HEALTH MONITORING AND ECCENTRICITY FAULT DIAGNOSIS OF INDUCTION MOTOR BY SIGNAL PROCESSING TECHNIQUES

By

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ABSTRACT

In the present time, there is a strong need to develop an efficient health monitoring system to diagnose air-gap eccentricity fault of the induction motor at early stages. If the fault is diagnosed in the early stages then one can save the industry for millions of dollars. The main aim of the researchers is to develop a non-intrusive health monitoring system for induction motor health detection in relatively low cost and also ought to be powerful for detection of developing online faults in the early stages. In the induction motor, due to unbalanced magnetic pull, the airgap eccentricity faults occur and if this fault is not diagnosed in the early stages then it will lead to large revenue losses for the industry. This issue has been addressed in this research paper and an effort is made to give an competent health monitoring technique for this kind of fault detection purpose. To achieve better results, hybrid technique has been used to extract relevant information of the fault from the raw signal in the developing stage. The EMD and wavelet algorithm has been used jointly for efficient health monitoring purpose for inverter fed induction motor machine. Two techniques have been used for fault diagnosis purpose, one is FFT technique and the other is hybrid technique. It has been observed that the hybrid technique has given encouraging results over FFT technique.

Keywords: Eccentricity Fault Diagnosis, Empirical Decomposition, Hybrid Technique, Induction Motor, Motor Current Signature Analysis, Signal Processing.

INTRODUCTION

Constant assessment of the well being of the related induction motor throughout their repair life is called health monitoring. The capability to identify faults as they are still rising is called intrusive failure finding (Vas et al., 1983). One can provide enough warning of forthcoming failure by implementing an efficient health monitoring. Hence, there is possibility to make plans for future protective safeguarding and repair work for induction machine (Belmans & Hameyer,1996; Finley & Burke, 1994).

In the past, several methods have been used for fault identification purpose and effectively applied to perceive the motor failures at diverse points. The motor changeable parameters, such as vibrations, noise, torque, speed, voltage, and current have been used for fault diagnosis purpose. Often, induction machine faults produce one or more analytical symptoms for example excessive heating, increased losses, line currents, torque fluctuations, and prejudiced air gap voltages. Mainly, in the induction motor, damages are occurring because of electrical and mechanical pressures (Hyun et al., 2010; Siddiqui et al., 2016a).

As per IEEE and EPRI reports (Bell et al., 1985; Cornell et al., 1982), bearings are most common reason of rotating machine faults and the eccentricity irregularity constitutes a substantial component of the three-phase rotating electrical machines. In the healthy motor, the air gap eccentricity inherently occurred up to 10%, but it depends upon the construction of the rotating machine.

In the eccentricity fault, the uneven air gap occurs between the stator and rotor, which is the major problem of induction motor. If unequal air gap occurs in the induction motor, then it produces imbalance and due to this, electromagnetic forces are produced between stator and rotor. These electromagnetic forces depend upon the movement of the axes. The rotor axis shifts away as of stator axis. The eccentric rotor motion will be in terms of its angular velocity. Many substantial effects have also occurred on the eccentricity due to loading, slotting, and winding arrangements (Dorrell et al., 1997; Hong et al., 2011).

The electromagnetic force works between the stator and rotor in an uneven manner and it pulls the rotor out of alignment. This phenomenon of the motor is known as Unbalanced Magnetic Pull (UMP). If UMP is increased further then it may damage the machine due to excessive generated vibrations. The eccentricity generally appears due to incorrectly positioned bearings or worn, manufacturing tolerances and inaccuracy of installation (Salah et al., 2017; Siddiqui et al., 2016b; Sinervo et al., 2011; Trabelsi et al.,2012).

