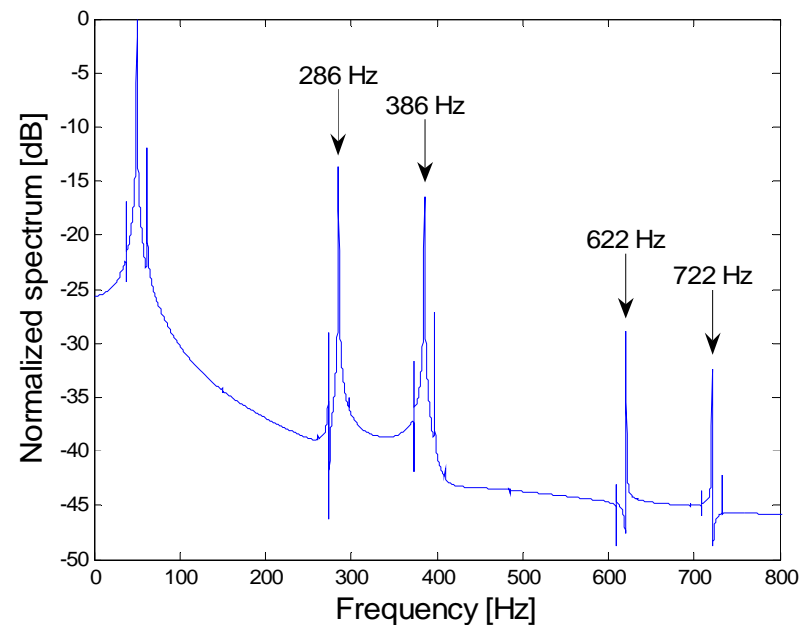
b) Rotor line currents

$$\omega_R = 1556 \text{rpm}$$

Frequency content of predicted and measured DFIG stator line current for a DFIG operating with balanced windings and unbalanced supply

