Early detection of rotor-bar faults of three-phase induction motor using motor current signature analysis method

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Abstract : Three-phase induction motors play a pivotal role in industry and there is a strong demand for their reliable and safe operation. They are generally reliable but eventually do wear out. Faults and failures of induction motor can lead to excessive downtimes and generate large losses in terms of maintenance and lost revenues, and this motivates the examination of on-line condition early detecting. On-line condition early detecting involves taking measurements on a motor while it is operating in order to detect faults with the aim of reducing both unexpected failures and maintenance costs. Motor Current Signature Analysis (MCSA) method is a way to detection of condition monitoring technique used to early detection problems in rotor bar fault of three- phase induction motors. In this paper presented the experimental results of frequency spectrum Fast Fourier Transform (FFT) stator current on-line censorship a three-phase induction motor using LabVIEW algorithm for detecting of rotor conductors faults. The stator current FFT analyzed using Motor Current Signature Analysis (MCSA) method.

Key words: Rotor-bar, driving power, MCSA, FFT

Introduction

Three-phase induction motor rotor cage is very commonly used in industries as driving power in a unit of production process, because this motor has any advantages compared with other types of electric motors, such as the construction is simple and robust, large power capacity, easy maintenances and high efficiency (W.T. Thomson and R.J. Gilmore, 2003). In addition, with technological advances in the power electronics and control system, they are very helpful in induction motor control system. The induction motor also has wide and smooth range controlling, rapid in torque and speed responses for broad application.

Fault and damage on rotor conductor of induction motor is very rare, but not close the possibility off (Peter Vas, 1993). Fault and damage on rotor of a three-phase induction motor can occurred due to a very high starting currents that cause broken or cracked rotor conductors, rotor installation errors, install the motor damage, the damage caused transportation (traveling) and others.

In an industry for one unit of production process may be using some of the electric motor to reach tens or even hundreds of motorcycles. If a motor is damaged or impaired, then the unit automatically to be stop, so it will trouble to all production activities. And consequently can cause harm to the company or industry (Peter Vas, 1993), (Benbouzid, M.E.K, 2000) and (Randy R. Schoen, Thomas G, Habetler, Farrukh Kamaran and Robert G. Bartheld, 1995). In addition, if the unit production engine is stop, so very hard to determining which one of electric motor was damage or fault, because a lot of the numbers of motors used in a production unit. If the damage or faults on a motor can be early impression or detection before hard damage occurred, than the company's losses will be deductible and the search of faulted motor can be determine.

Some of methods and way have been conducted to determine the initial symptoms of rotor damage of fault of a three-phase induction motor, such as by looking at the vibrations, the measurement of abnormal temperature and analyzing of the stator current waveform signal. But all of this way is rather difficult to determining validly when the load of motor is variety (R. Schoen, B.K. Lin, T.G. Habetler, Jay H. Schlag and Samir Farag, 1995), especially if the motor is operated at a distant and difficult located to reach, such as motors for submersible system.

In this paper carried out an early detection of damage on the rotor conductors of a squirrel cage three-phase induction motor using the analysis of wave frequency spectrum stator current method. A fault or damage on the rotor conductor can detected by looking at the frequency spectrum of the rotor currents that producing a symmetric frequency side bands around the fundamental frequency of stator current. With the help of FFT analysis (Fast Fourier Transform) of the LabVIEW program, the magnitude and frequency bands are very small side of the rotor currents can be observed and detected as show in the form of harmonic frequency spectrum on a computer monitor.

Conductor Rotor Fault Analysis

Fault or damage on the rotor conductor of the squirrel cage three-phase induction motor is not directly resulting damage to the motor, but the damage causing serious consequences of its influence, for example by a disturbance in the rotor, the motor become unbalanced running and resulting hit between the stator and rotor part which raises mechanical damage to the motor, rotor and stator insulation. Therefore, before severe damage occurs to the motor as a conductor rotor fault effect, than need do early detection of frequencies side band frequency that occur in the motor stator current.

