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BROKEN BAR DETECTION BASED ON MEASUREMENT OF INDUCTION MOTOR ONE PHASE START-UP CURRENT

JEDAN METOD DETEKCIJE OTKAZA TIPA SLOMLJENE ŠIPKE BAZIRAN NA MERENJU STRUJE ZALETA MOTORA U JEDNOJ FAZI

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ABSTRACT

The paper presents the method of the broken bar detection based on analysis of an induction motor start-up current for no load case. Motor Current Signature Analysis (MCSA) is far the most popular approach to detect induction motor failures these days due to its benefits. The transient analysis is conducted by calculating power spectrum density (PSD) via Sort Time Fourier Transformation (STFT). Discriminative feature is obtained by calculating skenwness statistical parameter for given PSD for total amount of power per segment. It is shown that values for chosen features differ for healthy and broken bar rotor condition for a wide load range. Based on the proposed features estimation of rotor condition can be made. Study is done on real motor data collected from laboratory and industrial environment.

Key words: *broken bar detection, sturt-up current, induction motor.*

REZIME

Rad daje prikaz metoda za detekciju otkaza tipa slomljene šipke asinhronog motora na osnovu merenja struje zaleta u praznom hodu. U današnje vreme analiza signala struje motora je najpopularniji pristup detekciji otkaza zbog pogodnosti koje pruža u radu. Analiza prelaznog procesa je sprovedena estimacijom gustine spektra snage (PSD) uz pomoć kratkovremenske Furijeove transformacije (STFT). Diskriminativno obeležje je izdvojeno na osnovu izračunavanja statističkog parametra tipa skewness za dati PSD za ukupnu količinu snage po segmentu. Pokazano je da se vrednost odabranog obeležja jednoznačno menja za slučaj ispravnog i rotora sa slomljenom šipkom za širok opseg opterećenja. Na osnovu predloženog obeležja moguće je jednoznačno izvršiti procenu stanja rotora. Analiza je izvršena na stvarnim procesnim podacima prikupljenim u laboratorijskim i pogonskim uslovima.

Ključne reči: *struja zaleta, metod detecije, otkaz, slomljena šipka.*

INTRODUCTION

Induction motors (IM) dominate the field of electromechanical energy conversion; they cover over 80% of industrial drive applications. Some examples are: petrochemical, mining, food and beverage, electric utility industry, aerospace and military equipment, as well as a restricted role in low MVA power supply systems as induction generators. A presence of induction motors in domestic and industrial applications requires a development of reliable and economically justified maintenance methods. A preventive maintenance is not economically justified in majority of cases. Preventive maintenance costs may significantly raise a price of a final product or a service. Rather, maintenance should be based on the information provided by condition monitoring system *(Sin et al., 2003)*.

On-line condition monitoring involves: collecting signals of interests, processing signals to extract discriminative features, examining the features to found out does fault exist or not and achieving all of this in real time. The system must detect presents of fault during operational work of an IM. A broken bar fault occupies 5-10% of the total induction motor faults and raises great attention in the academic and engineering societies *(Siau et al., 2003)*. Trough out the last decade many methods and techniques have been proposed which provide early broken bar detection. These techniques, among others, are based on Motor Current Signature Analyses (MCSA) technique. MCSA is the most popular technique for IM faults detection due to its benefits *(Benbouzid, 2000)*. IM phase current can be divided in a two segments, transient and steady state, figure 1.

