BROKEN ROTOR BAR DETECTION WITHOUT MOTOR LOADING

S. Masoud Shams Mosavi, Javad Poshtan*, and Jafar Zarei

Iran University of Science & Technology,

Department of Electrical Engineering

Narmak 16844, Tehran, Iran

M_smosavi@ee.iust.ac.ir

Abstract

One of the common induction motor defects is a broken rotor bar. Generally the Detection of the defective bars, via Motor Current Signature Analysis (MCSA), requires a proper loading on the motor and creation enough slip on it. Very often, the proper and correct loading would be a difficult or even impossible task. Hence, in this research the voltage reduction plan has been proposed instead of actual motor loading with the aim of the creation enough slip. In this new method, while the motor is operating with decreased voltage, the shaft inertia and friction as well as cooling force, act as a proper and uniform load without any oscillation and cause to appear the broken rotor bars frequencies in the electrical motor signals. In fact, the detection of these defects has been improved by the increasing of rotor's slip and the separation of the defect harmonics apart the main supplying frequency as well, which have been occurred via decreasing voltage.

INTRODUCTION

The induction motors are applied in many industries such as power plants, petrochemical, cement, sugar, and mining, … , due to their simple construction, low price, and reliability, and the final production of these industries strongly depend on their function.

These motors very often are acting with regard to mechanical system, so they make the electromechanical system. Since the past to now the diagnosis and isolation of the electrical and mechanical defects had been the main problem for maintenance and repairing of these systems. The importance of the isolation is mainly for making decision with regard to refer any defect to its own technicians for repairing. Therefore preparing a simple and influence method continuously has been studied by researchers for diagnosis and isolation the electrical defect from mechanical defect [1-3].

The induction motors life time could be influenced by some defects like stator's core or coil defect, broken rotor bars, eccentricity, misalignment, bearing defect, and driver defect, Where the broken bars defect's share is between 5% and 10% [1].

Although this amount are consisted of a low percentage of the induction motor defect, but due to two reasons the online rotor fault diagnosis methods paid more attention in comparison with the other defect by the researchers. The first one is that due to lake of access to the rotor directly, the using of the off-line diagnosis method for the rotor is impassible. However for the stator defects the offline method can be applied by the easy way, because the stator terminals are directly accessible, just as are widely used in the industry. The next one is that some of the rotor defects are appeared while the motor is running; consequently their diagnosis should be done on that time. For this kind of defects it can be mentioned the existence of crack on the motor bars.

To the online diagnosis broken bars various signals such as motor body vibrations [4], stator current, instantaneous power, and shaft flux are used. Mostly the usage of vibration and flux sensors are expensive or unsuitable. So in the several past decades the researchers would prefer, more than before, to use the motor current due to the low cost and noninvasive characteristic of the current sensors. In some reference instantaneous power analysis used to improve the noninvasive methods as well[5-7]. In this method for achiving the better result, should be utilized the voltage sensor to get instantaneous power.

There are various techniques for processing the signals which come from the motor, such as the fast Fourier transform (FFT), short time Fourier transform (STFT), wavelet transform (WT), and wavelet packet transform (WPT). Each of them in comparison with each other has its restriction and advantage[8]. In case of stationary signals the best and simplest technique is the fast Fourier transform.

The motor loading is the main restriction in fault diagnosis of induction motor which will be presented in the 2nd section. One of the influence approaches in the motor fault diagnosis is advanced Park's vector. The Park's vector, alone, includes almost the information of three stator phase current. The Park's vector will be studied in the 3rd section. Next, the experimental results of the laboratory motor is presented, which was compared actual and virtual loading for motor defect diagnosis.

LOAD PROBLEM

Broken rotor bars are detected by monitoring the motor current spectral components produced by the magnetic field anomaly of the broken bars. The broken rotor bar frequencies are given by

$$f_{brb} = f_e\left[k\left(\frac{1-s}{p}\right) \pm s\right] \tag{1}$$

where " f_e ", " p ," and " s " are, respectively, the electrical supply frequency, number of pole pairs, and the per-unit slip; $k/p = 1, 5, 7, 11, 13, \cdots$ due to the normal winding configuration [2]. For $k/p = 1$, the additional component in the current spectrum is:

$$f_{brb} = (1 \pm 2s)\, f_e \tag{2}$$

owing to interactions[9]. And can to be point the current modulation by $f_\upsilon = 2sf_e$ frequency.

