

An induction machine model including interbar currents for studying performances during transients and steady state

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ABSTRACT

This paper presents a mathematical model of a three-phase induction motor taking into consideration the interbar contacts. Several models have been available in the references. However, they consider the rotor of the induction motor as being constituted either a three-phase or a squirrel cage even if it operates under stator and/or rotor faults condition. Nonetheless, the contact between a bar and the iron core for the machine has to be considered, especially when a rotor fault occurs. It is obvious that rotor currents are under the influence of rotor constitution materials. So, the paper aim's concerns a transient model of the induction motors which can consider the rotor broken bars defect. Despite its increasing complexity, it could be able to provide with useful indications for diagnostic purposes. This model is advocated for the simulation of motors behavior under rotor defect which takes into account the interbar currents. The proposed technique is based on the mesh model analysis of the squirrel cage. As low power induction motors are prevalent in industrial plants, we pay a special attention on them. Notwithstanding, additional currents are due to the contact between the non-insulated bar constituting the squirrel cage to the rotor iron core. The monitoring of induction motors is predominantly made through the stator current analysis of the motor when it operates at nominal condition. Moreover, this one is observed in steady state operating system, knowing that the motor is generally fed by a sinusoidal supply. Consequently, simulation results showed in this paper prove the effectiveness of the proposed approach, and the impact of interbar resistance both on the model and the line current spectrum for the diagnostic. An experimental test proves the effectiveness of this model.

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1. Introduction

Today, induction motors can be found in many processes such as in industrial processes either in small or high power engine. Because of its simplicity of construction, its robustness, its ruggedness, and the low cost of its construction, the induction motor is obviously widespread in actuators applications all over the world. One can find at least two groups of induction motors. The former is constituted of small power induction motor. This category has huge applications. The latter deals with high power engines. In most cases, the asynchronous motor is connected directly to the power line. It is usually not fed by an inverter converter except in some special applications. At present, growing research in alternative energy systems like wind energy as in the electric traction system, favors such a kind of motor.

Among all induction motors, few are mass-produced with straight rotors. In small induction machines, skew is commonly used because these machines have generally been fabricated with a die-cast rotor. The difficulty in the fabrication process increases with the power-machine. So, the maximum power range is limited to about 20kW. The effect resulting of straight rotor is lesser degree in high power. One of the advantages is to diminish the slotting effect in small induction motor. Consequently, the iron diminishes as well but the interbar currents become more pronounced. Another point of view is in the consideration of stray losses. In fact, induction machines with rotor skewing have better performances with insulated rotor bars than uninsulated ones. When the rotor bars are uninsulated, interbars currents appear in the rotor core. These one are higher in case of a skewed rotor in comparison to a non-skewed one. Consequently, the interbars losses have an impact in such cases knowing that a rotor without skew bars is currently used in large power induction machine. Fig. 1 shows the defects due to interbar currents of a high power induction motor (1 MW, eight poles).

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Fig. 1. A zoom of the damaged area due to interbar current.

Fig. 2 shows a skewed rotor of the induction motor above-mentioned. The defect is close to the ventilation holes.

Very large research activities have been made on the detection of broken bars in the induction motor since the 1980s–1990s. In many of them, the induction machine is considered as having usually a copper cage and all bars are insulated [1–4]. Consequently, the interbar current does not exist. It is why previous research by a wide range of authors has been considered on the concept that current does not flow into a broken bar. Nevertheless, in die-cast aluminium cage, an electrical contact exists between the bars and the iron core [5–12]. Therefore, when a bar is broken, the current continues to flow into it knowing that interbar currents depend on the evolution of the defective bar.

Even if the stator fault is the major case of defect (40%), the rotor constitutes a significant part of induction motors failure (20–30%).