In normal conditions without fault on rotor, when the motor operation than the speed of the rotor is balanced. Where the rotating magnetic field speed or synchronous speed is produced by stator winding is :

$$n_1 = \frac{120\ f_s}{p} \qquad (1)$$

Where : n_s is rotating magnetic field (synchronous speed)
n_r is rotor speed
f_s is stator current frequency (frequency supply)
P is numbers of pole.
s is motor slip

At a condition for motor operation with the rotor speed is n_r, than the slip of motor can be expressed as :

$$s = \frac{n_s - n_r}{n_s} \qquad (2)$$

Where slip of speed or difference speed between stator (synchronous speed) and rotor is :

$$n = n_s - n_r \qquad (3)$$

From equation (2) and (1) can be calculated of motor slip is :

$$s = \frac{n}{n_s} \quad \text{or} \quad n_r = n_s\,(1 - s) \qquad (4)$$

The back forward of the rotor magnetic field due to conductor rotor fault referred to stator side can be written as :

$$\begin{aligned} n_b = n_r - n &= n_r - (n_s - n_r) \\ &= n_s\,(1-s) - (n_s - n_r) \\ &= n_s\,(1-s) - (n_s - n_r) \\ &= n_s\,(1-2s) \end{aligned} \qquad (5)$$

In the frequency form [Hz], the equation (5) is the speed of rotor that can be expressed as,

$$f_b = f_s(1-2s) \quad (6)$$

This frequency induced to stator, therefore the stator current has two side band frequencies e.i appear at $\pm 2sf_s$ around the fundamental frequency (stator current frequency). Both the two these is frequency side band upper and lower of stator current fundamental frequency (f_s) show there are any fault on rotor conductor of motor. Generally these side band can be written as :

$$f_b = f_s(1 \pm ks) \quad (7)$$

Where k is constant (k = 1, 2, 3,...)

The frequency spectrum of stator current $f_b = f_s(1+ks)$ is called upper side band frequency (USBF) and for $f_b = f_s(1-ks)$ is low side band frequency (LSBF).

As a illustration, application of the equation (7) can be draw in axis frequency vs magnitude stator current (Amp or dB), such as shown in Figure 1.

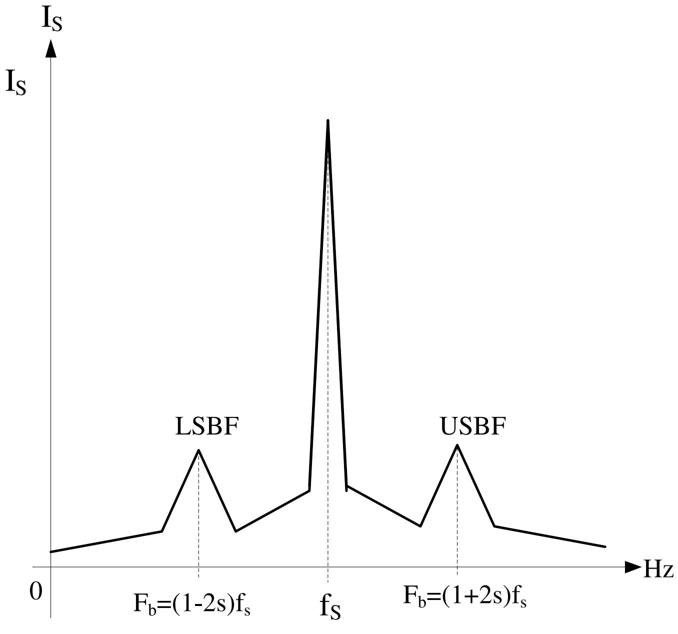


Figure 1. Side band frequency spectrum of stator current under rotor fault

Experimental Result and Discussion

In order this propose achieved, than to analysis the stator current signal or wave form need help a LabVIEW computer program. In this program, the stator current signal is extracted in Fast Fourier Transform (FFT) to determine the side band spectrum frequency. The circuit for this experiment such as shown in Figure 2 bellow.

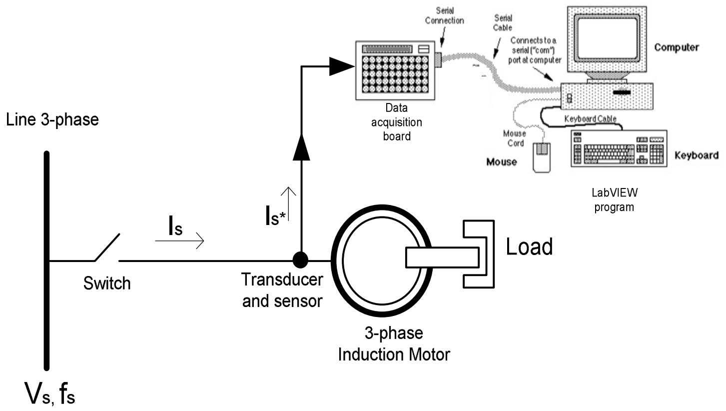


Figure 2. Experimental circuit

In this experiment done testing to a squirrel cage three-phase induction motor with rating as bellow, 0,5 hp, 415 V, 50 Hz, 1,05 A, 4 poles, 1380 rpm and it rotor has 24 slots. The LabVIEW 8.2 applied for detecting and analyzing of the stator current signal through a transducer with card NI-PCI 6251 and acquisition board ELVIS. Specification data acquisition card NI-PCI 6251 given in Table I and the parameter of data acquisition ELVIS given in Table II below :

