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SUBSTANTIATION AND EXPERIMENTAL VERIFICATION OF INSTANTANEOUS POWER SPECTRA ANALYSIS AS A METHOD FOR INDUCTION MOTORS FAULT DETECTION

Usage of instantaneous power signal spectra for detection of most frequently caused induction motor's damages was grounded. Efficiency of this method was verified experimentally.

Обґрунтовано використання спектру сигналу потужності асинхронного двигуна для діагностики найбільш типових його дефектів. Експериментально підтверджено ефективність його діагностики за спектром потужності.

Обосновано использование спектра сигнала мощности асинхронного двигателя для диагностики наиболее типичных его дефектов. Экспериментально проверена эффективность его диагностики по спектру мощности.

Introduction. Induction motors (IM) are most widely used energy consumers and energy converters for different industrial applications. In spite of a very simple and reliable construction, there happen sudden failures of IM, and they may lead to serious faults of the whole work station. This may results in significant pecuniary losses because of repair operations and idle time. Thus, timely diagnostics of incipient IM faults is a very important task. To achieve this effect the on-line IM diagnostic systems are being developed.

Analysis of previous researches. Different reviews [1] showed that most frequently caused IM defects are the following: the bearings defects (32-52%), stator windings defects (15-47 %), rotor bars/rings (less than 5%), shaft or coupling defects (about 2 %), defects caused by external devices (12-15 %), other defects (10-15 %). For detection of bearings faults there are well-developed and widely used methods of vibration diagnostics. Thus, this work is devoted to incipient faults detection of stator and rotor. Most common rotor faults are the rotor-to-stator eccentricity and the rotor bar breaks. Most common stator defects are the short circuits in windings and also the windings parametrical asymmetry.

There is a range of methods for incipient fault detection. Widely used are monitoring of mechanical vibrations, currents, reverse sequence pole and partial charges. The aim of these methods is to detect deviations in signal spectra.

Well-known IM incipient faults detection methods are successfully used for large and medium machines. However, there are some limitations to usage of these methods for low-voltage machines, because of economical reasons and sensors size.

The analysis of existing IM diagnostic methods gives the following results.

Motor stator currents analysis (MSCA) is a very popular diagnostic method because of simplicity of signal recording under operation mode. There is a number of works devoted to using MSCA as a medium for detection the stator windings short-circuits, rotor unbalances and rotor bar breaks, and also bearings defects [2]. But it has to be mentioned that electrical distortions and influence of supplying voltage low quality could lead to appearance of harmonics in current signal on the same frequency as a fault harmonics. This may lead to wrong diagnosis. To eliminate such shortcomings of this method the additional analysis by vibrations or more complicated mathematical apparatus for analysis are used. However, even this additional analysis does not protect from diagnostic mistakes when low-power IMs with significant influence of voltage unsinusoidality are under analysis. This fact is especially significant for IM fed from low-voltage supply of industrial plants.

Another well-known diagnostic method is supply voltage analysis [3,4]. The data are analyzed either according to supply voltage spectra with neutral voltage [3], or high frequency carrying signal [4]. As for the first mentioned method, diagnostic result significantly depends on voltage quality, which is not always ideal in low-voltage networks with IM. As for the second mentioned method, there is necessity of using additional equipment for making test carrying signals.

Also there is a range of methods for fault detections under transient conditions, as [5]. But these methods provides the best results for analysis of starting, braking modes, and modes under transient load, when there are significant signal changes both in time and frequency domains. Thus, these methods are less convenient for steady state modes analysis.

The instantaneous power spectra analysis allows avoiding shortcomings of above mentioned methods [6]. Instantaneous power spectra analysis allows both detection of fault presence and estimation of damage level by analysis of proper harmonic value. Thus, instantaneous power spectra analysis allows one to make estimation of the energy of fault and the correlation of this energy to additional damage of IM parts under influence of additional vibrations caused by proper harmonic. Moreover, the instantaneous power spectra analysis allows analyzing of IM operation modes under significant nonlinearity, when it is incorrect to use superposition principle for current harmonics. Also, instantaneous power analysis is more reliable, it is less dependent on noise, and gives additional harmonic components for analysis.