As it has been considered the broken bar frequency has direct dependant to the rotor slip and in case the slip is very low, i.e. no-load motor condition, the defect harmonics are merged with fundamental harmonic, so its diagnosis and isolation will be impossible. In addition, motor unloading causes to reduce the applied force on rotor bar and accordingly to hide the rotor bars' cracks.

On the other hand in loading motor case, if the load torque does vary with rotor position, the current will contain spectral components which coincide with those caused by a fault condition. In an ideal machine where the stator flux linkage is purely sinusoidal, any oscillation in the load torque at a multiple of the rotational speed mf_r will produce stator currents at frequencies of

$$f_{load} = f_e \pm mf_r = f_s\left[1 \pm m\left(\frac{1-s}{p}\right)\right] \tag{3}$$

where $m = 1, 2, 3, \cdots$ [2]. Since the same frequencies are given by (1), it is clear that when the induction machine operates with a typical time-varying load, or loading is not proper, the torque oscillation results in stator currents that can obscure, and often overwhelm, those produced by the fault condition[2]. The time varying load is due to inherent vary load or may be because of unbalance or misalignment load.

So in order to induction motor fault diagnosis there would be three limitations as follows:

a) The defect frequency may be mistaken for the fundamental harmonic in the no-load case
b) The hiding of rotor bar cracks under no-load
c) The production of frequencies similar to defect frequency in consequence of improper loading.

In order to solve these problems, when proper loading is impossible, voltage reduction plan up to several tenth of rated voltage can be use. In this paper has been shown that by this way will be gain good and acceptable results. While the motor is operating with much decreased voltage, the shaft inertia and friction as well as motor cooling force, act as a proper and uniform load without any oscillation and cause mentionable rotor slip. In consequence of this slip, the defect frequency are separated apart the fundamental harmonic and diagnosis is become easier. This creation slip can be named virtual loading.

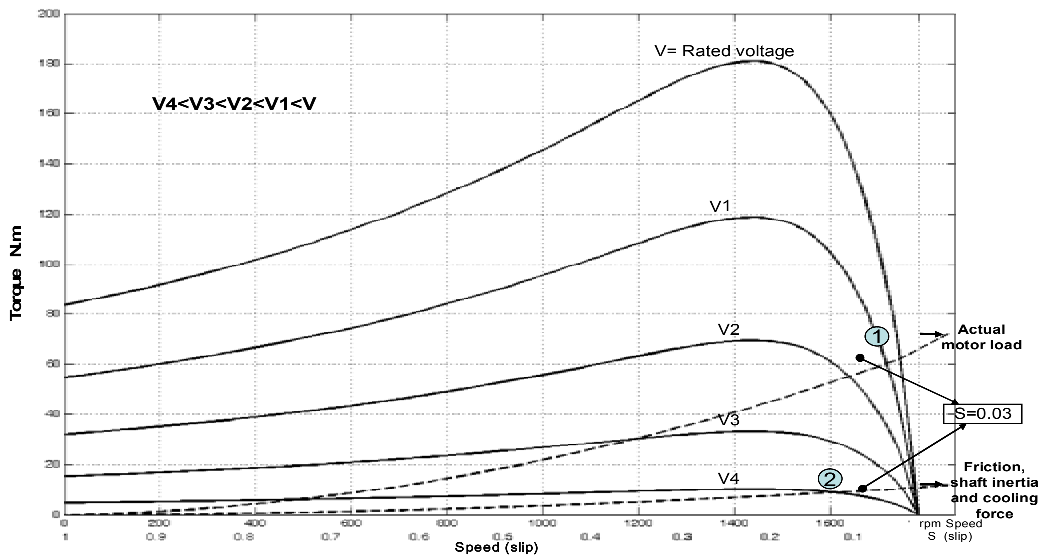

Figure 1 - motor torque-speed curve in terms of various voltage supply.

Figure 1 explains this issue well. In this figure it can be seen how the voltage reduction causes to reduce the output torque of motor. In the nominal condition if point 1 is the equilibrium of the motor load and torque with 0.03 slip, same slip can be achieved by voltage reduction under the smaller torque of friction and motor cooling force in point 2. (In this figure friction and motor cooling force were exaggeratedly considered large so far as it can be shown in comparison of nominal torque.)

Experimental results show nearly acceptable results even in case of only one thin bar. It can then be concluded that its sensitivity to rotor bar cracks would be probably fine.

