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Rotor Fault Detection System for Inverter Driven Induction Motors using Currents Signals and an Encoder

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ABSTRACT

In this paper, an induction motor rotor fault diagnosis system using current signals, which are measured using the axis-transformation method is presented. Inverter-fed motor drives, unlike line-driven motor drives, have stator currents which are rich in harmonics and therefore fault diagnosis using stator current is not trivial. The current signals for rotor fault diagnosis need precise and high resolution information, which means the diagnosis system demands additional hardware such as a low pass filter, high resolution ADC, an encoder and additional hardware. Therefore, the proposed axis-transformation method is expected to contribute to a low cost fault diagnosis system in inverter-fed motor drives without the need for any additional hardware. In order to confirm the validity of the developed algorithms, various experiments for rotor faults are tested and the line current spectrum of each faulty situation, using the Park transformation, is compared with the results obtained from the FFT(Fast Fourier Transform).

Keywords: fault diagnosis, induction motor, rotor fault, inverter driven system, currents signal

1. Introduction

In recent years, marked improvement based on the development of micro processors and power electronics has been achieved in motor drives. However, motors driven by solid state inverters have undergone serious voltage stresses because of the switch-on and switch-off voltage of semiconductor devices. As a result, condition monitoring and incipient fault detection technology have become an important research area in recent years to prevent systems from sudden shut-downs which occur due to significant motor faults in industrial manufacturing facilities. In some industrial applications, in order to prevent unexpected motor failures very expensive and regular maintenance is performed using high-priced instruments. Therefore, there is considerable demand for methods for reducing maintenance costs and preventing unscheduled downtime. Over the past several decades substantial research has been performed on new condition monitoring techniques for line-driven and inverter-driven motor drives.

Among these fault diagnosis techniques, analyzing vibration signals with accelerometers, air-gap flux measurement with search coils and thermal analysis provide satisfactory results [1-6]. However these methods usually need extra sensors, hardware and wirings for transmitting the signals which make these fault diagnosis

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techniques costly. New and promising research in the area of motor fault detection could be explored using expert systems, artificial neural networks (ANNs), fuzzy systems, genetic algorithms (GAs)[7,8] and adaptive neuron-fuzzy inference systems (ANFIS)[9]. But to extract normal and fault characteristics these techniques need offline training of diagnosis algorithms through simulations or experiments results. Additionally, these techniques need sophisticated computational procedures.

Therefore simple and low cost protection without using extra sensors and instruments is always the most attractive method for industrial applications. There is a tendency towards using line current signature analysis due to the disadvantages of the previous mentioned methods. Motor line current information of inverter fed motors is already available for control and protection purposes. Thus, by using the current sensor feedback and axis-transformation method instead of the FFT(fast Fourier transform), a new trend for low-cost protection applications is achieved without using any external hardware.

Even though numerous successful line driven motor fault detection methods are reported in the literature, inverter fed driven motor systems still require more attention due to high speed switching noise effects in the line current data and closed loop controller bandwidths [8, 9]. Contrary to the motor line current taken directly from the utility, the inverted-fed motor line current includes remarkable EMI noise. This EMI noise adversely affects the fault diagnosis due to the inherent floor noise which reduces the possibility of true fault pattern recognition using line current spectrum. Therefore, one should take into consideration as much fault signatures as possible to enhance the reliability of the fault diagnosis.

Although the rotor faults are commonly reported with an occurrence of 5-10%[10][11], the diagnosis of these faults are one of the most challenging in the case of line driven motors when compared to other faults, because of the low amplitude fault signatures in the current spectrum. However, rotor fault detection of the induction motor fed inverter has not been investigated in the literature adequately and there are limited resources on the diagnosis and side effects of current spectrum floor noise that masks small fault related signals.

Thus, in this paper in to order to detect broken rotor bar signals clearly, using a 12bit ADC, a park transformation of measured currents are investigated theoretically and experimentally for inverter driven motors. To verify the proposed algorithms, a 2.2 kW induction motor and a TMS320F2812 DSP are used.

2. Rotor Fault

Fig. 1 shows the results of motor defection conducted by IEEE study. The study is carried out on the basis of opinions as reported by the motor manufacturer. In Fig. 1, the reasons for the motor faults are classified by bearing faults, stator faults, rotor faults and others and it shows that rotor defection percentage is around 9%.

There are several reasons which cause rotor defections and these causes are shown below.

