Study of the faults Severity Progression in Induction Machines for Conditional Maintenance Purposes

Lahbib Sadiki[1], Soumia El Hani[1], Said Guedira[2], Khalid Dahi[1], Ilyas Ouachtouk[1],

[1] Mohammed V University Rabat
ENSET. Electrical Engineering
Research Laboratory
Lahbib.sadiki@um5s.net.ma

[2]ENSM Rabat-Research Laboratory
Of Control, Protection and
Monitoring of Industrial Plans

Abstract

In spite of the fact that, induction machine is strongly robust. It remains the seat of different faults. Those faults occur in all parts of the machine. The progression and the evolution of severity of these faults can cause the complete shutdown of production system in which the machine is introduced. An early detection is, then, necessary as well as the determination of fault severity degree. That, to prevent the complete shutdown of the machine. A novel approach for monitoring the fault severity progression, in IMs, is developed. This approach is used to define, with high accuracy, the maintenance conditions by the use of currents measurement obtained from an elaborated experimental test bench. This, through quadratic representations based on motor current signature analysis (MCSA) technique. The developed approach insure a simplicity of interpretation in time-frequency representation i.e., astatic indicator is affected to each degree of severity. After that, severity thresholds are defined for maintenance purposes.

1 Introduction

Robustness, reliability and the easiness of construction of induction machine (IM) are the secrets of its ubiquitousness in all industries. Its applications grow out more and more complexity. Wound rotor induction machines are widely used in application with variable-speed-constant-frequency wind generator systems[1]. It occurs production downtime due to faults in one of the parts of the induction machine[2]. Those faults arise with a minor severity and progress gradually to an intolerable level, which causes machine downtime. The early detection allows avoiding the machine out service. Moreover, making it possible to plan the production line for preventive and corrective maintenances operations.

Condition monitoring (CM) of electrical machines is developed based on the considerable advancement of processor-based signal acquisition and analysis. The necessity of early diagnosis of developing fault is required to plan maintenance operations. So, Much interests are made in fault diagnosis and the early detection.

Several research papers are focusing about the study of various types of faults in induction machine[3]-[5]. This by the use of several techniques. There are methods based on nonelectrical parameters, as example vibration signal where information about the health condition of the machine is given by vibration signal analysis. Air gap flux for eccentricity detection, There are also acoustic technique. In addition, of those techniques, motor current signature analysis (MCSA) is a paramount tool in faults diagnosis in induction machine due to its easiness for implementation and its effectiveness in the detection of faults. Several research works [6]-[8]was done to process stator current for the purpose of faults detection and they demonstrate their robustness and their effectiveness

Approaches based-on MCSA were used to spot different kind of faults in induction machine namely broken rotor bar fault, bearing fault, unbalanced rotor fault and stator winding fault etc[2].

Fast Fourier Transform (FFT) is the core of several signal-processing techniques used in motor current and vibration analysis[6]-[8]. Nevertheless, it has some limitations in term of analyzing the transient signal. FFT limitations are relatively resolved by the introduction of advanced techniques[9]-[13]. They process the signal with its instantaneous frequency. They regroup time representation and frequency representation in the same representation. The choice of signal processing techniques depends on the nature of the signals being considered. Thus, so-called classical techniques are used for signal of a stationary nature. For non-stationary signals, advanced techniques are required. As an example, mention may be made of the time-frequency processing methods

Determination of severity degree is one of most important task for machine's surveillance. It has been initiated by the use of FFT-based approaches. Color index-based method is presented in [14], it proposes a function to extract index of amplitude-related color in TFR. Progression of rotor-winding fault is simulated by additional resistor to introduce an asymmetry in rotor winding.

This work is organized as follows. Section 2 presents the mathematical concept of TFR and their interests. The test bench system when the machine is mounted is described in section 4. Fault severity progression is evaluated by means of several varying condition tests of rotor-winding fault; experimental results are presented and commented in Section 5.

