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Multi-class fault diagnosis of induction motor using Hilbert and Wavelet Transform

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ABSTRACT

The information extraction capability of two widely used signal processing tools, Hilbert Transform (HT) and Wavelet Transform (WT), is investigated to develop a multi-class fault diagnosis scheme for induction motor using radial vibration signals. The vibration signals are associated with unique predominant frequency components and instantaneous amplitudes depending on the motor condition. Using good systematic and analytical approach this fault frequencies can be identified. However, some faults either electrical or mechanical in nature are associated with same or similar vibration frequencies leading to erroneous conclusions. Genetic Algorithm (GA) is proposed and used successfully to find the most relevant fault frequencies in radial (vertical) frame vibration signal which can be used to diagnose the induction motor faults very effectively even in the presence of noise. The information obtained by Continuous Wavelet Transform (CWT) was found to be highly redundant compared to HT and thus by selecting the most relevant features using GA, the fault classification accuracy has considerably improved especially for CWT. Almost similar fault frequencies were found using CWT + GA and HT + GA for radial vibration signal.

1. Introduction

Induction motors (IM) are extensively used in industries because of its simple structure, reliability, ruggedness, cost effective design and ease of control [1,2]. The faults in induction motors may be due to mechanical and electrical stresses. Mechanical stresses caused by overloads and abrupt load changes can produce bearing faults, rotor bar breakage and rotor unbalance. On the other hand, electrical stresses usually associated with the power supply like voltage unbalance cause stator faults like winding fault and external fault. Induction motor can be energized from constant frequency sinusoidal power supplies or from adjustable speed ac drives. However, induction motors are more susceptible to fault when supplied by adjustable speed drives. This is due to the extra voltage stress on the stator windings, the high frequency stator current components, and the induced bearing currents, caused by ac drives [3]. Therefore condition monitoring is essential for reducing the maintenance cost and the unexpected failure of the induction motors [4].

There are various monitoring techniques including vibration, current, thermal, chemical and acoustic emission [4]. The different signal processing techniques such as Fast Fourier Transform (FFT) [5], Short Time Fourier Transform (STFT) [6], Wavelet Transform (WT) and Hilbert Transform (HT) have been extensively used to analyze both vibration and current signals to diagnose the faults of induction motor. Traditional techniques like FFT are easy to implement but not suitable for analyzing vibration signals having transitory characteristics. Moreover, the analysis is mostly load dependent and the correct classification of very closed fault frequencies requires very high resolution data [5]. Martin has demonstrated the limitation of using FFT approach for vibration signal analysis. The traditional treatment of vibration spectrum fluctuations is the averaging, which may tend to hide some features of short duration. The alternative approach to such non-stationary vibration signal is the Wavelet Transform (WT), which can provide the useful information about any signal in time domain with different bands of frequencies. WT gives variable time resolution for different frequency bands rather than short term FT (STFT), which gives constant resolutions [7]. Although Short-Time Fourier Transform (STFT) can be used for analyzing transient signals using a time–frequency representation, it can only analyze the signal with a fixed sized window for all frequencies, which leads to poor frequency resolution [6].

Hence, in recent years a significant amount number of research works are reported in literature on Discrete Wavelet Transform (DWT) [8–12] and Continuous Wavelet Transform (CWT) [13–15] based approaches for analyzing vibration signals. Wavelet

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analysis has certain limitations like selection of mother wavelet and scale/level [15] which plays a crucial role for capturing the inherent features corresponding to the characteristic frequencies of the signal under inspection. Moreover, due to the limitation of Heisenberg–Gabor inequality [16] the Wavelet Transform cannot achieve fine resolution in both time and frequency domain simultaneously. Recently, other time–frequency analysis methods named Hilbert Transform and Hilbert–Huang Transform (HHT) have become more and more popular because of their better time–frequency resolution [17–19]. However, automatic multi-class fault diagnosis of induction motor using Continuous Wavelet Transform (CWT) and Hilbert Transform (HT) is not attempted yet and still remains an open area of research. It is pertinent to mention that since Continuous Wavelet Transform (CWT) requires proper selection of scale and Hilbert Transform (HT) is applicable only to mono-component signal, prior information of the most important and relevant fault frequency components are required. These fault frequencies can be identified using systematic and analytical approach. It is also found that some faults either electrical or mechanical in nature may be associated with same or similar vibration frequencies leading to erroneous conclusions. Identifying the most characterizing features (or attributes) is also critical to minimize the classification error in any artificial intelligence based automatic fault diagnostic strategy. One of the most popular approaches of feature selection is maximal relevance wherein the features with the highest relevance to the target class are selected. It is likely that features selected according to Max-Relevance could have rich redundancy, i.e., the dependency among these features could be large. Thus, the combinations of randomly selected good features do not necessarily lead to good classification performance since the redundant features overshadow the actual information. A good feature selection tool is needed to remove redundant and irrelevant features and extract useful knowledge with minimum information loss. Genetic Algorithm (GA) is one of the well-known data mining tool, quite extensively and widely used to reduce the number of features for fault classification [21,22]. It has been successfully used by Rafiee et al. [23] to find the order of '*daubechies*' wavelet function, decomposition level of Wavelet Packet and number of hidden layer of the Neural Network for detection of gearbox fault. However, the feature extraction capability of GA has never been used to find most relevant CWT scales or the fault frequencies which can be used to extract the important fault related information to effectively diagnose different induction motor faults.