Tabel 1. Specification of NI PCI-6251

Spesifikasi	**Unit**
Analog Inputs	16
AI Resolution	16 bit
Analog Outputs	2
AO Resolution	16
Max Update Rate (MS/s)	2.8 MS/s
AO Range	± 10 V, ± 5 V, ext ref
Digital I/O	24
Correlated (clocked) DIO	8 MHz, up to 10 MHz

Tabel 2. Parameter Acquisition Data

Spesifikasi	**Unit**
Scan rate	25000 S/s
Jumlah sampel	200000
Frekuwensi resolusi	0.12 Hz
Time record	8000 ms
Sensor sensitivity	1000 mV/EU
Correlated (clocked) DIO	8 MHz, up to 10 MHz

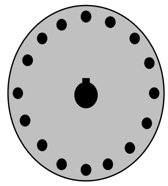
The experiment was done for under normal condition without conductor rotor or healthy condition and fault condition. Loads of motor for each condition done at no-load, half full load and full load. For all condition, the stator current signals was recorded and analyzed in form FFT spectrum frequency to look the both side band frequency USBF and LSBF. Faults of the conductor rotor formed with absent of certain conductor bar. In this experiment, the fist fault case of the conductor rotor is with through off one conductor bar and the second case of the conductor rotor is with through off four conductor bars.

a). Healthy Condition

Experiment result for healthy condition of a squirrel three-phase cage induction motor is given in Table III bellow. In this condition, the motor loaded with slip 0.01 without load, slip 0.04 for half full load and slip of 0.08 for full load. In this healthy condition, the stator current signal frequency only has one spectrum at fundamental frequency 50 Hz without appear side band frequency.

Tabel 3. The rotor in healthy condition

Load Condition	**Motor Slip**	**Side Band Frequency LSBF - USBF**			
	s		k=1		k=2
Without load	0.01	50 Hz	-	-	-
Half full load	0.04	50 Hz	-	-	-
Full load	0.08	50 Hz	-	-	-



Healthy rotor

The recording results frequency spectrum or FFT of the stator current in [dB] forr all loads under healthy rotor condition as shown in Figure 3, 4 and 5 respectively.