In [7] it was offered to provide monitoring and estimation of IM operating conditions by instantaneous power and electromagnetic torque spectra analysis. This analysis is based on developed in [8] algorithm. As it was mentioned, it is very important to take into account supply voltage quality for making proper diagnosis of low-power IM. A number of authors have investigated the influence of supplying voltage low-quality on parameters and operation modes of low-power IM. It leads to conclusion that it is necessary to eliminate the influence of noises, asymmetry and non-sinusoidality of supply voltage on analyzed currents and power signals. It improves accuracy and reliability of diagnostic.

Purpose of work. Investigation IM diagnostic method based on instantaneous power spectra analysis.

Material and results of research. To verify the instantaneous power spectra analysis as a method for IM fault detection the experimental tests were carried out. The most frequent caused damages as rotor bar breaks and stator windings short circuits were chosen to be investigated. IM diagnostics by 3-phase motor instantaneous power spectra analysis is carried out on the basis of measured stator currents and voltages. In case of voltage supply low-quality, both the motor non-linear elements and the network non-sinusoidality and dissymmetry cause harmonics in current signal spectra. Thus, IM diagnostic based on MCSA may lead to wrong result. It is possible to increase reliability of diagnostic methods based on current and power spectra analysis by elimination the influence of supply voltage and non-sinusoidality on analyzed signals, as it was proposed in [9].

The test motor used in the experimental investigation was a three-phase induction machine type АИР80В4У2, 50 Hz, 4-pole, 1,5 kW, 1395 rpm; 3,6 A. For investigation of turn-to-turn short circuit in stator windings, the taps were provided in one of the stator winding phases to imitate this type of damage (Fig. 1, Table 1). For broken bars investigation there were used two rotors of identical type which can be interchanged. One of these rotors has drilled hole to imitate break of one rotor bar. DC generator provided a mechanical load.

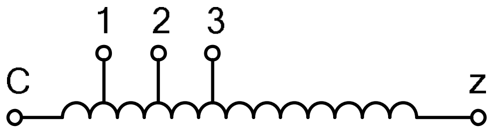

Fig.1. Stator phase winding taps circuit

IM winding resistance measurement data

Phase	Resistance value, ohm		
A	5,03		
B	4,99		
C	5,01		
Taps in phase C	Winding part	Resistance value, ohm	Reduction of winding turns number, %
	1-z	4,94	1,36
	2-z	4,88	2,52
	3-z	4,34	13,33

The following assumptions were accepted for experimental researches. The possibility of load variation was not taken into account. This variation may lead to appearance of interharmonics and low-frequency harmonics in power spectra. Interharmonics do not make significant influence on informative harmonics which are used for analysis. The influence of low-frequency harmonics could be compensated by analysis of three-phase IM instantaneous power mean value. The influence of heating appears in changes of windings active resistances. In case of uniform heating the active resistances will change symmetrically. Nonuniform heating mainly leads to more clear asymmetry demonstration. It could be observed by difference between amplitude harmonics by phases. Researches [7] showed that the main influence of saturation appears on 6-th and its multiple harmonics of instantaneous power. However, harmonics of lower frequencies also were used for analysis in this work. It has to be mentioned, that offered method could be used both for variable speed motor and for fixed speed motor based on voltage inverter (voltage inverters with PWM).

Analysis was carried out both for IM idle conditions and for half load conditions. Preliminary data showed that defects could be more obviously manifested in loaded machine signals. Thus, following analysis is presented for half loaded conditions. Experimental data analysis leads to conclusion that elimination of supply voltage unsinusoidality and dissymmetry, using proposed in [9] methods, allows removing from consideration harmonics caused by voltage low-quality. This simplifies the analysis and improves diagnostics results [9].

Experimental data analysis showed that the following defects were present in the basic variant of IM without artificial damages (Fig.2,3):

– rotation speed harmonics (24,8 Hz for tested IM) and its multiple in current and power spectra shows misalignment of shaft and actuator;
– double supply frequency in three-phase power spectra (100 Hz) shows base motor dissymmetry. Its low value confirms good motor condition;
– power harmonic multiple of six supply main harmonic shows IM nonlinearity and influence of magnetizing curve;
– power harmonics multiple of supply main harmonic shows presence of both motor nonlinearity and dissymmetry and appears as result of multiplying of proper current and voltage harmonics.

The values of considered harmonics for base IM are not significant. These values are less then 2 % of rated power. It shows motor good conditions.

