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Review

# A survey on time and frequency characteristics of induction motors with broken rotor bars in line-start and inverter-fed modes

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ABSTRACT

This paper deals with the comprehensive detailed concepts of the rotor broken bars fault in industrial induction motors. It reviews the most important and applicable techniques for fault detection, and addresses fault diagnosing procedures at different supply modes including line-start and inverter-fed modes. Moreover, new analytical and experimental aspects of fault are proposed using the time and frequency domain variations of the motor variables such as current, voltage, electromagnetic torque and speed. Since the faulty motor behavior cannot be correctly identified without considering the motor operating condition, and the capability of the previous fault indicators are studied deeply in order to investigate their applicability at different conditions. These conditions include various faults, load and reference speed levels and also fault location. All in all, a precise condition assessment of the rotor broken bar induction motors, suitable for industrial purposes, is presented considering motor supply and conditions changes.



**Contents**



*Abbreviations: dq*, direct axis and quadrature axis components; *emf*, electro motive force; *m1*, magnitude of the first harmonic; *mr*, magnitude of the right sideband component; *ml*, magnitude of the left sideband component; mf, magnitude of the fault component; FOC, field oriented control; EMI, electromagnetic interference; IMF, intrinsic mode functions; UMP, unbalanced magnetic pull; PI, proportional and integral controller; GR, gyration radius; FFT, fast Foriour transform; MCSA, motor current signature analysis; HT, Hilbert Transform; HHT, Hilbert–Huang Transform; WT, wavelet transform

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## 1. Introduction

Since normal and smooth operation of electrical machines plays a vital role in an efficient electromechanical system, their condition monitoring has been matter of different studies [1–10]. On the other hand, there is a major concern on life-threatening happenings which may be caused by improper operation of electrical machines. So, condition assessment and fault diagnosis of electrical machines is inevitable. Induction motor (IM) is a proper example of such electrical machines which provide the main driving force of the industry. These motors usually confront different stresses including thermal, magnetic, electric and mechanical stresses. As a result of these stresses, faults including eccentricity, short circuit and broken bars may occur [11–13].

The major concern of the maintenance procedures is to precisely assess and diagnose the fault type and level in order to choose appropriate fixing process. At this end, various factors such as supply mode, load level and motor speed directly influence the fault diagnosis procedure[14,15].

Broken bar rotor is a typical fault of IMs which distorts the air gap flux density by strengthening the low frequency backward field of IM which exist due to the inherent asymmetry of IM structure [14]. There is an undesirable highly saturated region around the broken bar [16]. If it is not diagnosed and then fixed, the level of the fault may gradually increase and go beyond the safe thresholds and the motor will eventually shut down. The motor current and consequently demagnetizing impact of the broken bars is almost negligible. This increases the induced voltage in the adjacent healthy bars [17]. Therefore, the current rises considerably in the adjacent bars and this leads to more thermal and magnetic stresses, resulting in a higher degree of fault.

On the other hand, different types of motor supplies play significant role in the fault diagnosis process. These supplies can be divided into two main categories: (1) line-start mode [17] (2) inverter-fed mode [14,15]. The second category uses both open-loop and closed-loop control strategies. In line-start mode, a pure sinusoidal supply voltage is applied to the motor while the supply voltage contains various harmonics in the inverter-fed mode. In the line-start mode, the motor variables directly depend on the load level, but, electrical and mechanical variables are controllable in the inverter-fed mode. Therefore, fault detection is more complicated. The reason is that the number of effective factors in fault diagnosing process increases considerably. The major influencing factor is the high-frequency switching supply voltage which amplifies the core saturation level and causes more distortion in the air gap flux density [18]. In an inverter-fed motor, the motor speed is controllable regardless of the motor slip. So, the characteristics of the broken bar indexes which depend on the motor slip, is different from that of the line-start mode [14]. Moreover, the electromagnetic torque is adjusted independent of the speed using the capability of changing the supply amplitude and frequency in inverter-fed mode. The saturation profile again changes upon the change of the supply amplitude and frequency. Based on the above discussions, selecting a proper signal which merely consists of the fault-related information is inevitable in precise fault diagnosis process. On the other hand, a proper processor has to be used for diagnosis purposes [19,20]. Although, all the motor variables reflect the fault effects, some of them such as air gap flux density are not easily measurable [21] or some of them like torque may have less sensitivity to the fault [22]. For the magnetic flux, the use of a search coil is the most reliable method. This coil is inserted in the stator slot and therefore it is an invasive technique. Since the complete motor behavior depends on the air gap magnetic flux, the flux method can be considered as the most reliable technique. However, due to the presence of the search coil, sampling the flux is not as easy as the motor current, voltage, torque and speed [23]. So, the most common signal, which has been matter of numerous researches, is the motor current signal [15–18]. Sometimes, the measuring instruments such as dynamometers affect the fault related components.

It is essential to consider both time and frequency domains analysis to precisely monitor the IM condition. Because they contain useful and intuitive information of motor behavior under fault condition. Mostly, the time domain analysis [24–30] is much sensitive to factors other than the fault. If necessary prerequisites are provided, useful information can be extracted [15]. The prerequisites will be discussed in the next section.

A promising way of diagnosing the fault is the frequency domain analysis of the motor variables [4]. This analysis is more qualified than the time domain analysis. The reason is the existence of the discriminative harmonic components of the different faults at different frequency patterns which is not the case in time domain analysis. Nevertheless, the indexes, neither in time domain nor in frequency domain, are addressed to be fully useful under every operating condition. So, being familiar with and knowing the situations in which a particular index could be used is very important in practice. On the other hand, combination of the time and frequency analysis provides an easy and reliable method to diagnose the fault even in worst operating condition including the transient periods.