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Instantaneous Power Spectrum Analysis To Detect Mixed Eccentricity Fault In Saturated Squirrel Cage Induction Motor

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***Abstract*— Mixed eccentricity fault is one of the most common faults occurring in squirrel cage induction motors. Several techniques have been used to detect this type of fault, such as those based on vibration, axial leakage monitoring, zero-sequence component, negative sequence current, and motor current spectrum analysis. However, these techniques do not take into account the effect of magnetic saturation. In this paper, Instantaneous Power Spectrum Analysis (IPS) technique is used to detect this kind of fault, it shows the effect of harmonic saturation on the mixed eccentricity fault diagnosis of squirrel induction motors. Both simulation and experimental results for healthy and faulty motors are shown and discussed.**

***Keywords*— squirrel cage induction motor, fault diagnosis, mixed eccentricity, instantaneous power analysis, magnetic saturation.**

I. INTRODUCTION

The Squirrel cage induction motors (SCIM) are widely used in many industrial applications, because they are characterized by high reliability, low cost per power unit, high power per volume unit and need very low maintenance. Although these are very reliable, they are subjected to different modes of failures faults. These faults may be inherent to the machine itself or due to the operating conditions. The inherent faults may be due to the mechanical or electrical forces acting on the machine enclosure. A variety of machine faults are studied in the literature [1, 2, 3], such as winding faults, unbalanced stator and rotor parameters, broken rotor bars, eccentricity and bearing faults. Several fault identification method have been developed and been effectively applied to detect machine faults at different stages by using different machine parameters, such as current, voltage, speed, efficiency, temperature and vibrations. A diagnosis technique which can detect a failure and prevent the total damage of the motor is therefore of great importance [4, 5, 6].

In our paper [7], a state of art of various approaches used in the modelling of the saturated induction motor, are presented. Also, in [7] a mathematical model based on of the modified winding function approach is developed, for the various inductances of SCIM calculating (taking into account both space harmonics of the magneto motive force and the magnetic saturation).

Simulation and the stator current spectral analysis, demonstrate at first, the importance of introducing the magnetic saturation in our model, which is reflected by the presence of harmonics, in the neighbourhood of the principal rotor slot harmonics (PSH) in the healthy motor, and secondly, for the faulty motor, the mixed eccentricity harmonics are in proximity of saturation harmonic position.

This paper introduces the application of instantaneous power spectrum analysis for diagnosis of the mixed air gap eccentricity, especially for the case of saturated squirrel cage induction motors (SSCIM).

The advantage of this technique is that, it enables us to monitor the motor by the use of the two electric parameters simultaneously, the voltage and the current.

The paper is organized as follows: Next section is focused on the presentation of the instantaneous power spectrum technique. In the third section, our results are presented, and validated.

II. INSTANTANEOUS POWER SPECTRUM TECHNIQUE

We consider an ideal three-phase supply voltage. The instantaneous power *p(t)*, is defined as:

$$p(t) = v(t)i(t) \tag{1}$$

Where *v(t)* is the voltage between any two of the three stator terminals and *i(t)* is the terminal current input. The expression of the voltage *v(t)*, current *i(t)* and instantaneous power are given by [6] :

$$v(t) = U_m \cos(2\pi f t) \tag{2}$$

$$i(t) = I_m \cos(2\pi f t - \varphi) \tag{3}$$

$$p(t) = \frac{U_m I_m}{2}\cos(2(2\pi f)t - \varphi) + \frac{U_m I_m}{2}\cos(\varphi) \tag{4}$$

Where U_m and I_m are the amplitude of the supply voltage and current, respectively, f is the supply frequency, and φ is motor phase angle.

If the air gap eccentricity fault occurs in SCIM, the instantaneous power can be expressed as [8, 9, 10]:

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$$p_{ecc}(t)=\frac{U_m I_m}{2}\cos(2\pi(2f)t-\varphi)+\frac{U_m I_m}{2}\cos(\varphi)+\sum_{k=1}^{\infty}\left\{\begin{array}{l}\frac{U_m I_{ecc},k_1}{2}\cos(2\pi(2f-kf_r)t-\alpha_1)\\+\frac{U_m I_{ecc},k_1}{2}\cos(2\pi(kf_r)t+\varphi_1)+\\\frac{U_m I_{ecc},k_2}{2}\cos(2\pi(2f+kf_r)t-\alpha_2)\\+\frac{U_m I_{ecc},k_2}{2}\cos(2\pi(kf_r)t+\varphi_2)\end{array}\right\}\tag{5}$$

Where α_1 and α_2 are the initial phase angle at a frequency $f+kf_r$ and $f-kf_r$ respectively.

It can be seen, that the instantaneous power contains a dc level and additional components at f_r frequency.

Now if we take into account the magnetic saturation, the saturation characteristic components at f_{sat} appear in the stator current [7].

$$f_{sat}=((k.n_b\pm n_d).\frac{(1-s)}{p}\pm 2.n_{sat}\pm\vartheta)f\tag{6}$$

Where, p is pole number, n_b is number of rotor bars, ϑ is harmonic order, n_d=0 (for healthy motor) and n_d=1, 2... (For faulty motor), n_{sat} is saturation and s is the slip.

These saturation characteristics (fundamental, principal rotor slot and mixed eccentricity fault), are added to the instantaneous power spectrum components.

