Detection of Rotor Bar Faults by Using Stator Current Envelope

Hayri Arabacı and Osman Bilgin

Abstract— **The paper presents detection of rotor bar faults at steady state operation in squirrel cage induction motor by using stator current envelope. Three different rotor faults and healthy motor conditions were investigated in experiments. One of the stator currents has been used in the investigation of effects of rotor faults on the current envelope. The ratios of fluctuation of the envelope were used as feature of fault conditions for diagnosis. In the literature a lot of studies are available about diagnosis and detection rotor many different analysis and feature extraction methods such as motor current signature analysis (MCSA), fast Fourier transform (FFT). Unlike the literature, in the present study the stator current envelopes are used. The use of the current envelope does not affect the performance of the fault detection, while requiring much less computation and low cost in implementation, which would make it easier to implement in embedded systems for condition monitoring of motor.**

Index Terms—**Broken rotor bar, fault diagnosis, induction motors, motor current signature analysis, stator current envelope.**

I. INTRODUCTION

Induction motors are widely used in industry because of stability, low production costs and ease of control. Despite their reliability and stability, some faults may still occur. It can cause unexpected safety risks and economic expenses. A certain portion of the faults are rotor faults. The rotor faults may occur during production as small faults or may result from production faults or mechanical, environmental, electromagnetic or thermal pressure on the rotor when the motor runs [1]. Even if these faults are small at first, the faults greaten because of these pressures in course of time. Especially transient events accelerate this growth [2]. Failed motors negatively affect torque, current and speed of the motor [3-5]. Therefore, many studies have used the occurred symptoms in these motor parameters. Analysis methods such as MCSA [3-5] and vibration analysis [6] have been used for detection of the rotor faults.

Current signals can easily be monitored for condition monitoring [5]. The problem is how to extract different features from the current signal and discriminate among various motor conditions. Most of the works on MCSA use second order based techniques like FFT analysis. Some work particularly uses the sidebands around the supply line frequency at twice the slip frequency and its multiples $(1 \pm 2s)f$ in frequency spectrum of the current [9, 10]. The amplitude of the fundamental frequency is considerably greater than the sideband amplitude and the sideband is very close the fundamental frequency component depending on the slip. Therefore, relied solely on current FFT particular solution has only limited ability to make an accurate detection [7]. Recent years, many upgrades of the basic MCSA algorithms have been proposed in order to improve detection accuracy and sensitivity. To solve the problem [8] determine broken bar fault through the analysis of specific oscillation in the duty cycle of the modulated stator voltage appears. To develop such fault-detection, several authors have used modern computing approaches such as neural networks [9], artificial immune system [10].

Requirement of much less computation and low cost in implementation make detection algorithms easier to implement in embedded systems for motor condition monitoring. Therefore, the main goal of this paper is to develop a simple diagnosis method, which would use only one phase stator current signal, without the need for any additional computations like FFT or similar techniques and any complex classifier.

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II. MATERIAL AND METHOD

The rotor consists of rotor bars, end-ring and rotor laminas. The bars and end-ring are made with aluminium casting in the conventional induction motor. These parts are differently made of copper bar and plate in submersible induction motors. The connection between the bars and end ring are made by weld. The squirrel cage faults generally cause by the welded regions. Mistakes during the welding cause bad conductivity in the manufacturing process or after the weld may be deteriorated by the motor stresses. If there isn't any conductivity between rotor bars and end ring, current don't flow through it. These conditions are called "Broken rotor bar".Rotor faults account for 5-10% of total induction motor faults.

In the investigating of rotor faults, the stator current has been generally used. The faults affect the current according to motor slip as in Equation (1).

$$f_b = (1 \pm 2ks)f \quad , \quad k = 1,2,3,.... \qquad (1)$$

Where *f* is main frequency and *s* is slip. The effects cause fluctuations on the current. The distortion of the rotor's magnetic field orientation and the resulting local saturation in the rotor laminations around the region of the broken bars lead to a quasi-elliptical trace of the magnetic field's space vector and consequently modulate in a sequential manner the three-phase stator current. The modulation of the three-phase stator current is the so-called envelope and that is cyclically repeated at a rate equal to twice the slip frequency.

In the present study one of the stator currents has been used in the investigating of effects of rotor faults on the current envelopes. The ratio of fluctuations of the envelope was used as features of faults conditions for diagnosis. The current is normalized for better feature extraction. The fluctuation ratio is calculated as Equation (2).

$$\text{The fluctuations ratio} = 2 * \frac{\text{Max. value} - \text{Min value}}{\text{Max. value} + \text{Min. value}} \qquad (2)$$

Maximum end minimum values and current envelope are given in Fig. 1.

