Detection of Rotor Bar Corrosion in Three Phase Asynchronous Motors Using Wavelet Analysis

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Abstract— **In this paper a new method for the detection of rotor bar corrosion in squirrel-cage asynchronous motor is introduced. Because of costly machinery repair, extended process down time, and health and safety problems, it is very important to focus on fault detection strategies for industrial plant. Detection of cage motor broken rotor bars has long been an important but difficult job in the detection area of motor faults. It is known that about 9% of induction motor failures are caused by failure of the rotor faults. Rotor bar corrosion causes cracked rotor bars. Most recent efforts are focusing on current spectrum analysis for detecting rotor bar faults. This paper represents instantaneous power analysis to detect rotor bar corrosion.**

Keywords- Rotor bar corrosion, rotor bar fault, asynchronous motor, wavelet analysis

I. Introduction

Nowadays, three phase asynchronous motor has been the workhorse of industry. The applications of asynchronous motors are widespread. Some have very important role in assuring the continuity of the process and production chains of many industries.

A majority are used in electric utility industries, military applications, nuclear plants and domestic appliances industries. All these industries motors are often used in hostile environments such as corrosive and dusty places. However, due to working environment, manufacturing factors, installing factors internal motor faults frequently occur. These failures can lead to economic loss and safety problems due to unexpected and sudden production stoppages. More important, these failures may even result in the loss of lives, which cannot be tolerated [1].

The major faults can broadly be classified as follows:

-Internal Faults

- Stator winding faults
- Broken rotor bar or cracked rotor bar faults
- Bearing faults
- Static and dynamic air-gap irregularities

-External Faults

To protect our plants, systems we have to develop protection strategies. There must be symptoms for detection of all these failures [1].

- Unbalanced line currents
- Increase losses and reduction in efficiency
- Excessive heating

In literature, motor current signature analysis is a condition monitoring technique that widely used to diagnose problems in electrical motors [2]. Various techniques have been purposed to detect rotor bar fault. Generally used technique is monitoring stator current to detect sidebands around the supply frequency [3-6].

Rotor bar corrosion is a symptom for broken rotor bar or cracked rotor bar faults. However, we need to know about reasons of rotor bar corrosion. In the next chapter, we introduce rotor bar corrosion fault.

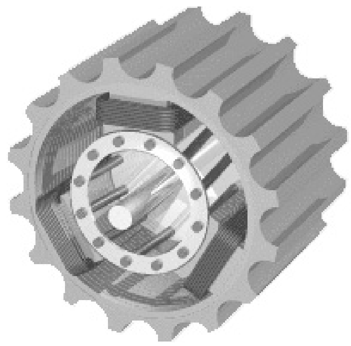

Figure 1. A squirrel-cage asyncronous motor

In chapter three; authors investigate the diagnosis of the induction motor corrosive rotor bar via instantaneous power. Wavelet transforms performed on this instantaneous power and by these wavelet coefficients rotor bar corrosion detected. Simulations are realized for 3kw three phase asynchronous motor. % 30 corrosion rates and % 50 corrosion rates with full load and half load simulations realized with Matlab Simulink software.

II. ROTOR BAR CORROSION

The corrosion model of a rotor bar was derived by electromagnetic theory. A corrosive rotor bar has a shell made with an oxidized material. And this oxidation causes rust covering rotor bar. The rust covering the rotor bar does not affect the mutual inductance between the rotor bar and stator winding, because the mutual inductance only depends on the geometric shape and the physical arrangement of conductors. It is important consider the current density, permeability, conductivity, and skin depth parameters [7].

The leakage inductance and resistance of rotor bar varies when rotor bar has corrosion. The variation of resistance and leakage inductance has an effect on the results of motor dynamic simulations and experiments. Leakage inductance and resistance of the corrosion model of a rotor bar is calculated from the relations of magnetic energy, inductance, current, and magnetic-field intensity [8].