2 Time-frequency representations

Time frequency representation (TFR) are introduced to deal with transient signals. Those types of signals are considered as non-stationary. As example, the voice recording is the best cited. Such signal is rich in frequencies, Contains a number of closely related transitions and must be meticulously processed to extract useful information. Depending on its non-stationary nature, TFR are highly required to deal with voice recording. rotor-related faults introduce non-stationary signature in the form of amplitude modulations in the stator current. Namely broken rotor bar and broken ring in squirrel rotor, unbalanced rotor mass that causes eccentricity and winding faults in wound rotor. The must known RTF is the Short Time Fourier Transform (STFT). It uses constant-sized window to analyze all frequencies, and for that, it is considered as linear TFR. Spectrogram is the quadratic representation of STFT.

A mathematical reminder is necessaire to understand their concept. This work is based on STFT and its quadratic representation the spectrogram. The STFT is interpreted mathematically by Fourier Analysis of successive portions weighted with a time window (Hamming, Hanning ...)[15].

$$G(t, f) = \int x(\tau) h_{t,f} * (\tau) d\tau \quad (1)$$

$$G(t, f) = \int x(\tau) h^*(\tau - t) e^{-2\pi j f \tau} d\tau \quad (2)$$

Equation 2 shows that it is a scalar product between the processed signal and a basic functions defined by:

$$h_{t,f}(\tau) = h(\tau - t) e^{-2\pi j f \tau} \quad (3)$$

Practically the spectrogram is widely used. It is computed as the quadratic representation of the STFT. From Equ.2, it is given by the following equation

$$S(t, f) = \left| \int x(\tau) h^*(\tau - t) e^{-2\pi j f \tau} d\tau \right|^2 \quad (4)$$

For the spectrogram and the STFT, the non-stationary signal is considered as a succession of quasi-stationary segments across the short-time window chosen.

- The time resolution is fixed by the width of the window;
- The frequency resolution is determined by the width of its Fourier transform;

Discrete expressions of the STFT and the spectrogram are given by the following equations (5) and (6):

$$STFT(k, f) = \sum_{n=0}^{N-1} h(n) x(k+n) e^{-2\pi j f n} \quad (5)$$

$$S(k,f)=\left|\sum_{n=0}^{N-1} h(n)x(k+n)e^{-2\pi jfn}\right|^2 \quad (6)$$

3 The colors index in TFR

The proposed method is based on the study of colors index to determine the fault severity and its characteristics frequencies. The time-frequency representations affect a level of color to each amplitude depending to its frequency. This is done according to the color map chosen. There is a color degree for higher amplitude and another for the lower one. In our case, the yellow color indicates frequencies with higher level and dark blue colors indicates frequencies with very low amplitude. To evaluate the fault severity, it is necessary to transform colors into numbers. For this aim, [14], proposed a method to extract the colors indexes.

Follow is the proposed function to extract colors index

$$Index(f)=SHADE(color((1\pm 2ks)f_s) \quad (7)$$

4 Experimental test bench

A test bench is installed to simulate the rotor-related electrical faults. Wound rotor induction machine (WRIM) is used, it drives a DC machine, which operates as a generator and delivers its current in a resistive load. The signal to be analyzed is acquired, to known current, with a sampling frequency of 25 kHz. The objective of using such a frequency is to avoid the loss of useful information. Acquisition is made for 10 seconds under permanent operating regime. The effectiveness of faults severity study is based on the knowledge of rotor windings resistance value. Voltammeter method is used to determine those values. Obtained values are given as follow:

R_{r1}=1.265Ω; R_{r2}=1.1350 Ω; R_{r3}=1.635Ω;

Typical insulation damage leading to inter-turn short circuit of the stator and rotor windings in WRIM. There are several types of faults in windings in both stator and rotor; (i) Inter-turn short circuits between turns of the same phase. (ii) Winding short-circuited. (iii)Short circuits between winding and stator/rotor core at the end of slot. (iv) Short circuits between winding and stator/and rotor core in the middle of slot. (v) Short circuit at the leads. (vi) Short circuit between phases.