Experimental data analysis for rotor with one broken bar leads to the following conclusions (Fig.4,5).

Two sideband components appears in current around fundamental component at following frequencies (Fig.4)

$$f_{bb} = f_n(1 \pm 2ns),$$

where f_n – is a fundamental frequency, s – is a motor slip, $n = 1,2,...$

When supply mains low-quality influence on current signal is eliminated, sideband components became more clearly visible (Fig.4,b).

3-phase power spectra, in addition to two sideband components around double fundamental component, contain component at the modulation frequency (Fig.5). This component provides additional diagnostic information about motor conditions, and allows improving reliability and accuracy of diagnostics.

When a turn-to-turn short circuit appears, as well as when there is stator windings asymmetry, the amplitude of harmonics of the frequency of 100 Hz increases significantly. Separation of these defects is possible when power factor $cos\varphi$ is calculated, as in the presence of turn-to-turn short circuits, unlike asymmetry of stator windings, the angle of current and voltage phase shear reduces, i.e. the value of this coefficient increases.

Thus, experimental verification of IM diagnostic method based on instantaneous power spectra analysis showed its utility for rotor bar breaks and stator

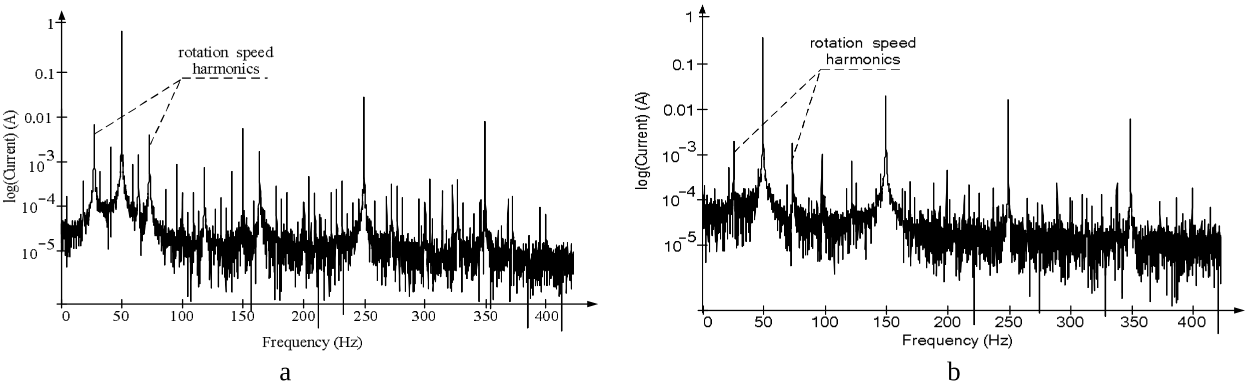

Fig.2. Current spectra of IM without artificial damages: base signal (a) and signal after supply low-quality elimination (b)

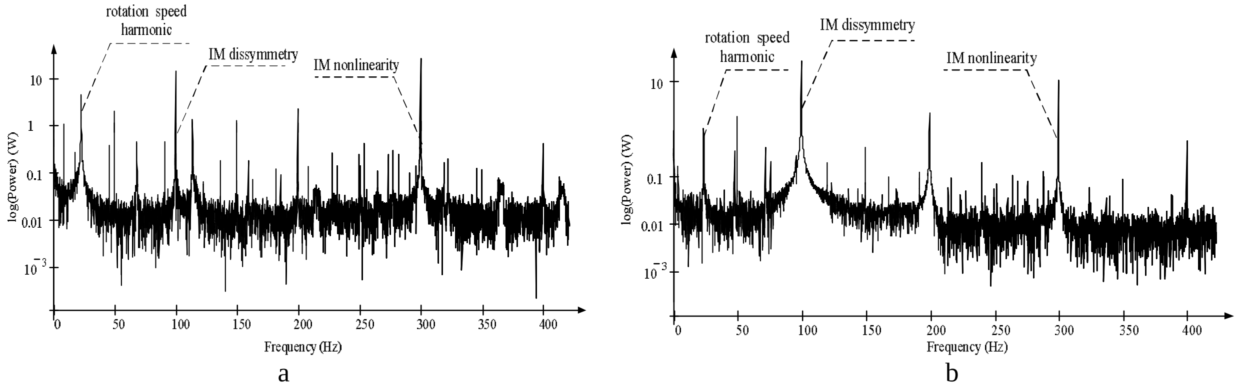

Fig.3. 3-phase power spectra of IM without artificial damages: base signal (a) and signal after supply low-quality elimination (b)

