ANALYSIS OF BROKEN ROTOR BARS FAULT IN INVERTER FED INDUCTION MOTOR BY MEANS OF MOTOR CURRENT SIGNATURE ANALYSIS AND STRAY FLUX OF MOTOR

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Abstract: In this paper the analysis of effect of broken rotor bar fault in squirrel-cage induction motor fed by frequency converter is presented. The motor current signature analysis as well as stray flux of motor were used in order to verify the capability of these techniques to identify the presence of different types of investigated fault in case of different types of supply and load. There were measured 4-pole motors with different level of broken rotor bar fault under different loads. Obtained data is presented in the form of graphs and tables and the comparison of obtained results was carried out.

Keywords: squirrel-cage induction motor fault; motor current signature analysis; stray flux; broken rotor bars; inverter; fault diagnosis; condition monitoring

1. INTRODUCTION

Induction machines are generally perceived as highly important in various types of industries because their cost is relatively low, and in the same time they can perform with certain reliability. So in order to prevent operational damage of motor and further financial losses early detection and diagnosis of present faults should be conducted.

Even when minor faults occur, electric machines can still run for a significant amount of time, however with time those minor faults can evolve and become a reason for a complete machine breakdown. This is why for the protection of industrial equipment preventive steps should be taken at times.

In this research, motor current signature analysis (MCSA) as well as the stray flux of the motor are used as the diagnosis techniques of investigated motors.

Inverter-fed motor line current, unlike a utility driven one, includes time harmonics that affect the fault diagnosis in a harmful manner: inherent floor noise interferes the quality of fault pattern recognition using line current spectrum. The MCSA shows low effectiveness because of the problem of interaction of fault induced harmonics with harmonics introduced by inverter, i.e. MCSA has lower monitoring sensitivity in this case [1].

Due to the fact that fault-related harmonics amplitude can differ depending on the motor supply and presence of noise in current signal, vast majority of current researches strive to improve MCSA method of fault diagnosis with the help of artificial intelligence and statistical analysis.

In this research, MCSA method together with the monitoring of stray flux of motor are applied on inverter-driven induction machines in order to verify the capability of this technique itself to identify specific for the broken rotor bars fault-indicative frequency components in cases of different types of supply.

2. THEORETICAL BACKGROUND

In the previous researches the generation and presence of frequencies related to the presence of broken rotor bar faults in the spectrums of magnetic flux density and current was described [2] from which it follows that magnetic flux density formula considering the presence of rotor asymmetry in the stator reference frame is

$$\begin{aligned} &B(\theta_1, t) = B_1 \cos(\omega_1 t - p\theta_1) + \\ &B_{1F} \cos((1-2s)\omega_1 t - p\theta_1) + \\ &B_{\nu} \cos(\nu\omega_1(1-s) - s\omega_1 - p\theta_1) + \\ &B_{\nu F} \cos(\nu\omega_1(1-s) + s\omega_1 - p\theta_1) \end{aligned} \tag{1}$$

where B – is the magnetic flux density, θ_1 – is angle around the periphery, t – is time, ω_1 – is angular stator supply frequency, p – is the number of pole pairs, s – is slip of the motor.

From stated above expression of the magnetic flux density the presence of the fundamental frequency can be clearly seen, as well as the presence of the sideband at frequency $2s\omega_1$. This is twice the slip frequency modulation of the supply current. Such a cyclic variation in the current reacts back onto the rotor to produce a torque variation at twice the slip frequency that, if the rotor does not have an infinitely high inertia, gives rise to $2s\omega_1$ variation on mechanical vibration that can be used for fault detection. This speed effect reduces the lower sideband current swing and produces an upper sideband at $(1+2s)\omega_1$, enhanced by modulation of the third harmonic flux in the stator and it can be seen that other sidebands at $(1\pm 2s)\omega_1$ are also found [3].