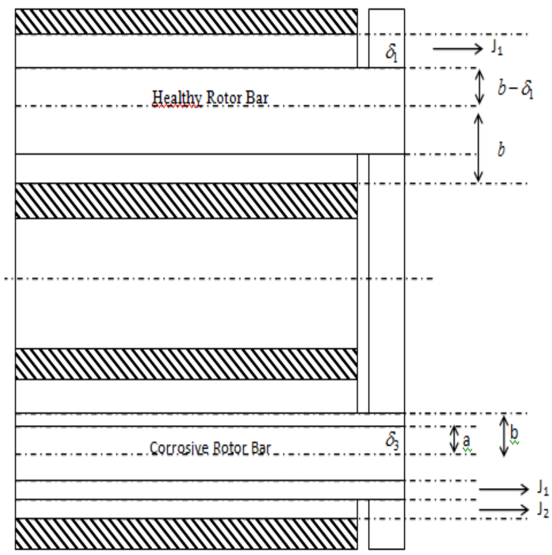

Figure 2. Healthy and corrosive rotor bar model

fs slip frequency, μ_1 is relative permeability, σ_1 is conductivity, δ_1 is the skin depth of normal material and μ_2 is relative permeability, σ_2 is conductivity, δ_2 is the skin depth shell of corrosive material in our corrosion model.

$$\delta_1 = \frac{1}{\sqrt{\pi\, fs\, \mu_1 \sigma_1}} \tag{1}$$

$$\delta_2 = \frac{1}{\sqrt{\pi\, fs\, \mu_2 \sigma_2}} \tag{2}$$

The magnetic-flux density of a corrosive rotor bar B_2 calculated as Eq.4 by using corrosive rotor bar skin depth δ_3 Eq.5.

$$B_1 = \mu_1 H_1 = \mu_1 \frac{r^2 - (b-\delta_1)^2}{2r} J_1 \tag{3}$$

$$B_2 = \mu_2 H_2 = \frac{\mu_2}{2r}\left[a^2(J_1 - J_2) + (b-\delta_3)^2 J_1 + r^2 J_2\right] \tag{4}$$

$$\delta_3 \cong (b-a) + \delta_1 \tag{5}$$

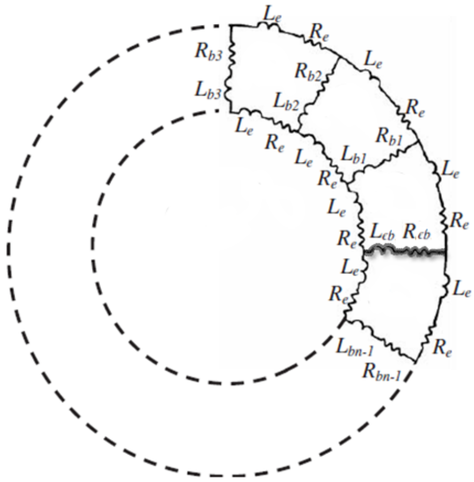

Figure 3. Healthy and corrosive rotor bar equivalent circuit model

I_b and I_{bc} are obtained as follows;

$$I_b = \pi\left(2b\delta_1 - \delta_1^2\right)J_1 \tag{6}$$

$$I_{cb} = \pi\left(a^2 - b^2\right)(J_1 - J_2) + \pi\left(2b\delta_3 - \delta_3^2\right)J_1 \tag{7}$$

To obtain healthy rotor bar leakage inductance and corrosive rotor bar leakage inductance rate magnetic energy relations used. (Eq.8, 9, 10, 11, 12)

$$W = \frac{1}{2} L I^2 = \frac{1}{2}\int_v \mu H^2 dV \tag{8}$$

$$L_b = \frac{2W_b}{\left[\pi\left(2b\delta_1 - \delta_1^2\right)J_1\right]^2} \tag{9}$$

$$L_{cb} = \frac{2W_{cb}}{\left[\pi\left(a^2 - b^2\right)(J_1 - J_2) + \pi\left(2b\delta_3 - \delta_3^2\right)J_1\right]^2} \tag{10}$$

$$R_b = \frac{l}{\sigma_1 S} = \frac{\frac{l}{\pi}}{\sigma_1\left(2b\delta_1 - \delta_1^2\right)} \qquad (11)$$

$$R_{cb} = \frac{l}{\sigma_1 S_1 + \sigma_1 S_2} = \frac{\frac{l}{\pi}}{\sigma_1\left(2a\delta_1 - \delta_1^2\right) + \sigma_2\left(2ab - a^2\right)} \qquad (12)$$

By using conductivity and permeability of materials we can determine the relation between corrosive rotor bar and healthy rotor bar inductance, resistance. Materials conductivity and permeability were given with Table I.

