

# Frequency Converter Influence on Induction Motor Rotor Faults Detection Using Motor Current Signature Analysis – Experimental Research

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**Abstract** - Induction motors have nowadays been more frequently used with frequency converters. The use of frequency converters affects the behavior of the machine and makes fault diagnosis more complicated. One of the widely used diagnostic methods is Motor Current Signature Analysis (MCSA). This method is based on measurement of sidebands in the stator current spectrum. Those sidebands are usually located close to the main supply frequency. Frequency converter causes supply frequency to slightly vary in time and, as a result, some additional harmonics in the current spectrum are induced and sidebands are reduced. Those harmonics can be easily misinterpreted as the sidebands caused by the rotor faults. Although the rotor faults in the case of frequency converter supply are not so often, precaution is still necessary. In this paper the experimental results of fault diagnosis carried out using standard supply and using frequency converter have been compared and presented. All tests were performed on 22 kW, 380 V, 1470 r/min induction motor. The current spectra are given for the motor with two broken bars with both types of supply.

## I. INTRODUCTION

Induction motors have been used in all kinds of electric drives more often than any other electric motor. During the exploitation motor is exposed to the different electrical and

mechanical stresses [ 1 ], [ 10 ], [ 6 ], [ 11 ]. As a result of those stresses, different faults can occur. In order to reduce unexpected failures and system breakdown it has become very important to detect failures at their inception [ 10 ]. For that purpose many methods have been developed. [ 1 ], [ 3 ], [ 5 ], [ 7 ], [ 8 ], [ 9 ].

One of the most popular diagnostic methods, Motor Current Signature Analysis (MCSA), is based on measurement of sidebands in the stator current spectrum, which are usually located close to the main supply frequency.

The development and utilization of frequency converters have made induction motor control simpler, so it can be used even in very complicated drives. However, the use of frequency converter has introduced some new problems in induction motor fault diagnosis. Frequency converter causes supply frequency to slightly vary in time and, as a result, some additional harmonics in the current spectrum are induced. For this reason, fault detection in the case of a frequency converter supply is not easy to perform.

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Authors thanks Croatian Ministry of Science and Technology, KONCAR Generators and Motors Inc. Inc. and KONCAR Switchgear Inc. for their financial support.

In this paper we tried to investigate frequency converter influence on rotor fault detection using MCSA.

The 22 kW induction motor with 40 bars has been tested from a healthy condition to the condition where two bars were broken. All tests were done for standard 50 Hz power supply and frequency converter supply.

## II. THEORY

If a symmetrical three-phase stator winding of a three-phase induction motor is supplied by a symmetrical three-phase voltage system, a rotating field is induced in its air gap. The rotating field rotates at a synchronous speed with respect to the stator. In the case of symmetric machine, a backward rotating component does not exist.

Stator rotating field induces EMF and current in the rotor winding with frequency

$$f_2 = s \cdot f_1 \quad (1)$$

where  $s$  – slip  
 $f_1$  – supply frequency

Those currents induce rotor rotating field which rotates at speed  $n_s \cdot s$  with respect to the rotor, where  $n_s$  is synchronous speed. In the case of symmetric rotor winding only direct component of the current exists.

If any kind of asymmetry occurs in the rotor cage (broken bar) backward component is induced. Backward component rotates at slip frequency with respect to the rotor, but in the opposite direction. Consequently, an EMF is induced in the stator winding [ 5 ] at frequency given by

$$f_{bh} = f_1(1-2s) \quad (2)$$

These current oscillations cause torque and speed oscillations at twice the slip frequency ( $2sf_1$ ) [ 5 ]. Speed oscillation also depends on motor and drive inertia. Speed oscillation reduces the magnitude of  $f_1(1-2s)$  component, but the upper component at  $f_1(1+2s)$  is induced as well. The upper component is enhanced by the third time harmonic of the flux. Therefore, broken rotor bars induce sidebands in the stator current at frequencies given by

$$f_{bh} = f_1(1 \pm 2s) \quad (3)$$

Rotor winding faults can be detected in a very early stage by examining these sidebands.

The magnitudes of the sidebands depend on the rotor fault stage, but also on some other factors that have to be considered in diagnostics [ 6 ], [ 11 ].