Those faults changes the resistance value of the affected phase. For that, an additional resistance is inserted with one of the rotor phases to simulate rotor-winding faults. The test bench worked in no load condition and powered directly from electrical network of laboratory

5 Experimental results

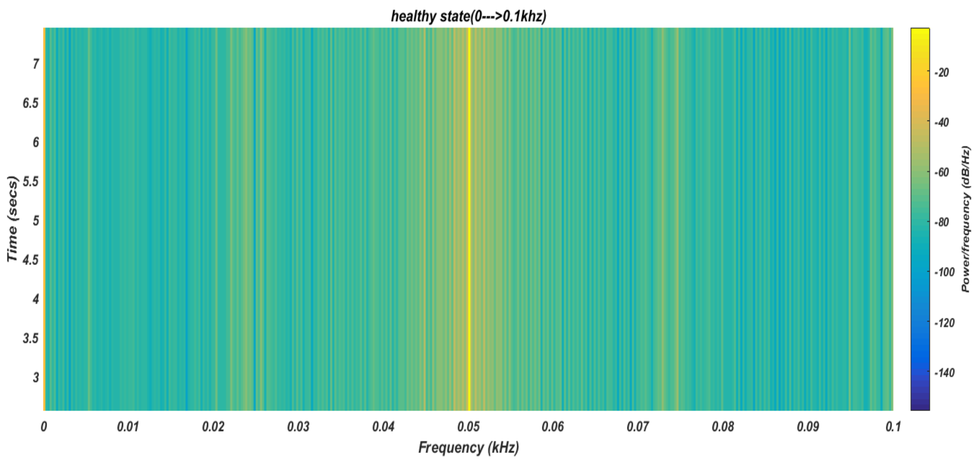

Figure 1 spectrogram of stator current for healthy machine

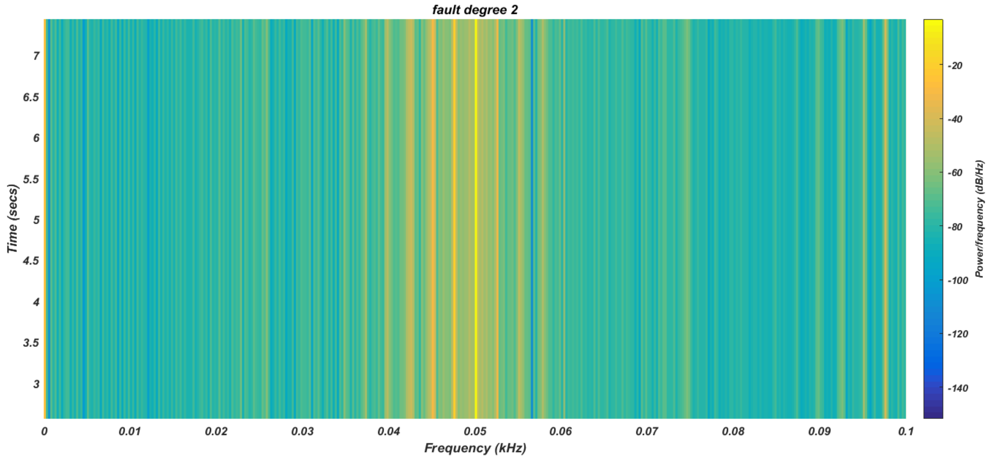

Figure 2 spectrogram of stator current for second set of faulty machine

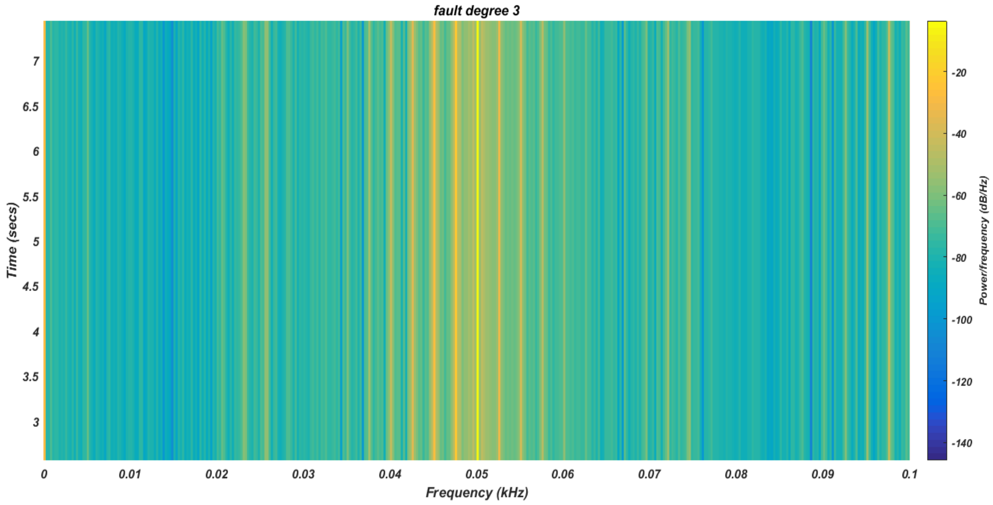