PARK APPROACH

A two-dimensional representation can be used for describing three-phase induction motor phenomena, a suitable one being based on the stator current Park's vector. As a function of mains phase variables $(i_a \; i_b \; i_c)$, the current Park's vector components

$(i_d \; i_q)$ are:

$$\begin{cases} i_d = \sqrt{\frac{2}{3}} i_a - \frac{1}{\sqrt{6}} i_b - \frac{1}{\sqrt{6}} i_c \\ i_q = \frac{1}{\sqrt{2}} i_b - \frac{1}{\sqrt{2}} i_c \end{cases} \tag{4}$$

Under ideal conditions, three-phase currents lead to a Park's vector with the following components:

$$\begin{cases} i_d = \frac{\sqrt{6}}{2} i_M \sin \omega t \\ i_q = \frac{\sqrt{6}}{2} i_M \sin(\omega t - \frac{\pi}{2}) \end{cases} \tag{5}$$

where i_M is the supply phase current maximum value and ω_s is the supply frequency [2].

By two methods the park vector can be use for fault diagnosis of induction motor. In the first method, the Lissajou's curve of $i_d - i_q$ is analyzed. According to (5), in the ideal and healthy condition this curve is a circular pattern centered at the origin of the coordinates while in the defect situation this circle is destroyed due to the introduced additional harmonic by defect. In this method diagnosis is occurred by comparison of Lissajou curve of healthy and defect motor.

The main disadvantage of this method is that the healthy pattern differs slightly from the expected circular one, because supply voltage is generally not exactly sinusoidal. Also, with this method only can determine the faulty condition and can not isolate the defect cause and area.

According to follow expression, another advanced way to fault diagnosis by Park's vector is that the studying of its modulus

$$\begin{aligned} \left| i_d + j i_q \right|^2 &= \frac{2}{3}(i_f^2 + i_{dl}^2 + i_{dr}^2) \\ &+ 3 i_f i_{dl} \cos(2\pi[\left| f_\upsilon - f_e \right| + f_e]t - \alpha + \beta_l) \\ &+ 3 i_f i_{dr} \cos(2\pi f_\upsilon t - \alpha + \beta_r) \\ &+ 3 i_{dl} i_{dr} \cos(4\pi f_\upsilon t + \beta_l + \beta_r) \end{aligned} \tag{6}$$

where “i_f, i_{dl}, and i_{dr}” are the peak values of, respectively, the fundamental supply phase current, the current's lower sideband component at frequency $(1-2s)f_e$, and the current's upper sideband component at frequency $(1+2s)f_e$; three angles “α_0 , β_l , and β_r ” denote the initial phase angle, respectively, for fundamental supply current, the current's lower sideband component and, finally, the current's upper sideband component[9]. This expression is verified by adding the defect harmonic to the motor currents and inserting them to expression (4).

As it is seen that Park's vector modulus includes the defect frequency directly, and in the mean time the fundamental harmonic is not appeared in this variable.

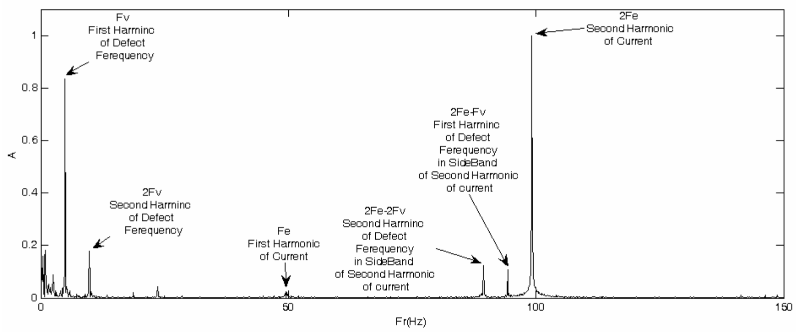

Figure 2 - Spectrum of the stator current Park's vector for a induction motor with One broken rotor bar .

Figure **2** shows a current Park's vector spectrum for the experimental motor with one broken bars. As it was theoretically predicted, the spectrum obtained has practically only defect frequency, 2nd harmonic, and no fundamental harmonic. Although, in practice, there still exists some negligible spectral components at the fundamental harmonic, due to the residual asymmetries that are inherent to any motor and to the voltage supply system.

