BROKEN ROTOR BARS DETECTION IN SQUIRREL-CAGE INDUCTION MACHINES BY MOTOR CURRENT SIGNATURE ANALYSIS METHOD

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Abstract Condition monitoring is an important issue in the maintenance of electrical machines. In the last years several methods for fault diagnosis of the squirrel-cage induction motors were cited in the literature. Among these methods the Motor Current Signature Analysis (MCSA) is considered the most effective non-invasive fault detection method, because it can easily detect all the common electrical machine's faults. The method in discussion uses the harmonic content of the line current of the induction machine to detect diverse faults of the analyzed electrical machine. In the paper experimental results on detecting broken rotor bars in squirrel cage induction motors by using MCSA are given.

Keywords: induction machine, rotor faults, fault diagnosis, condition monitoring, Motor Current Signature Analysis.

1. INTRODUCTION

Due to their robustness, low cost, and easy maintenance the squirrel cage induction machines are widely used in modern industry applications. Many of its basic components are susceptible to failure. About 40% of the faults that occur in induction machines are in the bearings, 30 to 40% in the stator, 10% in the rotor and the remaining ones in the auxiliary devices of the machine [1]. An interruption of a manufacturing process due to a mechanical or electrical problem induces a significant financial loss. In order to avoid such problems these faults has to be detected, so they not to lead to major failures of the machine [2].

Numerous fault detection methods have been proposed in the literature. The most frequent used detection methods are [2]:
- Motor current signature analysis (MCSA),
- acoustic noise measurements,
- artificial intelligence and neural network based techniques,
- noise and vibration monitoring,
- electromagnetic field monitoring using search coils,
- temperature measurements,
- infrared recognition,
- radio frequency (RF),
- emissions monitoring, chemical analysis, etc.

Most of the diagnostic methods require expensive sensors or specialized tools. The current monitoring methods have an advantage over the methods mentioned above: they require only (in most cases already existing) simple and cheap current sensors.

The current monitoring based techniques can be used to detect almost all of the faults of a squirrel cage induction machine:
- bearing faults,
- rotor bar faults,
- air-gap eccentricity faults,
- shorted winding fault,
- load faults, etc.

These methods are non-intrusive and can be applied both on-line and in a remotely controlled way.

The condition monitoring of induction machines is a vital component of preventative and predictive maintenance programs that seek to reduce cost and avoid unplanned downtime of industrial processes. Condition monitoring systems include both measurement hardware and software that acquire and process signals generated by the machine being monitored [3], [4].

2. THE MOTOR CURRENT SIGNATURE ANALYSIS METHOD (MCSA)

The MCSA is a reliable method for fault detection that provides a precise analysis based on the detection of specific current sideband harmonics by means of Fast Fourier Transform (FFT), with frequencies that are characteristic to each type of fault [5].

In a working electrical machine fault indicators can be chosen from a wide range of parameters that influence the condition of the machine, like: flux, stator current, stator line voltage, impedance, power, electromagnetic torque, etc. Among these the easiest to analyze is the stator current, as it is very easy to measure [6], [7].

In an induction machine, depending of the type of fault, the detected sideband harmonic components of the line current may differ. To determine the existence of a certain fault the measured data has to be analyzed in the
frequency domain. This is done by verifying and comparing certain parts of the analyzed signal's harmonic content with those of the signal measured for a healthy machine [8], [9]. Although the broken rotor bars of a squirrel-cage induction machine do not initially cause the motor to fail, they can have serious secondary effects. The breakings or cracks of a rotor bar can easily extend to the neighboring bars. This type of fault progresses slowly in time and can be easily detected by using MCSA technique [10]. When a rotor bar fault occurs, it induces in the current spectrum two frequency sidebands that appear at \( \pm 2sf_l \) around the supply frequency \([11]:\)

\[
f_b = (1 \pm 2s)f_l
\]

The lower sideband is induced due to broken bar, and the upper sideband is due to consequent speed oscillation. Several authors have shown that broken rotor bars create additional sideband components in the current spectrum at frequencies given by \([11]:\)

\[
f_b = (1 \pm 2ks)f_l, \quad k = 2, 3, 4... \tag{2}
\]

An idealized current spectrum is shown in Figure 1.