3. EXPERIMENTAL RESULTS

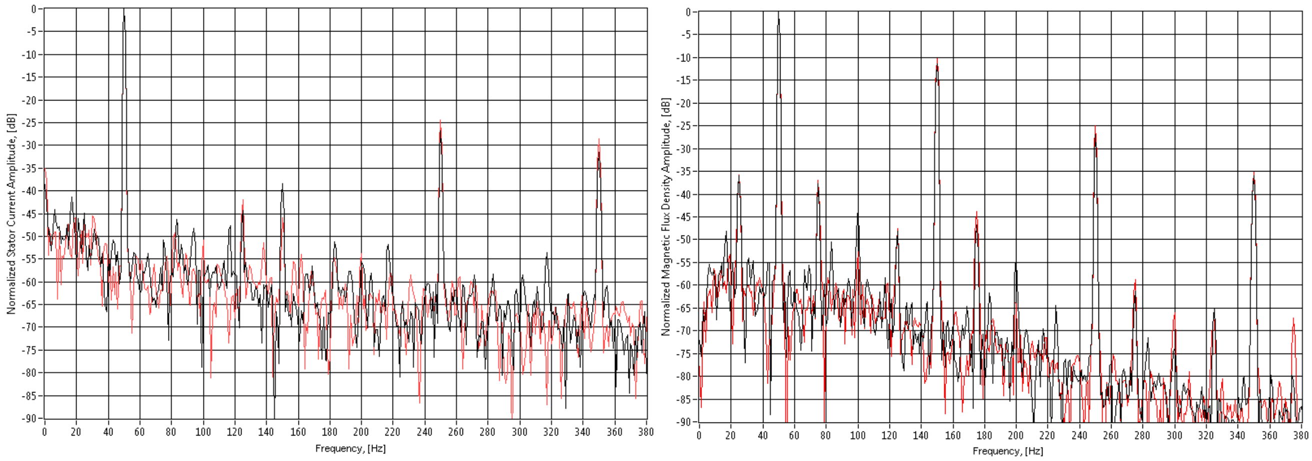
The current of motor as well as its stray flux were monitored and analyzed using the experimental installation with F.W. Bell 7030 Gauss/Teslameter and the Hall probe as a magnetic flux sensor and DAQ board by National Instruments. To analyze obtained data LabView software was used. The Unidrive M701 from Emerson Control Techniques was used as a supply source with the open loop control type.

There were measured motors with one broken rotor bar, two adjacent and two oppositely located broken rotor bars, as well as the healthy one. Measurements were carried out for three types of loads: no-load, half-load and full load and with switching frequencies of inverter of 3kHz. Table I shows parameters of investigated motors.

Measured results were also compared with the data obtained from the investigation of the same motors but with the line feeding [2].

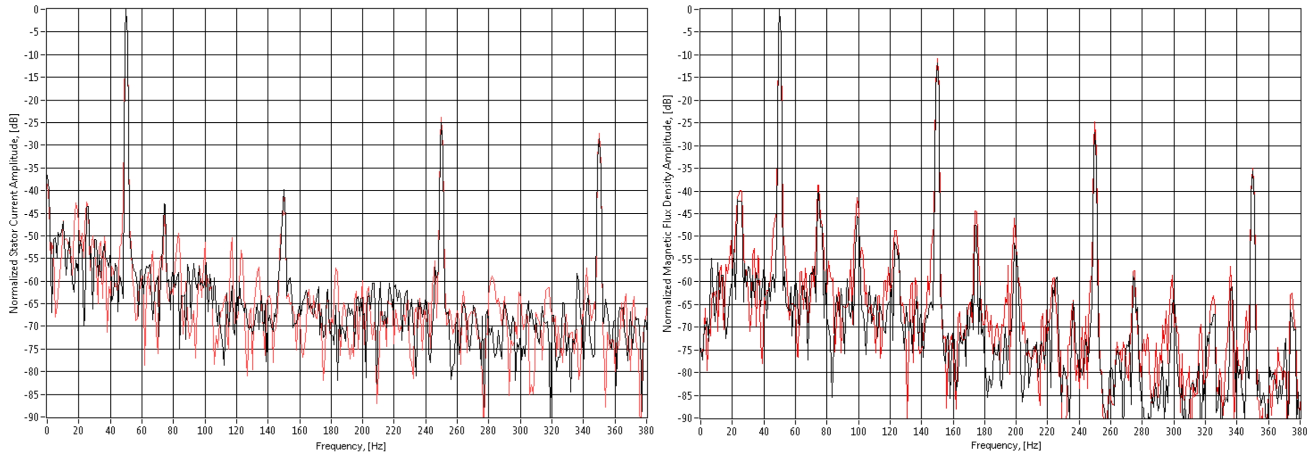
Rated power	1.1 kW
Rated stator voltage	400 V
Rated frequency	50 Hz
Rated speed	1440 rpm
Number of poles	4
Number of stator slots	36
Number of rotor slots	28

