Monitoring techniques of Induction Motors Faults

A.Medoued *. A.Lebaroud. A.Boukadoum *****

**Department of electrical engineering, University of 20 August 1955*
Skikda, Algeria (e-mail: amedoud@yahoo.fr).
***Department of electrical engineering, University of 20 August 1955*
Skikda, Algeria (e-mail: lebaroud@yahoo.fr).
****Department of electrical engineering, University of 20 August 1955*

Skikda, Algeria (e-mail:boukadoum2003@yahoo.fr).

Abstract: This study presents a survey of monitoring techniques of stator and rotor faults of induction machines without modelling. The fault signature is based on the analysis current stator. Both techniques have been presented, the Short Discrete Fourier Transforms (SDFT) and Instantaneous frequency signature analysis (IFSA). Both techniques are a non-intrusive, on-line monitoring technique for the faults diagnosis. The techniques are validated on an experimental bench.

Keywords**:** Induction motor, Short Discrete Fourier Transforms, Instantaneous frequency

1. INTRODUCTION

Three-phase induction motors are the most widely used electrical machines. In an industrialized nation, they can typically consume between 40 to 50% of its generated capacity. Consequently, they have to be safe and reliable.

However, adverse service conditions may lead to unexpected machinery failure including costly repair as well as extended process downtime. The monitoring and diagnosis of induction machine faults are largely study in the literature. Two approaches are deduced: A system approach (H. Nejjari et al, 2000, W.W. Tan et al, 2001, F. Filippetti et al, 2000, F. Filippetti, 1993) which relates the detection of the fault with the networks of neurons, fuzzy logic, pattern recognition. A signal approach, which is more widespread in the literature. Its principle deals with the monitoring of the time evolution or the spectral contents of voltages and currents stator (D, Kostic-Perovic et al, 2000, M. Arkan, 2001 et al, A. Lebaroud et al, 2003). In the spectrum of the current and voltage stator space vector, the major advantage of this approach is represented by its non dependence on the slip. However, it requires a long calculation procedure of the currents and voltages.

In this paper, we present both techniques, the first one results from the discrete Fourier transforms, is the Short Discrete Fourier Transforms (SDFT). The second one is based on analysis of the Instantaneous frequency signature (IFSA) of the stator current vector. In this paper, the SDFT technique is applied to the computing of the symmetrical component of negative sequence induced by a short-circuit in a stator phase of induction motor. The IFSA technique relates to the monitoring of the fundamental frequency modulation for the diagnosis of both stator and rotor faults. It essentially needs a sensor for measuring the stator current, and a data-acquisition system for acquiring the signal waveform. In the present case, the induction machine is connected to a voltage source, which is rich in harmonics (inverter or disturbed network). The suggested techniques are applied to the computing of stator current vector.

2. SPECTRAL ANALYSIS OF THE CURRENT VECTOR

The spectral analysis of the stator current is an effective tool that gives all the frequencies and in particular those related to the fault. For example the case of unbalanced currents fault due to inter turn short-circuit of 30% stator phase (Figure 1). The spectrum of the phase current does not permit having the negative component of the current. On the other hand, the spectral analysis of the stator current space vector allows the separation of two sequences from spectra: one positive defined in $[0 \quad f_{MAX}]$ and the other negative defined in the $[-f_{MAX} \quad 0]$.

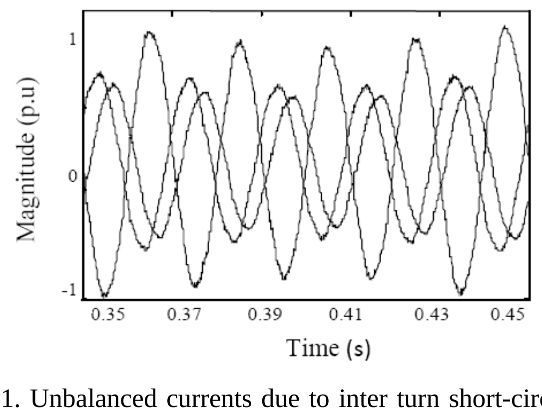

Fig. 1. Unbalanced currents due to inter turn short-circuit of 30% stator phase

The balanced current vector does not present a negative sequence current component. A short circuit in the stator windings generates an unbalance of the currents that provides a negative spectral component $-f_s$ (Fig. 2). The amplitude of this component increases with the severity of the fault. It provides a reliable index of monitoring.

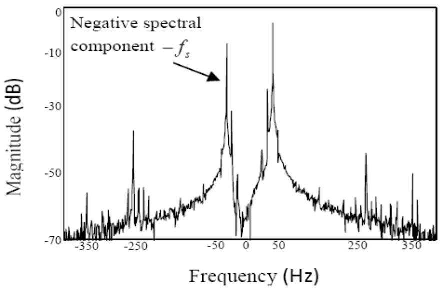

Fig. 2. Spectrum of the stator current vector (30% unbalance)

3. SHORT-TIME DISCRETE FOURIER TRANSFORM OF CURRENT VECTOR

The SDFT is a technique of real time calculation, for which it is imperative that the calculations duration remains lower than sampling period. The SDFT is applied to the stator currents. The induction machine is supplied by a 50Hz main network.