Suppose the stator and rotor surfaces are in perfectly circular form, mainly, two types of eccentricities occur in the induction motor: first is static eccentricity and second is dynamic eccentricity. When the rotor axis is at a constant distance from the center of the stator and the rotor still rotates about its own axis, then it is called static eccentricity. Though, if the rotational axis of the shaft is not the true axis, although it still rotates on the stator axis is called dynamic eccentricity. However, above mentioned conditions may occur jointly and down the bore eccentricity is not essentially constant (Antonino-Daviu et al., 2018; Dehina et al., 2019; Siddiqui et al., 2014; 2015).

If the eccentricity fault occurs then the magnetic flux density allocation will be changed in between the stator and the rotor. Because of this reason, the resultant radial force is generated and it operates at the least airgap side. The static eccentricity generates a steady pull on the rotor side while the dynamic eccentricity generates a rotating force vector acts on the rotor and rotates with rotor velocity. The electromagnetic force in the induction motor can be calculated by two methods, first is analytical method and second is numerical method. Both methods have their own merits and demerits (Binns & Dye,1973).

In this paper, an adjustable speed induction motor drive setup has been proposed and by using this setup, the eccentricity fault has been diagnosed by FFT and hybrid techniques.

1.Proposed Adjustable Speed Induction Motor Drive Setup

The setup shown in Figure 1 has been used to diagnose air gap eccentricity fault. The analysis has been done for an induction motor having rating 3 HP, 50 Hz, 1430 RPM.

The block diagram has been built by the simulation model and is shown in Figure 1. From this setup, the air gap eccentricity fault analysis has been examined by advanced signal processing techniques. The processes of the proposed fault diagnostic system may be understood by Figure 1. The fault diagnostic system comprises of PWM inverter, a squirrel cage induction motor, current transducer, anti-aliasing filter, and an analog to digital converter. The information obtained by the output of analog to digital converter is applied to the chosen signal processing techniques and it will provide desired results. From the obtained results, one can do fault analysis by non-invasive technique.

In the proposed fault diagnostic system, the supply is given to the induction motor by pulse width modulated inverter. The line current is sensed by the closed loop sensor with merits such as fast response and greater accuracy. Further, the bandwidth of the signal is limited through anti-aliasing filter for satisfying sampling theorem. The digital output will be obtained in the output of A/D converter. In the proposed system, two approaches have been used for fault detection purpose. First is FFT technique and second is hybrid technique. The hybrid technique is the combination of wavelet algorithm and MALLET algorithm. The hybrid technique will remove the strong fundamental component and will provide band limited signals. These obtained signals will be completely free from any kind of noise or aliasing or interference. Hence, one will get best results by using hybrid technique.

2. Results and Discussion

2.1 Eccentricity Fault Diagnosis by FFT

The proposed simulation model and time domain analysis has

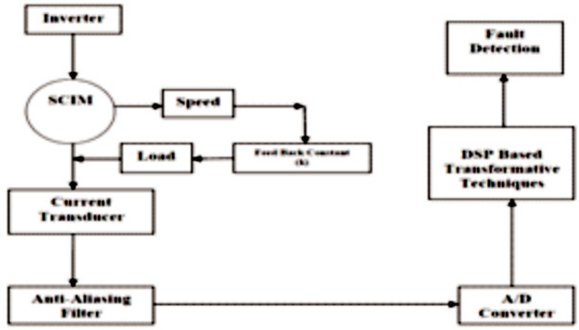


Figure 1. Proposed Inverter Fed Induction Motor Setup

been given by (Siddiqui et al., 2016a; 2016b). In this section, eccentricity fault has been diagnosed by Fast Fourier Transform (FFT) technique. The line current sidebands are monitored through FFT technique. The sensed time domain signal has been applied in the FFT algorithm for extraction of frequency information, which was not displayed in the raw signal. In the time domain analysis, one cannot acquire the information at what time which frequency exists.