The two slip frequency sidebands due to broken rotor bars near the main harmonic can be clearly observed in the figure [12]. The amplitude of these sideband harmonics dependents of three factors [13]:

- Motor's load inertia
- Motor's load torque (current in the rotor bars)
- Severity of the rotor fault

3. LABORATORY SETUP FOR FAULT DETECTION

In order to perform the required measurements for the detection of broken rotor bars a test bench was set up (see Figure 2).

The laboratory test bench consists of two coupled electrical machines: the squirrel cage induction machine to be tested and a disc rotor type dc machine for braking and loading purposes. The rated data of the tested three-phase squirrel cage induction machine is:

- Rated power: 1.5 kW
- Rated voltage: 220/380 V (Δ/Y)
- Rated current: 6.18/3.56 A (Δ/Y)
- Rated speed: 1500 1/min.

The measurement part of the test bench uses voltage and current sensors. The measured data is acquired by a PC having a National Instruments PCI-MIO-16E-4 12-Bit Multifunction DAQ type data acquisition board. For the data acquisition several virtual instruments (VIs) were built up in LabVIEW. Besides data acquisition the VIs can also perform the real time graphical processing of the tested induction machine's measured currents and voltages. These VIs can be easily transformed and used also for the data processing if it should be required [16], [17]. The VI developed for the data acquisition and the analyzing of the acquired data is given in Figure 3.

The sample frequency for data acquisition was set to a high value \((2^{16}=65,536\) samples/seconds). One second long measurements were performed, which means that on each channel 65,536 values were saved.
4. RESULTS OF THE MEASUREMENTS

The tests were carried out for four different loads for two conditions of the motor in study: healthy and having 3 broken rotor bars. Two similar rotors were used during the tests. In one of the rotors 3 bars were interrupted by drilling holes into the rotor near the end rings, as shown in Figure 4.

![Figure 4. The rotor with 3 broken bars](image)

During the measurements the three line currents and three line voltages were acquired.

The measured data was processed using the National Instruments DIAdem software.

DIAdem is software specifically designed to help engineers and scientists quickly locate, inspect, analyze, and report on measurement data using a single easy-to-use comprehensive software tool.

By using this program it is very easy to perform FFT based spectral analysis of the data acquired by means of NI's advanced data acquisition boards [19], [20].

NI DIAdem is a software tool that is used to quickly locate, load, visualize, analyze, and report measurement data collected during data acquisition and/or generated during simulations.

The acquired data also can be stored in simple ASCII-type text files in order to be easy imported in any other programming environment.

The measured line currents for the healthy and faulty rotors of the induction machine at no-load and full load are given in the Figures 5 and 6.

![Figure 5. The line current for a healthy motor](image)

![Figure 6. The line current for 3 broken rotor bars](image)

As it can be seen in Figures 5 and 6 the amplitude of the currents is intensifying with the increase of the load. Also a pronounced fluctuation of the line currents can also be observed in the case of the induction motor having rotor faults.

Several measurements were performed by using the above mentioned test bench and the virtual instruments developed.
The obtained results of the measurements were compared. The sideband components’ frequencies due to the broken rotor bars given by equations (1) or (2) were searched in the spectrum of the measured line currents. Due to the limited space in the paper only the most significant results will be presented and discussed in details. The main results of the line current's spectral analysis performed by using the DIAdem software tool for the healthy condition and for 3 broken rotor bars of the squirrel cage induction machine in study are given in the next figures. In Figure 7 the spectrums of the line current for the healthy condition and for the case of the rotor having 3 broken bars are given at the rated (full) loading of the tested induction machine.

![Figure 7. The line current's spectrum at full load](image)

For a better view of the harmonic content of the line currents a zoom taken on the previous picture is given in Figure 8.