Table 1: Parameters of investigated motor.



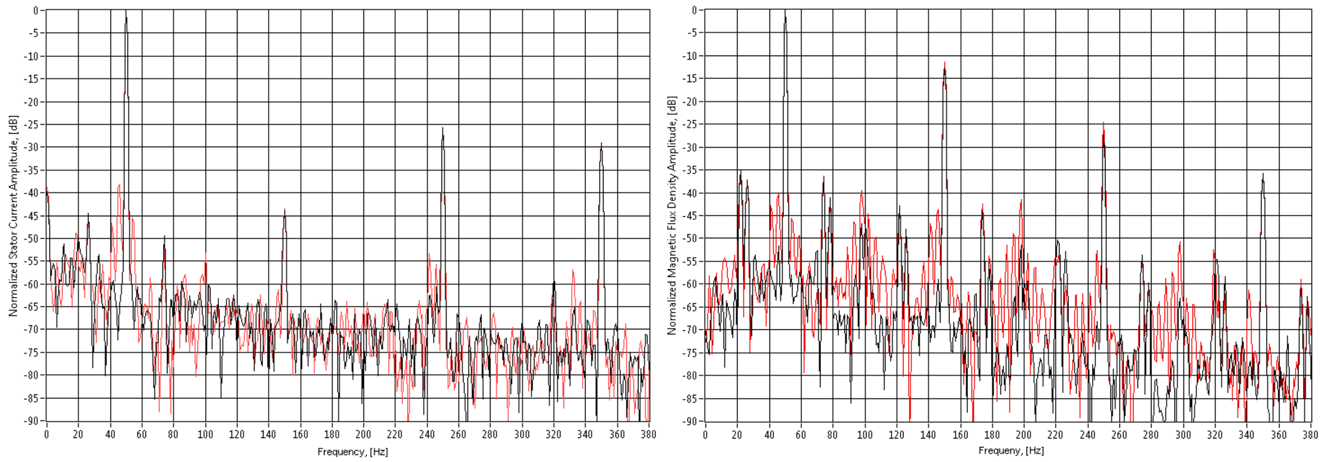
a) b)

Figure 1: Measured spectrums of current (a) and magnetic flux density (b) of the healthy motor (black) compared to the motor with 2 adjacent broken rotor bars(red) under no load



a) b)

Figure 2: Measured spectrums of current (a) and magnetic flux density (b) of the healthy motor (black) compared to the motor with 2 adjacent broken rotor bars(red) under half load



a) b)

Figure 3: Measured spectrums of current (a) and magnetic flux density (b) of the healthy motor (black) compared to the motor with 2 adjacent broken rotor bars(red) under full load

Results of the measurement of healthy motor compared to the motor with two adjacent broken rotor bars fed by the frequency converter are presented on Fig. 1, Fig. 2 and Fig. 3. On these figures spectrums are presented in normalized form. They give clear representation of healthy motor compared to the motor with two adjacent broken rotor bars under different loads: at no-load, half-loaded and fully loaded respectively.

Considering obtained results it can be seen that with the increase of the load the rise in the characteristic frequencies located around fundamental frequency and its multiples is clearly seen. The most significant are the sidebands around the 1st harmonic located at frequency 50 Hz that can be seen on the presented figures. Presence of the fault is clear in the case of current spectrums.