- Thermal stress, hot spot or excessive losses, sparking caused by imbalance and overload
- Magnetic stress due to electromagnetic forces, unbalanced magnetic pull(UMP), electromagnetic noise and vibration.
- Residual stress produced by manufacturing problems.
- Dynamic stress due to shaft torque, centrifugal forces and cyclic stress.
- Environmental stress caused by abrasion of rotor material or contamination.
- Mechanical stresses produced by loose lamination, fatigued parts and bearing failure.

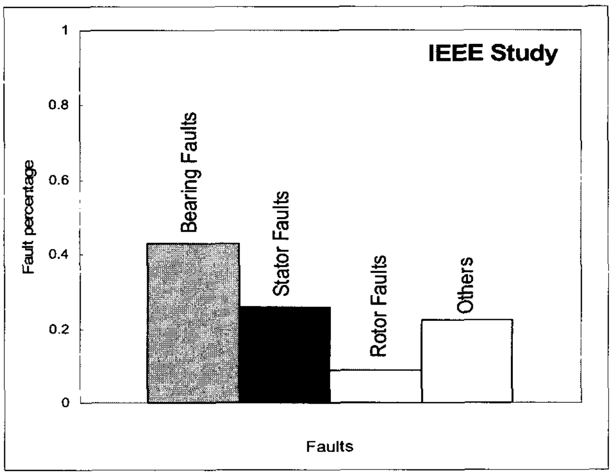


Fig. 1 Results of motor defection.

In order to detect rotor bar faults, spectrum analysis of the machine line currents [11] [12] [13] [14] and sideband components (f_b) which are a fundamental currents component for broken bar faults were investigated and are described in the equation is below.

$$f_b = (1 \pm 2s)f \tag{1}$$

Where, s is slip, f is supply frequency, and f_b is detectable broken rotor bar frequency.

While the lower sideband frequency presents a broken rotor bar, the upper sideband frequency is due to the consequent speed oscillation. A broken bar [13] gives rise to a sequence of sidebands given by (2)

$$f_b = (1 \pm 2sk)f \tag{2}$$

Where, $k = 1,2,3\cdots$

3. Proposed Algorithms and System Configuration

In order to calculate the specific frequency component, generally the FFT(fast Fourier transform) method is used, but the FFT method needs considerable calculation time, sophisticated algorithms and much memory. Therefore in this paper, the axis transformation or Park transformation, which is a very simple and effective method, is presented to estimate the exact sideband current frequency components.

Axis transformation method makes conversion from an AC value to a DC value possible. With the axis transformation rotates at a specific frequency expected to cause fault, the AC component and DC components are decoupled, i.e. if the axis transformation is employed, the AC component, which is expressed in the stationary reference frame, is transformed into a new rotation reference frame, which rotates together with selected frequency components expected to cause a broken rotor bar and an AC value expected to produce noise.

Fig. 2 shows a block diagram of the proposed method. Through axis transformation, the AC current components and DC current components are decoupled. And in order to calculate the exact DC component value expected to cause the broken rotor fault it is necessary to estimate a mean value over several periods. Based on the previous process, ix_ave and iy_ave are calculated and by means of a classifier the status of the rotor is determined.

Fig. 3 shows the overall system configuration for rotor fault diagnosis. The inverter control and fault diagnosis system are implemented on the TMS320F2812 digital signal processor board from Texas Instruments. Various blocks used in the rotor bar fault diagnosis package are shown in Figure 3. Through the 12 bit on-chip ADC the current signals for motor control and fault diagnosis is collected with a 4 kHz sampling frequency. Using the Clarke transformation and digital filter the raw current signals are transferred. To calculate the fundamental frequency and the specific frequency component which is expected in the fault component caused by the broken rotor bar, the Park transformation, signal conditioning, signal tracking and calculation of the average values, the classifier and fault frequency estimation block are used. Each part is described in Fig.3 below