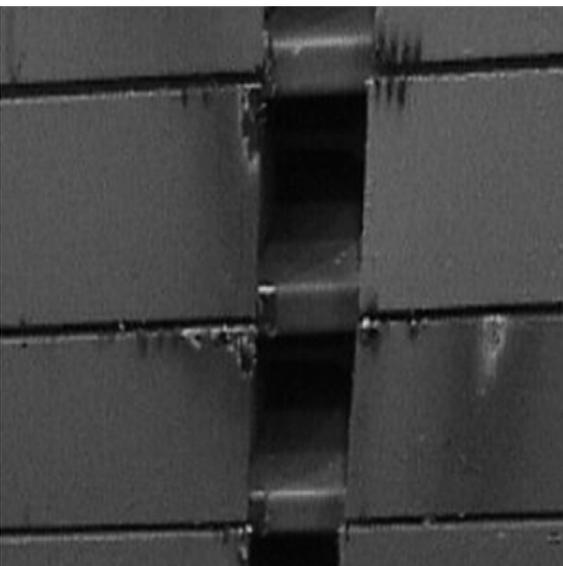


Fig. 2. A picture of a skewed rotor with defects.

Thus, techniques based on the motor current signature analysis (MCSA) to sense rotor faults have been developed [13–15]. In order to carry out this type of analysis, the most precise model of the motor is needed. Nonetheless, the more the model is precise the more it induces computation time. As therefore-mentioned, an effective diagnostic requires an accurate model which unfortunately needs a huge computational power.

2. The model

The analysis of the induction motor is traditionally viewed as a two-dimensional coupled-circuit as represented in Fig. 3. The motor is considered as a three-phase squirrel cage induction machine having three phases in the stator and N_r phases in the rotor where N_r is the number of rotor slots. The stator is viewed as a wye connection and the stator windings are sinusoidally distributed. The rotor is viewed as N_r identical loops. So, the model is suitable to simulate a squirrel cage induction motor as a wound rotor. In order to have a model, we assert the following assumptions:

- the air-gap is uniform,
- there is no space harmonic,
- the magnetic material is linear (negligible saturation),
- there is no eddy current,
- the magnetic circuit is symmetric,
- the slotting effect is negligible.

With these assumptions, we could describe the equations of the induction machine as depicted in Fig. 4. A three-phase stator and N_r rotor phases is written in vector-matrix form as follows:

$$[v] = [R][i] + \frac{d}{dt}[\lambda] \tag{1}$$

$$[v] = \begin{bmatrix} [v_s] \\ [v_r] \end{bmatrix}, \quad [i] = \begin{bmatrix} [i_s] \\ [i_r] \end{bmatrix}, \quad [\lambda] = \begin{bmatrix} [\lambda_s] \\ [\lambda_r] \end{bmatrix} \tag{2}$$

with:

$$\begin{aligned} [v_s] &= [v_{s1} \ v_{s2} \ v_{s3}]^t, & [i_s] &= [i_{s1} \ i_{s2} \ i_{s3}]^t, \\ [\lambda_s] &= [\lambda_{s1} \ \lambda_{s2} \ \lambda_{s3}]^t, & [v_r] &= [0 \ 0 \ 0 \ \dots \ 0 \ 0]^t, \\ [i_r] &= [i_{r1} \ i_{r2} \ i_{r3} \ \dots \ i_{rN_r} \ i_e]^t, \\ [\lambda_r] &= [\lambda_{r1} \ \lambda_{r2} \ \lambda_{r3} \ \dots \ \lambda_{rN_r} \ \lambda_e]^t \end{aligned} \tag{3}$$

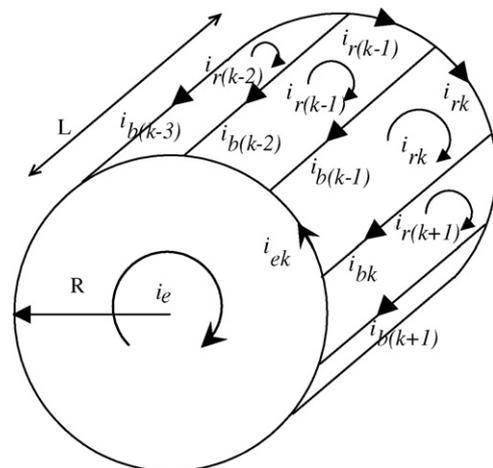


Fig. 3. A representation of current flow.

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