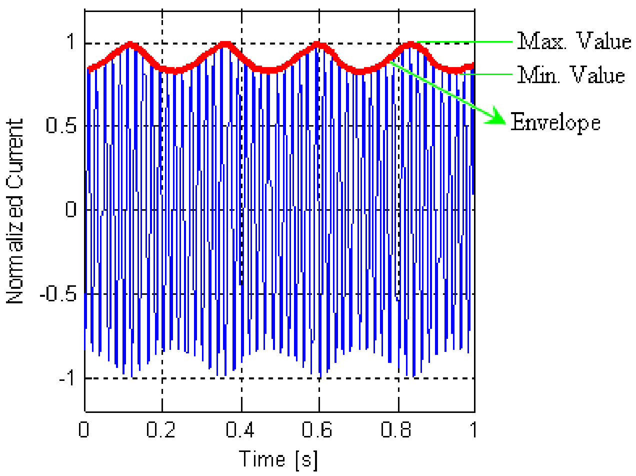

Fig. 1. Time variations of stator current for three adjacent broken rotor bars fault.

The fluctuation ratio is analyzed for each fault size and they are compared with other fault sizes and healthy rotor.

III. Experimental Study and Test Results

The experiments are made by 30 HP, 8'', with 18 bars, 380V, 2 poles and 50 Hz squirrel cage submersible induction motor. The purposed three different rotor faults were created in the factory at the production phase. The analyzed rotor faults are shown as follows:

- A rotor with one broken rotor bar,
- A rotor with two adjacent broken rotor bars,
- A rotor with three adjacent broken rotor bars.

In order to ensure accurate measurements, each rotor fault was created separately and passed through each assembly phase. To obtain broken rotor bar faults, a small part (5 mm length) is cut from the mid side of rotor bar and the two parts of bar are stacked from both sides. So conductivity of the bar is decreased to 0, as shown in Fig. 2. Broken rotor bar photograph is given in Fig. 3.

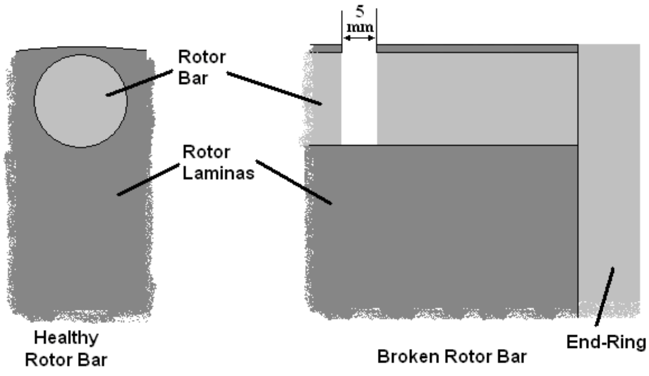

Fig. 2. Obtaining of broken rotor bar.

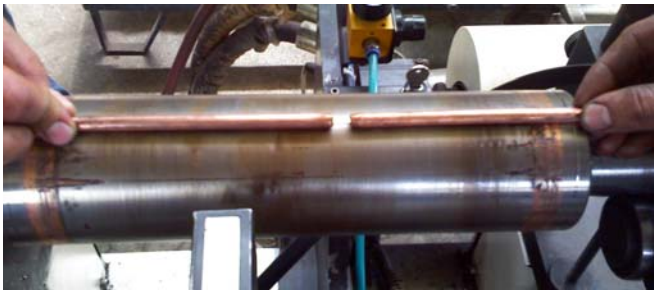

Fig. 3. Photographs of broken rotor bar parts and rotor.

The motors were tested in the motor factory by using experiment system. The tested motor was loaded by generator. Load is leveled by using resistors which conducted to the generator. The photographs of the used experiment system are given in Fig. 4. The one phase current of stator was obtained in steady state operation for each fault.

Fig. 4. Photograph of experiment system.

The current was sampled by using Hall-effect current sensors from the tested motor. Sampling was made at 7.5 kHz and the data length is 2 second so it has 15000 values. Fig. 5 shows time variations of motor currents in cases of a healthy rotor and faulted motors. When compared to the healthy motor, the currents of faulted motors show significant fluctuations.