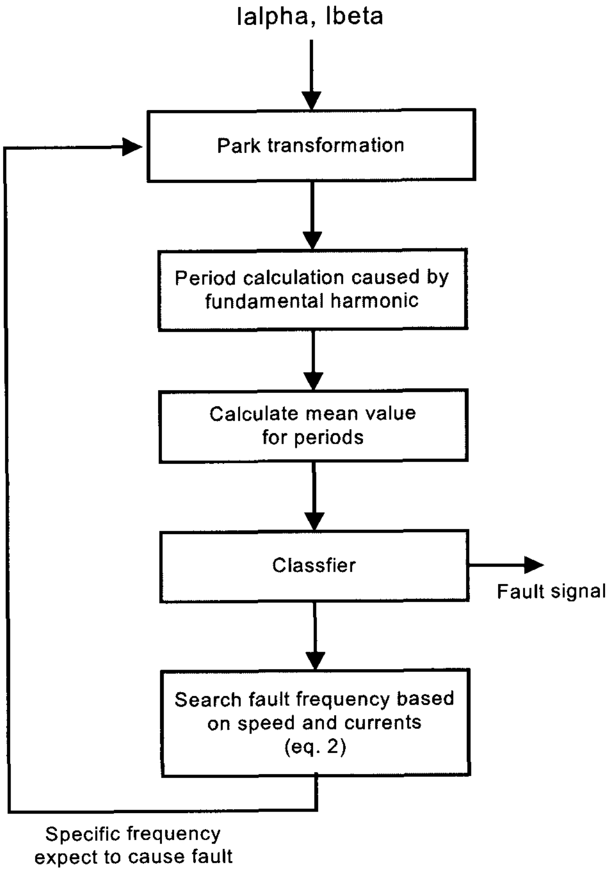


Fig. 2 Block diagram of the proposed method

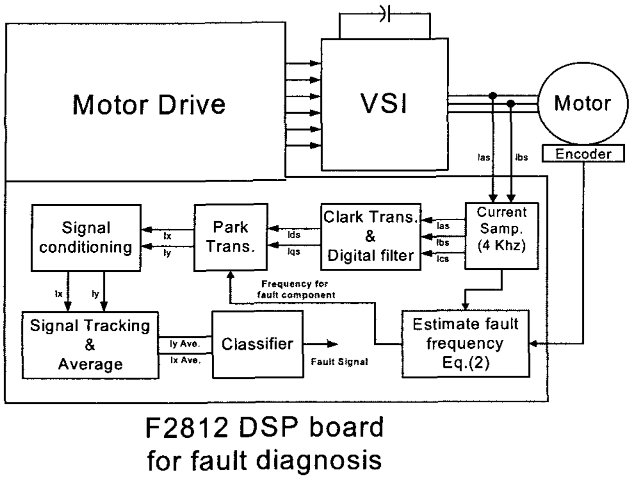


Fig. 3 System configuration.

3.1 Current Sample

In order to measure phase currents (Ias, Ibs), in this research an on-chip ADC(Analog to digital converter) was used, which has a 4kHz sampling frequency (250usec) while the other phase current, Ics , is estimated using the below equation

$$I_{cs} = -I_{as} - I_{bs} \tag{3}$$

3.2 Clarke Trans. & Digital Filter

Using the measured three-phase currents of the motor and Clarke transformation, real part current, I_α and imaginary part current , I_β , can be calculated, for calculation these current components, eq.(4) and eq.(5) are applied. Also, a digital filter, which is a low pass filter, is used to reduce unwanted noise.

$$I_\alpha = I_{as} \tag{4}$$

$$I_\beta = (I_{as} + 2 \times I_{bs}) / \sqrt{3} \tag{5}$$

3.3 Park Trans.

This module is used to transfer a specific frequency component, which is expected to cause fault, to a DC value, while the other frequency components remain at a AC value. Equations used for this transformation are (6) and (7).

$$I_x = I_\alpha \times \cos(\theta_{fault}) + I_\beta \times \sin(\theta_{fault}) \tag{6}$$

$$I_y = -I_\alpha \times \sin(\theta_{fault}) + I_\beta \times \cos(\theta_{fault}) \tag{7}$$

3.4 Signal Conditioning

Park transformed Ix, Iy have an AC value and DC value simultaneously. So it is necessary to calculate only the DC. component. In this module, the period caused by the fundamental component is estimated to remove the AC component.

3.5 Signal Tracking & Average

In this module the average values of Ix and Iy, Ix ave and Iy ave, are calculated for several periods from the Signal conditioning module while the AC component which is contained in Iy, Ix is removed. In other words

If $f_x = f_{ac} + f_{dc}$,

$$\text{Then } \frac{\sum_{n=1}^{k} f_{ac} + f_{dc}}{k} = f_{dc\_ave} \tag{8}$$

Where, k = (period for AC component) / (sampling time)

4. Simulation Results

4.1 Simulation Results

In order to verify the proposed algorithms an axis transformation is used to detect the specific frequency component and the simulation was done using the Matlab program. The simulation system was configured as in Figure 4.

