Review Diagnosis Methods of Induction Electrical Machines based on Steady State Current

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1. Introduction

Nowadays three-phase induction motors are used in a wide variety of industrial applications. They are the most used kind of electrical machines, for their reliability and simplicity of construction. But they are subjected to failures, due to operating conditions or inherent to the machine itself by construction. In an industrialized nation motors can consume between 40 to 50 % of all the generated capacity of that country [1]. Failure surveys [2], [3] have reported that percentage failure by components in induction motors is typically

- Stator Faults (38%)
- Rotor Faults (10%)
- Bearing balls Faults (40%)
- Others Faults (12%)

Traditionally motors are supervised by measuring noise, vibration and temperature but the implementation of the systems to measure these quantities are expensive and they don't allow the discrimination between all types of faults. For this reason, recently other magnitudes are used, such as a stator current motor, or instantaneous power.

Key Words: MCSA, FFT, Hilbert Transform, Diagnosis, Broken Bars, Eccentricity.

2. Motor Current Signature Analysis (MCSA)

MCSA has become one of the most extended methods for motor diagnostic. Also it requires only one measurement of stator current, it is non-invasive, it can identify different simultaneous failures, and being an on-line method, it does not perturbed process the installation operation conditions. MCSA is based on the detection of specific current harmonics, with frequencies that are characteristic of each type of fault.

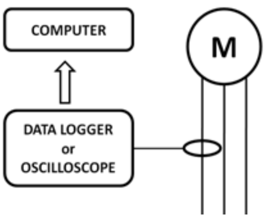

Figure 1. Experimental Test Bench

One of the simplest ways of performing MCSA is to sample the stator current of a phase during a fixed time, Figure 1, with the motor running at constant speed, and then to obtain the frequencies spectrum, using for example the Fast Fourier Transform (FFT) to analyze the spectrum and decide the existence of the fault. In this way the monitored characteristics can be used to predict the need for maintenance before breakdown occurs.

3. Frequencies Characteristic of each type of fault

Normally, each type of fault produces a characteristic frequency in the stator current. This paper will focus on broken bar rotor and eccentricities faults.

A. Broken Bars

Breakages in the rotor cage winding introduce a distortion in the airgap field that produces sideband components f_b in the line current spectrum around the fundamental and around other harmonics caused by non ideal winding distribution [4], at frequencies given by:

$$f_b = \left(k/p\left(1-s\right) \pm s \right) f_1 \quad where\ \ k/p = 1,3,5... \tag{1}$$

where f_1 is the supply frequency, s is the rotor slip and p the pole pairs number.

The left sideband harmonic (LSH) is obtained by substituting k/p=1 in (1); this component produces oscillations in the rotor speed, originating a new family of fault related components [5], with frequencies given by:

$$f_b = \left(1 \pm 2\cdot k\cdot s\right)\cdot f_1 \qquad k = 1,2,3.... \tag{2}$$

The diagnosis indicator in this case is particularly simple: the value of this modulus harmonics marks the presence or absence of the fault.

B. Eccentricities

Rotor eccentricity can result from a variety of sources such as design features, manufacturing tolerances, and operation conditions. The rotor may be positioned slightly off center in the stator bore. Eccentric rotor running of induction motors can result sufficient to increase in the unbalanced magnetic pull to cause stator-rotor contact [6]. Four types of Eccentricities can be identified via MCSA:

1) Static Eccentricity

Static eccentricity is characterized by a displacement of the axis of rotation, which can be caused by a certain misalignment of the mounted bearings or the bearing plates or stator ovality. Since the rotor is not centred within the stator bore the field distribution the air gap is no longer symmetrical. The non-uniform airgap gives rise to a radial force of electromagnetic origin, called unbalanced magnetic pull (UMP). This produces distortion frequencies given by:

$$f_{static} = \left[\left(\left(k\cdot N\right)\cdot\left(\frac{1-s}{p}\right) \pm \upsilon\right)\right]\cdot f_1. \tag{3}$$

where k is a positive constant or cero, N is the number of slots machine and v is the harmonic order.

