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Rotor Fault Diagnosis

6.1 INTRODUCTION

Breakages in the rotor bars causes asymmetry in the rotor which changes the rotor cage structure. This electrical or magnetic dis-symmetry modifies the distribution of the rotor mmf. The rotor current produces counter rotating magnetic field, that induces stator emf which interacts with mechanical parts to produce the following frequency components around the fundamental as given by following equation:

$$f_b = (\frac{n}{p}(1-s) \pm s)f \tag{6.1}$$

where, $n = 1, 2, 3...$, f is the fundamental frequency, s is the slip frequency. Under healthy motor conditions, the frequency of the induced rotor current is sf. With the advent of breakages in the bar, two rotating magnetic fields are produced; forward and backward rotating fields at $\pm sf$ frequencies respectively. If these fields added to the rotor speed, then with respect to stator winding, they would appear as, f and $(1-2s)f$ for forward and backward field respectively. The $+sf$ frequency component interacts with the stator field, while the $-sf$ induces emf at $(1-2s)f$ frequency in the stator. The current with this frequency give rise to ripples in torque and speed at $2sf$ frequency. This oscillatory component produces another component at $3sf$, thereby producing another set of frequencies in the current at: $3sf + (1-s)f = (1+2s)f$ and $3sf - (1-s)f = (1-4s)f$. Thus, with broken bars, harmonic components of currents at $(1 \pm 2s)f, (1 \pm 4s)f, (1 \pm 6s)f....$, $(1 \pm 2ks)f$ are induced in the stator. The main component for broken rotor bar analysis is left-side band component with $k = 1$, given as:

$$f_{lsb} = (1-2s)f \tag{6.2}$$

The left side-band component can be produced by other anomalies in the motor such as intrinsic mechanical dis-symmetry which however is lower in magnitude as compared to that of broken bars. The component can be uncompromisingly used as a broken rotor bar (BRB) detector but its amplitude correlation with fault severity is not established under various conditions of the motor.

All these frequency components are important in terms of diagnosis of rotor faults, but their presence due to other phenomena such as load/torque variations, unbalanced supply, mechanical vibrations, bearing defects etc. can hinder the fault detection strategies. Therefore, it is important to analyse the stator current signals from other directions to explore relevant signatures of BRB faults. In this work, time-frequency analysis and multi-resolution analysis based Stockwell transform is used to analyse the behaviour of frequencies with respect to time. Based on this, two fault indices are proposed to detect the fault and to measure the severity of the BRB faults. Under this study, three cases of BRB faults are taken into consideration: 1BRB, 2BRB and 3BRB cases where one, two and three holes are drilled in three consecutive bars (with complete bar depth) of the rotor respectively. The methodology of BRB fault diagnosis is detailed in the following section.

In this work, Shannon entropy of the transformed current signal in a time-frequency plane has been analysed for fault diagnosis. The energy which has been widely used in the literature, is also computed to compare from entropy.

6.2 EXPERIMENTAL SET-UP

The induction motor ratings 5 HP, 415 V, 4-pole, 7.5 A, 1500 rpm, has been used in the study. The motor is coupled with a DC generator ratings 3kW, 220 V, 16 A, 1500 rpm with field voltage 220 V and field current 1.8 A, which drives a lamp load. The stator current signals are acquired using a Data Acquisition System (DAQ) with NI cDAQ 9178 chassis, NI 9247 current module with 50 A capability at a sampling rate of 6400 Hz. The current signals are recorded under healthy conditions as the reference for various loading at 25%, 50%, 75% and 100% of full-load. To emulate the broken rotor bar faults, holes are drilled in the rotor at consecutive bars. For 1BRB, one full bar depth hole of 18 mm is drilled in one bar of the rotor. Similarly, another hole/s of same depth are drilled in the nearby bars to emulate 2BRB and 3BRB conditions. The experimental set-up is shown in Figure 6.1 and the rotor with holes drilled in bars are shown in Figure 6.2.