It was stated that due to the fact that fault-related harmonics amplitude can differ depending on the motor supply and presence of noise in current signal, the MCSA shows low effectiveness because of the problem of interaction of fault induced harmonics with harmonics introduced by inverter, i.e. MCSA has lower monitoring sensitivity in this case. But the results of present research show totally different picture. Considering the current spectrum of motors under the full load that are presented on Fig. 3a, the presence of broken rotor bars fault is easily detectable and it is not considerably differs from the spectrums of motors fed by the sinusoidal voltage.

Considering spectrums of magnetic flux density of investigated motors under varying level of load that are presented on Fig. 1b, Fig. 2b, and Fig. 3b, the rise in the characteristic frequencies around the fundamental one can be seen with the increase of the load as well.

The difference in the amplitudes of characteristic frequencies in the case of current and magnetic flux density signals and with the different types of supply can be seen in Table 2 and Table 3.

	Healthy motor				Motor with 2 adjacent broken bars			
	Half-load		Full load		Half-load		Full load	
	C*	F*	C*	F*	C*	F*	C*	F*
$(1-2f_s)\ f_1$	-57	-57	-37	-44	-44	-50	-58	-50
f_1	0	0	0	0	0	0	0	0
$(1+2f_s)\ f_1$	-54	-56	-44	-50	-45	-53	-59	-55
$(1-2f_s)\ 5f_1$	-63	-66	-58	-56	-59	-63	-64	-66
$5f_1$	-41	-26	-42	-27	-39	-26	-45	-27
$(1+2f_s)5f_1$	-75	-71	-86	-78	-101	-74	-77	-72
$(1-2f_s)7f_1$	-71	-74	-71	-63	-72	-71	-77	-73
$7f_1$	-51	-35	-61	-34	-57	-33	-54	-36
$(1+2f_s)7f_1$	-77	-77	-81	-78	-81	-78	-79	-73

Table 2: Measured current and flux amplitudes of motors fed by line voltage (*C – current; F-flux).

	Healthy motor				Motor with 2 adjacent broken bars			
	Half-load		Full load		Half-load		Full load	
	C*	F*	C*	F*	C*	F*	C*	F*
$(1\text{-}2f_s)\ f_1$	-64	-50	-65	-52	-43	-45	-38	-40
f_1	0	0	0	0	0	0	0	0
$(1+2f_s)\ f_1$	-49	-62	-62	-58	-48	-49	-46	-46
$(1\text{-}2f_s)\ 5f_1$	-58	-65	-61	-68	-55	-58	-56	-53
$5f_1$	-25	-27	-26	-27	-24	-27	-26	-25
$(1+2f_s)5f_1$	-66	-70	-74	-83	-60	-63	-82	-69
$(1\text{-}2f_s)7f_1$	-61	-81	-73	-85	-68	-73	-66	-75
$7f_1$	-28	-36	-29	-36	-27	-35	-29	-36
$(1+2f_s)7f_1$	-69	-80	-72	-89	-71	-73	-76	-73

Table 3: Measured current and flux amplitudes of motors fed by frequency converter (*C – current; F – flux).

4. CONCLUSION

In this paper the analysis of 4-pole induction motors fed by frequency converter was carried out. There were analyzed motors with different types of broken rotor bars fault under different load conditions. Present research is focused on the MCSA as well as stray flux of motor in order to verify the capability of these techniques to identify specific for the broken rotor bar fault-indicative frequency components in the case of different types of supply. The measurement results were compared with the results obtained in the previous research. Obtained results for the healthy motor and motor with two adjacent broken rotor bars are presented in graphical form as well as in the form of tables. From the presented figures it is clear that it is still possible to recognize the presence of broken rotor bars in motor by means of analysis of characteristic frequencies even in the case of inverter feeding. Monitoring of stray flux shows the presence of characteristic frequencies and rise in their amplitudes with increase of severity of fault as well as with the increase of the load.

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