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ORIGINAL SCIENTIFIC PAPER

Induction Motor Broken Bar Detection for a Thermal Power-Plant Application. A Case Study

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Abstract. The paper presents a case study results emoting detection for a broken bar in an induction motor thermal power-plant. Two identical 3.15 MW motors are analyzed. The malfunctioning motor suffers from increased vibrations. A fault on the rotor is suspected. The induction motor phase current is analyzed for the healthy and the malfunctioning motor. The feature extraction is based on transient and steady state analysis. The Fourier, Hilbert and Wavelet transforms are used. Because of the operational setting shaft-load is low. It is shown that a broken bar of a high-voltage high-power induction motor can be reliable detected by using state-of-the-arte digital signal processing techniques.

Keywords: broken bar, induction motor, feature based, current analysis

Detekcija zlomljenih rotorskih palic pri pogonih z asinhronskim motorjem v termoelektrarnah

V članku je predstavljena študija odkrivanja zlomljenih rotorskih palic pri pogonu z asinhronskim motorjem v termoelektrarnah. Analizirali smo delovanje okvarjenega in brezhibnega motorja z močjo 3.15 MW. Vzrok za predvideno okvaro so bile povečane vibracije. Analizirali smo fazni potek toka za oba motorja. Izvedi smo tranzientno analizo in analizo mirovnih stanj. Pri tem smo uporabili Fourierjev in Hilbertov transform ter valjčne transformacije. Pokazali smo, da je možno s tehniko digitalne obdelave signalov zanesljivo odkriti zlomljene rotorske palice.

1 INTRODUCTION

Induction motors cover over 80% of the overall electro-mechanical conversion at the installed power of 3 kW per person [1]. They are widely used in domestic and industrial applications. Malfunctioning of the induction motor can harmfully affect the environment, humans or can rise a significant financial loss, depending on the application involved. To prevent unwanted situations early fault detection techniques are used. Generally, they are financially more acceptable than periodic maintenance procedures [2], [3].

Common induction motor faults are related to the stator, rotor and bearing malfunctioning (Fig.1). Rotor faults cover some 10% of the faults and are paid a lot of attention on the academic and industrial level [4]. A broken-bar fault increases the motor vibration, noise, star-up sparking, power losses and detriments of the torque [5]. It is caused by the mechanical and thermal stress of the rotor cage or by an inappropriate production process. Despite their relatively small share in the overall motor faults, the reason the bar gets broken is of crucial concern. Methods, either analytical [6], statistical [7] or artificial intelligence techniques [8-10] can be successfully used in fault detection.

Our work was motivated by a researche conducted to detect the broken bar in large-power induction motor in a real industrial application for low-load operational setting.

The paper is organized in seven sections. Intruduction is followed by section describing on industrial application, the third section describes the data acquisition process, in the fourth and fifth sections broken-bar methods are discussed, in the sixth section broken bar is verified by dismounting the rotor. In the seventh section conclusions are drawn. In the appendix motor data are shown.

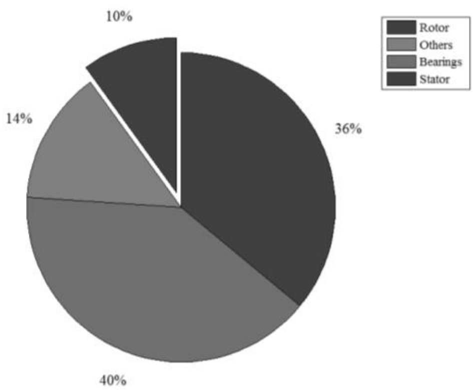

Figure 1. Percentage of the induction motor faults

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2 THERMAL POWER PLANT APPLICATION

The investigated combined heat and power-plant (CHPP) was constructed to produce energy in a modern co-generation process. CHPP consists of the main production unit (MPU) and the auxiliary one used to excite the MPU. There are two boilers in MPU of the capacity of 330 t/h and 11.77 MPa each.

The vital part of the CHPP is the high-pressure pump that supplying water continuously to the boiler. The feed-water is pumped from a reservoir to the suction. System of the high-pressure boiler feed pump by a low-pressure pump. A variable-speed hydrodynamic coupling controls the amount of feed-water. The two pumps are driven by two high-voltage squirrel-cage induction motors 3.15MW each and are directly connected to the mains. A part of the motor drive is shown in Fig.2.