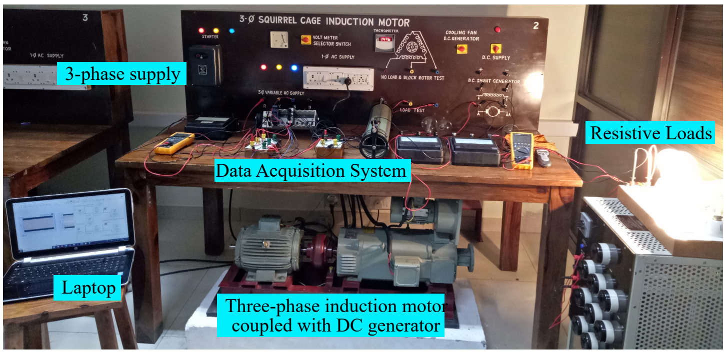
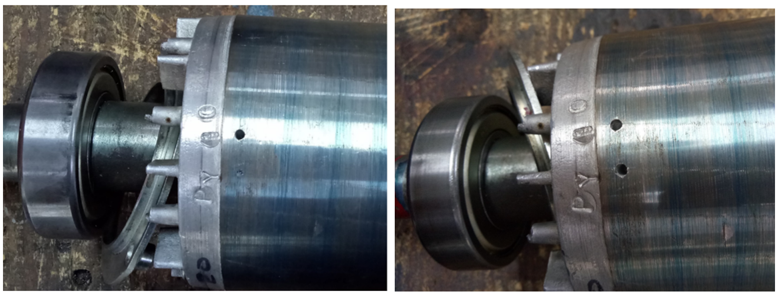


Figure 6.1 : Experimental set-up for recording current signals under healthy and BRB fault conditions



(a) (b)

Figure 6.2 : Pictures of the rotor with (a) one BRB and (b) two BRB faults

6.3 BROKEN ROTOR BAR FAULT DIAGNOSIS

The stator current signals are recorded from the three-phase induction motor under healthy and BRB fault conditions. Current signals for healthy, 1BRB, 2BRB and 3BRB fault conditions are shown in Figure 6.3. Stockwell transform is used to transform the signal into 2-D time-frequency plane. This provides a complex matrix, ST matrix which can further be broken into magnitude and phase-angle matrices. The magnitude matrix has been taken into consideration for further

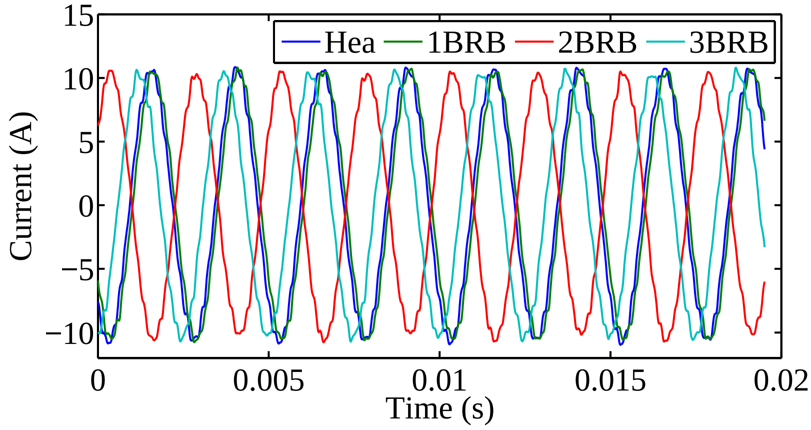


Figure 6.3 : Current signals for different rotor conditions under full-load case

analysis. This matrix is composed of real numbers signifying the content of frequencies with time. An example of the matrices can be seen in the Figure 6.4(a), 6.4(b) and 6.4(c) showing contours of ST matrix and its magnitude for healthy and faulty cases respectively. The magnitude matrix