![Figure 8. A zoomed view of the line current's spectrum at full load](image)

In the figure, the above mentioned sideband components can be very clearly distinguished in the case of the induction machine having broken rotor bars. The existence of these harmonic components is the clear evidence of the existence of broken rotor bars in the machine.

The qualitative analysis of the sideband harmonics should be joined with a more precise quantitative study. As the speed of the machine was measured during all the laboratory tests performed for all the cases taken into study the frequencies of the sideband components can be easily computed by using equations (1) and (2). The sideband frequencies of the main interest, computed for \( k = 1 \) and \( k = 2 \) for different loads of the squirrel cage induction machine in study having 3 broken rotor bars are given in Table 1.

<table>
<thead>
<tr>
<th>speed [1/rot]</th>
<th>slip</th>
<th>frequency [Hz]</th>
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</thead>
<tbody>
<tr>
<td>full load</td>
<td>0.049</td>
<td>40.13</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45.06</td>
</tr>
<tr>
<td></td>
<td></td>
<td>54.93</td>
</tr>
<tr>
<td></td>
<td></td>
<td>59.86</td>
</tr>
<tr>
<td>75% of load</td>
<td>0.033</td>
<td>43.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>46.66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53.33</td>
</tr>
<tr>
<td></td>
<td></td>
<td>56.66</td>
</tr>
<tr>
<td>50% of load</td>
<td>0.016</td>
<td>46.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>51.60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>53.20</td>
</tr>
<tr>
<td>25% of load</td>
<td>0.08</td>
<td>48.40</td>
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<tr>
<td></td>
<td></td>
<td>49.20</td>
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<td>50.60</td>
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Next it should be checked if the sideband components from Table 1 can be identified in the spectrums of the measured line current. In Figure 9 the main sideband components of the line current in the case of the induction motor having 3 broken rotor bars at full load are given.

![Figure 9. The main sideband components of the line current in the case of the induction motor having 3 broken rotor bars at full load](image)
In the figure the sideband harmonic components indicating the existence of rotor bar faults are marked with circles. The four sideband harmonic components corresponding to the given condition and load of the induction machine from Table 1 (40.13 Hz, 45.06 Hz, 54.93 Hz and 59.86 Hz) are clearly observable in Figure 9. All these emphasize both the effectiveness of the selected fault detection method and the correctness of the measurements and of the following data processing (spectral analysis).

As the load of the machine is greater also the magnitude of the typical, fault type dependent sideband harmonic components are higher, as it can be seen in Figure 10, where the spectral contents of the line currents for the faulty machine at different loads are plotted.

![Figure 10. The line current's spectrum at different loads in the case of the induction machine having 3 broken bars](image)

As it can be seen in the figure at no load the typical sideband components are not evidenced although the induction machine's rotor is faulty. At the half of the rated load these components already can be seen, but they are clearly detectable only in the case of the full load of the machine.

This is the main drawback of the motor current signature analysis: the sideband harmonic components indicating diverse machine faults can be hardly observed at lower loads of the monitored electrical machines. But in industrial environment in most of the cases the electrical machines are working mainly near they rated load, hence the fault diagnosis methods studied in this paper can be widely applied.

5. CONCLUSIONS

The motor current signature analysis fault detection method provides a highly sensitive, selective, and cost-effective means for non-invasive and on-line monitoring of a wide variety of electric machinery. This technique can be used also combined with other methods, such as motor circuit analysis, as part of motor diagnostics program in order to give a complete view of motor system health.

A way forward is for the technology and intelligent diagnosis to be integrated into a technologically advanced hand-held instrument that is applicable to a diverse range of induction motor derives.

All the given results show that the method in study is a suitable fault diagnosis method in the field of fault detection of electrical machines.

The LabVIEW and DIAdem software used for data acquisition and processing purposes can be successfully used also in fault detection of electrical machines in industrial environment.

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7. REFERENCES