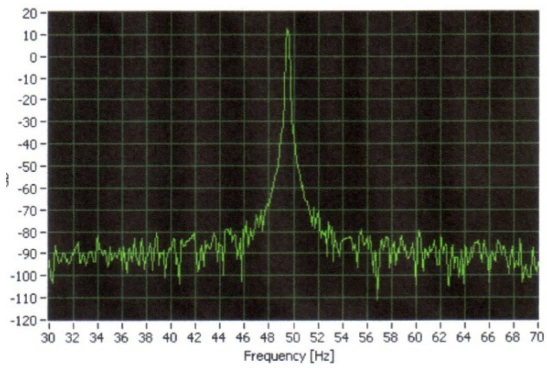


Figure 3. Healthy rotor, on without load

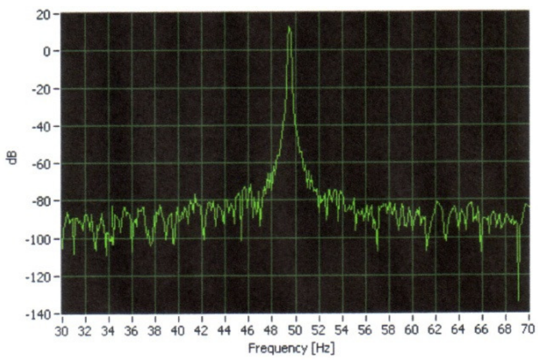


Figure 4. Healthy rotor, on half full load

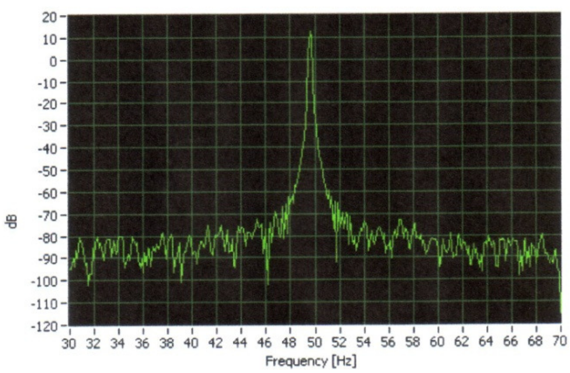


Figure 5. Healthy rotor, on full load

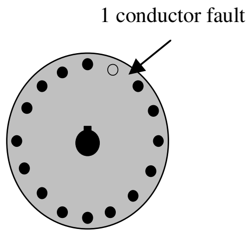
b). One Conductor Rotor Fault Condition

Experiment result for one conductor bar through off as rotor fault given in Table IV. In this condition for motor without load with slip is 0.01, the both frequency side appear at 49 Hz for LSBF and 51 Hz for USBF of the stator current. But this frequency spectrum almost near with the fundamental frequency 50 Hz therefore difficult to finding the spectrum this side band such as shown in Figure 6.

In this case for half full-load condition, where the motor slip is 0.04 the both frequency side band occurred at 46 Hz for LSBF and 54 Hz for USBF. These both side band frequencies indicate there is fault on rotor. In this case for full load condition where the motor slip is 0.08 has the both side band frequency at 42 Hz for LSBF and 58 Hz for ASBF of stator current such as shown in Figure 7 and 8. Also these both side band frequencies indicate the rotor of motor is faulted.

Tablel 4. One Conductor Rotor Fault Condition

Load Condition	Motor Slip	Side Band Frequency			
	S	k=1		k=2	
		LSBF	USBF	LSBF	USBF
Without load	0.01	49 Hz	51 Hz	48 Hz	52 Hz
Half full load	0.04	46Hz	54 Hz	42 Hz	58 Hz
Full load	0.08	42 Hz	58 Hz	34 Hz	66 Hz



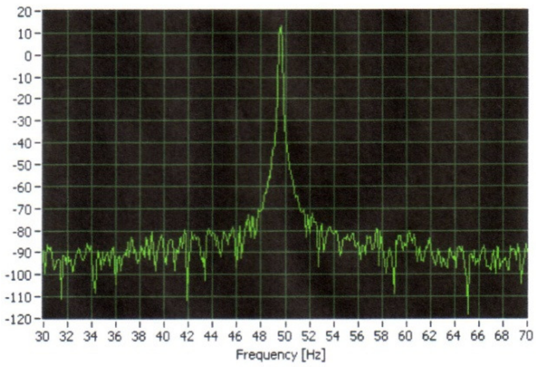


Figure 6. One rotor conductor bar fault – on without load

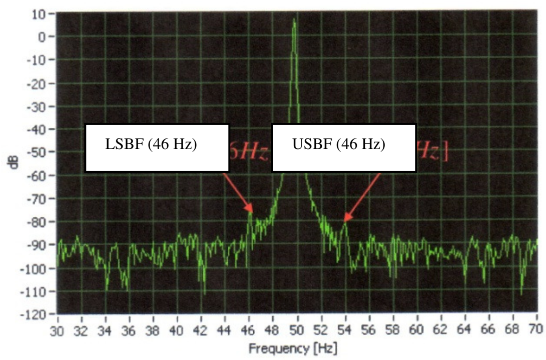


Figure 7. One rotor conductor bar fault – on half full load

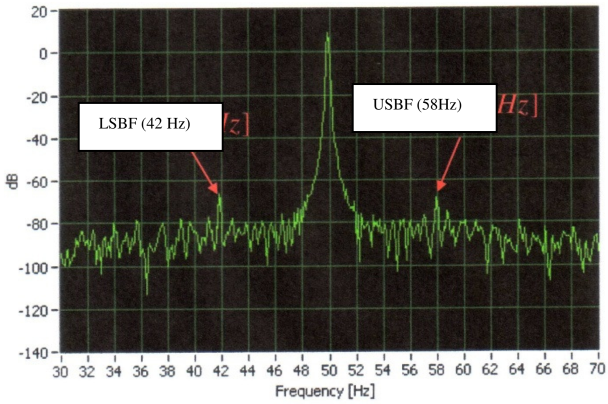


Figure 8. One rotor conductor bar fault – on full load

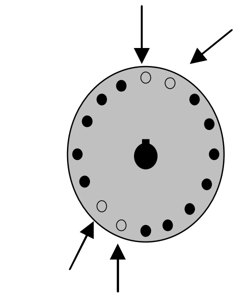
c). Four Conductors Rotor Fault Condition

Experiment result for four conductors bar through off as rotor fault given in Table V below. In this condition for motor without load with slip is 0.01, the both frequency side appear at 49 Hz for LSBF and 51 Hz for USBF of the stator current. But this frequency spectrum almost near with the fundamental frequency 50 Hz therefore difficult to finding the spectrum this side band such as shown in Figure 9.