One of the motors operates at mechanical vibration rate above the normal value, and the other within the set limits. It is believed that malfunctioning is caused by a mechanical fault. Usually, the mechanical faults taking place in an induction machine with this kind of symptoms are either rotor broken bar or eccentricity.

Figure 2. Induction motor power plant application

3 MOTOR CURRENT ACQUISITION

For the current acquisition were used: National Instruments USB-6251 digital acquisition card, standard PC and measuring clamps of the ratio 400/5 A. The single phase current signal was acquired from the motor standstill to its nominal speed; the motor data is given in the appendix. The current signals were obtained from the healthy and the malfunctioning motor (Figs. 3-6). Sampling frequency was set at 5 kHz with the sampling interval of 100 s for the steady state, and 8 s for start-up. During the signal acquisition, shaft load was some 30% of the nominal value.

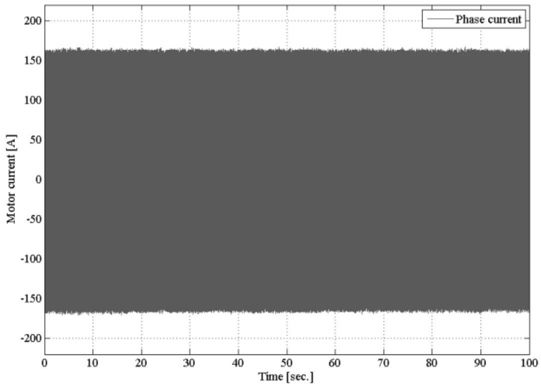

Figure 3. Current signal of the healthy motor in steady state

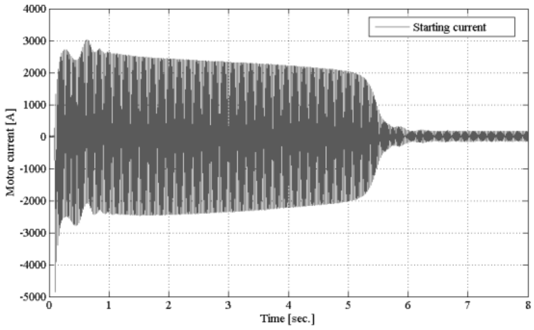

Figure 4. Current signal of the healthy motor when started-up

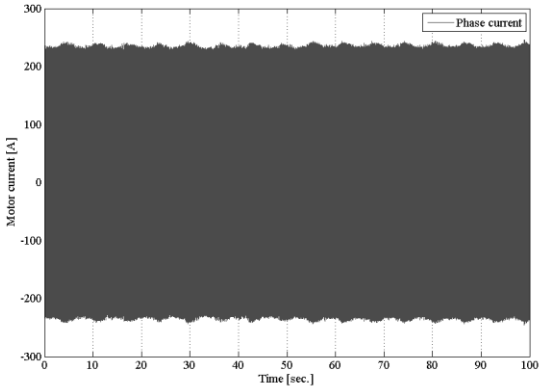

Figure 5. Current signal of the malfunctioning motor in steady state

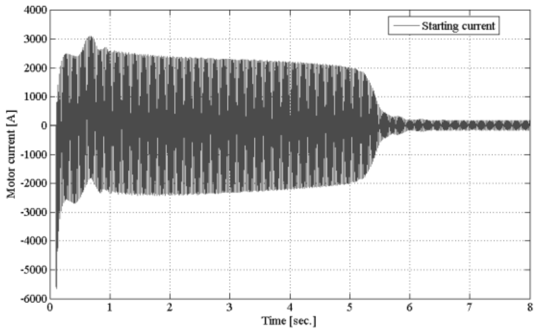

Figure 6. Current signal of the malfunctioning motor when started-up

4 STEADY-STATE CURRENT ANALYSIS

A broken bar in the rotor can be detected by analyzing the current or vibration signal of the motor. Motor current signature analysis (MCSA) is widely spread method to detect a broken bar [2, 3, 11-14].

4.1 Motor Current Signature Analysis

In this paper broken bar detection is based on motor current analysis. The motor current is measured only in one phase. The broken bar features appear in the current spectrum [2, 3, 14]:

$$f_{bb} = [1 \pm 2ks] f_n, \quad k = 1, 2, 3... \tag{1}$$

where f_{bb} is the frequency of the broken-bar feature, f_n is the supply frequency, and s is the slip.