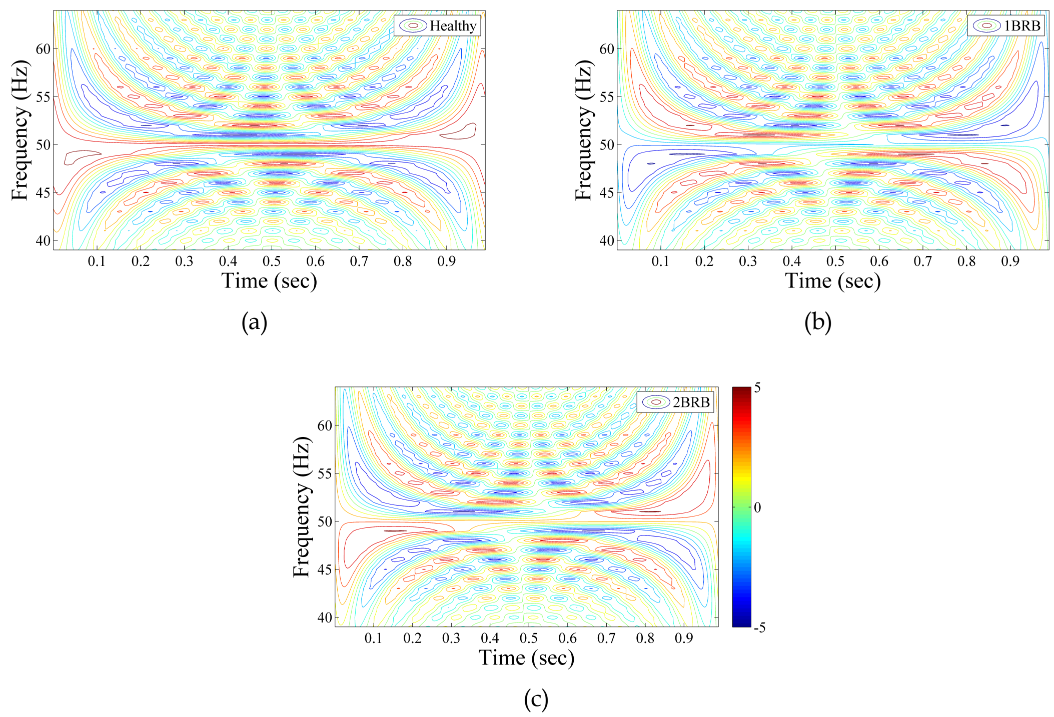


Figure 6.4 : Contour figures of the ST matrix of stator current signals with (a) healthy, (b) 1BRB fault, and (c) 2BRB fault conditions

contains frequency information with time. Within fault affected frequency bands, this frequency domain information can be used to distinguish healthy and fault cases.

In [Antonino-Daviu et al., 2006a,b], energy of the detail coefficients obtained from the discrete wavelet transform of current signals, is reported to be useful in discriminating healthy and faults. Therefore, the energy (E) is computed for the magnitude of the ST matrix under various load conditions. The energy is given as:

$$E = \sum_{k} x_k^2 \tag{6.3}$$

where k and k are an element and the length in the signal respectively. For any time-series signal, the squared sum of the elements (x) of the series gives the energy of the signal.

To estimate the difference between healthy and faulty conditions, the standard deviation of the energy is calculated.

The variation in the frequency information can also be captured using entropy. The entropy signifies the amount of uncertainty present in one variable. Under fault condition, the uncertainty is presumed to be increased. This shall increase the magnitude of entropy. The information in the entropy can be useful for fault diagnostic purposes. Shannon Entropy is given as:

$$S = s_i^2 log(s_i^2) \tag{6.4}$$

The standard deviation is computed to define another fault index (FI_2) for fault detection and severity estimation of BRB faults.

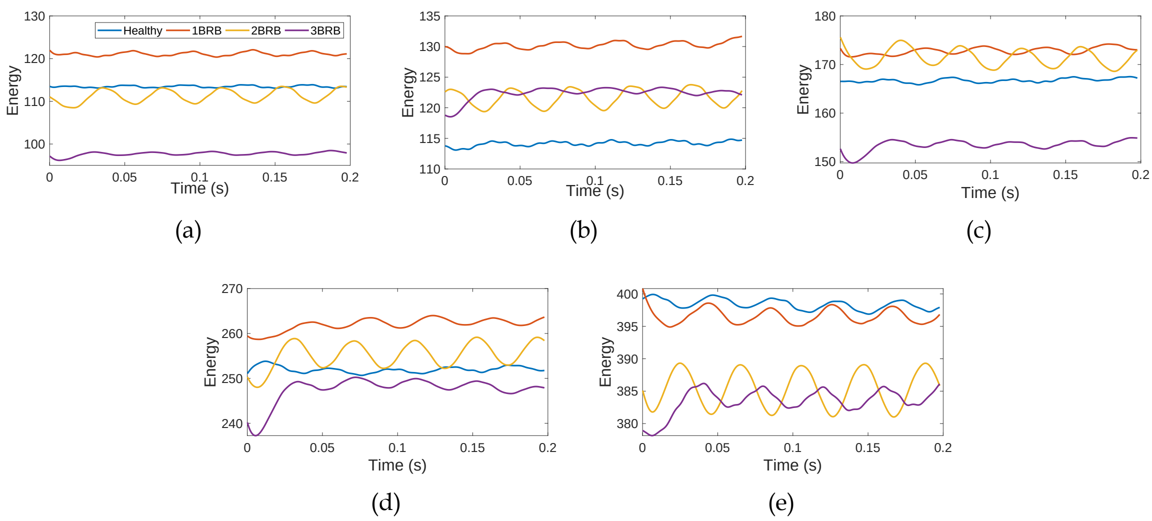


Figure 6.5 : Energy of the ST matrix for different loads and various BRB fault conditions