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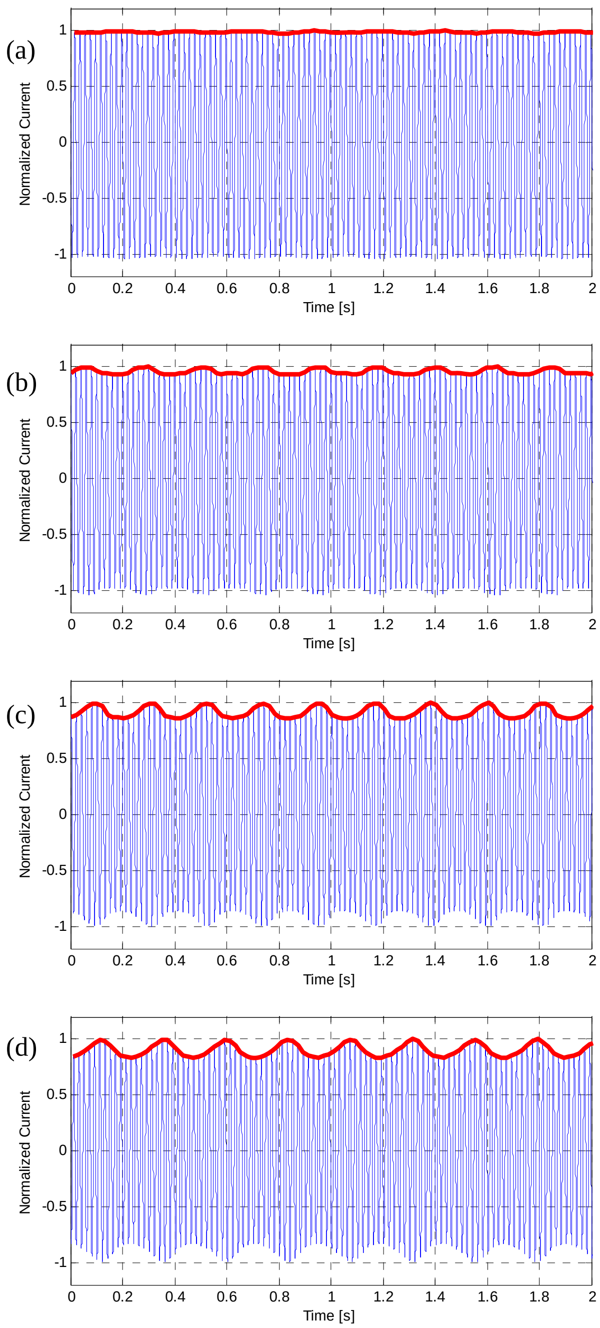

Fig. 5. Experimental time variations and envelopes of stator current: (a) healthy rotor; (b) one broken rotor bar; (c) two adjacent broken rotor bars; (d) three adjacent broken rotor bars.

The ratios of fluctuation of envelope were calculated according to Equation 2 for healthy and faulty data sets. They are depicted in Fig. 6. From Fig. 6, it can be seen that as the discrimination of the faults groups becomes significant. It shows that the ratios of fluctuation can be used to detect the rotor bar faults. If threshold values are determined for the fault groups (it is shown in Fig. 7), the faults can be easily classified according to these threshold values.

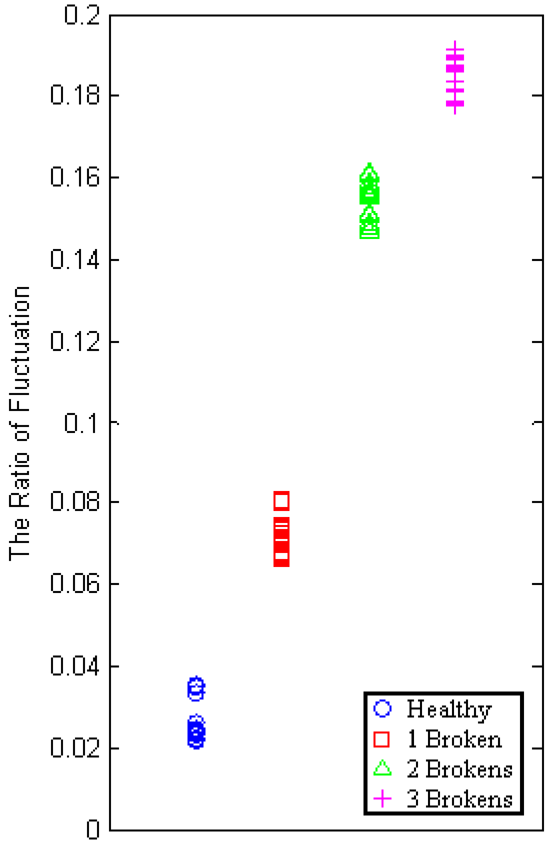

Fig. 6. The ratio of fluctuations of envelopes for healthy and faulty data sets.