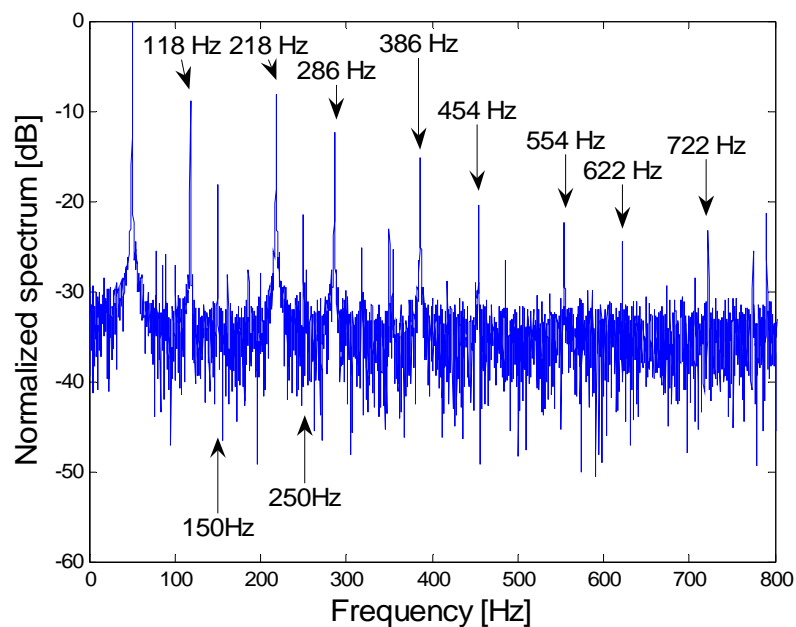


a) Experimental current spectrum

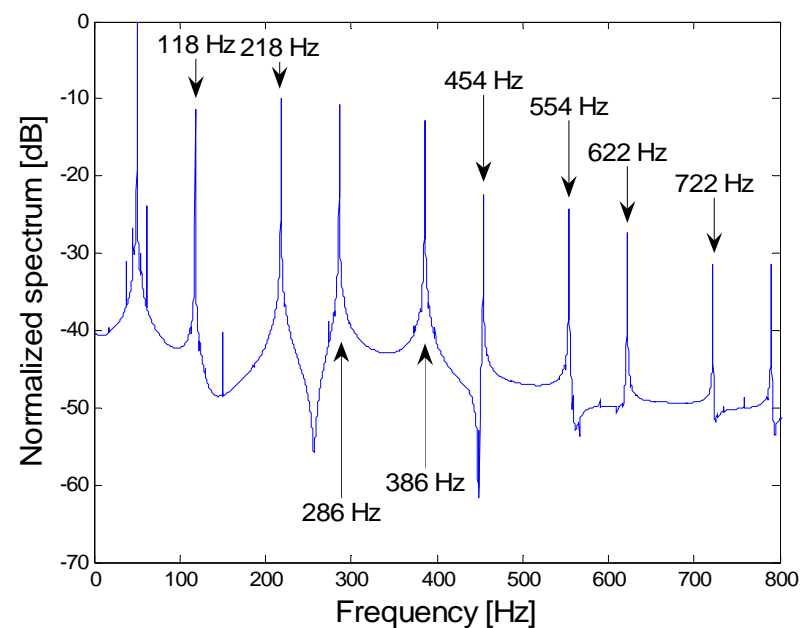


b) Predicted current spectrum

Frequency content of predicted and measured DFIG stator line current for a stator short-circuit fault