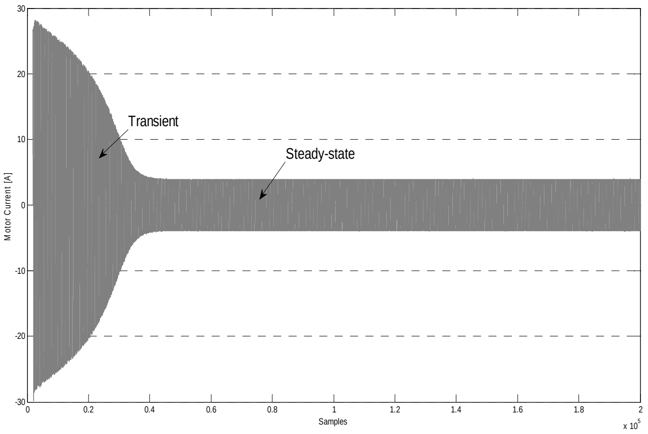

Fig. 1. Induction motor phase current

Features extraction from steady-state current signal is based on spectrum estimation based on Fast Fourier Transform (FFT) due to the nature of considered signal. Characteristic sidebands are considered to determent presents of broken bars. This technique is sensitive to load fluctuations and gives good results in cases when near nominal load is applied to the motor shaft. When the start-up transient is under consideration time-frequency techniques must be applied. In this paper PSD estimation is done via STFT due to nature of the transient signal. Other, most advanced techniques, like Wavelet Transformation and Wigner-Vile Distribution can be applied to prevent loss of time and frequency resolution (Antonino el at., 2009). The fault classifiers can be realized as statistical (Stepanić et al., 2009), artificial intelligent or expert systems *(Kamenko et al., 2010).*

MOTOR CURRENT SIGNATURE ANALYSIS FOR BROKEN BAR DETECTION

Analysis of steady-state current signal

Analyses of steady-state IM current for broken bar detection can be successfully conducted by examine magnitude of the left sideband of current spectrum. This approach is the far most popular one due to its simplicity and reliability *(Thomson, 2001)*. Frequency of the left sideband is function of IM slip:

$$f_{bb} = (1-2s)f_n \,. \tag{1}$$

Where: s-slip, f_n-supply frequency. When shaft load is near nominal, slip is maximal; the left sideband magnitude gives unique information related to rotor condition *(Thomson and Fenger, 2001)*. This can be simple formulized as: if magnitude of left sideband is less than -54dB rotor is healthy, if it is greater than -45dB at least one broken bar is present, if it is fallen inside the spam [-54 -45] dB reliable conclusion cannot be made *(Sin et al., 2003)*. Few authors proposed analytical models which gives dependency between magnitude of the left sideband and number of broken bars at nominal shaft load. The models reliable cover cases from 1 to 4 broken bars *(Matić et al., 2010)*. Figure 2 gives overview of IM current spectrum for cases when one broken bar is present and there is no load attached to the motor shaft. From figure 2 easily may be spotted that described method, based on FFT, is not suitable for cases when no load is attached to the motor shaft. Characteristic sidebands come under supply frequency and they are not easy to extract *(Bellini et al., 2001)*. Analysis of steady state current in no load case should relay on method based on Hilbert Transformation *(Puche-Panadero et al., 2009)*. Methods based on analysis of the current transients are more suitable for cases when there are fluctuations of load or no load applied. In addition, other faults different from broken bar (ball-bearings defect, voltage and torque oscillations) can implies frequencies close to those introduced by broken bar fault, making the diagnosis process more challenging *(Antonino el at., 2009)*.

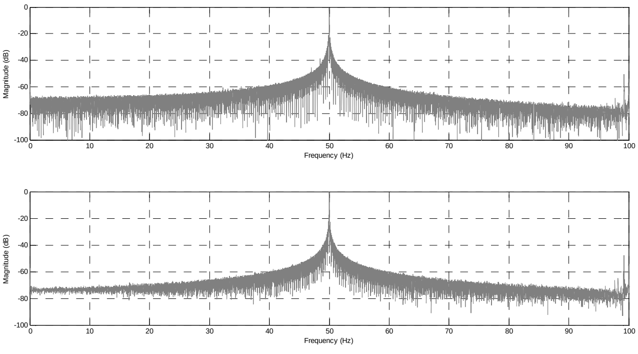

Fig. 2. Upper plot - healthy motor, lower plot - one broken bar

Analysis of current start-up transient

When looking at a Fourier transformation of a signal, it is impossible to tell when a particular event took place. This is a consequence of a loss of time information during transformation. If signal properties are non-stationary or transitory windowing of signal should be applied. This technique was introduced by Dennis Gabor in 1946, which conducts Fourier transformation over a small section of a signal at a time, named window. Gabor's adaptation, called the Short Time Fourier Transformation, maps a signal into a two-dimensional function of time and frequency. The STFT represents a sort of compromise between the time-frequency based views of a signal. However, this information can be obtained with limited precision, and that precision is determined by the size of the window *(Mehala and Dahiya, 2009)*. This is relatively non-flexible approach, and for some types of signals, variably windowing techniques are require, like Wavelet Transformation for example.