Keeping the above viewpoints in mind, the proposed investigation aims to develop an automatic multi-class fault diagnosis of induction motor using Continuous Wavelet Transform (CWT) and Hilbert Transform (HT) as signal processing tools. Radial (vertical) frame vibration is used for analysis since vibration analysis is one of the most successful techniques used for condition monitoring of rotating machines. Genetic Algorithm (GA) is used to find the most relevant fault frequencies which can be used to effectively diagnose the multiple induction motor faults even in the presence of noise, consequently, reducing the dimension of the feature space without affecting the overall classification accuracy along with significant reduction in computation time.

2. Induction motor vibration

The motor condition monitoring science is moving toward an automated computerized scheme, trying to remove human experts from the condition monitoring process. The development of automatic diagnostics methods for electrical machine condition monitoring is still in its infancy and despite the considerable amount of work in this field, there is still much scope of work especially in the area of feature extraction from vibration signals using powerful signal processing tools.

Vibration in induction motors is an important and complex subject [23]. It is very important to realize that vibration signals are always a compound of forcing function effects (the source) and transfer function effects (the structural transmission path). Motor torque is produced where balanced forces exist on either side of the rotor. Vibration results whenever the forces of attraction are not balanced. This can be related to current or air-gap variations in induction motors. There are two major types of vibration sources in induction motors: mechanical and electromagnetic. The major vibration sources of mechanical origin in induction motors are: rotor unbalance, bowed rotor, broken rotor bar and discrepancies in bearing. Electromagnetic vibration in induction motors is a result of effects of the electromagnetic forcing functions onto the motor rotor and stator. There are two major sources of electromagnetic vibration in induction motors: radial electromagnetic forces and tangential electromagnetic forces. Well designed, normally operating modern induction motors do not have a significant amount of variable components of electromagnetic forces. However, due to internal motor faults or external issues, such as low power supply quality and type of load, electromagnetic vibration may create serious problems to a normal motor's operation [1].

When a vibration problem occurs due to a fault, finding all the possible causes for the particular identified fault frequency of vibration needs good systematic and analytical approach. Moreover, some faults either electrical or mechanical in nature can cause vibration at the same or similar frequencies like the 1× RPM component and for a 2-pole induction motor, 2× line frequency and 2× RPM are very close especially on light load. Thus, identification of the root cause of vibration becomes elusive [24,25]. Further analysis is needed to distinguish such faults having same vibration signatures like bowed rotor and rotor unbalance. Research being carried out in this aspect is still in infancy.

Another important aspect in analysis of induction motor vibrations is that there are many harmonic components present in the electromagnetic force caused by electrical motors along with the slot frequency components. Thus, the motor vibration contains all the components arising from the cross products of the fundamental wave with itself and its harmonics and with slot frequency components. These harmonic components also induce the structural vibration and noise.

In a recent literature survey it is reported that induction motor condition monitoring using vibration analysis provides reliable detection of electrical problems in motors and no other technique can, as effectively, detect mechanical problems in all types of rotating machines. It is possible to see some kind of mechanical problems by using motor current analysis, but this technique cannot replace the vibration analysis for fault detection (revealing an excessive machinery vibration) and diagnosing vibration problems. Vibration analysis has been used to successfully identify mechanical and electrical faults and offers the most accurate fault diagnosis compared to any other technique.

3. Wavelet Transform (WT)

In the signal processing field wavelets have proved themselves to be an indispensable addition to the analyst's collection of tools and continue to enjoy a burgeoning popularity even today. Wavelet analysis is capable of extracting local as well as global information from a signal which is not possible using other signal analysis techniques. Wavelet analysis is capable of revealing important aspect like trends, breakdown points, discontinuities in higher derivatives, and self-similarity that characterizes a signal. Continuous Wavelet