Mechanical Systems and Signal Processing 23 (2009) 2336–2351

Contents lists available at ScienceDirect

Mechanical Systems and Signal Processing

journal homepage: www.elsevier.com/locate/jnlabr/ymssp

Detection of combined faults in induction machines with stator parallel branches through the DWT of the startup current

J. Antonino-Daviu [a,*], P. Jover Rodriguez [b,1], M. Riera-Guasp [a], M. Pineda-Sánchez [a], A. Arkkio [c,2]

[a] Universidad Politécnica de Valencia, Departamento de Ingeniería Eléctrica, P.O. Box 22012, 46071 Valencia, Spain
[b] ABB AB, Corporate Research, Forskargränd 8, 72222 Vasteras, Sweden
[c] Laboratory of Electromechanics, Helsinki University of Technology, P.O. Box 3000, 02015 HUT, Finland

ARTICLE INFO

Article history:
Received 2 July 2008
Received in revised form
6 February 2009
Accepted 12 February 2009
Available online 25 February 2009

Keywords:
Fault diagnosis
Discrete Wavelet Transform
Startup transient
Rotor asymmetries
Mixed eccentricities
Inter-turn short-circuits

ABSTRACT

The main objective of this paper is to diagnose the presence of combined faults in induction machines. For this purpose, a methodology based on the application of the Discrete Wavelet Transform (DWT) to the stator startup current is used. This approach was applied in previous works with success to the diagnosis of rotor asymmetries and mixed eccentricities in motors with different sizes and conditions. However, as most of the diagnosis methods hitherto developed, the application of the proposed approach was circumscribed to situations in which a single fault was present in the machine. In addition, the influence of other phenomena such as load torque oscillations or voltage fluctuations was studied, but without considering the combination of these phenomena and the fault in the machine. This work is intended, first, to apply the proposed transient-based methodology to several cases in which different faults (rotor asymmetries, mixed eccentricities and inter-turn and inter-coil stator short-circuits) are simultaneously present in the machine and, second, to apply it to cases regarding faults combined with other phenomena making difficult the diagnosis, such as load torque oscillations. Interesting considerations regarding the preponderance of the effects of some of the faults are also done in the paper. The application of the methodology is focused on induction machines with stator parallel branches; in this sense, the suitability of the use either of the phase current or of the branch current for the diagnosis of each particular fault is analysed. The results look promising with regard to the validity of the methodology for the reliable discrimination of simultaneous electromechanical faults and the diagnosis of faults combined with other phenomena.

1. Introduction

Predictive maintenance of electrical machinery, and more concretely of induction machines, is a field drawing increasing attention in the industrial and academic environment. The huge costs caused by unexpected faults in these machines, often involved in critical industrial processes, constitute a clear motive justifying this concern.

* Corresponding author. Tel.: +34 96 3877592; fax: +34 96 3877599.
E-mail addresses: joanda@die.upv.es (J. Antonino-Daviu), pedro.rodriguez@se.abb.com (P. Jover Rodriguez), mriera@die.upv.es (M. Riera-Guasp), mpineda@die.upv.es (M. Pineda-Sánchez), antero.arkkio@tkk.fi (A. Arkkio).
[1] Tel.: +46 730757030.
[2] Tel.: +358 9 4512991; fax: +358 9 4512392.

0888-3270/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ymssp.2009.02.007

Most of the works hitherto developed in the field of fault diagnosis of induction machines, have been focused on the detection of single faults. Rotor asymmetries [1–3], eccentricities (static, dynamic or mixed) [4], inter-turn short-circuits [5] or bearing failures [6] have been the motivation of many papers in the literature [1]. However, most of the studies have been carried out considering that only one fault is present in the machine. The simultaneous presence of two or more faults has been rarely considered [7,8], despite the fact that this situation can be quite usual in the industrial environment. For instance, the appearance of broken rotor bars in induction machines operating under a certain level of eccentricity is not rare to be found. Most of the previous diagnosis approaches are based on the application of the FFT to the stator current or to other alternative quantities [7,8].