2) Dynamic Eccentricity

Dynamic eccentricity appears when the stator bore axis does not match with rotor bore axis. This kind of eccentricity may be caused by a bent shaft, mechanical resonances, bearing wear on movement. Therefore, the non-uniform airgap of a certain spatial position is sinusoidal modulated and results in an asymmetric magnetic field. This produces distortion frequencies given by (n_d is a positive integer):

$$f_{dinamica} = \left[\left(\left(k \cdot N \pm n_d\right) \cdot \left(\frac{1-s}{p}\right) \pm \upsilon\right)\right] \cdot f \quad (4)$$

3) Mixed Eccentricity

This eccentricity is the combination of static and dynamic eccentricity. It causes characteristic sideband currents in the current spectrum given by:

$$fl = \left| f_1 \pm k \cdot f_r \right| \quad \rightarrow k = 1,2,3 \quad (5)$$

where f_r is the mechanical frequency.

4) Axial Eccentricity

This eccentricity appears when there are varying of the eccentricities along the axis of the rotor. Therefore, the axis of rotor rotation is not parallel to the stator axis and has different eccentricity in each section of the machine.

4. Current Analysis Methods

Frequency information is extracted of one stator current of a phase, measured during a fixed time via any of the following techniques:

A. Fast Fourier Transform (FFT)

Fourier analysis is very useful for many applications where the signals are stationary, as in diagnostic faults of electrical machines [7]. FFT is used to detect eccentricity and broken bars; it is shown in Figure 2. However, the application of this method on an industrial environment has some drawbacks: spectral leakage, high frequency resolution, varying load conditions, confused mechanical frequencies, can difficult the detection of the broken bar fault at low slip in Figure 3.

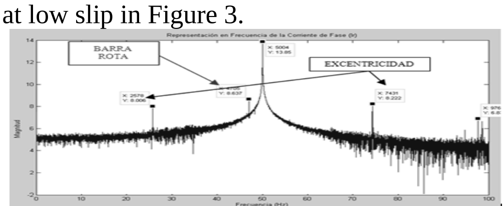

Figure 2. Spectrum (FFT) of the phase current of the machine with a broken-bar and static eccentricity.

B. Hilbert Transform(HT)

HT is a well-known signal analysis method, used in different scientific fields, also to diagnostic faults in electrical machines. In Figure 4 is shown the spectrum of an electrical machine with a broken bar obtained via its HT. This method eliminates the spectral leakage [8]. It can be useful when traditional FFT analysis does not offer clear results.

4. Conclusions

MCSA is a powerful technique for monitoring and diagnosis the electrical machines, as shown on industrial case histories. The measurement of one stator current allows the diagnosis of electrical machine.

Nowadays, the classical signal processing techniques, such as FFT are being extended with modern advanced signal processing, such as the HT. These extend the field of application of MCSA.

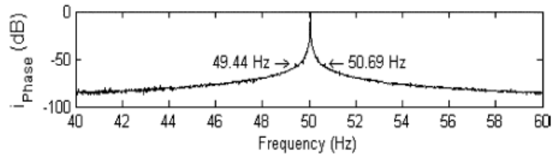

Figure 3. Spectrum (FFT) of the phase current of the machine with a broken-bar under low load.

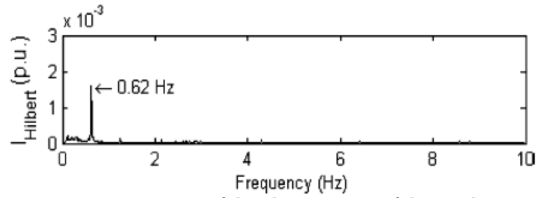

Figure 4. Spectrum (HT) of the phase current of the machine with a broken-bar under low load

Acknowledgments

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