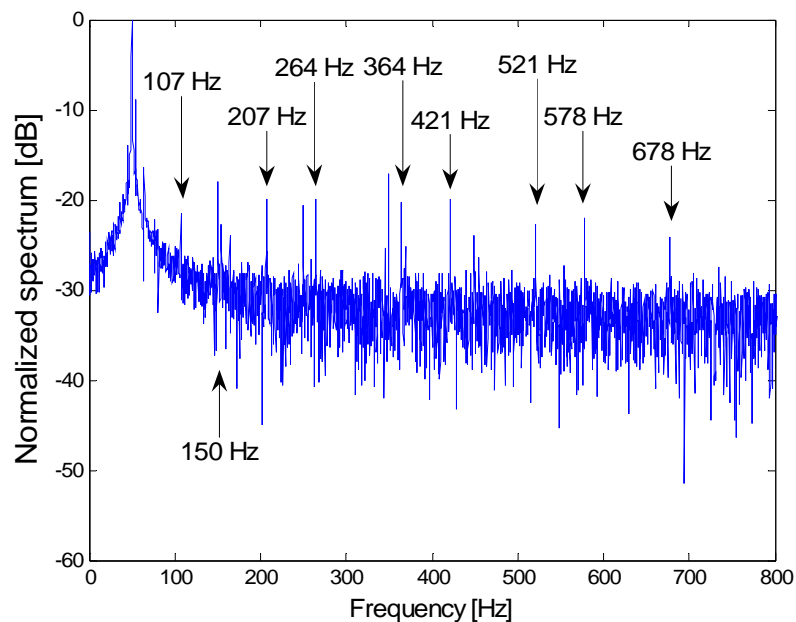


a) Experimental current spectrum

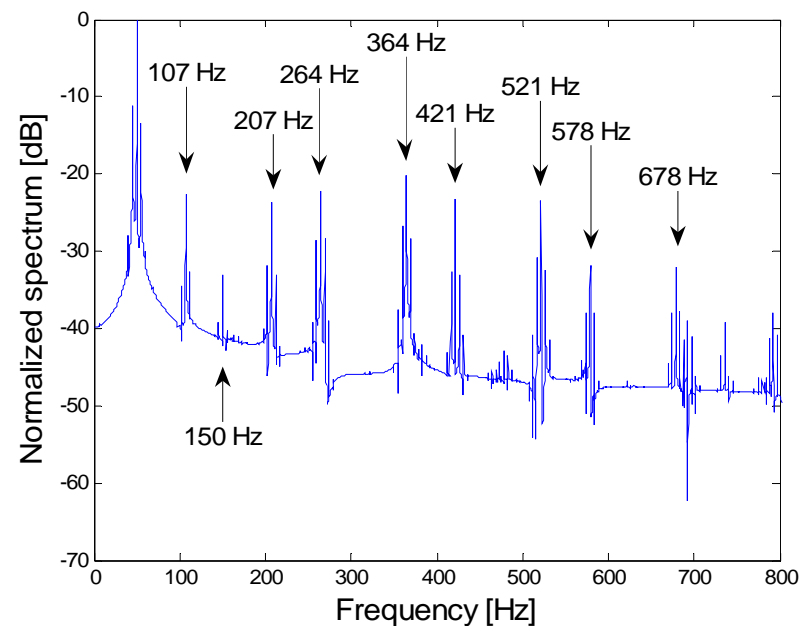


b) Predicted current spectrum

Frequency content of predicted and measured DFIG stator line current for a stator open-circuit fault

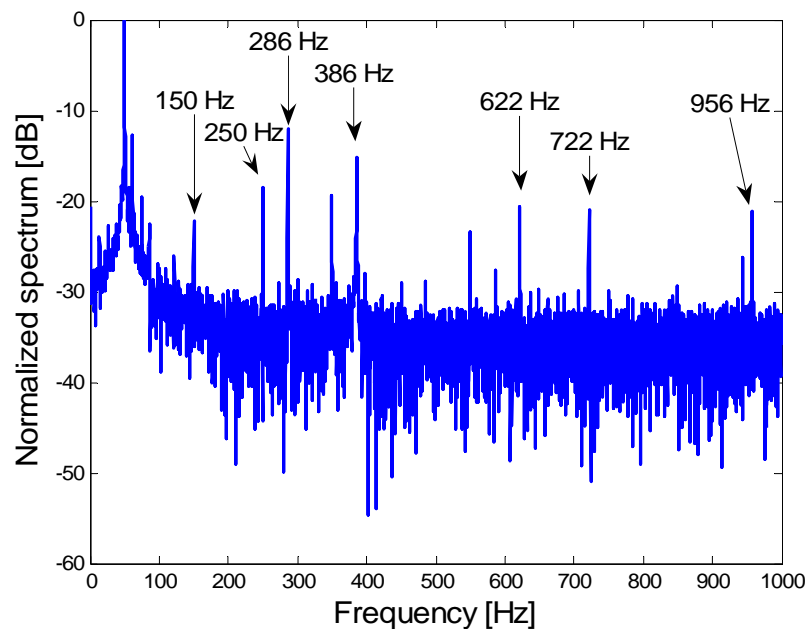


a) Experimental current spectrum

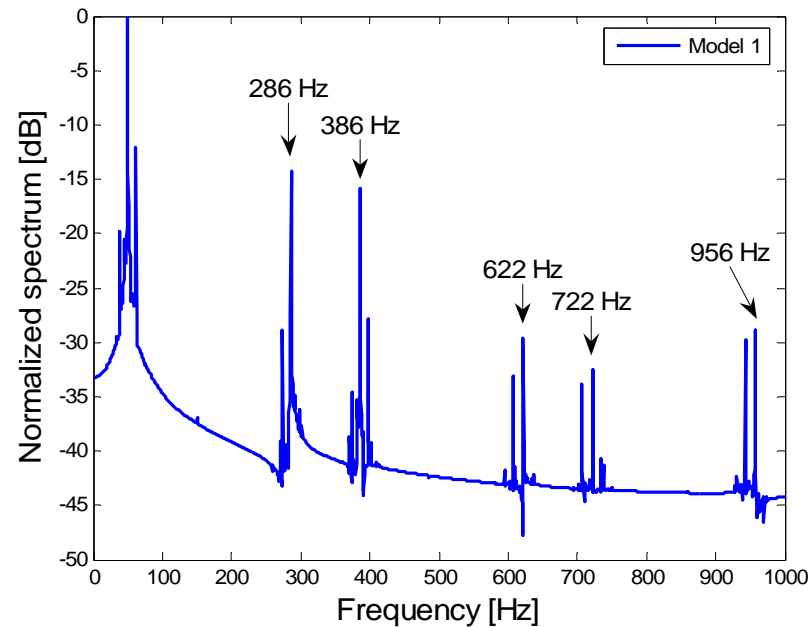


b) Predicted current spectrum

Frequency content of predicted and measured DFIG stator line current for a healthy DFIG