A healthy motor simulation used for modeling a damaged motor. Simulation made under load conditions and corrosive rotor bar fault modeled by the variation of rotor bar resistance and inductance. Corrosion rate was given with the Eq.13. Resistance and inductance rates were given with Table II and rate relations shown with the Fig.4.

We can determine inductance and resistance for %30 corrosion with the Eq. (1-12), Table I, using the values b=10mm a=7mm, slip frequency 0.5, we obtained L_{cb}/L_b rate and R_{cb}/R_b rate as Eq. 14, Eq.15.

$$\%\ \text{Corrosion Rate} = \frac{b-a}{b} = 30 \qquad (13)$$

$$R_{cb} = R_b \times 1.55552 \qquad (14)$$

$$L_{cb} = L_b \times 11.5654 \qquad (15)$$

For modeling %50 corrosion with parameters from Table I, using the values b=10mm a=5mm, slip frequency 0.5, determined rates were given with Eq. 17, Eq.18

$$\%\ \text{Corrosion Rate} = \frac{b-a}{b} = 50 \qquad (16)$$

$$R_{cb} = R_b \times 2.47051 \qquad (17)$$

$$L_{cb} = L_b \times 21.6247 \qquad (18)$$

TABLE I. CONDUCTIVITY AND PERMEABILITY OF MATERIAL

Material	Conductivity (S/m)	Permeability ($H \cdot m^{-1}$)
Normal Material Steel	1.1×10^{7}	1.2×10^{-6}
Shell Material Iron Dioxide	1.0×10^{2}	3.6×10^{-6}

TABLE II. ROTOR BAR CORROSION RATES

Lcb/Lb	***Rcb/Rb***	***Corrosion Rate (%)***
11.5654	1.55552	30
12.6700	1.63488	32.5
13.7747	1.71424	35
14.9702	1.81164	37.5
16.1657	1.90904	40
17.4675	2.03141	42.5
18.7694	2.15378	45
20.1970	2.31214	47.5
21.6247	2.47051	50

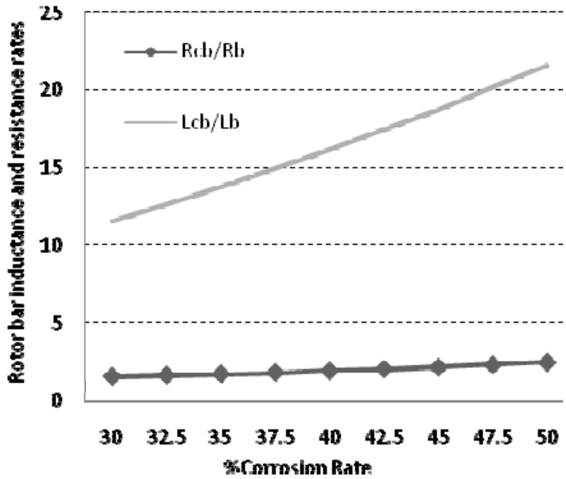

Figure 4. Corrosion rate and rotor bar inductance-resistance rate relation

III. WAVELET ANALYSIS OF INSTANTANEOUS POWER

A change in instantaneous power waveform is defined as the instant at which a sudden increases, decreases or transients are observed in the magnitude of the instantaneous power. Fourier transform and wavelet transform have been used for damage detection, broken bar detection. The classical Fourier transform is a frequency domain method. Fourier analysis is suitable method to analyze stationary signals but it is inadequate to detect non-stationary signals as transient signals. For overcoming this problem a short time fourier transform is used. Short time fourier transform is adequate for solving time location problem. But this transform cannot be suitable for non-periodic and high frequency transients [9]. Analyzing signals with multiple resolutions in time, in high frequency and in low frequency is very important for fault detection.

Wavelet transform is effective time frequency analysis tool for non-stationary signals, trends repeating patterns as fault signals of asynchronous motors. The wavelet analysis provides a kind of mathematical "microscope" to zoom in or zoom out on waveforms. Wavelets features of extraction and representation properties can be used to analyze instantaneous power of motor with rotor bar corrosion faults. The discrete wavelet transform analyze the signal at different frequency bands with different resolutions by decomposing the signal into a coarse approximation and detail information [10].