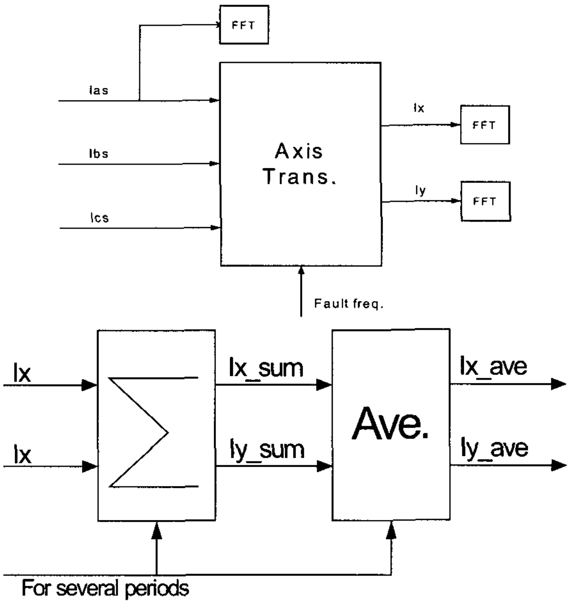


Fig. 4 System configuration of simulation

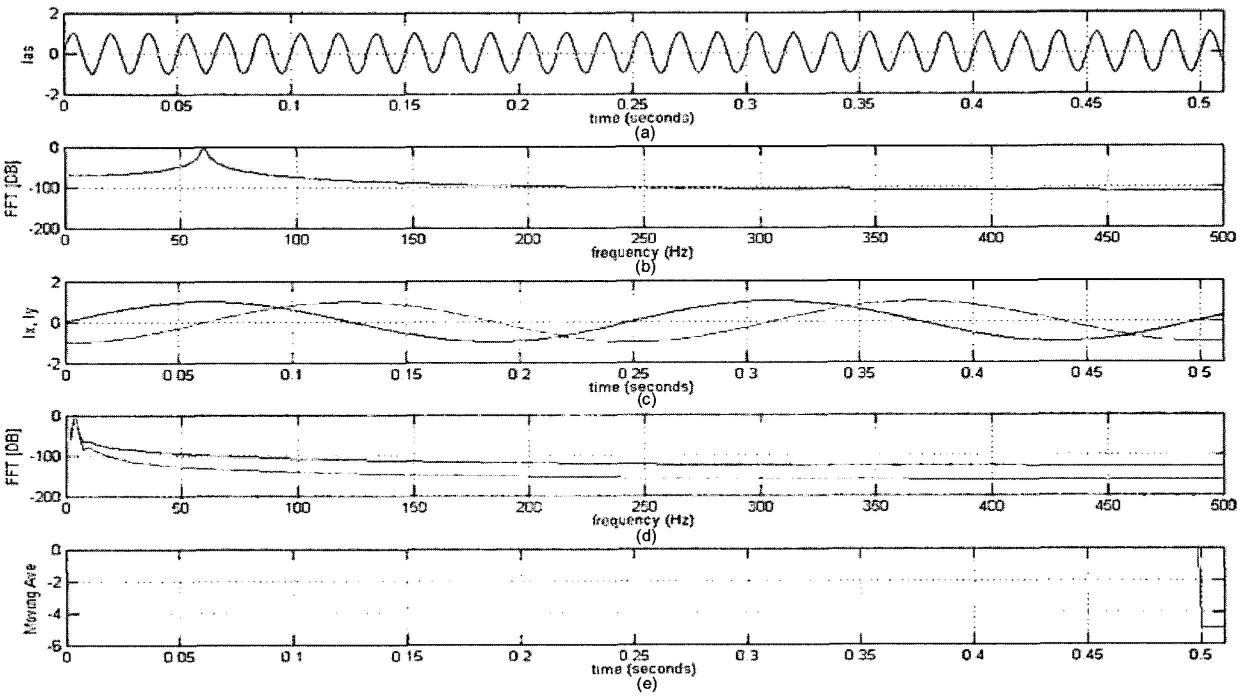


Fig. 5 Simulation Results

To imitate the current signal with a side band component, the below equation is used.

$$I_{as} = \sin(2\pi f) + 0.01 \cdot \sin(2\pi f_1) + 0.01 \cdot \sin(2\pi f_2)$$
$$I_{bs} = \sin(2\pi f - \pi/3) + 0.01 \cdot \sin(2\pi f_1 - \pi/3) + 0.01 \cdot \sin(2\pi f_2 - \pi/3)$$
$$I_{cs} = \sin(2\pi f + \pi/3) + 0.01 \cdot \sin(2\pi f_1 + \pi/3) + 0.01 \cdot \sin(2\pi f_2 + \pi/3) \quad (9)$$

Where, $f = 60hz$, $f_1 = 56hz$, and $f_2 = 64hz$.