Figure 3 spectrogram of stator current for third faulty degree machine

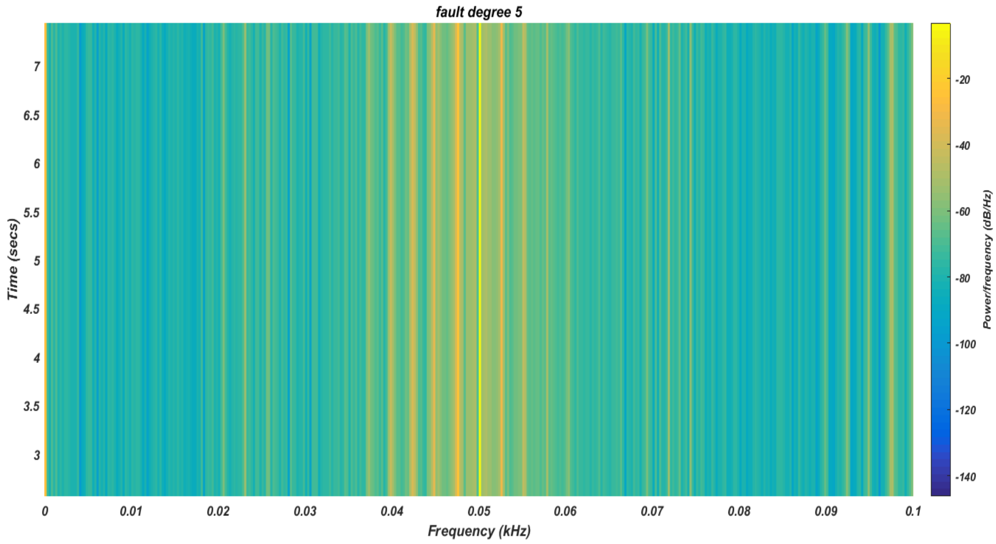

Figure 4spectrogram of stator current for fourth fault fifth machine

6 Conclusions & discussions

Progression of rotor winding fault severity in WRIM is simulated and represented in this article. STFT and its quadratic representation, spectrogram, are used to process stator current recorded from an experimental test bench. Obtained results are represented with several level of fault. Full analysis to determine a limen, a threshold, will be published in related next work.