Determining a suitable wavelet type and number of level is very important in analysis of signals. Different types of wavelets and levels performed and which type of wavelet and level give the maximum efficiency is selected (Table III).

The Daubechies order three; discrete wavelet transform was applied to the instantaneous power. The instantaneous power signals are decomposed into six different levels. Levels identified by D_1-D_6.

TABLE III. D_6 DETAIL MAX VALUES DAUBECHIES ORDER COMPARISON

Db2	Db3	Db4	Db5	Db6	Db7	Db8
905	949	770	625	688	728	677

Corrosion faults under %50 loaded asynchronous motor instantaneous power waveforms were given with Fig.6 and Fig.7. D_6 and D_5 details are seen in Fig.6 and Fig.7 and details maximum and minimum values comparison was given with Table IV and Table V.

TABLE IV. D_6 DETAIL MAX-MIN VALUE COMPARISON

Motor Condition	%50 Load		%100 Load	
	Max	Min	Max	Min
Healthy Motor	0	0	0	0
%30 Corrosion Fault	949	-652	3530	-2451
%50 Corrosion Fault	1280	-1017	3904	-3890

TABLE V. D_5 DETAIL MAX-MIN VALUE COMPARISON

Motor Condition	%50 Load		%100 Load	
	Max	Min	Max	Min
Healthy Motor	0	0	0	0
%30 Corrosion Fault	1064	-922	4690	-4320
%50 Corrosion Fault	1541	-1034	5050	-2892

Corrosion faults under %100 loaded asynchronous motor instantaneous power waveforms were given with Fig.9 and Fig.10.

These comparisons show us we can clearly detect corrosion rate and corrosion faults under load conditions. We can classify corrosion rate with the maximum and minimum values.

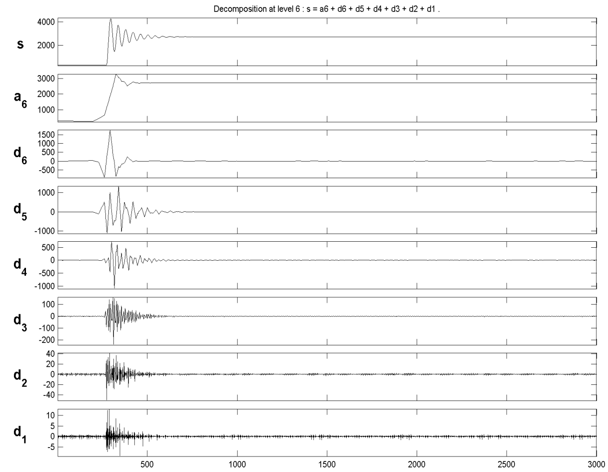

Figure 5. Healty motor under %50 load instantaneous power wavelet analysis details

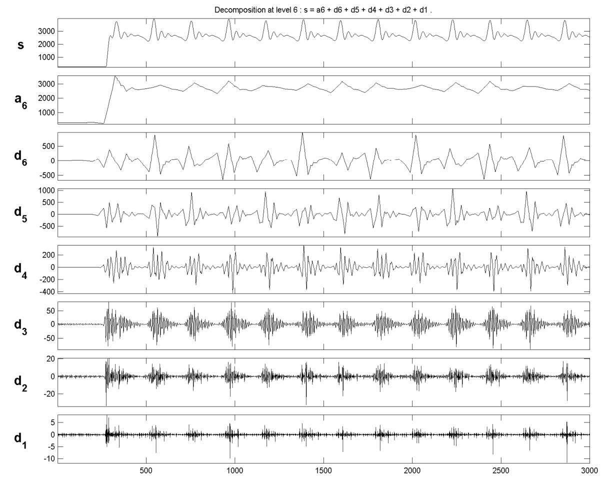

Figure 6. %30 Corrosion faulty motor under %50 load instantaneous power wavelet analysis details

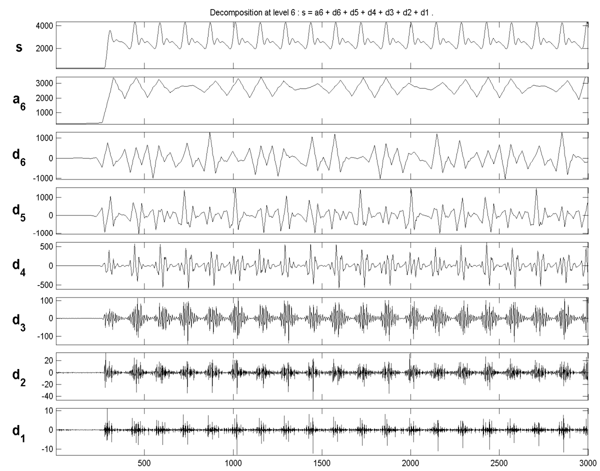

Figure 7. %30 Corrosion faulty motor under %100 load instantaneous power wavelet analysis details