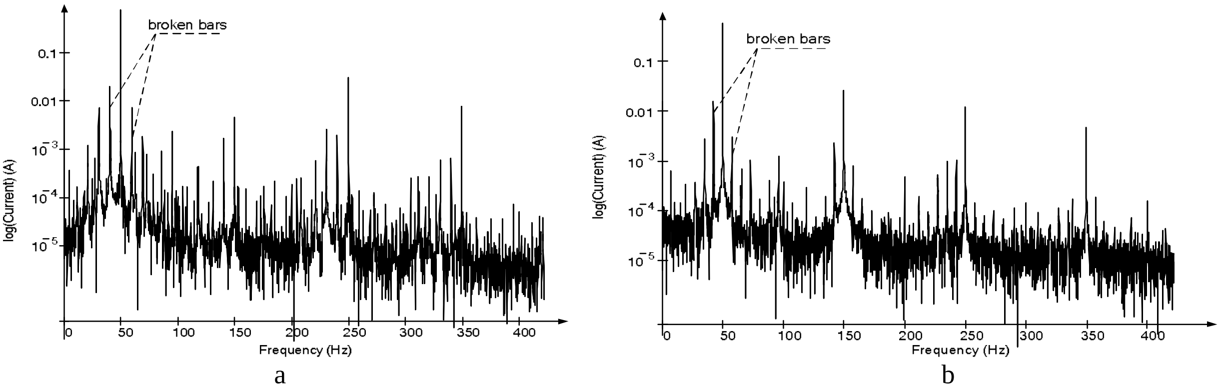

Fig.4. Current spectra of IM with one broken bar: base signal (a) and signal after supply low-quality elimination (b)

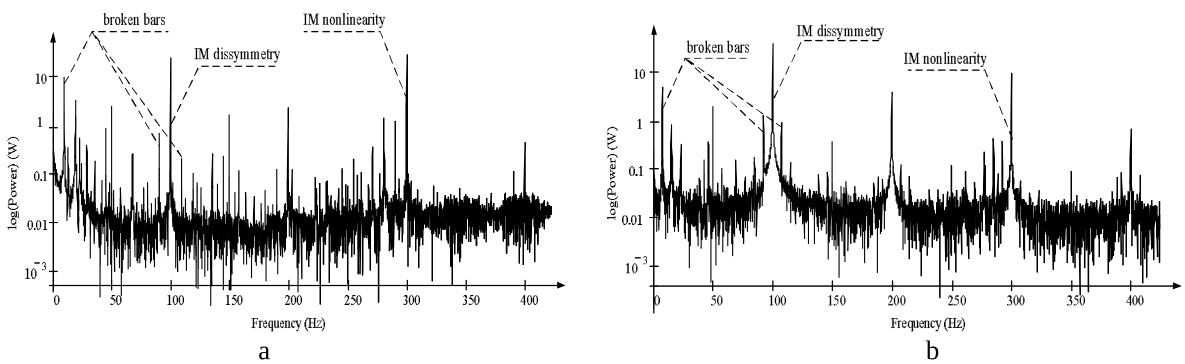

Fig.5. 3-phase power spectra of IM with one broken bar: base signal (a) and signal after supply low-quality elimination (b)

windings short-circuits detection. The diagnostics simplification and improvement due to elimination of supply voltage low-quality, was confirmed.

Conclusions. An IM diagnostic method, based on three-phase instantaneous power spectra analysis, was considered. Usage of supply voltage low-quality elimination method makes it possible to analyze the spectrum of consumed three-phase instantaneous power without components caused by supply mains low-quality parameters. This method provides improved accuracy and information value of IM diagnostics on the basis of the analysis of the spectrum of consumed three-phase instantaneous power.

The method of IM diagnostics on the basis of the analysis of three-phase instantaneous power has been checked experimentally and its applicability to determination of stator and rotor winding several defects simultaneously has been proved. The possibility of estimation of the extent of defects development according to the value of the amplitude of consumed power correspondent harmonic has been shown.

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