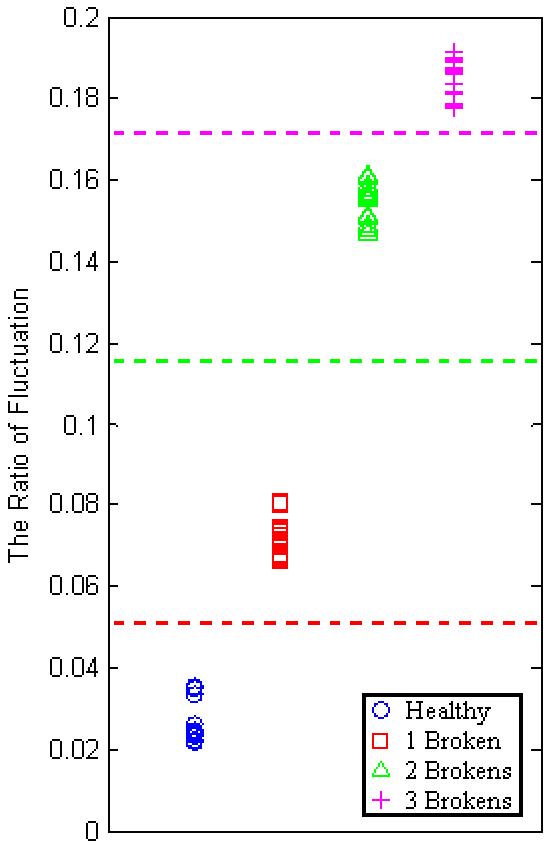

Fig. 7. Threshold values for healthy and faulty data sets.

IV. Conclusion

This study presented analysis of the feature extraction of rotor cage faults on current envelope at steady state operation. For the analysis, experiments performed for 3 different rotor faults and healthy motor conditions. The experimental results illustrate that the fluctuations of current envelope can be successfully applied for the broken bar diagnosis. The method is significantly important because using of the proposed method means less computation and low cost in implementation, which could lead to more effective and less costly embedded system designs for motor condition monitoring applications.

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References

[1] A.H. Bonnett and G.C. Houkup, "Cause and analysis of stator and rotor faults in three-phase squirrel-cage induction motors", IEEE Transactions on Industry Applications 28, No. 4, pp. 921–937, Aug. 1992.

[2] J. Penman and A. Stavrou, "Broken Rotor Bars Their Effect on the Transient Performance of Induction Machines", IEE Proc.-Electr. Power Appl., Vol. 143, No. 6, pp. 449-457, Nov. 1996.

[3] H. Arabaci and O. Bilgin, "Automatic Detection and Classification of Rotor Cage Faults in Squirrel Cage Induction Motor", Neural Computing And Applications, Vol. 19, No. 5, pp. 713-723, Jan. 2010.

[4] X. Ying, "Characteristic Performance Analysis of Squirrel Cage Induction Motor with Broken Bars", IEEE Transactions on Magnetics, Vol. 45, No. 2, pp. 759-766, Feb. 2009.

[5] M. Haji and H.A. Toliyat, "Pattern recognition – a technique for induction machines rotor fault detection 'Eccentricity and broken bar fault' ", IEEE Industry Applications Conference, 2001. Industry Applications Conference, 2001. Thirty-Sixth IAS Annual Meeting. Vol. 3, pp. 1572-1578, 2001.

[6] H. Su and T. Chong, "Induction machine condition monitoring using neural network modeling", Transactions On Industrial Electronics, Vol. 54, No. 1, pp. 241–249, 2007.

[7] M. Benbouzid, M. Vieira and C. Theys, "Induction motors' faults detection and localization using stator current advanced signal processing techniques," IEEE Transactions on Power Electronics, vol. 14, no. 1, pp. 14–22, Jan. 1999.

[8] M. Nemec, K. Drobnic, D. Nedeljkovic, R. Fišer and V. Ambrožic, "Detection of Broken Bars in Induction Motor Through the Analysis of Supply Voltage Modulation", IEEE Transactions on Industrial Electronics, Vol. 57, No. 8, pp. 2879-2888, Aug. 2010.

[9] B. Ayhan, M.-Y. Chow and M.-H. Song, "Multiple Discriminant Analysis and Neural-Network-Based Monolith and Partition Fault-Detection Schemes for Broken Rotor Bar in Induction Motors", IEEE Transactions on Industrial Electronics, Vol. 53, No. 4, pp. 1298-1308, Aug. 2006.

[10] P.J.C. Branco, J.A. Dente and R.V. Mendes, "Using Immunology Principles for Fault Detection", IEEE Transactions On Industrial Electronics, Vol. 50, No. 2, pp. 362-373, Apr. 2003.