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Time- Frequency Techniques for Fault Identification of Induction Motor

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Abstract

Condition monitoring and fault diagnosis of engineering plant has increased recently because of the widespread use of automation and consequent reduction in direct human-machine interaction to supervise the motor drive system operation. With advances in digital technology in recent years, adequate data processing capability is now available on cost-effective hardware platforms, to monitor motors for a variety of abnormalities on a real time basis in addition to the normal motor protection functions. Such multifunction monitors are now starting to displace the multiplicity of electromechanical devices commonly applied for many years. For such reasons, this paper is devoted to a comparison of signal processing techniques for the detection of common faults of electric machines. These techniques show different pattern of stator current of motor for different types of fault. This paper also presents the features of these techniques which will help us to decide most appropriate technique for induction motor fault detection. STFT, Gabor Transform and WVD are some techniques that are discussed in this paper.

Introduction

Induction motors are one of the rotating electrical machines most widely used. Due to its low cost, reasonably small size, and operation with an easily available power supply, induction motor is widely used in industries such as automotive, aerospace, and industrial equipment. However, operational environment, duty, and installation issues may combine to accelerate induction motor failure far sooner than the designed motor lifetime. Faults can occur in the stator, rotor, bearing, or the external systems connected to the induction motor. It is well known that induction motors dominate the field of electromechanical energy conversion. These machines find a wide role in most industries in particular in the electric utility industry as auxiliary drives in central power plants of power systems, as well as a restricted role in low MVA power supply systems as induction generators, mining industries, petrochemical industries, as well as in aerospace and military equipment. Therefore, assessments of the running conditions and reliability of these drive systems is crucial to avoid unexpected and catastrophic failures. Consequently, the issue of preventive maintenance and noninvasive diagnosis of the condition of these induction motors drives is of great concern, and is becoming increasingly important .In recent years, marked improvement has been achieved in the design and manufacture of stator winding. [3] However, motors driven by solid-state inverters undergo severe voltage stresses due to rapid switch-on and switch-off of semiconductor switches. Also, induction motors are required to operate in highly corrosive and dusty environments. Requirements such as these have spurred the development of vastly improved insulation material and treatment processes. But cage rotor design has undergone little change. As a result, rotor failures now account for a larger percentage of total induction motor failures. Broken cage bars and bearing deterioration are now the main cause of rotor failures [4].

In general, condition-monitoring schemes have concentrated on sensing specific failures modes in one of three induction motor components: the stator, the rotor, or the bearings. Even though thermal and vibration monitoring have been utilized for decades, most of the recent research has been directed toward electrical monitoring of the motor with emphasis on inspecting the stator current of the motor. Fault detection based on motor current relies on interpretation of the frequency components in the current spectrum that are related to rotor or bearing asymmetries [2]. However, the current spectrum is influenced by many factors, including electric supply, static, and dynamic load conditions, noise, motor geometry, and fault conditions. These conditions may lead to errors in fault detection. With advances in digital technology in recent years, adequate data processing capability is now available on cost-effective hardware platforms, to monitor motors for a variety of abnormalities on a real time basis in addition to the normal motor protection functions.

Fault detection of induction motor using signal processing techniques

The first step for condition monitoring and fault diagnosis is to develop an analysis technique that can be used to diagnose the observed current signal to get useful information. There are several signal processing techniques which are very useful for fault diagnosis purpose because these techniques show different patterns of stator current. These are classified below [11]:

- Frequency domain: Fast Fourier Transform (FFT)
- Time-Frequency techniques: Short Time Fourier Transform (STFT), Gabor Transform (GT), Cohen class distribution , Wigner –Ville distribution (WVD), Choi-Williams distribution, Cone shaped distribution
- Time series methods: Spectral estimation through ARMA models, Welch method, MUSIC method, Periodogram
- Wavelet Transform (WT)

Time-Frequency Techniques

Short Time Fourier Transform (STFT)

To study the properties of the signal at time t, one emphasizes the signal at that time and suppresses the signal at other times. This is achieved by multiplying the signal by a window function, h(t), centred at t, to produce a modified signal [11,12,14,15].

$$s_t(\tau) = s(\tau)h(\tau - t) \qquad (1)$$

The modified signal is a function of two times, the fixed time we are interested in, t, and the running time τ . The window function is chosen to leave the signal more or less unaltered around the time t but to suppress the signal for times distant from the time of interest. That is,

$$s_t(\tau) \square \begin{cases} s(\tau) & \text{for } \tau \text{ near t times} \\ 0 & \text{for } \tau \text{ for away from t times} \end{cases} \qquad (2)$$