Some of the factors are:

- different cage designs can affect sideband magnitudes,
- power rating – the same number of broken bars can produce different sideband magnitude for different machine power rating,
- mechanical load characteristics – mechanical load often produces some additional harmonics.

These factors have not been considered in this research. We have only examined the influence of the frequency converter. Therefore, load characteristics remained the same for all stages.

Knowing only the sideband magnitude, the number of broken bars can be estimated from the equation [ 1 ]:

$$n_p = \frac{2 \cdot N_2}{10^{\frac{A}{20}} + 2p} \quad (4)$$

where  $n_p$  – estimated number of broken bars  
 $N_2$  – number of rotor bars  
 $A$  – difference in dB between the main harmonic and lower sideband  
 $p$  – pole pairs

The estimates of the number of broken bars were made with the results at standard supply and using frequency converter.

## III. EXPERIMENTAL RESEARCH

The induction motor has been tested at four different fault stages, with different loads

*Stage 1:* New rotor, no broken bars.

*Stage 2:* One of the bars was partly cut (this represents an early stage of a rotor fault). The bar was cut in the region close to the end ring joint because faults usually start in that region.

*Stage 3:* One of the bars was completely broken.

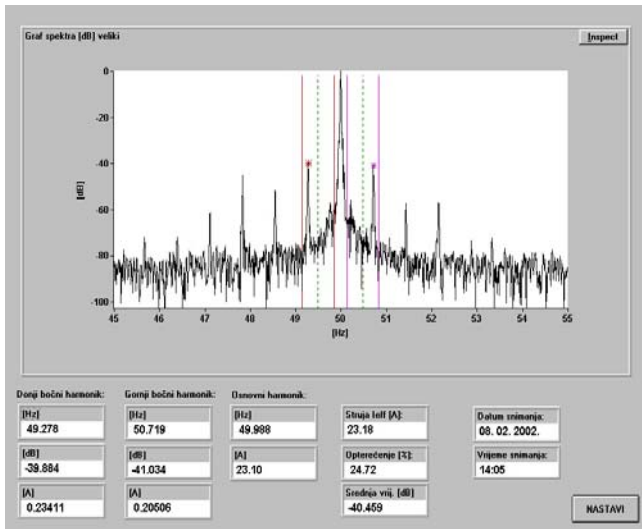
*Stage 4:* Motor was examined with two broken rotor bars.

### A. MCSA usage in broken rotor bar detection

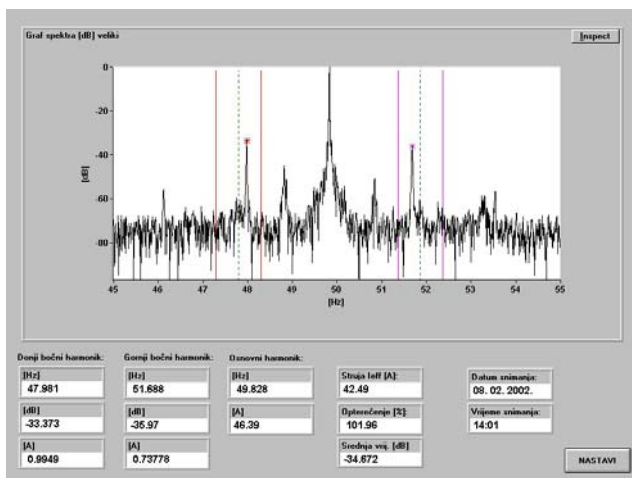
#### 1) Standard power supply 50 Hz

Our goal was to find how motor load and fault stage affect sidebands in the current spectrum.

Fig. 1 shows current spectrum for the motor with two broken bars at two different loads. It can be seen that the magnitudes of the sidebands for 25 A are smaller than for 45 A.



a) 25 A load



b) 45 A load

Figure 1. Current spectrum at different loads on standard power supply, motor with two broken bars

Fig. 2 and Fig. 3 show the influence of motor load on the sideband magnitude. Fig. 2 shows magnitudes for motor with one broken bar and with two broken bars as a function of motor load. Fig. 3 shows magnitudes for the same motor, but in a healthy condition and with one slightly cut rotor bar (Stage 1 and Stage 2). It should be mentioned that the values in dB present the difference between the amplitudes of the main harmonic and the sidebands. Therefore, larger number indicates healthier condition. A second order polynomial was used to fit the curves.