By analyzing the magnitudes at given frequencies (1) the rotor state is determined. Usually the magnitudes of the first characteristic feature around the supply frequency, left side band (LSB) and right side band (RSB) are observed.

Detecting a broken bar by using the FFT analysis has several disadvantages: spectral leakage due to finite-time window, need for high-frequency resolution, variations of the load and confusing mechanical frequencies [15].

Fig.7 shows amplitude spectra of the motor phase current. The spectrum is obtained by using the FFT, sampling frequency of 5 kHz, and sampling interval of 100 s, the number of FFTs is equal to the number of samples, no windowing is applied.

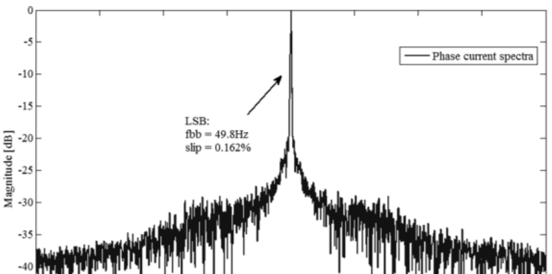

Figure 7. Current spectrum of the malfunction motor, no conclusion can be made.

The low load working conditions are present in the case study. Because of the spectral leakage the LSB feature is buried under the supply frequency of 50 Hz (Fig.7). Consequently, the rotor condition cannot be determined and an alternative approach should be taken. One of the real-time solutions to the problem is based on applying the windowing technique. This will increase the spectral resolution. Implementation of the windowing technique requires more memory, but with current low memory prices, this approach is applicable and it is presented in ref. [11]. In this paper the issue of the spectral leakage is solved by analyzing the analytical signal of the motor current. Among others, benefits of used approach are short sampling interval and low memory requirements [15].

4.2 Spectral analysis of analytical signal modulus

Because of the disadvantages of MCSA an alternative approach is used. It is based on the amplitude spectral analysis of the modulus of the analytical motor-current signal. The modulus of the analytic signal shows a pulsation with the characteristic frequency of the machine fault [15]:

$$\vec{i}_b(t) = \left[1 + \frac{n_b}{N_b}\cos(2\pi(2sf_s)t)\right] I_m e^{j\omega t}, \tag{2}$$

where n_b is the number of the broken bars, N_b is the total number of the bars in the rotor and I_m is the magnitude of the motor line current.

The presents of the characteristic spike in the low frequency range indicate a broken bar. The analytical signal is obtained by using the Hilbert transform (HT). By removing the direct component (DC) from the observed signal, the reliable broken-bar feature covering the full-load range is obtained. The observed variable is shown as a pseudo code [15]:

$$I_H = abs(hilbert(i_a)) - mean(abs(hilbert(i_a))), \tag{3}$$

where i_a is the motor line current. For the 3.15 MW motor in its steady-state, the spectrum of the modulus of the analytical signal is observed. It is shown in Fig. 8. Existence of the spike at the frequency of 0.162 Hz clearly indicates the presence of a broken bar fault.

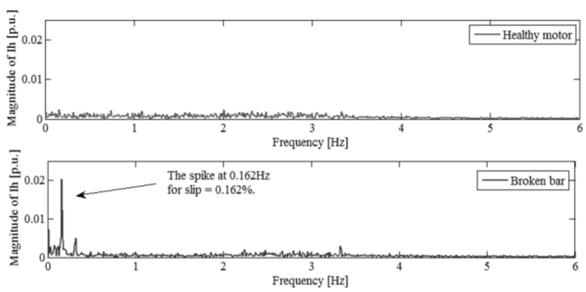

Figure 8. Detection of a broken-bar fault

5 TRANSIENT SIGNAL ANALYSIS

By analyzing the star-up current of an induction motor, can be determine the existence of a broken bar. In this paper, Digital Wavelet Transform (DWT) is used to decompose transient current signal [16]. The original signal is decomposed in details and approximations. The level of decomposition depends on the used sampling frequency and is to be chosen so as to cover the full frequency range of the broken-bar fault. If LSB is observed frequency range is 0-50 Hz [16]. When using the Daubechies 44 mother wavelet the characteristic features of the broken-bar appear at the 8^{th} level of decomposition [18] (Fig.9). The features provided by DWT decomposition are highly discriminative. When there is a broken bar oscillations of a higher magnitude appears at 8^{th} level of decomposition (Fig.10). To detect the rotor state, the operator's experience in signal assessment is crucial. It is challenging to establish an automated procedure for broken bar detection based on transient analysis, which is relatively simple for previously described methods [11]. Detection of a broken bar is confirmed by applying transient signal analysis and expert inspection.