For an induction motor operating at a variable speed, it is necessary to know the fundamental frequency to be able to calculate its negative component. The advantage of this technique is to have a new signal spectrum at each sampling period and thus to have a real time detection, this one allows to follow the evolution in amplitude of the required frequency. A tolerance level on the latter allows tracking, on line, any fault occurrence, without stopping the machine. The zoom effect obviously makes it possible to limit the current spectrum to the request frequency $(-f)$. In our case the window is selected between 45 Hz and 55 Hz. Knowing that, we took current stator vector rotating in opposite direction. However, the network harmonics hardly influences the current negative component. Nevertheless, this one have a frequency much lower than that the network harmonics components.

The calculation of the DFT at the moment p/f is carried out through:

$$\left[\bar{I}_p(f_k)\right] = \frac{1}{N}\sum_{n=0}^{N-1}\bar{i}(p-n)\cdot W^{nk} \qquad [1]$$

The transform in Z of this equation leads to:

$$z\left(\left[\bar{I}_P(f_k)\right]\right) = z\left(\frac{1}{N}\sum_{n=0}^{N-1}\bar{i}(p-n)W^{nk}\right) \qquad [2]$$

$$z\left(\left[\bar{I}_P(f_k)\right]\right) = \frac{1}{N}I(z)\sum_{n=0}^{N-1}z^{-n}W^{nk} \qquad [3]$$

The expression $\sum_{n=0}^{N-1}z^{-n}W^{nk}$ is a geometrical series that converges towards:

$$\sum_{n=0}^{N-1}z^{-n}W^{nk} = \frac{1-z^{-n}}{1-W^k z^{-1}} \qquad [4]$$

The transform in Z of $\bar{I}_P(f_k)$ at the moment p is :

$$z\left(\bar{I}_P(f_k)\right) = \frac{1}{N}I(z)\frac{1-z^{-n}}{1-W^k z^{-1}} \qquad [5]$$

The choice of a limited part of the spectrum is called "zoom effect" and is defined by:

$$\left[\bar{I}_p(f_k)\right] = \left(\frac{\bar{i}(p)-\bar{i}(p-N_2)}{N_2}\right) + \exp\left(\frac{-j2\pi k}{N_2}\right)\left[\bar{I}_{p-1}(f_k)\right] \qquad [6]$$

Where $\bar{I}_P(f_k)$ is the DFT calculated previously.

The obtenstion the zoom effect is REAL by increased number of samples to obtain a good resolution, and the desired spectral window is selected transformed by calculating the slip in the interval f_k containing the desired frequency, in our case it - 50Hz

The main advantage of the SDFT is represented by its ability to be used as an effective computational tool for the on-line and real-time monitoring of the negative sequence current component.

Fig. 3 presents the computation of the negative component from stator current Spectrum (Fig. 2) using the SDFT approach. The short window is defined for k 1 = 45Hz and k2 = 55Hz . The -10 dB magnitude remains unchanged, and the spectral resolution remains sufficient.

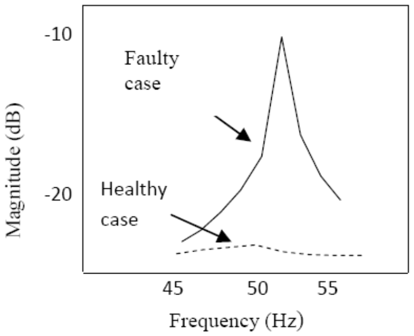

Fig. 3. Extraction of unbalance component by the SDFT

4. INSTANTANEOUS FREQUENCY SIGNATURE ANALYSIS (IFSA)

The instantaneous frequency $f(t)$ uses the concept of the instantaneous phase of the signal and is defined as the derivative of the phase $\varphi(t)$.

Obtaining the phase $\varphi(t)$ from a real signal $x(t)$, one would have to associate the signal $y(t)$ determined by the Hilbert transform leading to the complex form:

$$x(t) + j\,y(t) \qquad (7)$$

The phase φ being defined as the arctangent between $y(t)$ and $x(t)$, the frequency is expressed as:

$$f_i = \frac{1}{2\pi}\frac{d}{dt}\arctan\left(\frac{y}{x}\right) = \frac{1}{2\pi}\frac{xy' - yx'}{x^2 + y^2} \qquad (8)$$

Where: $x' = dx/dt$

The instantaneous symmetrical component of stator currents is given by:

$$i(t) = \frac{\sqrt{2}}{3}\left(i_a(t) + a i_b(t) + a^2 i_c(t)\right) \qquad (9)$$

If the currents are sampled periodically so that the angle between two moments of sampling $\Delta\varphi$ is weak, we can obtain the instantaneous frequency of the instantaneous symmetrical component figure 4 as:

