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A new approach to detect broken rotor bars in induction machines by current spectrum analysis

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Abstract

This paper deals with a new technique to detect broken rotor bars in polyphase induction machines. Like most techniques, we employ the Fourier Transform of the stator current to make detection. But where the other methods use the Fourier Transform modulus, this alternative approach proposes to analyse its phase. As shown by results, the Fourier Transform phase allows to detect one broken rotor bar when the motor operates under a low load but the method robustness decreases for a half-broken rotor bar. So, in order to improve the diagnosis and to permit the detection of incipient broken rotor bar, the analysis is completed with the Hilbert Transform. This transform provides good results and a partially broken rotor bar can be detected when the load torque is equal or greater than 25%. The main advantage of these methods is that the final decision on the rotor cage state is took without the healthy motor reference.
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1. Introduction

Nowadays, no one can deny the important role of asynchronous motor in industry applications. It is well-known that a manufacturing process interruption due to a mechanical or electrical problem induces a significant financial loss for the firm. Interruptions can be caused by rotor faults (broken rotor bars or cracked rotor end ring), stator faults (opening of a stator phase or inter-turn short circuits), rotor–stator eccentricity (static and dynamic eccentricity) and bearing failures [1,2]. In order to avoid such problems, these faults have to be detected to prevent a major failure from occurring.

Broken rotor bars rarely cause immediate failures, especially in large multi-pole (slow speed) motor. However, if there are enough broken rotor bars, the motor may not start as it may not be able to develop

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sufficient accelerating torque. Regardless, the presence of broken rotor bars precipitates deterioration in other components that can result in time-consuming and expensive fixes.

Various techniques have been developed to detect broken rotor bars in induction motors. We can quote vibration measurement [3], temperature measurement [4], coils to monitor the motor axial flux [5] or the radial flux [6], Park's Vector current monitoring [7], artificial intelligence-based techniques [8]. However, the most popular techniques are based on the monitoring of the stator current spectrum (called motor current signature analysis) because of its non-intrusive feature [9–12]. In this technique, the amplitudes of the lateral bands created by the rotor fault around the supply frequency are monitored. An augmentation of these amplitudes allows dimensioning the failure's degree. Others use the instantaneous power spectrum of one stator phase to calculate a global fault index [13]. The disadvantage of all these methods is that the knowledge of the healthy motor stator current is necessary to take a decision about the rotor state.

In this paper, a broken rotor bar detection method using the line current discrete Fourier transform (DFT) phase is proposed. This technique does not require the healthy motor current knowledge anymore, which is a major advantage compared to the classical ones. We will show that the basically calculated phase give good results when the motor operates near its nominal load. For weak load, the results obtained are not robust enough for the detection of an incipient rotor fault. This problem will be solved by using the Hilbert Transform (HT) applied to the line current spectrum modulus. Thanks to this method, the diagnosis of a partially broken rotor bar could be carried out without reference even if the motor operates at low load (25% of the rated torque).

2. Current monitoring

Consider an ideal three-phase supply and an asynchronous motor connected in wye. Thus, the instantaneous current circulating in one phase is defined as

$$i_{s0}(t) = \sqrt{2} I_s \sin(\omega_s t - \varphi) \tag{1}$$

with regard to the instantaneous voltage

$$v(t) = \sqrt{2} V_s \sin(\omega_s t). \tag{2}$$

The terms φ, f_s, and ω_s, respectively, represent the phase angle between the voltage and the line current, the fundamental frequency, and the fundamental pulsation $\omega_s = 2\pi f_s$.

When one bar breaks, a rotor asymmetry is created. This asymmetry involves the appearance of a backward rotating field at the slip frequency sf_s (s is the slip of the induction machine in p.u.). The representation of this rotating field in the stator current spectrum is an additional component at frequency $f^{-}_{bb_1} = (1 - 2s)f_s$. This cyclic current variation causes a speed oscillation at twice the slip frequency $2sf_s$ [14] and finally, this speed oscillation induces, in the stator current spectrum, an upper component at $f^{+}_{bb_1} = (1 + 2s)f_s$, and so on. By extension, the broken rotor bar creates additional components in the spectrum modulus at frequencies given by [14]

$$f^{\pm}_{bb_k} = (1 \pm 2ks)f_s, \quad k = 1, 2, 3, \ldots. \tag{3}$$

The effects of a broken rotor bar can be seen in Fig. 1. Fig. 1(a) represents the line current spectrum in the case of a healthy rotor, and Fig. 1(b) with one broken rotor bar. The presence of a rotor fault increases the amplitude of components situated at frequencies $f^{\pm}_{bb_k}$. The amplitude of the latter are dependent of three factors. The first is the motor's load inertia, the second is the motor's load torque (current in the rotor bars) and the third is the severity of the rotor fault. For example, the component magnitude will be more important with three broken bars than with a fissured bar. The analysis of Fig. 1(a) shows that the current spectrum contains a component at the frequency $f^{-}_{bb_1} = (1 - 2s)f_s$. This frequency is created by the natural asymmetry existing in all induction motors and is usually used as reference for the rotor fault diagnosis.

The classical broken bar detection methods usually use the monitoring of the line current Fourier Transform modulus. They are based on the appearance or the increase of the component amplitude at frequencies defined in Eq. (3). Appearance or increase are two terms which imply the comparison with a

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