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Online computational tools dedicated to the detection of induction machine faults

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ABSTRACT

This paper presents online components calculation techniques for stator and rotor of the induction machine. Four techniques have been developed for online components calculation; the first one starts the calculation of the negative component of stator current space vector using the Discrete Fourier Transform (DFT) in order to detect the stator fault. The second technique is dealing with the detection of rotor fault by the Recursive Fourier Transform (RFT), This technique improves the signal acquisition and enhanced detection of components near the fundamental. The third technique allows improving of the rotor fault detection by the spectrum of analytical signal. The fourth and the last technique is the frequency analysis of the instantaneous power, which allows obtaining a singular signature of faults. These techniques have shown better detection, where each fault is characterized by a singular signature and therefore they improve the detection and diagnosis of faults. Experimental results applied on an asynchronous machine 5.5 kW, approve and validate these calculation techniques.

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1. Introduction

A variety of faults can occur within induction motors, during normal operation. Several faults, such as unbalanced stator, broken rotor bars, rotor eccentricity, can result in a complete breakdown of the machine, if the progress of the fault is not detected. The machine parameters which are most often monitored include line current, leakage flux, and vibration. Line current is probably the most convenient of these parameters, since in an industrial environment it is the most accessible parameter, this can be measured remotely if needed, and requires simple instrumentation. In recent years many research works have been carried out on the monitoring condition and diagnosis of electrical machines. Many tools of calculation have been proposed for electrical machine faults detection and localization. These tools include the measurement of stator current and voltage, torque, external magnetic flux density and vibration. On-line calculation of induction machine faults such as broken rotor bars and stator unbalanced can be carried out by analyzing the stator current by temporal or spectral, or both at once as time–frequency. Broken rotor bars result in twice slip frequency sidebands around the fundamental frequency of stator current, while unbalanced stator, such as stator winding short circuits, which cause changes in three-phase stator current system and the occurrence of negative sequence current. Many diagnostic techniques for induction motors have been reported in the literature as to diagnose electric machine faults, Therefore some researchers have investigated the monitoring of machine conditions, mainly based on the signature of external variables, for instance by means of all voltage and current signals, speed, torque and instantaneous power. They can be computed, and more information may be retrieved for diagnostic purpose. The Park's vector approach and the motor angular fluctuation of the current space vector have been used as a new source of diagnostic data for stator and rotor induction motor faults [1,2]. These techniques depend upon specific harmonic components location in the motor current, which are usually different for different types of faults. Exploitation of instantaneous power factor is interesting because it varies according torque oscillation and hence the stator current [3]. Differential diagnosis is based on multivariable monitoring to assess induction machine rotor conditions [4]. The calculation of the negative impedance is used to the monitoring of the stator fault [5]. The major advantage of this technique is the non dependence on the slip. The negative sequence of the stator current represents a reliable index for the on line monitoring of stator unbalanced [6]. Exploitation of the line neutral voltage for the diagnosis of stator and rotor faults has been proposed [7]. Artificial Intelligence (AI) based on statistical machine learning approach [8], artificial neural networks [9], time–frequency for classification induction motor faults [10].

Recent advances and new techniques have been reported in the literature concerning calculation of faults in electrical machines these are; Multidimensional demodulation techniques for diagnosis of induction motors faults [11], polynomial-phase transform of the current for diagnosis of three-phase electrical machines [12], symmetrical components and current Concordia of an induction motor by feature pattern extraction method and radar analysis [13], Monte Carlo approach for calculating the thermal lifetime of

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transformer insulation [14], intelligent approach by an artificial immune system for the detection of induction machines faults [15], independent component analysis for fault detection and diagnosis of turbine [16], signature analysis for fault diagnosis of mixed eccentricity [17].

FFT algorithm is one of the most popular signal-processing algorithms in motor-fault-detection applications. However, in real-time applications, the $(N/2) * \log(N)$ complexity of FFT-radix 2 brings an overwhelming burden to the DSP where significant amounts of data need to be processed in order to produce sufficiently high resolution [18]. The problem in the spectral approach is that we intend to use systematically the Fourier transforms and its different variants particularly the fast Fourier transform (FFT), for signals of machine faults whose frequencies are known before hand. It means that we calculate the remain of frequencies without need them and therefore the calculations are cumbersome and unnecessary.

In this paper we will investigate the applications of Discrete Fourier Transforms on the complex vector of three-phase stator currents; this will allow making the choice on the most appropriate alternatives to the calculation of the faults components at lower computational cost. We will begin this work by the presentation of a three phase unbalanced system and harmonic pollution. The Fourier transformed applied to three-phase system will allow understanding and calculating the unbalanced current caused by the negative system. Recursive Fourier Transform (RFT) will highlight the sidebands of broken bar fault without the presence of the fundamental, which at low spectral resolution or at low load inhibit these sidebands. This technique is also used in real time. The technique of phase spectrum allows us to better characterize the fault rupture bar. In order to make the technique less sensitive to harmonic pollution we proposed the technique of phase of the analytical signal. The spectrum of the instantaneous power facilitates the detection at low frequencies of few Hertz.