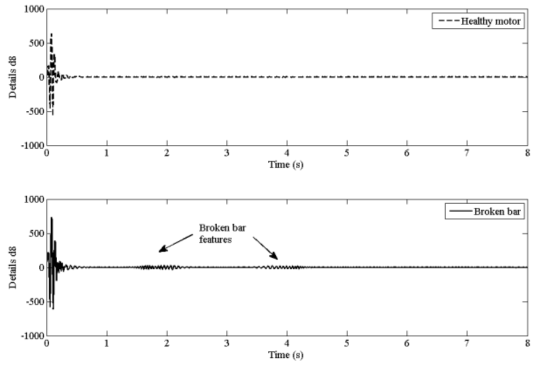

Figure 9. Wavelet decomposition to confirm the presence of broken-bar

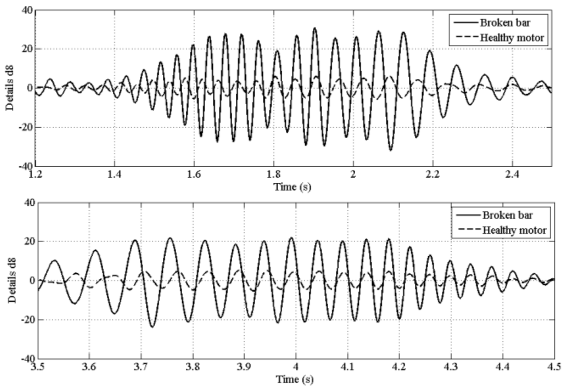

Figure 10. Comparison of the broken-bar features

6 Broken Bar Verification

Based on the above analysis the rotor of the malfunctioning induction motor was dismounted. The presence of the broken-bar is done by visual inspection (Fig. 11). Being the consequence of a long time mechanical and thermal stress two cracked broken bars can be easily spotted at the end ring joint.

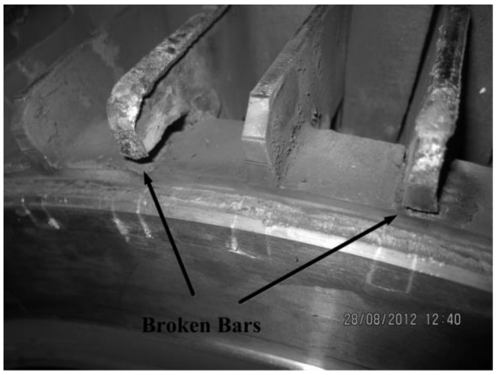

Figure 11. Two broken bars at the end-ring joint

7 Conclusion

In this paper is shown the method to detect the broken-bar of the high-voltage high-power induction motor. Low-load working conditions enforce use of digital signal processing techniques alternative to MCSA approach. Broken bar detection based on MCSA cannot be successfully used due to spectral leakage, which made feature extraction difficult.

The advantage of the presented method is in its using the advanced digital signal processing techniques to study the high-voltage high-power induction motor to detect the broken-bar. Shown procedures are applicable in real working conditions, relatively easy to implement and deploy. Diagnostic procedures seems to have an advantage to periodic maintain, they are less costly and more reliable.

Appendix

Induction motor data: 1 ZKV6 630 M-2, P_n = 3150 KW, U_n = 6 kV, I_n = 373 A, f_n = 50 Hz, ω_n = 2982 rpm, $\cos\varphi$ = 0.92, star connection, rotor type: single cage, 56 bars.

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References

[1] Crowder, R., Electric drives and electromechanical systems. Oxford: Elsevier, 2006.

[2] Taliyat, H. A. and Lipo, T.A. "Transient analysis of cage induction machines under stator, rotor bar and end ring faults," *IEEE Transactions on Energy Conversion*, vol.10 no.2,pp.241-247, 1995.