The term ‘window’ comes from the idea that we are seeking to look at only a small piece of the signal as when we look out of a real window and see only a relatively small portion of the scenery. In this case we want to see only small portion.Since the modified signal emphasizes the signal around the time t, the Fourier transform will reflect the distribution of frequency around that time,

$$s_t(\omega) = \frac{1}{\sqrt{2\pi}} \int e^{-j\omega\tau} . s_t(\tau)\, d\tau. \qquad (3)$$

$$= \frac{1}{\sqrt{2\pi}} \int e^{-j\omega\tau} . s_t(\tau) h(\tau - t)\, d\tau \qquad (4)$$

The energy density spectrum at time *t* is therefore

$$P_{SP}(t,\omega) = |s_t(\omega)|^2 = \left| \frac{1}{\sqrt{2\pi}} \int e^{-j\omega\tau} . s_t(\tau) h(\tau - t)\, d\tau \right|^2 \qquad (5)$$

Thus, the magnitude of squared of the STFT yields the spectrogram of function, which is usually represented like color plots. Since we are interested in analyzing the signal around time *t*. we presumably have chosen a window function that is peaked around t. Hence the modified signal is short and its Fourier transform (equ. 8) is called short-time Fourier transform [18]. STFT spectrogram can be used for fault detection of motor.

Gabor Transform (GT)

Gabor Transform (GT) is a linear time-frequency analysis method that computes a linear time-frequency representation of time-domain signals. Gabor spectrogram has better time frequency resolution than the STFT spectrogram method and less cross term interference than the WVD method. Gabor Spectrogram represent a time domain signal, s(t), as the linear combination of elementary functions $h_{m,n}(t)$, as shown in following equation [14,15]:

$$s(t)=\sum_{m=0}^{m-1}\sum_{n=0}^{n-1}c_{m,n}h_{m,n}(t) \qquad (6)$$

where $h_{m,n}(t)$ is the time frequency elementary function, $c_{m,n}$ is the weight of $h_{m,n}(t)$ and $c_{m,n}$ is the Gabor coefficients. The Gabor Transform computes the coefficients $c_{m,n}$ for the signal s(t).

The following equation defines the time shifted and frequency –modulated version, $h_{m,n}(t)$, of a window function, h(t):

$$h_{m,n}(t)=h(t-mdM)e^{j2\pi nt/N} \qquad (11)$$

where h(t) is the synthesis window, dM is time step and N is sample frequency. $c_{m,n}$ reveals how the signal behaves in the joint time frequency domain around the time and frequency centers of $h_{m,n}(t)$.We can use the Gabor transform to obtain the Gabor coefficients $c_{m,n}$ with the following equation:

$$c_{m,n}=\sum_{t}s[t]y^*[t-mdM]e^{-j2\pi nt/N} \qquad (12)$$

where y(t) is the analysis window, y(t) and h(t) are a pair of dual functions.

Wigner-Ville Distribution (WVD)

The Wigner-Ville Distribution in terms of signal, s(t) or its spectrum, S(ω),is [14,15]:

$$W(t,\omega)=\frac{1}{2\pi}\int s^*\left(t-\frac{1}{2}\tau\right)s\left(t+\frac{1}{2}\tau\right)e^{-j\tau\omega}d\tau \qquad (13)$$

$$=\frac{1}{2\pi}\int S^*\left(\omega-\frac{1}{2}\theta\right)s\left(\omega+\frac{1}{2}\theta\right)e^{-jt\theta}d\theta \qquad (14)$$

Conclusion

Some signal processing techniques are presented in this paper. Faults of induction motor can be diagnosed just by comparing the pattern or spectrum of stator current. Pattern is obtained by Time-Frequency (T-F) analysis of current. Time-frequency analysis is the three-dimensional time, frequency, and amplitude representation of a signal, which indicates transient events in the signal. Time-frequency distributions are commonly used to diagnose faults in mechanical systems. The Time-Frequency distributions can accurately extract the desired frequencies from a non-stationary signal. The short time Fourier transforms is a mathematically linear Time-Frequency distribution. Time-Frequency distributions also include quadratic distributions, such as the Wigner-Ville distribution. The quadratic Time-frequency distributions offer more frequency resolution than the linear Time-frequency distributions. Therefore, Fast Fourier Transform, Short Time Fourier Transform, Gabor transform and Wigner –Vile distribution may be helpful in preventive maintenance of electric motors.

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