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Transient-based rotor cage assessment in induction motors operating with soft-starters

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Abstract

The reliable assessment of the rotor condition in induction motors is a matter of increasing concern in industry.
Though rotor damages are more likely in line-started motors operating under high inertias, some cases of broken rotor bars in motors supplied via soft-starters have been also reported in the industry.
The classical methodology, Motor Current Signature Analysis (MCSA), due to the inherent nature of the FFT is only strictly suitable for machines operating under pure stationary regimes.
This paper extends a recently introduced diagnosis methodology relying on the start-up current analysis.
The approach has proven to provide very satisfactory results even in cases where the classical MCSA does not lead to correct diagnosis conclusions.
However, its extension to operation under soft-starters was still a pending issue.

Background

- The proposed approach relies on analyzing the start-up current.
- The fault components frequencies change in time, following well characterized evolutions.
- In the event of broken bars, during a line start-up, as the slip *s* changes between 1 and near 0, the lower sydeband harmonic (LSH) evolution leads to a very characteristic L-shaped pattern.
- This evolution can be noticed through the DWT signals that are, indeed, time-frequency representations of the analyzed current.
- This pattern appears only when a bar breakage is present, since no other cause (load torque oscillations, cooling ducts…) leads to a similar pattern.
- The pattern appears regardless of the loading condition of the machine.
- Quantification indicator is based on the DWT.
  Relates the energy of the total startup current signal (*i*) with that of the DWT signal containing most of the fault component evolution (*d*).
- The higher the value of the indicator γ_{DE}, the lower the energy of the *d* signal and hence, the healthier the motor is.

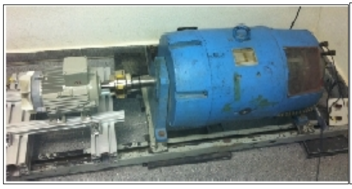
$$\gamma_{DE}(dB) = 10 \cdot \log \left[\frac{\sum_{j=-Nb}^{Ns} i_j^2}{\sum_{j=-Nb}^{Ns} \left[d_{nf+1}(j) \right]^2} \right]$$

COMPUTATION OF FAULT INDICATOR γ_{DE}

Startup method	Condition	Fault Indicator γ_{DE}
Direct	Healthy	51.5
Sort-starter (voltage ramp)	Healthy	44.2
Soft starter (current limitation + voltage ramp)	Healthy	45.2
Direct	2 broken bars	28.3
Sort-starter (voltage ramp)	2 broken bars	30.3
Soft-starter (current limitation + voltage ramp)	2 broken bars	35.3

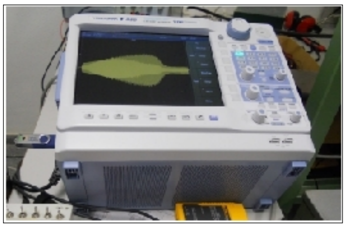
- The indicator remains within a narrow band for a certain faulty condition, regardless of the startup method -

Experiments



Rated Power	1.1 kW
Rated frequency	50 Hz
Rated Voltage	400 V
Rated primary current	2.7 A
Rated speed	1410 rpm
Rated slip	0.06
Connection	Star
Number of pole pairs	2
Number of rotor bars	28

1,1 Kw induction motors with different levels of failures



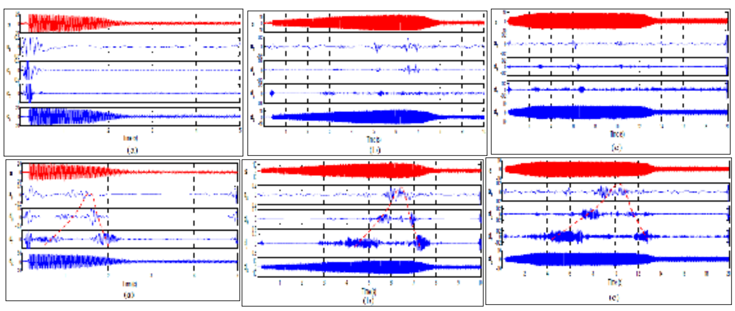
The start-up current waveform was recorded by means of a YOKOGAWA SCOPECORDER DL850.

Sampling rate *fs* = 5 kHz

FREQUENCY BANDS COVERED BY HIGH LEVEL DWT SIGNALS

Wavelet signal	App. Frequency band
a8	[0~9] Hz
d8	[9~19] Hz
d7	[19~39] Hz
d6	[39~78] Hz

The DWT was applied to each signal using *n*=8 decomposition levels and *dmeyer* as mother wavelet



Figures above: (a) started direct online
(b) initial voltage = 30% of rated voltage and startup length=7.5s
(c) maximum current = 2'5·rated current
Figures bellow: are analogue but for the motor with 2 broken bars

Conclusions

- The pattern clearly appears for the faulty machine operated with soft-started, while it is absent in healthy condition
- Fault severity indicator shows clear differences between its values for faulty and healthy conditions in every startup method (slight variations with same faulty condition may be attributed to the noise introduction by the soft-starter)