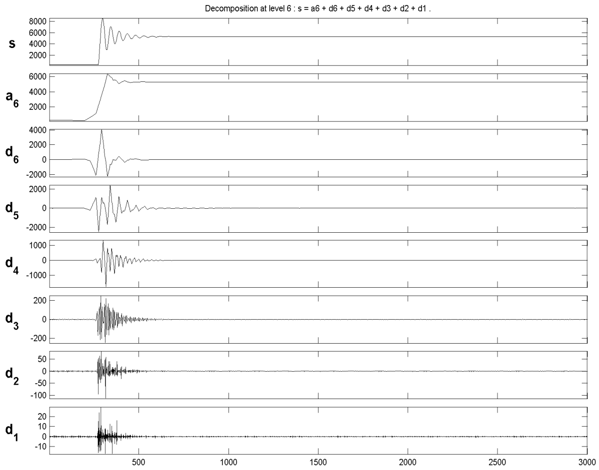

Figure 8. Healty motor under %100 load instantaneous power wavelet analysis details

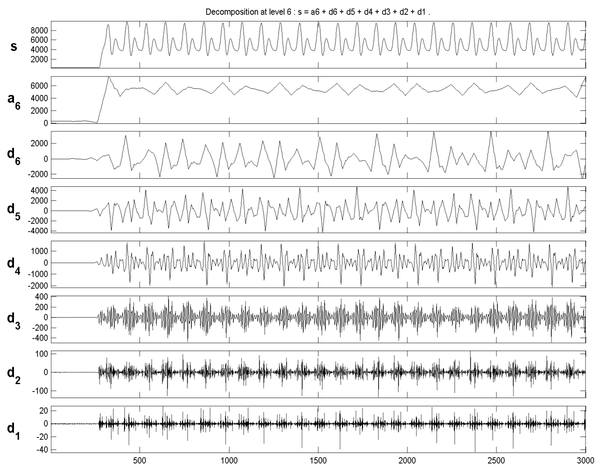

Figure 9. %50 Corrosion faulty motor under %50 load instantaneous power wavelet analysis details

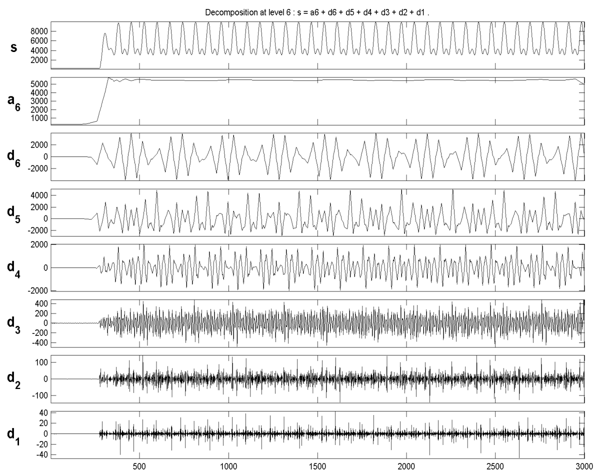

Figure 10. %30 Corrosion faulty motor under %50 load instantaneous power wavelet analysis details

IV. CONCLUSION

In this study, we carried out rotor-bar corrosion fault detection using discrete wavelet analysis of instantaneous power. As shown in chapter three, the results of discrete wavelet analysis give the advantageous information to decide the faulted situation. We can say that the corrosion faults eligibility increases with load increment and corrosion rate increment.

As a result it is clearly shown that when a rotor bar has corrosion its resistance and inductance increases and wavelet analysis of the instantaneous power detects the fault of a corrosive rotor bar as the progress of a rotor-bar fault under load condition. Computer simulations were achieved using the MATLAB Simulink with an electrical model of a 3-kW, three-phase squirrel-cage asynchronous motor.

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