In this case for half full-load condition, where the motor slip is 0.04 the both frequency side band occurred at 46 Hz for LSBF and 54 Hz for USBF. These both side band frequencies indicate there is fault on rotor. In this case for full load condition where the motor slip is 0.08 has the both side band frequency at 42 Hz for LSBF and 58 Hz for USBF of stator current such as shown in Figure 10 and 11 respectively. Also these both side band frequencies indicate the rotor of motor is faulted.

Table 5. Four Conductor Rotor Fault Condition

Load Condition	Motor Slip	Side Band Frequency			
	s	k=1		k=2	
		LSBF	USBF	LSBF	USBF
Without load	0.01	49 Hz	51Hz	48 Hz	52 Hz
Half full load	0.04	46 Hz	54 Hz	42 Hz	58 Hz
Full load	0.08	42 Hz	58 Hz	34 Hz	66 Hz



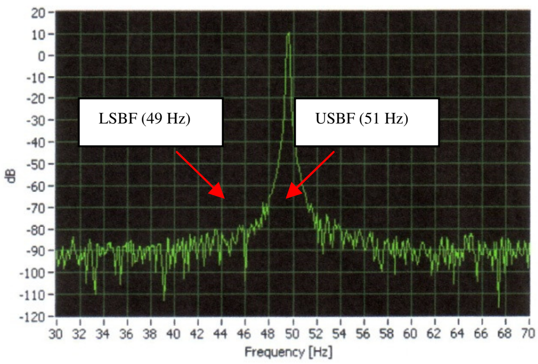


Figure 9. Four rotor conductor bar fault – without load

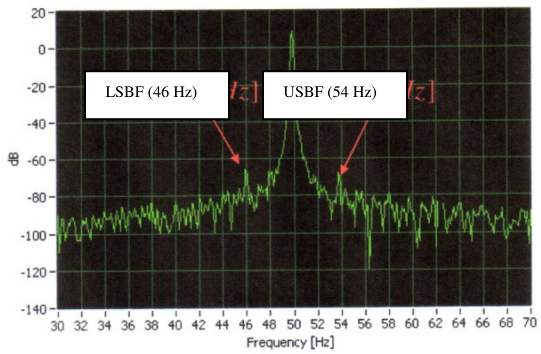


Figure 10. Four rotor conductor bar fault – on half full load

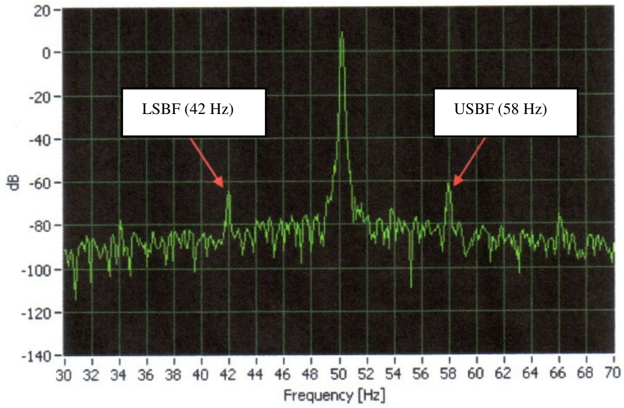


Figure 11. Four rotor conductors bar fault – on full load

Conclusion

In this paper was conducted analysis of a squirrel cage three-phase induction motor to determine or detect the presence of fault or damage on the rotor conductor bar. A fault or damage on the rotor can be seen from the two side band frequency spectrum that arising in the rotor current waveform, i.e in the lower frequency spectrum of stator current LSBF, $f_b = f_s(1-ks)$ and upper stator current frequency spectrum USBF, $f_b = f_s(1+ks)$. The stator current analysis method FFT that used to determine the fault or damage on rotor conductor is not valid for no-load condition of motor. This stator current analysis method is very helpful to detect the early presence of rotor conductor faults or damage on the squirrel cage three-phase induction motor.

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