Therefore, there is a need of FFT for extraction of frequency information. Earlier, this technique has been used for many induction motor fault analysis purposes, which were operated directly by the mains and able to diagnose faults in the steady state condition. Hence, it is called steady state fault diagnosis analysis method. In this work, the FFT method has been applied for eccentricity fault diagnosis purpose for inverter-fed induction motor drives. It will be interesting to see how FFT will give results for variable speed induction motor because there is a challenge of high switching frequency. The air gap eccentricity fault has been diagnosed by FFT method and the results are obtained for 30%, 50%, and 70% air gap eccentricity.

The solution of the above question has been explained by the results as shown in Figures 2 and 3. The power spectrum of healthy condition of the motor is given in Figure 2. From this figure, one may observe the changing of the side lobes. The amplitude corresponding to the frequencies are shown in Figure 2 under healthy condition of the motor.

If one observes the obtained results of Figure 3 for eccentricity faulty condition of the induction motor then it can be said that the amplitude of the side lobes are decreasing as per the nature of faults. Therefore, one can say that it is a non-intrusive technique of the detection of airgap irregularities hence all the results are different from the healthy power spectrum of the motor. Therefore, an effective method has been applied for the diagnosis of airgap irregularities of the induction motor. The main drawback of this method, it is only used for diagnosis of fault in the steady state condition and also unable to give at what time incident takes place. In other words, one can say that this method is unable to give time-frequency information simultaneously and also not able to diagnose eccentricity fault in the transient conditions. This problem has been trounced in the next section by the anticipated investigation.

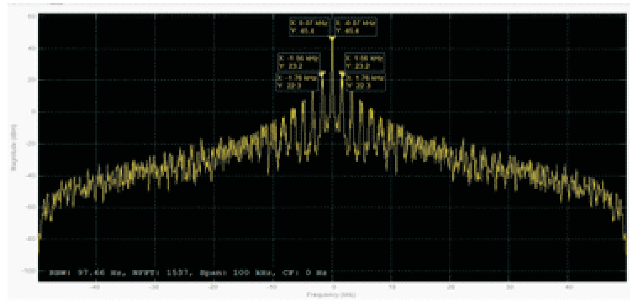
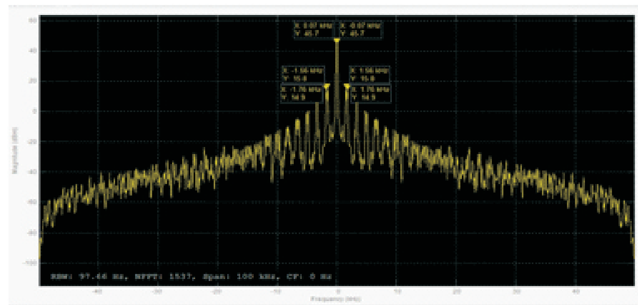


Figure 2. Power Spectrum of Healthy Condition of the Motor



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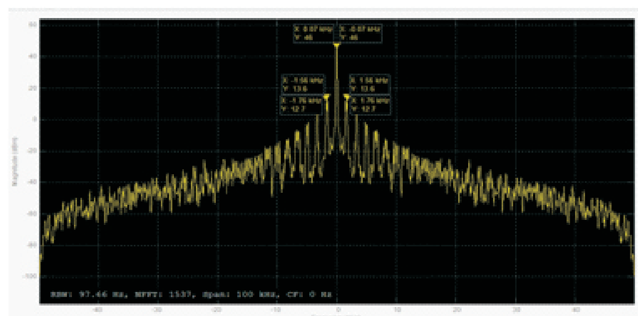

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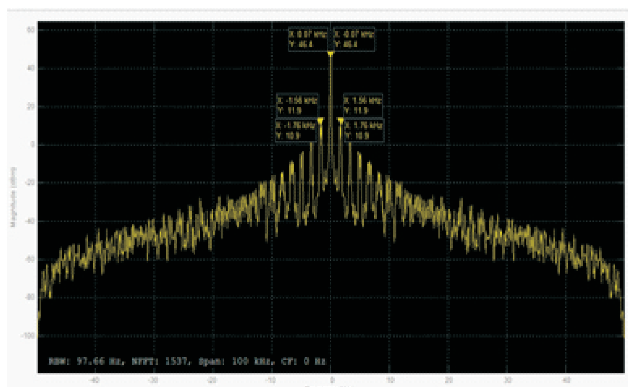