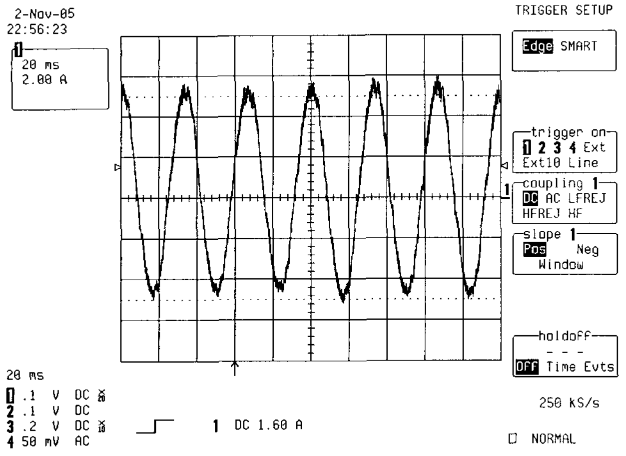
During the FFT analysis, it is almost impossible to detect the sideband component because of insufficient data. However, the axis transformation and average method give an exact DC value for the sideband component after 0.5 seconds. It is shown that the proposed algorithm can detect a broken rotor defect using a 12 bit ADC.

Fig. 5(a) shows the current waveform that contains fundamental signals and noise signals expressed in Eq.(9). Fig. 5(b) represents the FFT results of the current signal. Fig. 5(c) presents the Park transformation results rotating a specific frequency, 56hz, which is expected to cause a broken rotor fault as shown this figure. These signals are composed of a DC value, 56hz and an AC value for the other frequency components, 60hz and 64hz. Fig. 5(d) indicates the FFT results of Fig. 5(c). Fig 5(e) shows the results of the proposed algorithms using the Park transformation configured in Fig. 4 and after 0.5 secs can detect a specific frequency, a 56hz component having 0.01[p.u.].

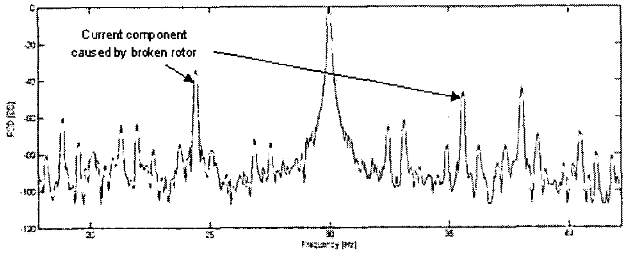
4.2 Experimental Results

Figure 6(a) represents the current waveform of the rotor defect motor. Figure 6(b) shows the PSD results of a faulty motor, which has a broken rotor fault current component around 24 Hz. As shown in this figure, a rotor faulty component is -36 [dB] which means this induction motor has some rotor problems.

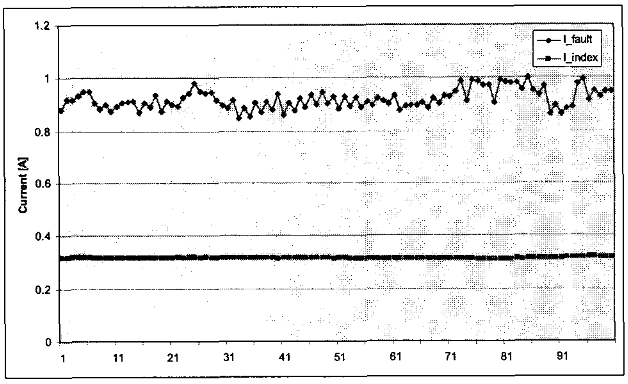
Figure 6(c) shows the results of the current spectrums using the proposed algorithm which uses the axis transformation and average method and I_index mean reference value whether the motor has a rotor fault or not, which is at a value of 35[dB] and I_fault mean actual current component which is expected to cause the rotor defect. As shown in these results, the proposed algorithm can detect a bearing defect using a 12 bit ADC. Table 1 shows the motor parameters which were used in this paper.



(a) Phase current waveform



(b) PSD results of phase current



(c) Fault signal with the proposed algorithm

Fig. 6 Experimental results

Table 1 Induction motor parameters

Rated power	3Hp	Rated speed	1760rpm
Rated voltage	230V	Rated current	7.6A

5. Conclusion

This paper has investigated the feasibility of detecting broken rotor faults using an axis transformation and average method of the current spectrum of an inverter driven induction machine.

Induction motor defects caused by broken rotor faults produce visible changes in the stator current spectrum at predictable frequencies. However it is very difficult to detect using the FFT method because it takes a very long time and needs a lot of data information. However, using an axis transformation and average method instead of the FFT method is proved to be very effective and low in cost through simulation and experimental results. The present paper was limited and further studies on transient state assessments are needed.

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