EXPRIMENTAL RESULT

The test motor used in the experimental investigation was a three-phase, 50 **Hz,** 4-pole, **1.1 kW, Motozhen** induction motor, type **90L4A,** with two rotors of identical type, which can be interchanged. Each of them is a single-squirrel cage type rotor with **28** skewed and uninsulated bars. The motor mechanical load was provided by a simple magnetic clutch. The diagnostic instrumentation system used basically comprises a PC computer, supporting an ADVANTECH-1711 data acquisition board which is connected to three Hall effects current sensor, through a preconditioning module and MATLAB software was used for signals processing.

For crack and broken bars simulation, the rotors' bars in 3 stages were sparked. At first for the crack bar, an half of one bar was sparked (Fig. 3), which means thin bar.

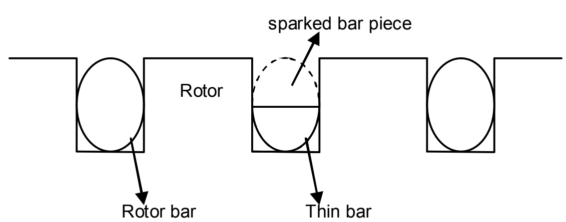

Figure 3 - The first stage for crack bar simulation

At the Second stage, one bar and then two bars were sparked, for simulation of the severity broken bar.

For applying the proper virtual loading, two points had to be reminded. At first, the voltage should not be reduced as mach as the motor could not to be run. Next the voltage reduction could make the remarkable slip, about 3%-7% per-unit. For our experimental motor, it could be reached to above conditions, with the voltage amount of 25v (one tenth of the rated voltage).

In the Table 1 the defect frequencies for difference conditions have been given. As it can be seen there are difference defect frequencies, which have been occurred because of the unequal rotor speeds due to lack of precision on the used voltage variation instruments, but it acknowledges the experimental park spectrum and show the sensitivity and applicatory of this method as well.

To process of obtained signal in the first the currents are normalized respect to their maximum amplitude then remove their DC level. After the Park's vector modulus computing to get better insight into the obtained results, its DC level was deliberately removed.

Figure 4 shows the Park’s vector spectrum for the case of the healthy motor and also Two broken bar with rated voltage under loading. As it can be observed by advanced Park's vector, fault diagnosis has been done clearly.

Figgure 4, 6 and 7 indicate the Park’s vector spectrum for the Thin bar, One broken bar and Two broken bars respectively, in comparison with the Healthy rotor under virtual loading. Obviously, the defect existence on the rotor with One broken bar is remarkable by increasing amplitude at the defect frequency (fig. 6). The Thin defect on the rotor bar is considered in the related Park's vector spectrum that is occurred by a little amplitude increasing at the defect frequency as well.

Table 1-broken bar frequency

Motor Condition		Phase Voltage	RPM	Slip per unit	Defect Frequency
Healthy	Without load	25	1428	4/93	4/93
		220	1499	0/06	0/06
	With load	220	1425	5/16	5/16
One Thin Bar		25	1444	3/37	3/37
		220	1499	0/06	0/06
One Broken Bar		25	1428	4/8	4/8
		220	1499	0/06	0/06
Two Broken Bar	Without load	25	1433	4/56	4/56
		220	1499	0/06	0/06
	With load	220	1427	5/02	5/02

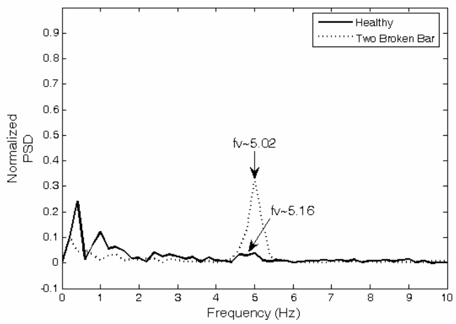

Figure 4 - Spectrum of the stator current Park's vector for Healthy induction motor and Two broken rotor bar (phase voltage= 220v).

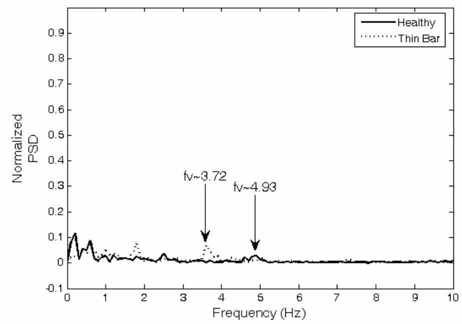

Figure 5 - Spectrum of the stator current Park's vector for Healthy induction motor and One thin rotor bar (phase voltage= 25v).