In the case of a healthy rotor and in the case of a small damage, the increase of load increases the difference between harmonics. In the case of a damaged rotor, the increase of load decreases the difference. It can be concluded that larger load gives us a better picture of the machine state.

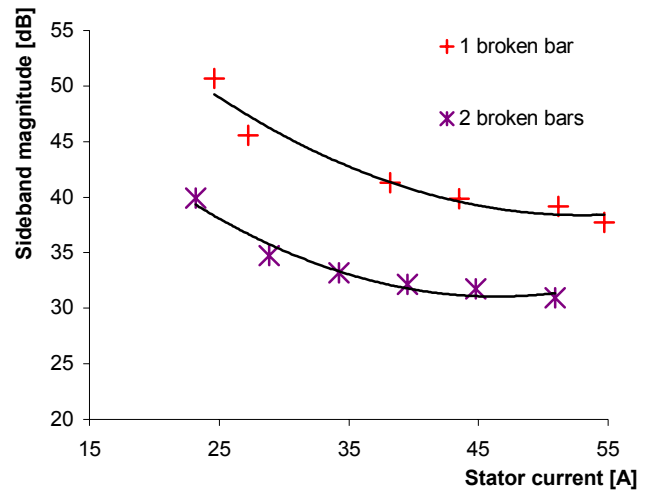


Figure 2. Sideband magnitude at different loads; motor with one broken bar and two broken bars

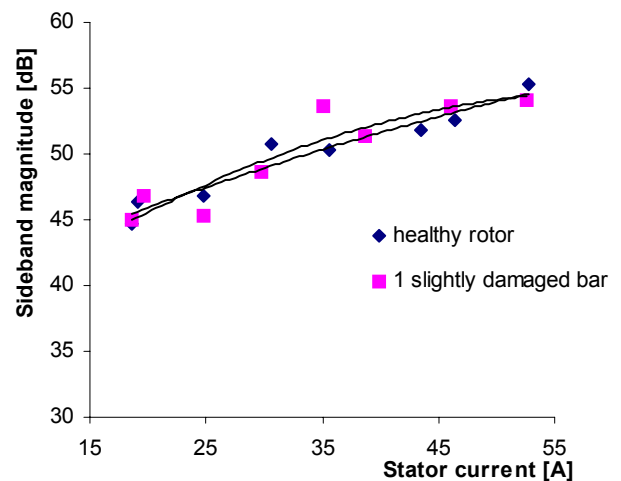


Figure 3. Sideband magnitude at different loads; healthy motor and motor with slightly damaged rotor

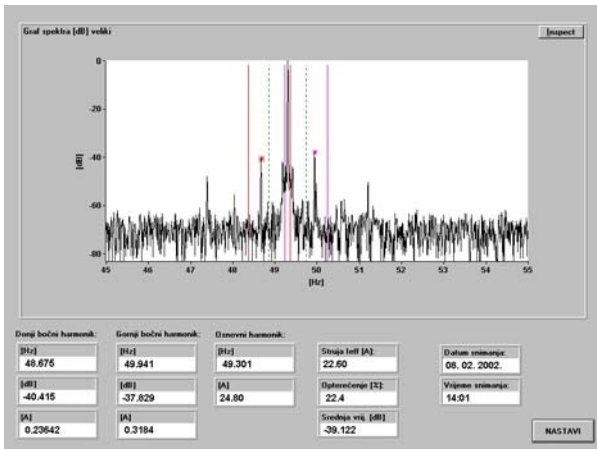
Those facts should be taken into account when examining machines at loads smaller than nominal, and the measured values should be increased.

The estimated number of broken bars for different rotor faults at nominal load is given in Table I.