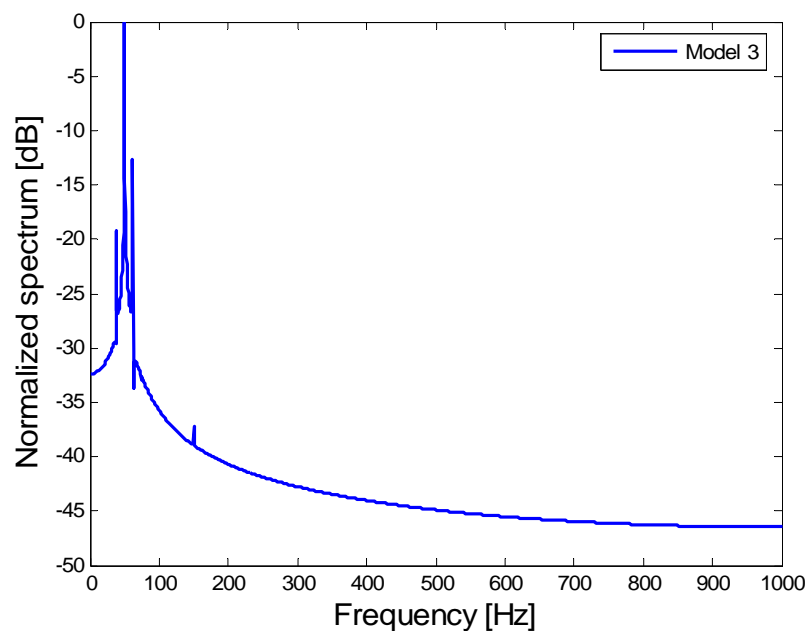


a) Experimental current spectrum

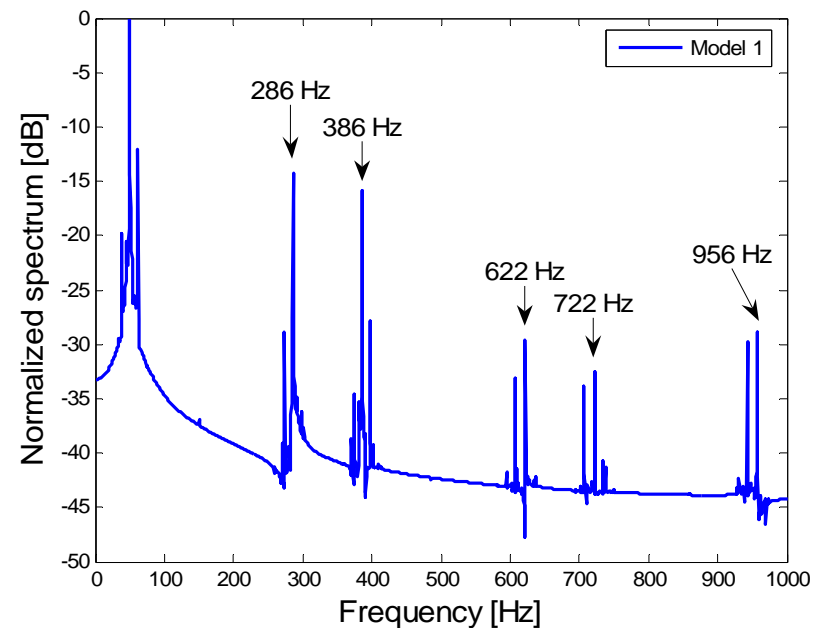


b) Predicted current spectrum,
Includes high order field harmonics

Frequency content of predicted DFIG stator line current for a healthy DFIG



a) Predicted current spectrum, includes fundamental only



b) Predicted current spectrum, Includes high order field harmonics

Conclusions

- A detailed DFIG analytical model developed
- DFIG Test Rig built
- The developed model's validity is verified through comparison of model predictions against the experimental results obtained from the test rig
- Advantages of modelling the effects of higher order field harmonics demonstrated
- Some stator current fault-specific harmonic components are identified. These are slip dependant.

Thank You