Improving Wind Turbine Induction Generator Diagnostic Reliability by Combining Electrical and Mechanical Fault Signals

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Abstract

Rotor electrical unbalance (REU) is one of the major contributors to WT generator failure rate[1-3]. Most fault detection techniques developed so far rely on the analysis of a single signal, with a risk of missed faults or false alarms, making accurate diagnosis difficult. This research investigates REU wide-band spectral effects on wind turbine induction generator electrical and mechanical signals. Predictions from analytical expressions derived from a harmonic time-stepped generator model are compared with measurements made on a 30kW induction generator laboratory test rig. Results show that REU results in substantial increases of slip-dependant side-bands of supply-induced, inter-harmonic components of current, power, electromagnetic torque, shaft speed, mechanical torque and frame vibration spectra.

Objectives

- Investigate the wide-band manifestation of REU-related side-bands of supply harmonic and slotting induced frequencies in electrical and mechanical signals.
- Define and cross-correlate the best diagnostic REU reliability condition monitoring indicators for incorporation into existing commercial wind turbine condition monitoring systems.
- Fuse results from simultaneous real-time side-band monitoring in multiple signals to enhanced REU fault recognition sensitivity and allow assessment of damage severity.

Generator Rotor Electrical Unbalance

Model Study

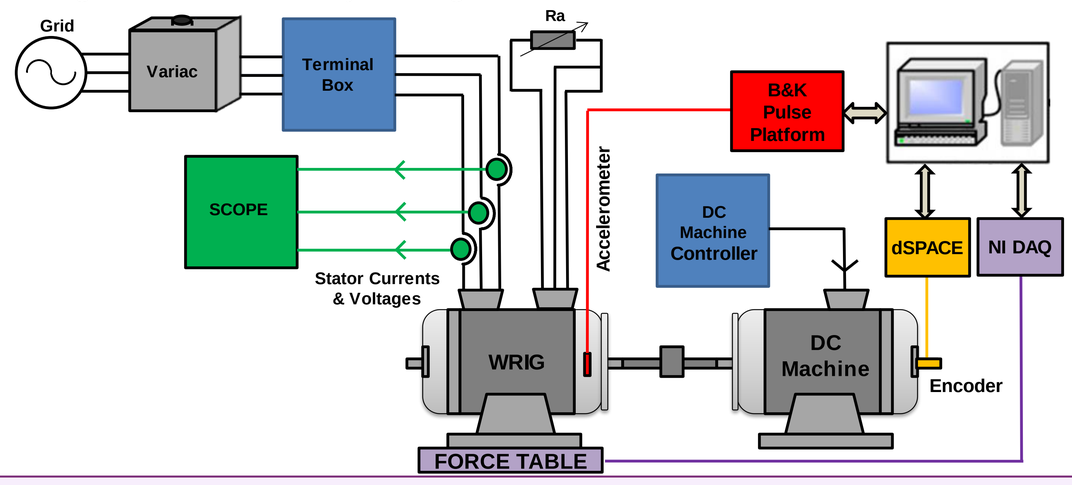
Generator Signal	Closed-Form Analytical Expressions: Balanced Rotor (CF)	Closed-Form Analytical Expressions: Unbalanced Rotor (CF ± *2nsf*)
Stator Current, I_s	$\|i \pm 6k(1-s)\|f$	$\|(i \pm 2ns) \pm 6k(1-s)\|f$
Stator Active Power, Electromagnetic Torque, Rotational Speed, P_e, T_e and N_s	$\|[l \pm i] \pm 6k(1-s)\|f$	$\|([l \pm i] \pm 2ns) \pm 6k(1-s)\|f$

f = supply frequency; *s* = rotor slip; *i*, *l* = supply harmonic order = 1,2,3..; *k* = air-gap magnetic field pole pair number = 1,2,3..; *n* = 0,1,2,3…

REU-induced side-band equations can be resolved into two distinct sub-groups depending on whether they are manifested on the harmonic (HS) or slot harmonic carriers (SHS). A harmonic time-stepped generator model has been used to examine faults and validate proposed closed-form analytical expressions to describe them.

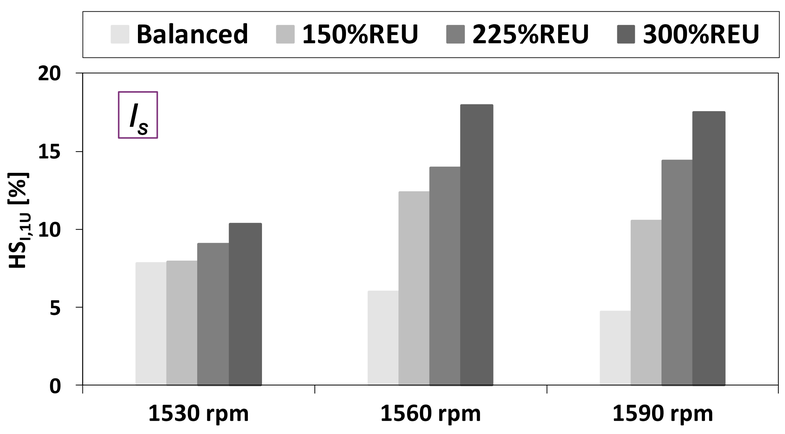
Experimental Study

Model predictions have been validated in a series of experiments on a 30 kW induction generator laboratory test rig.