6.4 RESULTS

The recorded stator current signals are decomposed using Stockwell transform to obtain ST matrix in time-frequency plane. The magnitude of the ST matrix is determined. The analysis is restricted to a pre-specified frequency range. The important information for motor operation can be observed under 400 Hz [Antonino-Daviu et al., 2006b], therefore, a frequency range of [1 400] Hz has been chosen.The signal has been taken for a ten-cycle time period i.e. 0.2 seconds. The resolution of the data acquisition is kept at 1 Hz, such that 6400 samples are acquired with a sampling rate of 6.4 KHz. The energies are plotted and shown in Figure 6.5.

As can be seen from the Figure 6.5, the energy values are considerably different under different conditions of rotor bars. The difference is persistent under varying load conditions. The standard deviation of the energy vectors are shown in Figure 6.6

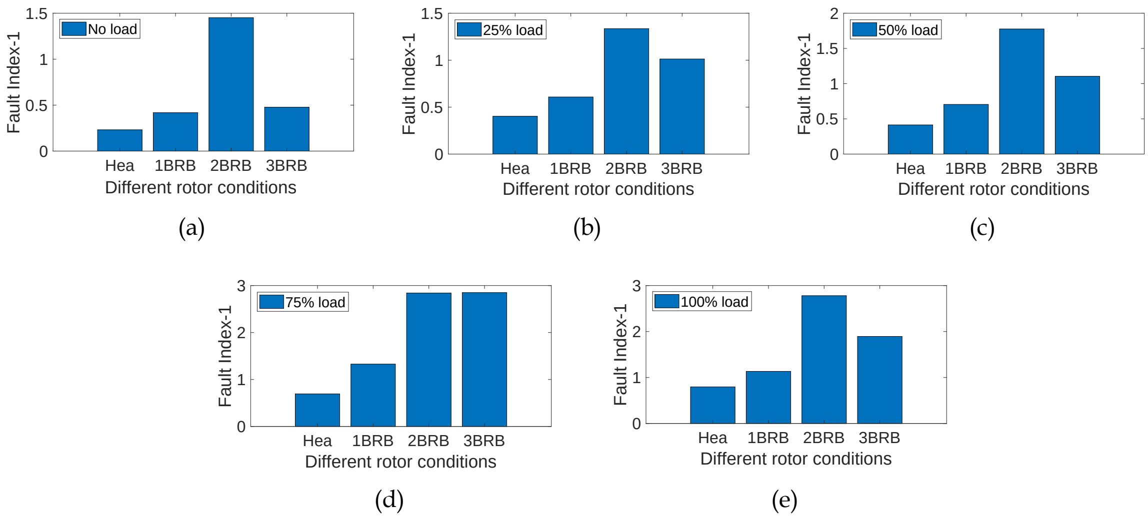


Figure 6.6 : Standard deviation of the energies

The variation in the energy is low for the healthy condition of the rotor under varied load conditions. However, it is not monotonous with the increased severity of the rotor bar. Thus, energy can be used a faulty detection parameter i.e. it can detect the presence of BRB fault.

The entropy is calculated with the same frequency range and time period of the current signal. The entropy vector for all rotor fault conditions is shown in Figure 6.7.

