Bar breakage detection on Squirrel Cage Induction Motors via Transient Motor Current Signal Analysis based on the Wavelet Transform. A Review.

Joan Pons-Llinares[1], Vicente Climente-Alarcón[1], Rubén Puche-Panadero[1] and Jose A. Antonino-Daviu[1]

[1] Departamento de Ingeniería Eléctrica
Universidad Politécnica de Valencia
Campus de Vera – Valencia, 46022 Valencia (España)
Tel.:+34 963877007, fax:+34 963879009, e-mail: jpons@die.upv.es, vicial@csa.upv.es, rupucpa@die.upv.es, joanda@die.upv.es

1. Introduction

The startup current (SC) of a squirrel cage induction motor (SCIM) with a broken bar, does not differ at first sight from the startup current of a healthy one. However, the current under the faulty condition contains harmonics which are characteristic of the fault. More precisely, the breakage of a rotor bar produces a perturbation on the air-gap field inducing characteristic frequencies in the stator current. Those frequencies, dependant on the slip s and on the mains frequency f_{net}, are given by (1) and (2) [1]:

$$f_{bb} = \left[1 \pm 2ks\right] f_{net} \qquad (1)$$

$$f_{bb} = \left[\frac{k}{p}(1-s) \pm s\right] f_{net} \qquad (2)$$

where p is the number of pole pairs. In (1) k is any positive integer and in (2) $k/p = 1,3,5,\ldots$.

Among this set of harmonics, the most important are the so-called Lower Sideband Harmonic (LSH) and the Upper Sideband Harmonic (USH). Their frequencies are given by (1) when $k=1$:

$$f_{LSH} = f_{net}\left|1-2s\right| \qquad (3)$$

$$f_{USH} = f_{net}\left(1+2s\right) \qquad (4)$$

In (3), we have considered the absolute value in order to obtain a positive value of the LSH frequency.

The so-called Transient Motor Current Signal Analysis (TMCSA), analyzes the stator current during a transient, usually the startup. The analysis consists of applying a certain mathematical tool to the transient stator current, usually a signal analysis technique able to characterize non-stationary signals such as the Wavelet Transform (WT). The result of the analysis must be sensitive to the presence of the SH. This sensitiveness allows the detection of a bar breakage.

An important advantage of the TMCSA methods is that, regardless of the load conditions, the amplitudes of the SH during the startup, reach values several times higher than those in steady state [2]. As a result of that, the proofs of the bar breakage are much more evident. For some TMCSA methods, the diagnosis of light – loaded or unloaded machines is no longer a problem.

Moreover, when the slip changes during the startup, the frequencies given by (3) and (4) change, leading to a unique time-frequency evolution pattern of the LSH and USH harmonics. Supposing a linear evolution of the slip during the startup and taking $f_{net} = 50$ Hz we obtain:

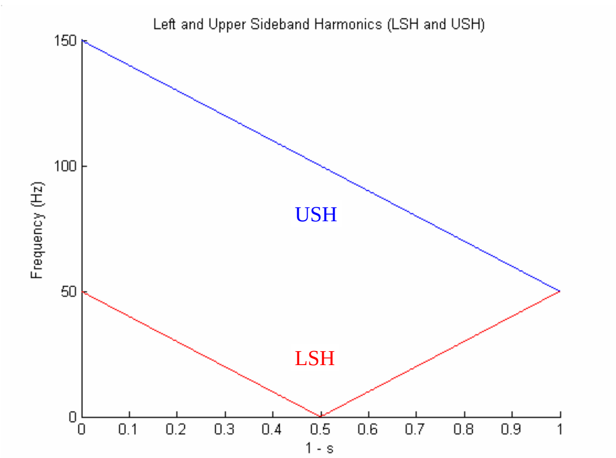

Fig. 1. Time - frequency evolution of the LSH and USH during the startup, supposing a linear evolution of the slip and considering $f_{net} = 50$ Hz .

In other words, the fault produces a distinctive pattern on the startup current recognizable, in the time-frequency plane, like a person signature. The problem is to make it visible in order to detect the fault. This is the objective of some TMCSA methods, achieved by representing in the time-frequency plane the time evolution of the startup current harmonics. If a fault is present, not only the fault related harmonics will be identified, but also their unique time – frequency evolution pattern. This feature greatly increases its reliability, helping to discard non-fault related harmonics like those generated by periodic loads or voltage unbalances.

TMCSA has other advantages: it is non-invasive, it requires only the measurement of a single phase current, it can discriminate between multiple types of failures occurring simultaneously, and it can be performed online, without perturbing the installation operation conditions.

The difference between TMCSA methods is the mathematical tool used to analyze the transient stator current. This leads to advantages and drawbacks. Most TMCSA methods are based on the WT, which has proved to give very good results. On the present paper, TMCSA methods based on the WT are reviewed, specially the ones that analyze the SC.

Kew words: TMCSA, startup current, fault diagnosis, induction machines, wavelet transform, broken bars.