[3] Thomson, W.T. and Fenger, M. "Current Signature Analysis to Detect Induction Motor Faults," *IEEE Industry Application Magazine*,vol.7, no.4, pp.26-34, 2001.

[4] Matić, D., Kulić, F. and Bugarski, V. “Survey of the methods for online broken bar induction motor fault detection,” *Journal on Processing and Energy in Agriculture*, vol.14, no.2, pp.90-93, 2010.

[5] Bellini, A., Fillippeti, F., Franceschini, G. and Tassoni, C. ”Quantitative Evaluation of Induction Motor Broken Bars by Means of Electrical Signature Analysis,” *IEEE Transactions on Industry Applications*, vol.37, no.5, pp.1248-1255, 2001.

[6] Valh, D., Bratina, B. and Tovornik, B. “On-line fault detection and isolation using analytical redundancy”, *Elektrotehniški vestnik*, vol.73, no.5, pp.267-272, 2006.

[7] Stepanić, P., Latinović I.V. and Đurović, Ž. “A new approach to detection of defects in rolling element bearings based on statistical pattern recognition,” *Journal of Advanced Manufacturing Technology*, vol.45,pp.91-100, 2009.

[8] Dovžan, D., Logar, V., Hvala, N. and Škrnjac, I. “Monitoring and sensor fault detection in a waste-water treatment process based on a fuzzy model”, *Elektrotehniški Vestnik*, vol.78, no.3, pp.142–146, 2011.

[9] Matić, D., Kulić, F., Pineda-Sánchez, M. & Kamenko, I. “Support vector machine classifier for diagnosis in electrical machines: Application to broken bar.”, *Expert Systems with Applications*, vol.39, pp.8681-8689, 2012.

[10] Keskes, H., Braham, A. & Lachiri, Z. “Broken rotor bar diagnosis in induction machines through stationary wavelet packet transform and multiclass wavelet SVM”, *Electric Power Systems Research*, vol.97, pp.151 – 157, 2013.

[11] Fiser, R., Lavrić, H., Amrozić, V., and Bugeza, M. Diagnostic system for on-line detection of rotor faults in induction motor. Diagnostic for Electric Machines, (SDEMPED), 8th IEEE International Symposium on Power Electronics & Drives, pp.77-83, 5-8th Sept., 2011, Bologna, Italy.

[12] Benbouzid, M.E.H. “Bibliography on induction motors faults detection and diagnosis,” *IEEE Transactions on Energy Conversion*, vol.14, pp.1065–1074, 1999.

[13] Benbouzid, M.E.H. ”A review of induction motors signature analysis as a medium for faults detection,” *IEEE Transactions on Industrial Electronics*, vol.47, pp.984–993, 2000.

[14] Kilman G.B. and Stein, J. “Methods of motor current signature analysis,” *Electric Machines and Power Systems*, vol.20, pp.463–474, 1992.

[15] Puche-Panadero, R., Pineda-Sanchez, M., Riera-Guasp, M., Roger-Folc, J., Hurtado-Perez E. and Perez-Cruz, J. “Improved resolution of the MSCA method via Hilbert transform, enabling the diagnosis of rotor asymmetries at very low slip,” *IEEE Transactions on Energy Conversion*, vol.24, no.1, pp.52–59, 2009.

[16] Ertugrul; N., Soong, W.L., Gray, D.A., Hansen C. and Grieger, J. “Detection of broken rotor bars in induction motor using starting-current analysis and effects of loading,” *Electric Power Applications, IEE Proceedings*, vol.153, no.6, pp.848-855, 2006.

[17] Antonino-Daviu, J.A., Riera-Guasp, M., Folch, J.R. and Palomares, M.P.M. “Validation of a new method for the diagnosis of rotor bar failures via wavelet transform in industrial induction machines,” *IEEE Transactions on Industry Applications*, vol.42, no.4, pp.990-996, 2006.

[18] Antonino-Daviu, J.A., Climente-Alarco, V., Pons-Llinares, J., Puche, R. and Pineda-Sanchez, M. “Transient-based analysis for the detection of broken damper bars in synchronous motors,” *Mechanical Systems and Signal Processing*, vol.34, pp.367-377, 2013.

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