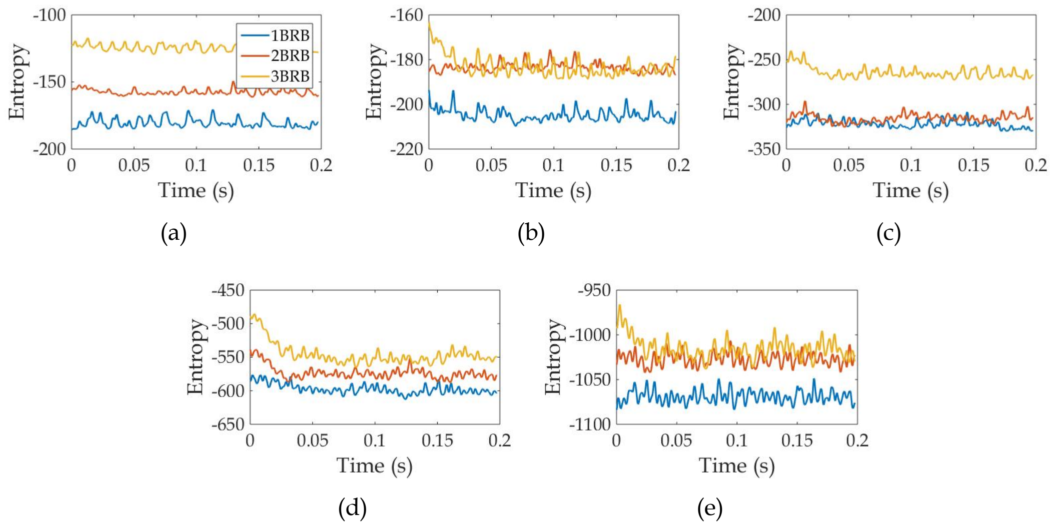


Figure 6.7 : The entropy of the ST matrix under different load and BRB fault conditions

The variations in the entropy can be observed for various severity of faults. To quantify the severity of BRB faults, the fault index, FI is calculated which is shown in Figure 6.8. Under varying load conditions, the FI follows a monotonous pattern with increasing fault severity.

This fault index varies in proportion to the severity under all load conditions. It has the lowest value under healthy conditions. Thus, the variation in the entropy can be utilized as a fault diagnostic parameter which can not only detect the fault but also estimate the severity of the BRB fault.

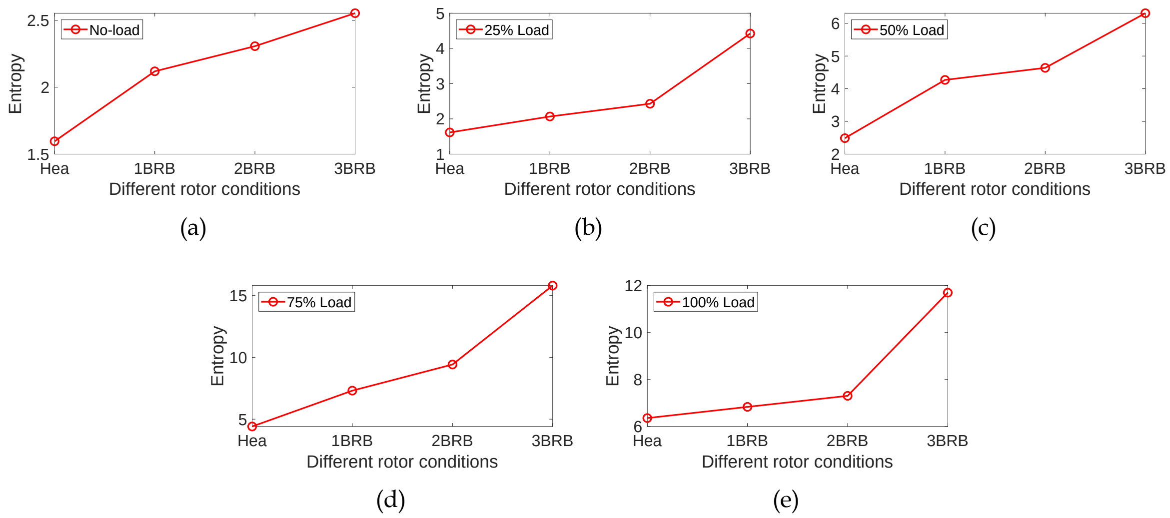


Figure 6.8 : The fault index, FI under different load and rotor fault conditions

6.5 CONCLUSION

In this work, Stockwell transform is applied on the stator current signals to decompose them into magnitudes in time-frequency plane. The current signals have been recorded using experimental set-up for a healthy motor and a motor with a BRB faults in the rotor. Using the magnitude of ST matrix, the fault detection has been performed with the help of energy and entropy calculated for a fixed frequency range over ten cycle time period. The entropy is found to be useful parameter for the detection of BRB fault. Also, it can be utilized to measure the severity of the BRB faults.