(c)

Figure 3. Power Spectrum of Eccentricity Faulty Condition of the Motor,(a) 30% Airgap Eccentricity (b) 50% Airgap Eccentricity (c) 70% Airgap Eccentricity

2.2 Eccentricity Fault Diagnosis by Hybrid Technique

The Empirical Decomposition Technique (EMD) with wavelet algorithm is becoming the most economical, accurate and attractive technology in induction motor fault monitoring. This MCSA based approach monitors the line current by non-intrusive technique, but this technique provides us the time and frequency information simultaneously. Therefore, at what time incident takes place may be observed through multi resolution analysis efficiently. In this technique, no additional hardware is required to the machine and very suitable for cage type induction motors in terms of profitable system improvement (Bessous et al., 2017a, 2017b).

This approach is very suitable because only a separable current transformer is employed to sense the current indicator and also admittance is not required to the rotating induction machine. The main advantage of this technique in terms of safety of the motor is that the current is computed in the source region without any trouble to the motor operation. This same technique is used in all stator current monitoring techniques, but the main difference is the applied signal processing technique for extraction of the required information. In this paper, empirical decomposition technique with wavelet transform has been used for fault diagnosis purpose in an efficient way. In this paper, hybrid fault diagnosis method has been applied for eccentricity fault diagnosis purpose. The hybrid fault diagnosis technique consists of wavelet transform and empirical mode decomposition. Since, the wavelet transform analysis is commonly used for processing signals and this transform maps any signal to a set of base functions.

By the mother wavelet's dilation and translation feature, one can obtain base functions and hence can achieve a reasonable decomposition of the signals in different frequency bands at different time points. Though, intricate aliasing may be present in the high-frequency portion. Therefore, as a signal processing method, EMD provides better performance for nonlinear and non-stationary signals as compared to the conventional method.

Therefore, hybrid technique has been proposed and used in this paper to achieve better results. The flowchart of fault diagnosis process using the hybrid diagnosis method is given by Belmans and Hameyer (1996).

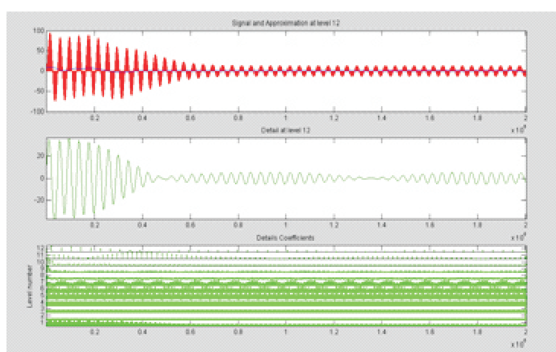
The results obtained by hybrid technique for healthy and air gap eccentricity faulty conditions is presented by Figure 4. Daubechies mother wavelet (db10) has been used for this application due to their advantages over other wavelets, and up to 12th level empirical decomposition has been done for extraction of relevant information related to fault. The high frequency band stator current signal has been used for differentiating healthy motor from faulty motor. The analysis has been done for 30%, 50%, and 70% airgap eccentricity faulty conditions. If one compares all results from healthy condition of the motor then it can be said that all the results are different from each other. The harmonics are increasing in the high frequency band detailed signal as per nature of the fault. For better understanding purpose, detailed coefficients have also been shown along with high frequency band detailed signal in Figure 4 .

The power density has also been estimated for above waveforms achieved by hybrid technique. The change in power density can be understood from Table 1.

