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Fast Fourier and discrete wavelet transforms applied to sensorless vector control induction motor for rotor bar faults diagnosis

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ABSTRACT

This paper presents new techniques to evaluate faults in case of broken rotor bars of induction motors. Procedures are applied with closed-loop control. Electrical and mechanical variables are treated using fast Fourier transform (FFT), and discrete wavelet transform (DWT) at start-up and steady state. The wavelet transform has proven to be an excellent mathematical tool for the detection of the faults particularly broken rotor bars type. As a performance, DWT can provide a local representation of the non-stationary current signals for the healthy machine and with fault. For sensorless control, a Luenberger observer is applied; the estimation rotor speed is analyzed; the effect of the faults in the speed pulsation is compensated; a quadratic current appears and used for fault detection.

1. Introduction

Electrical motors are extensively used in industrial applications requiring high performances, where motor speed should closely follow a specified reference trajectory regardless of any load disturbance, parameters variations and model uncertainties. In order to achieve high performance, the field-oriented control of the induction motor drive is employed. However, the control design of such system plays a role in system performance improvement. The decoupling characteristics of vector control induction motor affect adversely the parameters changes in the motor [1]. However, they are subject to failures due to production processes or operating conditions [2]. The rotor failures are caused by a combination of various stresses that act in the rotor, which can be electromagnetic, thermal, residual, dynamic, environmental and mechanical [3].

The diagnosis of induction motor faults in line-connected motors has been extensively investigated in the last decade, and several diagnostic procedures have been proposed with this aim. However, it is recognized that the techniques developed in line-fed induction motors, and open loop drives cannot be used straightforward when the motor is included in a more complex control structure based on direct torque control and field oriented control [4]. For closed-loop drives, the control loops mask the fault effect. Some attempts can be found in literature about using *d* (direct) and *q* (quadratic) axis components, if available, to diagnosis purposes [5,6]. Other authors consider the rotor flux components and the current error signals while the stator torque current is proposed as a diagnostic index [6,7].

The field-oriented control (FOC) approach is presented in [7,8], and applied for the diagnosis of machines with broken rotor bars in closed loop (Park model) [9–12]. So, in this paper, it has been used for reduced model of induction machine in cases of none and faulted modes.

Fault detection has been already largely investigated, and different techniques applied for motor. Some methods utilized to detect motor failures, such as chromatographic analysis, noise analysis, temperature analysis and vibration analysis, have been slowly changing to new on-line monitoring techniques for electrical equipments [13–15]. Vibration monitoring techniques are usually installed on expensive and sensitive machines, where the cost of such systems can be justified. Moreover, the environmental sensitivity of the sensors can provide unreliable indications. Other approaches are based on the spectrum analysis; the advantage of this technique is that it is well recognized nowadays as a standard

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Nomenclature

V_{DC}	DC bus voltage
V_a, V_b, V_c	instantaneous voltage a, b, c components
V_α, V_β	instantaneous voltage α, β components (Clarke)
V_d, V_q	instantaneous voltage d, q components (Park)
i_a, i_b, i_c	instantaneous current a, b, c components
i_α, i_β	instantaneous current α, β components (Clarke)
i_d, i_q	instantaneous current d, q components (Park)
V_{dsref}, V_{qsref}	d-axis voltage and q-axis voltage references (stator)
i_{dsref}, i_{qsref}	d-axis current and q-axis current references (stator)
I_{bk}	current of the bar k
I_{rk}	rotor current of mesh k
I_e	current in the ring of short circuit
I_{ek}	current in a portion of ring k
$[I]$	motor-current vector
$[L]$	motor-inductance matrix
$[R]$	motor-resistance matrix
$[V]$	motor-voltage vector
s	motor slip
K	integer
α	angle position between two broken bars
θ	angle between stator phase 1 and od axis
ω_r	electrical speed of the rotor in rad/s
C_e, C_r	electromagnetic and load torques
μ_0	Magnetic permeability of the air
mmf	magneto motive force