2. Spectral analysis of stator current vector

The spectral analysis of stator current is a powerful analytical tool that can highlight the presence of characteristic frequencies, including those related to faults.

2.1. Unbalanced and polluted three-phase system

A balanced system of three-phase current represents only a system of positive sequence; in contrast, an unbalanced system of three-phase current can be represented by the combination of positive sequence system, negative sequence system and homopolar system. In a system where the neutral is not connected, the current in the phase "m" is written in general form:

$$i_m(t) = \sum_{k\epsilon\{-1,1\}} \sum_{h=0}^{n} I_{6h+k}\sqrt{2}\cos\left((6h+k)\omega_s t + \varphi_{h,k} - k(m-1)\frac{2\pi}{3}\right) \tag{1}$$

where I_{6h+k} is the fundamental RMS value for ($h = 0$), remained harmonics ($h \neq 0$), positive sequence ($h = 1$) or negative sequence ($h = -1$).

The development of eq. (1) yielded a vector of stator currents following:

$$\bar{i}_s = I_1\sqrt{2}e^{j(\omega_s t-\varphi_1)} + \sum_{h=1}^{n} I_{6h+1}\sqrt{2}e^{j((6h+1)\omega_s t-\varphi_{6h+1})} + I_{-1}\sqrt{2}e^{-j(\omega_s t-\varphi_{-1})} + \sum_{h=1}^{n} I_{6h-1}\sqrt{2}e^{-j((6h-1)\omega_s t-\varphi_{6h-1})} \tag{2}$$

From Eq. (2) the complex magnitudes of different components are defined by:

$$\bar{I}_{6h+k} = I_{6h+k}e^{kj(6h+k)-\varphi(6h+k)} \tag{3}$$

Stator current vector becomes:

$$\bar{i}_s = \sum_{h=0}^{n1} \bar{I}_{6h+1}e^{j(6h+1)\omega_s t} + \sum_{h=0}^{n1} \bar{I}_{6h-1}e^{-j(6h-1)\omega_s t} \tag{4}$$

Equation of the stator current vector (4) is composed of two systems, one of positive sequence:

$$\bar{i}_p = \sum_{h=0}^{n1} \bar{I}_{6h+1}e^{j(6h+1)\omega_s t} \tag{5}$$

And the other negative sequence:

$$\bar{i}_n = \sum_{h=0}^{n1} \bar{I}_{6h-1}e^{-j(6h-1)\omega_s t} \tag{6}$$

$$\bar{i}_s = \bar{i}_p + \bar{i}_n \tag{7}$$

In the complex plane, the stator current vector of positive sequence has a circular shape. During the time of unbalanced fault, a negative sequence current appears and transforms the circular shape of the current vector to an elliptical shape. The spectrum of the stator current phase 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 of sequences: one positive defined in $[0 \quad f_{\max}]$ and the other negative defined in the $[-f_{\max} \quad 0]$. Fourier analysis is one of nonparametric methods of spectral estimation. Its application to analyze the stator current vector will provide further information on its spectral content.

2.2. Discrete Fourier Transform of stator current vector

The discretization of the stator current vector (4) gives the following equation:

$$[\bar{i}_s(n)] = \left[\bar{I}_1 e^{\frac{2\pi n f_s}{N}} + \sum_{h=1}^{n} \bar{I}_{6h+1}e^{\frac{2\pi n(6h+1)f_s}{N}} + \bar{I}_{-1}e^{\frac{2\pi n f_s}{N}} + \sum_{h=1}^{n} \bar{I}_{6h-1}e^{\frac{2\pi n(6h-1)f_s}{N}}\right] \tag{8}$$

The Discrete Fourier Transform of this vector is evaluated within the meaning of [19] to determine the harmonics of a Fourier series:

$$\bar{I}(f_k) = \frac{1}{N}\sum_{N=0}^{N-1} \bar{i}_s[n] \cdot e^{-j\frac{2\pi kn}{N}} \tag{9}$$

With:

$$W^{k \cdot n} = e^{-j\frac{2\pi kn}{N}} \tag{10}$$

We obtain the following notation with

$$[\bar{I}](f_k) = \frac{1}{N}[W^{kn}][\bar{i}_s(n)] \tag{11}$$

The DFT is characterized by:

An acquisition time: $T = \frac{N}{f_e}$.

The maximum frequency of the signal: $f_{\max} = \Delta f \cdot N/2$ and the Nyquist frequency: $f_e = 2 \cdot f_{\max}$.

The multiplication of the rotation matrix $[W^{nk}]$ by the current vector allows separation of the positive and negative sequences of the current vector:

$$[\bar{I}(f_k)]^t = [\ldots, \bar{I}_1, \ldots, \bar{I}_7, \ldots, \bar{I}_{6h+1}, \ldots, \bar{I}_{6h-1}, \ldots, \bar{I}_5, \ldots, \bar{I}_{-1}, \ldots] \tag{12}$$

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