2. Examples of specific solutions proposed.

The diagnosis methods reviewed in the present section, apply the WT to the SC of the SCIM being diagnosed in order to detect a bar breakage. They have been classified depending on the version of the WT used: the Discrete Wavelet Transform (DWT) or the Continuous Wavelet Transform (CWT).

A. CWT

Supangat el al. [3] propose to analyze the SC via the generation of the scalogram using a DB8 wavelet. The presence of the SH produces some differences between the scalogram of the SC belonging to a SCIM with a broken bar and the scalogram of a healthy SC. However, the FC overshadows those differences. In order to eliminate that undesirable effect, they propose to analyze the envelope of the SC, which does not depend on the FC. The effect of the SH presence was highlighted, obtaining a much more objective diagnosis criterion.

B. DWT

In [2] and [4], the DWT was used to decompose the SC in an approximation signal and n details (n is the decomposition level), each one containing the harmonics of a different frequency band.

Figure 4 reproduces some of the results of [4] (Fig. 4 and 5 of [2]). It shows the approximation signal of a healthy and a rotor broken bar machine driving a pure inertia load (startup of 2 seconds), using a DB44 wavelet, $n=6$, $f_s=5000$ samples/second.

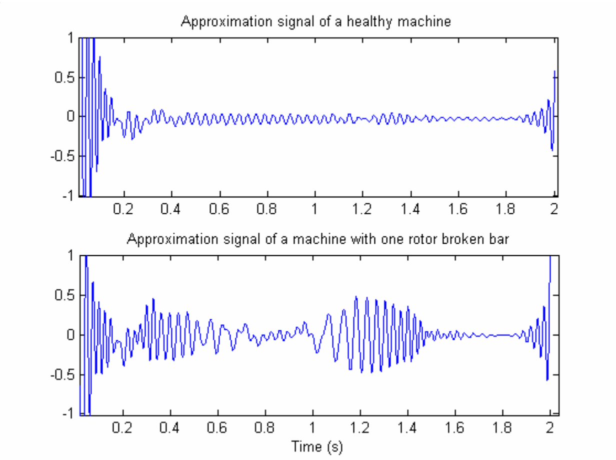

Fig. 2 Approximation signal of a healthy and a broken bar machine.

The approximation signal contains the harmonics with frequencies in the interval $\left[0,2^{-(n+1)}\right] f_s \approx [0,39]\,Hz$, that is, almost the whole band where the LSH is present $[0,50]\,Hz$. In other words, the approximation signal contains almost the whole LSH.

When a machine has a broken rotor bar, the presence of the LSH increases the amplitude of the approximation signal, enabling the fault detection and diagnosis. On the other hand, taking into account that in that frequency range the LSH is the only significant component (apart from the electromagnetic transient and the beginning of some Principal Slot Harmonics), obtaining that approximation signal means to extract the LSH from the SC (if there is any LSH).

In [2], a parameter to quantify the fault severity has been introduced. It is defined as 10 times the logarithm of the quotient between the SC energy and the approximation signal energy.

3. Conclusions

The Wavelet Transform can be used to analyze the SC of the SCIM being diagnosed in order to detect bar breakages. The four main approaches are explained on the final version. Examples of those main approaches are given, with the specific solutions proposed by their authors.

The main problem of the CWT is that it consumes a lot of computational time. On the other hand, when it is well used it can give an excellent view of the SH frequencies evolution. The DWT can be computed very quickly. Moreover, the SC can be easily reconstructed as a sum of the approximation signal and the details.

Through the revision, the Wavelet Transform has proved to be an excellent mathematical tool for the detection of broken bars.

Acknowledgments

This work was supported by the European Community's Seventh Framework Program FP7/2007-2013 under Grant Agreement 224233 (Research Project PRODI "Power plant Robustification based on fault Detection and Isolation algorithms").

References

[1] A. Bellini, F. Filippetti, G. Franceschini, C. Tassoni, and G. B. Kliman, "Quantitative evaluation of induction motor broken bars by means of electrical signature analysis," *IEEE Transactions on Industry Applications*, vol. 37, no. 5, pp. 1248–1255, Sep./Oct. 2001.

[2] M. Riera-Guasp, J.A. Antonino-Daviu, J. Roger-Folch and M.P. Molina-Palomares, "The use of the wavelet approximation signal as a tool for the diagnosis of rotor bar failures", *IEEE Transactions on Industry Applications*, vol. 44, pp. 716-726, 2008.

[3] R. Supangat, N. Ertugrul, W. L. Soong, D. A. Gray, C. Hansen, and J. Grieger, "Detection of broken rotor bars in induction motor using starting-current analysis and effects of loading," *IEE Proceedings Electric Power Applications*, vol. 153, pp. 848-855, 2006.

[4] J. Antonino-Daviu, M. Riera-Guasp, J. Roger-Folch, F. Martínez-Giménez, and A. Peris, "Application and optimization of the discrete wavelet transform for the detection of broken rotor bars in induction machines," *Applied and Computational Harmonic Analysis*, vol. 21, pp. 268-279, 2006.