Figures 3 and 4 represent the PSD estimation of IM start-up current, based on STFT, for healthy and broken bar case respectively for no shaft load case. PSD is calculated in decibels [dB]. Size of window is 1000 samples with overlap of 750 samples. Difference between the two PSDs is visually obvious. Extraction of various reliable features in this case is possible.

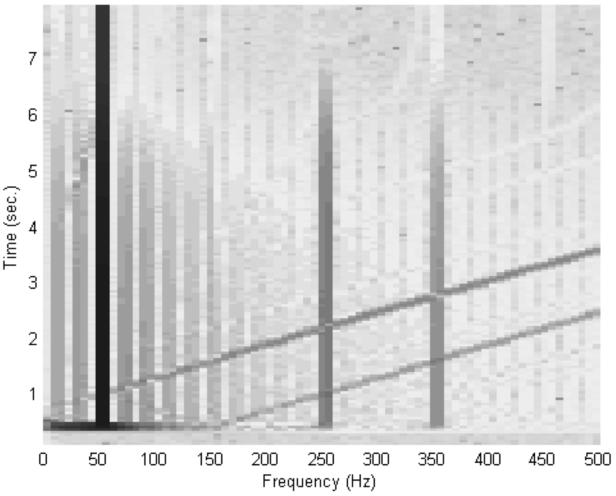

Fig. 3. PSD of the healthy motor

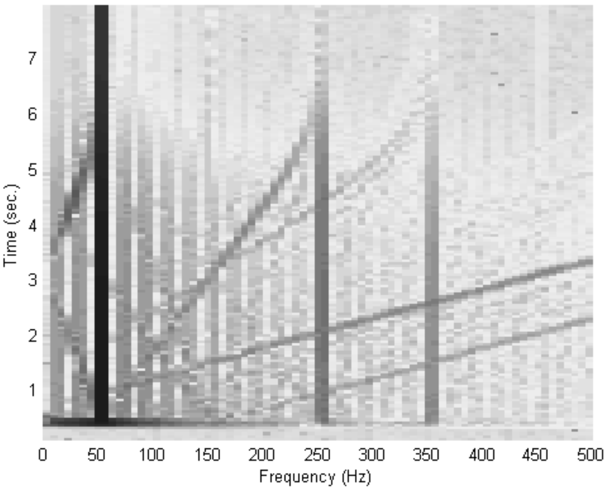

Fig. 4. PSD of the motor with one broken bar

FEATURE EXTRACTION FOR BROKEN BAR DETECTION

Based on information presented in previous sections, extraction of discriminative features is the next challenging step. Attempt to numerically describe visual difference of figures 3 and 4 are found in following procedure. First for each segment of PSD values of power are summarized, which gives total amount of power per segment. Than following statistical parameters are applied: skewness, kurtosis, standard deviation, central moment, variance and mean value, and gained data are observed *(Stepanić et al., 2009)*. One pair of poles induction motor is tested. Table 1 gives overview of the values of the considered statistical parameters for given PSDs. The firs column represents four experiment and two fault cases, one healthy condition and three faulty. In following columns, values of observed parameters are shown for every experiment.

Table 1. Overview of considered statistical parameters

Rotor condition	Skewness	Kurtosis	Standard deviation	Central moment	Variance	Mean value
Healthy	-0.2385	1.7707	15.9631	-957.5501	254.8204	27.9613
One bb.no.1	-0.0713	1.6504	16.3622	-308.3729	267.7210	25.3855
One bb.no.2	-0.0774	1.6478	16.1334	-320.8522	260.2860	25.0814
One bb.no.3	-0.0684	1.6356	16.1138	-282.4037	259.6543	24.8592

By analyzing data given in table 1 could be concluded that skewness moment holds greatest discriminative margin with relative index of 3.1. Because of that skewness moment is the best discriminative candidate from group of considered. Based on his value could be uniquely determent a rotor condition in respect of appearance of the broken bar fault.

CONCULSION

Due to importance of IM early fault detection and diagnosis systems are of great interest. Based on the previously presented results could be concluded that proposed procedure yields the classifier which is capable of early detecting the broken bar fault, based on a measurement of the start-up motor current in no shaft load case. Relatively simple and low time consuming procedure is presented. More study need to be undertaken to determine validity and applicability of the proposed procedure.

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