Nevertheless, the FFT diagnosis technique, deeply spread in the industry, consisting of the detection of some characteristic frequencies in the FFT spectrum of the steady-state current is not always able to discriminate the frequencies caused by these different faults, since they are sometimes quite similar. This might imply wrong decisions regarding the maintenance strategy to be adopted, since frequencies introduced by more critical faults can be masked by others caused by less important faults or faults enabling a longer actuation time.

Moreover, the presence of other phenomena such as load torque oscillations, voltage fluctuations, noises, etc., which could make notably difficult the diagnosis, has been also studied [9,10]. Nevertheless, the simultaneous presence of these phenomena and the fault in the machine has been seldom investigated, despite this situation is frequent. Indeed, it is not unusual to find induction motors with a certain level of eccentricity or even with broken bars driving mills, compressors, or other mechanisms introducing torque oscillations. This situation, for instance, often takes place in motors operating in power generation plants.

In these cases, the application of the classical FFT method implies important constraints; frequencies caused by load torque fluctuations or voltage oscillations can be similar to some fault-related frequencies [9,10], a fact leading to a confusion or even to a wrong diagnosis of the fault. Fig. 1 shows the similarities between the FFT spectra corresponding to a 1.1 kW motor with 2 broken bars (Fig. 1(a)) and to the same motor in healthy condition but subjected to an oscillating load torque (Fig. 1(b)). The clear resemblance between both spectra might lead to an incorrect diagnosis of a faulty condition in a healthy machine or vice versa.

Due to all these drawbacks, alternative diagnosis approaches based on techniques such as parameter estimation [30] and transient analysis have been proposed. Some of them have shown validity even for the diagnosis of mixed faults. The analysis of the current demanded by the machine during the startup transient in order to detect the characteristic evolution of fault-related components has been also proposed during previous years [9,11–15]. This has been proven to be a reliable way for the diagnosis of some of the aforementioned electromechanical faults (rotor asymmetries, mixed eccentricities), even in cases in which the classical Fourier approach does not lead to correct results [9,11]. In this context, the use of modern time–frequency decomposition tools such as the Discrete Wavelet Transform (DWT) becomes appropriate, if we consider the excellent properties of this tool for the analysis of signals with a time varying spectrum. However, as stated above, the application of the methodology has been restricted to cases in which a single fault is present in the machine [9,11–14].

This paper proposes the application of the DWT to the diagnosis of mixed faults in electrical induction machines with parallel branches in the stator, which are the most common machines in many industrial applications, due to their inherent properties [16]. Several cases corresponding to simultaneous presence of broken rotor bars, mixed eccentricities as well as inter-turn/inter-coil short-circuits are considered. Important conclusions regarding the comparative importance of the effects of different faults are also obtained. In addition, due to the option of analysing both the branch and the phase current in this type of machines, a double alternative arises. In this context, the study of the better suitability of the use of

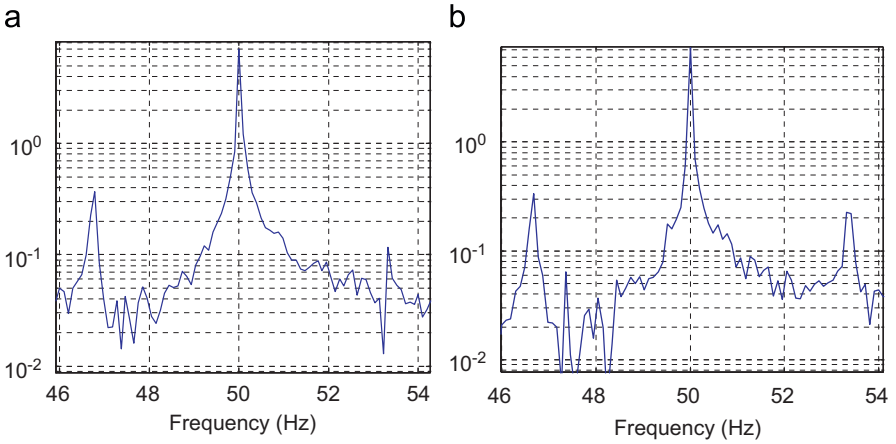

Fig. 1. FFT of the steady-state current for: (a) 1.1 kW motor with two broken bars and (b) 1.1 kW healthy motor with fluctuating load torque.