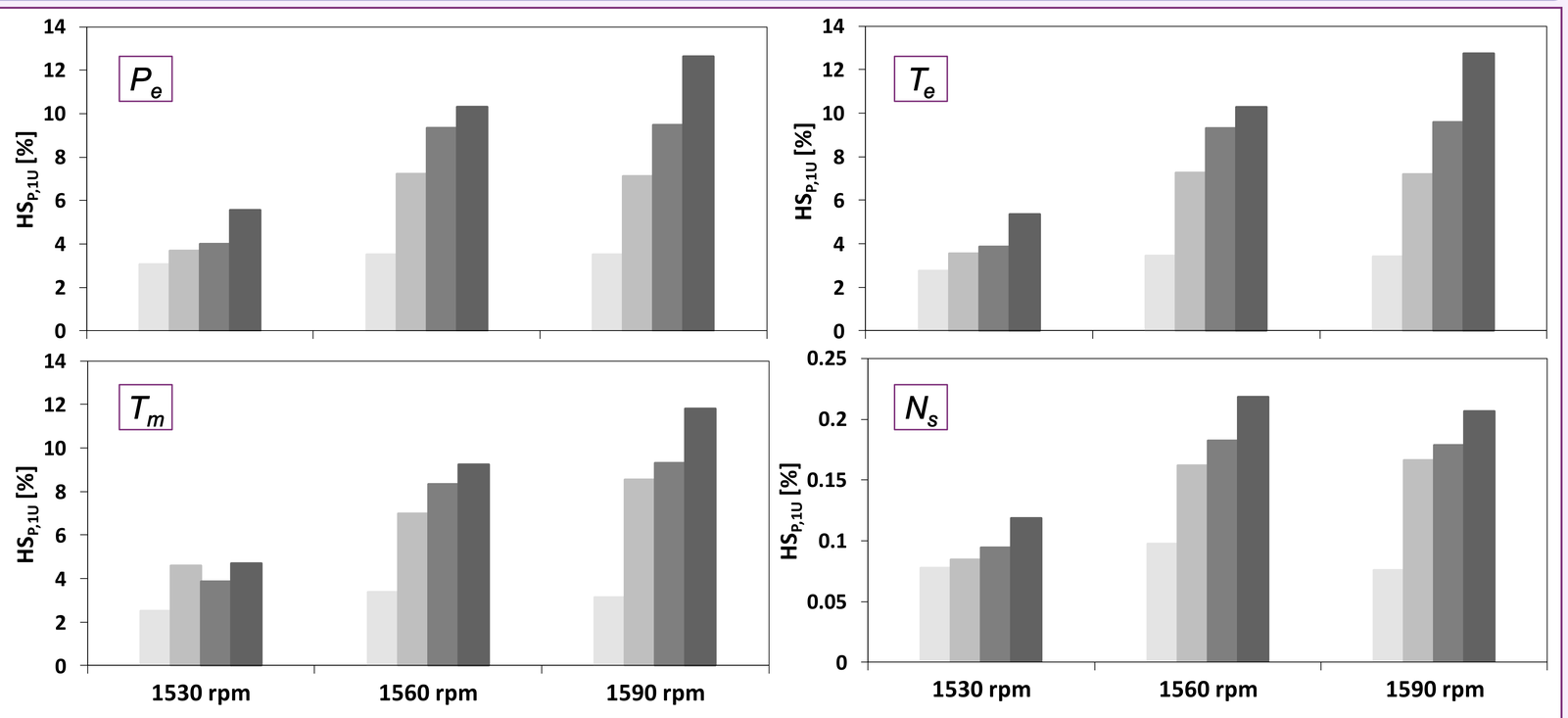


Fault indicators: load and REU severity dependency

Supply frequency harmonic side-bands (HS)



First supply frequency harmonic normalised upper *2sf* side-band ($HS_{I,1U}$, $i = 1$, $k = 0$)



DC component normalised *2sf* side-band ($HS_{P,1U}$, $i = 1$, $l = 1$, $k = 0$))

P_e, T_e, T_m and N_s signals all show similar characteristics to I_s, however, due to the nature of how these signals are formed, their spectral signatures map into different co-ordinates[4].

Slotting harmonic side-bands (SHS)

Experimental results show that REU produces consistent, high fault and load sensitivity **current** ±*2sf* side-band spectral increases around slotting components ($i = 1$, $k = 1,2$), in addition to the traditional $HS_{I,1U}$.

In the Table, the tick and cross marks indicate whether or not the progressive increase in REU corresponds to consistent increase of the examined side-band magnitude.

Most of the I_s SHS components are able to progressively track REU severity within the full generator operating range.

CF	Side-band	1530 rpm	1560 rpm	1590 rpm
$SH_{I,1}$	$SHS_{I,1L}$	✓	✓	✓
	$SHS_{I,1U}$	×	✓	✓
$SH_{I,2}$	$SHS_{I,2L}$	×	✓	✓
	$SHS_{I,2U}$	×	✓	✓
$SH_{I,3}$	$SHS_{I,3L}$	×	✓	✓
	$SHS_{I,3U}$	×	✓	✓
$SH_{I,4}$	$SHS_{I,4L}$	✓	✓	✓
	$SHS_{I,4U}$	✓	✓	✓

Conclusions

Closed-form analytic expressions defining electrical and mechanical signal spectral content for healthy and faulty conditions have been derived and validated by comparison with predictions from a harmonic generator model and experiments on a fully instrumented 30 kW laboratory test rig.

Magnitude of slip-dependant side-bands of a wide range of both supply frequency and slotting harmonics show a significant increase under faulty REU conditions.

Specific side-bands of I_s, P_e, T_e, T_m and N_s giving clear and consistent fault recognition across the generator operating range have been identified as high diagnostic reliability indicators of REU.

References

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