Reference

[1]Y.Gritli, L. Zarri,, C. Rossi, F. Filippetti, G. Capolino, and D Casadei, "Advanced Diagnosis of Electrical Faults in Wound-Rotor Induction Machines" *IEEE Trans. Ind.* Ele, Vol. 60, NO. 9, pp.4012-4024,Sep 2013.

[2]Subrata Karmakar ,Surajit Chattopadhyay ,Madhuchhanda Mitra ,Samarjit Sengupta "Induction Motor Fault Diagnosis, Approach through Current Signature Analysis" springer 2016.

[3] M. BENBOUZID and G. KLIMAN," What stator current processing based technique to use for induction motor rotor fault diagnosis?" *IEEE Transaction on Energy Conversion vol, 18, no 2 pp 238-244, 2003.*

[4]A. Stefani, A. Yazidi, C. Rossi, F. Filippetti, D. Casadei, and G. A. Capolino, "Doubly fed induction machines diagnosis based on signature analysis of rotor modulating signals," *IEEE Trans. Ind. Appl.*, vol. 44, no. 6, pp. 1711–1721, Nov./Dec. 2008.

[5]V. Dinkhauser and F. W. Fuchs, "Rotor turn-to-turn faults of doublyfed induction generators in wind energy plants-modelling, simulation and detection," in *Proc. EPE-PEMC*, Posnan, Poland, Sep. 1–3, 2008, pp. 1819–1826

[6] A. Stefani, F. Filippetti, and A. Bellini, "Diagnosis of induction machines in time-varying conditions," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4548–4556, Nov. 2009.

[7] Y. Gritli, C. Rossi, L. Zarri, F. Filippetti, A. Chatti, D. Casadei, and A. Stefani, "Double frequency sliding and wavelet analysis for rotor fault diagnosis in induction motors under time-varying operating condition," in *Proc. IEEE Int. Symp. Diagn. Elect. Mach., Power Electron. Drives*, Bologna, Italy, Sep. 5–8, 2011, pp. 676–683.

[8] B. Akin, S. Choi, U. Orguner, and H. A. Toliyat, "A simple real-time fault signature monitoring tool for motor-drive-embedded fault diagnosis system," *IEEE Trans. Ind. Electron.*, vol. 58, no. 5, pp. 1990–2001, May 2011.

[9] J. Cusido, L. Romeral, J. A. Ortega, J. A. Rosero, and A. G. Espinosa, "Fault detection in induction machines using power spectral density in wavelet decomposition," *IEEE Trans. Ind. Electron.*, vol. 55, no. 2, pp. 633–643, Feb. 2008.

[10] S. H. Kia, H. Henao, and G.-A. Capolino, "Torsional vibration assessment using induction machine electromagnetic torque estimation," *IEEE Trans. Ind. Electron.*, vol. 57, no. 1, pp. 209–219, Jan. 2010.

[11] I. P. Tsoumas, G. Georgoulas, E. D. Mitronikas, and A. N. Safacas, "Asynchronous machine rotor fault diagnosis technique using complex wavelets," *IEEE Trans. Energy Convers.*, vol. 23, no. 2, pp. 444–459, Jun. 2008.

[12] R. Yan and R. X. Gao, "Hilbert–Huang transform-based vibration signal analysis for machine health monitoring," *IEEE Trans. Instrum. Meas.*, vol. 55, no. 6, pp. 2320–2329, Dec. 2006.

[13] J. Antonino-Daviu, P. J. Rodriguez, M. Riera-Guasp, A. Arkkio, J. Roger-Folch, and R. B. Perez, "Transient detection of eccentricity related components in induction motors through the Hilbert–Huang transform," *Energy Convers. Manage.*, vol. 50, no. 7, pp. 1810–1820, Jul. 2009.

[14] L. Sadiki, S. El Hani, S. Guedira and I. Ouachtouk "assessment of time frequency color index for electrical machines diagnosis and fault severity" *international review on modelling and simulation vol*. 9, N. 1,2016, pp 1-10.