Hence, an efficient approach has been applied to diagnose airgap eccentricity fault in the transient conditions with time-frequency information simultaneously, and in future this proposed technique may be implemented in the industries for induction motor real time online monitoring purpose.

Conclusions

This research paper has presented a novel hybrid technique for detection of airgap eccentricity fault of the squirrel cage induction motor in a variable speed induction motor drive. The hybrid fault detection approach joining EMD and wavelet algorithm is proposed to address the non-stationary and non-linear fault signals of induction motor's eccentricity fault. The line current signal is first analyzed using wavelet algorithm and then EMD is applied to reduce aliasing and interference. The FFT and hybrid techniques have been used for airgap eccentricity fault



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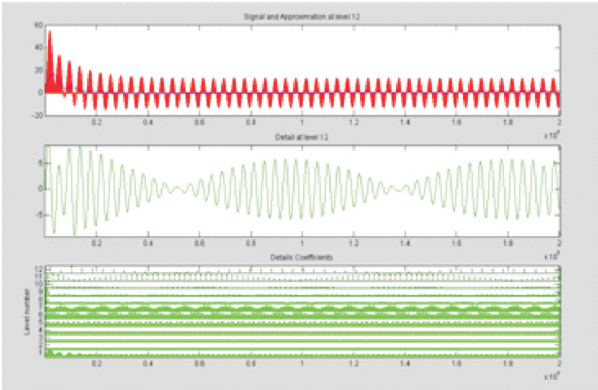

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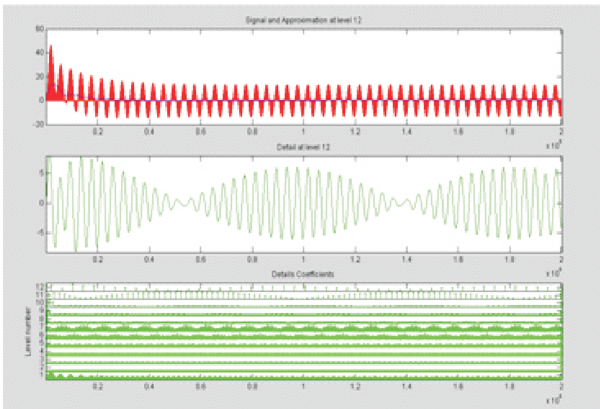

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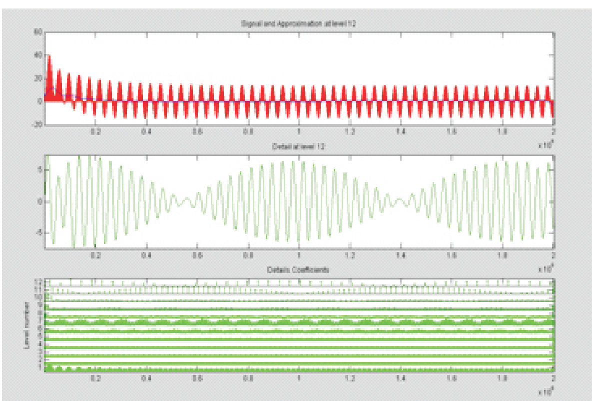

(d)

Figure 4. High Frequency Band Stator Current Signal (a) Healthy Mode (b) 30% Airgap Eccentricity Mode (c) 50% Airgap Eccentricity Mode (d) 70% Airgap Eccentricity Mode

S.No.	Motor Condition	Estimated Density
1.	Healthy	0.084
2.	30% Eccentricity	0.109
3.	50% Eccentricity	0.124
4.	70% Eccentricity	0.135

Table 1. Power Density Estimation

detection purpose. The results based on hybrid technique for airgap eccentricity fault are able to diagnose in the early stages accurately. The high frequency band detailed signal has given accurate results as per nature of the fault. Hence, one can state that the efficient approach has been proposed for detection of eccentricity fault for adjustable electric drive and now it can avert the motor before reaching in the disastrous conditions and may save large revenue for industries.

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