due to its simplicity: it needs only one current sensor per machine and is based on straightforward signal processing techniques such as fast Fourier transforms (FFT). However, it has mainly been designed for fixed frequency supply, such as for machines connected to the electrical grid (steady-state) [3,10]. Fault diagnosis in a closed-loop drive presents difficulties that are not presented when a constant 50/60 Hz power supply or an open-loop drive (motor is also supplied by a voltage source) are considered [12]. Some authors have addressed this problem using soft computing techniques or extensions of the motor current signature analysis (MCSA) method (requiring the analysis of the input electrical quantities spectrum) [3,15]. The major shortcomings of MCSA are its dependency on the motor speed and load; it does not always achieve good results when the speed or the load torque are not constant, which leads a variation on the motor slip (non-stationary signal); the fast Fourier transform cannot be used [16]. The solution is based on using the wavelet decompositions, which constitutes an alternative approach that avoids some problems encountered with the traditional method. The main goal of this paper is to proposition of a new method based on the discrete wavelet transform.

Wavelet transform is an analysis method for time-varying or non-stationary signals and uses a description of spectral decomposition via the scaling concept. Wavelet theory provides a unified framework for a number of techniques, which have been developed for various signal-processing applications [17]. One of its features is multi-resolution signal analysis with a vigorous function of both time and frequency localization. This method is effective for stationary as well as non-stationary signal processing. References [18,19] describe the pyramidal algorithm based on convolutions with quadrature mirror filters, which is a fast method (similar to the fast Fourier transform for signal decomposition and reconstruction), It can be interpreted as a decomposition of original signal in an orthonormal wavelet basis or as a decomposition of signal into a set of independent frequency bands. This independence is due to the orthogonality of the wavelet functions [20].

In this paper, an analysis of induction motor fault for closed loop using sensorless field oriented control is presented. The rotor speed is estimated by Luenberger observer. In this context, the main aim for this paper is to present a new method based on stator torque current and stator-current analysis for online fault detection in case of induction motors, which would overcome the averaging problems of classical FFT. Also, the proposed solution is based on analysis by wavelet decompositions. Simulation results are given for illustration.

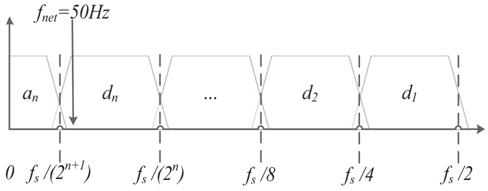

Fig. 1. Filtering process performed by the DWT.

2. Discrete wavelet transforms (DWT)

The wavelet transform is a time–frequency analysis technique. It decomposes a signal in terms of oscillations (wavelets) in both time and frequency. Its main idea is the dyadic bandpass filtering process carried out by this transform. Given a certain sampled signal $S=(S_1, S_2 \ldots S_n)$, the DWT decomposes it into several wavelet signals an approximation signal a_n, and n detail signals d_j $(j \in [1,n])$ [21,22]. The frequencies of approximation and detail signals can be given by

$$f(d_j) \in [2^{-(j+1)} f_s, 2^{-j} f_s] \tag{1}$$

$$f(a_n) \in \left[0, 2^{-(n+1)} f_s\right] \tag{2}$$

More concretely, f_s (samples/s): the sampling rate used for capturing S, the detail signal d_j contains the information concerning the signal components with frequencies included in the interval.

Therefore, the DWT carries out the filtering process shown in Fig. 1. Note that the filtering is not ideal, a fact leading to a certain overlap between adjacent frequency bands. This causes some distortions if a certain frequency component of the signal is close to the limit of band.

Due to the automatic filtering performed by the wavelet transform, the tool provides a very attractive flexibility for the simultaneous analysis of the transient evolution of rather different frequency components present in the same signal.

In comparison with other tools, the computational requirements are low. In addition, the DWT is available in standard commercial software packages. So no special or complex algorithm is required.

3. Modeling of induction motor rotor fault

In this study, the start-up transient current signature is selected for detection and diagnosing of faults in an induction motor. This method is effective because the machine is subjected to more stresses during the start-up above those of normal operation. These stresses can highlight the machine defects, those are early in

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