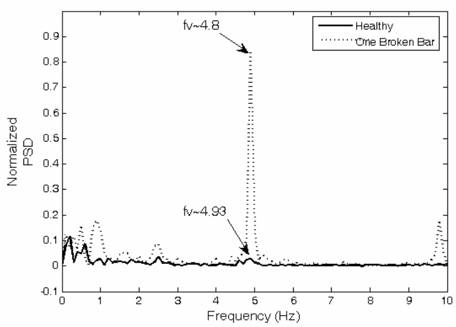

Figure 6 - Spectrum of the stator current Park's vector for Healthy induction motor and One broken rotor bar (phase voltage= 25v).

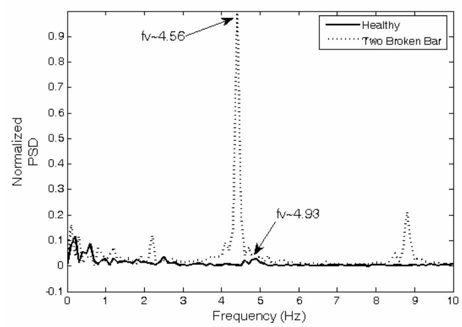

Figure 7 - Spectrum of the stator current Park's vector for Healthyinduction motor and Two broken rotor bar (phase voltage= 25v).

By the way, in the case of two broken bars the amplitude of the defect frequency has been increased slightly in comparison with the case of One broken bar.
According to the figure 4 and 7 it can be considered that the virtual loading method diagnoses the two broken rotor bars better than the actual loading.

CONCLUSION

As a matter of fact in this paper a practical method has been presented for the broken bars diagnosis without actual loading. In this method the supply voltage reduction has been applied as a virtual loading which means without loading. Then after to be sure about the probable loading harmonic the rotor defect was diagnosed, based on the well known Park's vector spectrum approach. This plan would be useful where instruments for decreasing the supply voltage are available. Then better results can be obtained in comparison with the actual loading. This research would be a suitable substitution for loading when repairing induction motor firms where the proper loading is impossible and a diesel generator is used for the reduction of the induction motor's voltage easily.

Also experimental results show good results even in case of only one thin bar. It can then be concluded that its sensitivity to rotor bar cracks would be probably fine.

REFERENCES

[1] G.K. Singh, S. A. S. AlKazzaz "Induction machine drive condition monitoring and diagnostic research--a survey," Electric Power Systems Research, vol. 64, pp. 145_/158, 2003.

[2] M. E. H. Benbouzid, "A review of induction motors signature analysis as a medium for faults detection," IEEE Trans. Ind. Electron., vol. 47, pp. 984–993, Oct. 2000.

[3] S. Nandi, H. A. Toliyat, X. Li, "Condition Monitoring and Fault Diagnosis of Electrical Motors—A Review," IEEE Trans. Energy Conv. , vol. 20, no. 4, Dec 2005.

[4] P. J. Mccully , C. F. landy, "Evaluation of current and vibration signals for squirrel cage induction motor condition monitoring," EMD 97, IEE Conf. Publication, No. 444, Sep 1997.

[5] M. Trzynadlowski, M. Ghassemzadeh, and S. F. Legowski, "Diagnostics of mechanical abnormalities in induction motors using instantaneous electric power," IEEE Trans. Energy Conversion, vol. 14, pp. 1417–1423, Dec. 1999.

[6] F. L. Stanislaw, A. H. M. S.A. H. M. Sadrul Ula, and A. M. Tryzynadlowski, "Instantenous power as a medium for the signature analysis of induction motors," IEEE Trans. Ind. Applicat., vol. 32, pp. 904–909, July/Aug. 1996.

[7] S. M. A. Cruz and A. J. M. Cardoso, "Rotor cage fault diagnosis in three-phase induction motors by the total instantaneous power spectral analysis," in Conf. Rec. IEEE-IAS Annu. Meeting, vol. 3, 1999, pp. 1929–1934.

[8] 8 M. Aiello, A. Cataliotti, S. Nuccio, "A Comparison of Spectrum Estimation Techniques for Nonstationary Signals in Induction Motor Drive Measurements," IEEE Trans. Ins. Measur. , vol. 54, no. 6, Dec 2005.

[9] M. Eltabach, A. Charara, I. Zein, "A comparison of external and internal methods of signal spectral analysis for broken rotor bars detection in induction motors," IEEE Trans. Industrial Electronics, vol. 51, no. 1, February 2004.