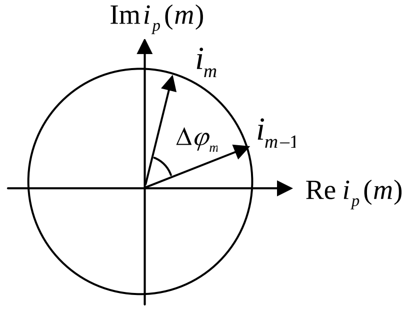

Fig. 4. Instantaneous frequency of instantaneous symmetrical component

$$\Delta\varphi \cong \sin(\varphi_m - \varphi_{m-1}) \qquad (10)$$

$$\Delta\varphi \cong \sin\varphi_m \cos\varphi_{m-1} - \sin\varphi_{m-1}\cos\varphi_m \qquad (11)$$

According to the equations (9) and (10) and for a balanced three-phase system, we can write:

$$\mathrm{Re}\, i(m) = i_m \cos(\varphi_m) \qquad (12)$$

$$\mathrm{Im}\, i(m) = i_m \sin(\varphi_m) \qquad (13)$$

The instantaneous symmetrical component along the axis α and β are then expressed as:

$$i_{\alpha\, m} = \mathrm{Re}\, i(m) \qquad (14)$$

$$i_{\beta\, m} = \mathrm{Im}\, i(m) \qquad (15)$$

$$i_m = \sqrt{i^2_{\alpha\, m} + i^2_{\beta\, m}} \qquad (16)$$

This allows rewriting the equation (7) by:

$$f_i = \frac{1}{2\pi T}\frac{1}{i_m i_{m-1}}\left(i_{\beta m} i_{\alpha m-1} - i_{\beta m-1} i_{\alpha m}\right)) \qquad (17)$$

Fig. 5 represents the instantaneous frequency in the case of three broken bars of the motor supplied by inverter. The amplitude modulation of the stator current appears through equidistant wraps of a duration corresponding exactly to $1/2 f_s = 0.36$ second

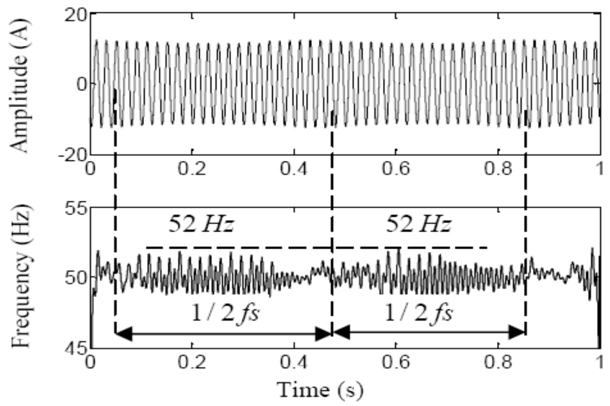

Fig.5. Stator current (top) and instantaneous frequency (inverter supply) (bottom)

The magnitude of Instantaneous Frequency Maximum

(IFM) 52Hz informs on the severity of the rotor fault

(number of broken bar).

The instantaneous frequency of the instantaneous symmetrical component (real and imaginary) in the case of imbalance stator of motor supplied by inverter is represented in Figure 6. The instantaneous frequency is characterized by a number of equidistant peaks regularly spaced with duration 1/ 2 f = 0,01 second. However, we can conclude that each fault is characterized in the instantaneous frequency by a specific signature.

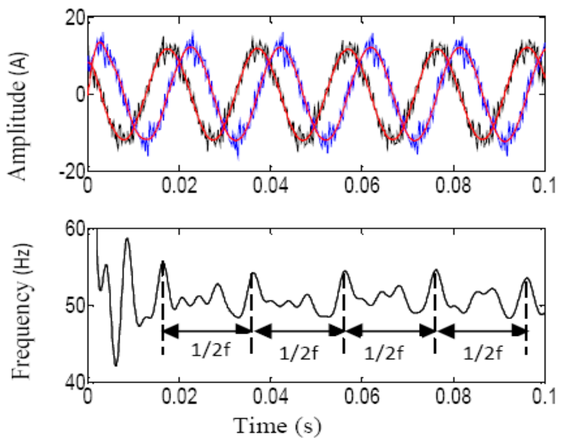

Fig.6. Stator current (top) and instantaneous frequency (inverter supply) (bottom)

5. CONCLUSIONS

The symmetrical component of the negative sequence of the stator current represents a reliable index for the on line monitoring of stator unbalances of induction motors. The discrete Fourier transform (DFT) allows calculating precisely the negative current component but it requires a great number of computing operations, strongly dependant of the spectral resolution. SDFT provides a reduction of the computing time. It can be used in real-time, but requires an initial calculation of the DFT. Instantaneous frequency signature analysis (IFSA) presents, also, reliable indices of diagnosis. The signatures are specific to each type of fault. The problems concerning the spectral resolution as well as the signal duration to be analyzed vanished because this method is independent of the analysis of Fourier and its various versions. The re sampling of the original signal with a down-sampling rate of 50 allowed the smoothing of the instantaneous frequency and removed the frequencies induced by the network or the inverter thus preserving the original signatures of the faults. Thus, this technique presents a good alternative to those resulting from the Fourier's transforms.

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