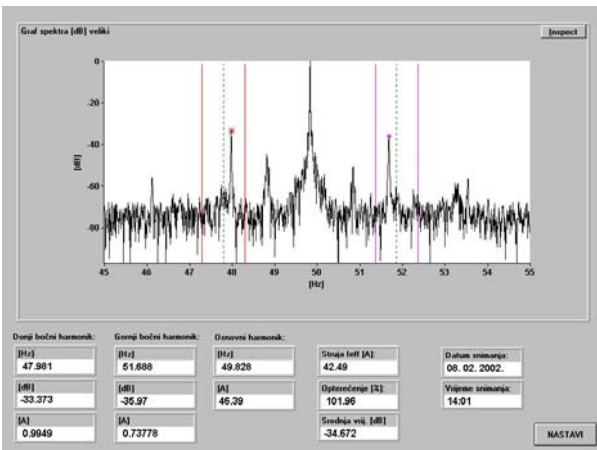
## 2) Frequency converter supply

In this research 30 kVA, ABB frequency converter was used in the direct torque control mode. In this mode output frequency changes to keep motor speed constant regardless of the load. This mode is one of the widely used modes in drives. The nominal speed of 1470 r/min was chosen as a referent speed

The current spectrum for the motor with two broken bars at two different loads is shown in Fig. 4.



a) 25 A load



b) 45 A load

Figure 4. Current spectrum at different loads on standard power supply, motor with two broken bars

It can be seen from Fig. 4 that the frequency converter supply does affect the sidebands. For the same level of damage at the same load, the spectrum sidebands have smaller magnitude than those in the case of a standard power supply.

From Fig. 4 it can be seen that in the case of frequency converter supply, some additional harmonics at frequencies close to the main frequency of 50 Hz are induced. Those harmonics are the result of small output frequency changes. Therefore, one should be very careful not to confuse these harmonics with sidebands which are result of a fault.

Table I shows sideband magnitude values and estimated number of broken bars for different rotor faults. All values in Table I were measured at approximately nominal load of 42 A. The results for the motor fed from the frequency converter show that the magnitude for different rotor faults does not change as much as in the case of a standard power supply. Furthermore, the estimated number of broken bars in the case of the frequency converter supply is smaller and can lead to a conclusion that the motor condition is better than it actually is. Fig. 5 also shows that the sideband magnitudes, as a function of motor load are not so easy to approximate

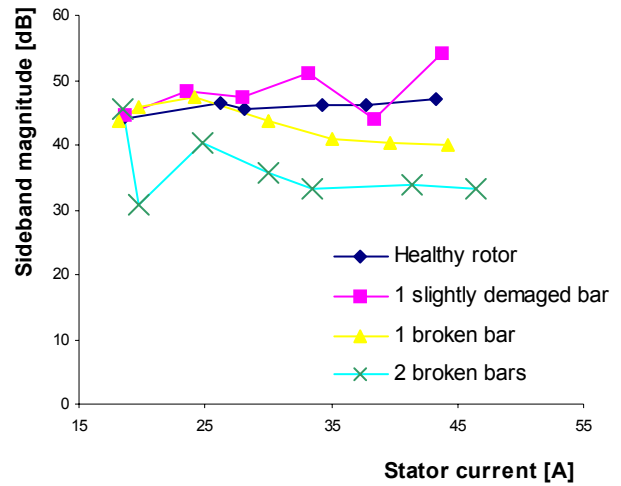


Figure 5 Sideband magnitude at different loads

TABLE I  
SIDE BAND MAGNITUDE AND ESTIMATED NUMBER OF BROKEN BARS (NOMINAL LOAD)

Fault stage	Standard power supply		Frequency converter supply	
	Sideband magnitude	Estimated number of broken bars	Sideband magnitude	Estimated number of broken bars
Stage 1	51.5	0,21	46,90	0,355
Stage 2	50.4	0,238	43,00	0,55
Stage 3	40.1	0,76	40,20	0,752
Stage 4	30.9	2,047	33,00	1,643

#### IV. CONCLUSION

The experimental research has clearly shown that the motor current signature analysis of the induction motor fed from the frequency converter is much more complicated than in the case of standard supply. The values of the sidebands are smaller and can be confused with harmonics that are result of the frequency change. The number of broken bars estimated from (4) is smaller than in the case of a standard supply. All these reason can lead to a conclusion that the motor is in much better state than it really is. Therefore, in the case of a frequency converter supply, great caution should be taken, and some other methods should be considered as well.

#### ACKNOWLEDGMENT

Authors thank KONCAR Generators and Motors Inc. for help in revitalizing the motor rotor.

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