III. DIAGNOSIS OF MIXED ECCENTRICITY FOR SATURATED SQUIRREL INDUCTION MOTOR

A. *Simulation results*

A software is developed to solve the various differential equations by employing the fourth order Runge-Kutta technique, this for the study of the SCIM behaviour for the case of a healthy and mixed eccentricity faulty motor, with and without the saturation conditions. Simulations confirm the advantages of the IPS technique (the parameters of SCIM are presented in appendix).

For the case of the healthy motor loaded with a constant torque, the instantaneous power spectrum without and with saturation including the fundamental component 100Hz and principal rotor slot harmonics (PSH1, PSH2 and PSH3), are shown in Figure 1 and Figure 2 respectively.

Figure 2 shows, that the low and up, saturation harmonics (SHL and SHU) are in the neighbourhood of the principal rotor slot harmonics (PSH_1 and PSH_3).

For the case of the faulty motor (by introduction of the mixed eccentricity fault), the Figures 3 and 4 show the IPS with and without saturation. The results show also that without saturation effect, the mixed eccentricity harmonics Low and Up (MEL and MEU) are sided band, in the neighbourhood of the PSH_1 and PSH_2 (Figure 3). On the other hand the effect of saturation seems very well by the presence of the harmonics of saturation on both sides the harmonics of eccentricity faults (Figure 4).

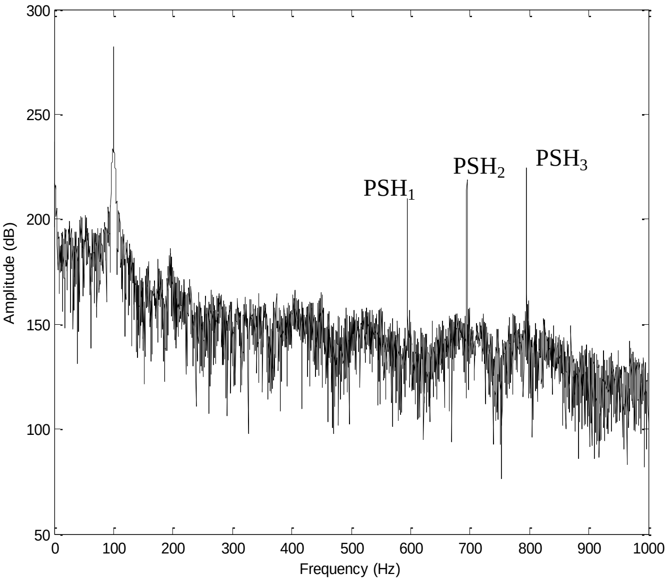

Fig.1. IPS for healthy motor and without saturation.

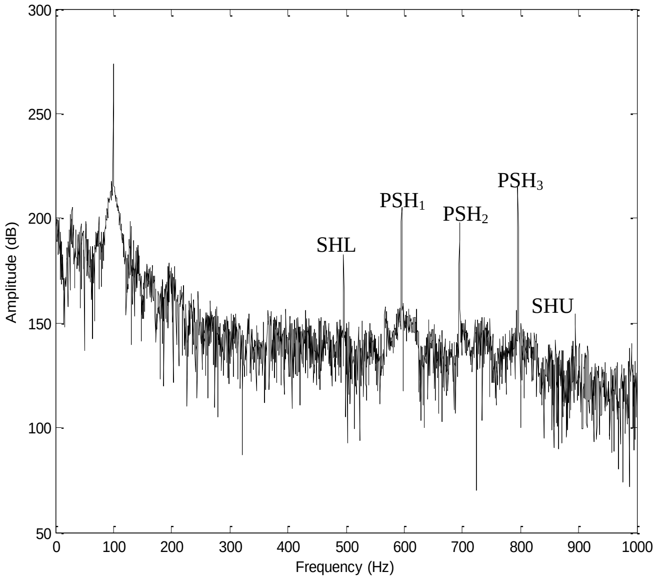

Fig.2. IPS for healthy motor and with saturation.

B. *Experimental results*

Figure 5 illustrates experimental system scheme to detect faulty conditions. This bench includes two 3-phase squirrel cage induction motors, 4 kW, 1500 rpm, rated supplied 380 V, 50 Hz, coupled to a permanent magnet synchronous generator. One of the motors is the healthy machine and the other is the faulty machine with mixed eccentricity of the squirrel cage. The synchronous generator is connected to a variable resistive load. Figure 6 shows the implemented test bench.

Instantaneous power spectrum analysis of the healthy

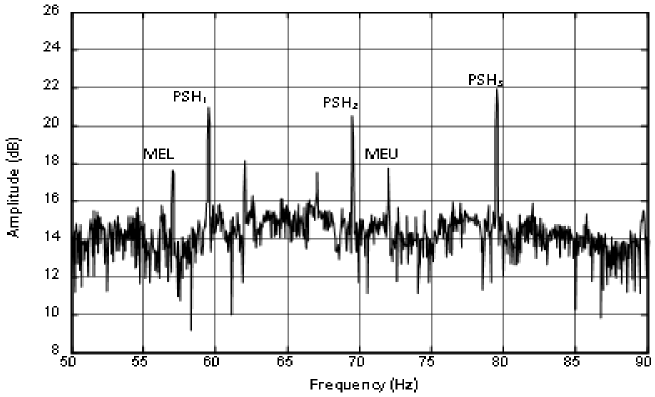

Fig.3. IPS for Mixed Eccentricity and without saturation.

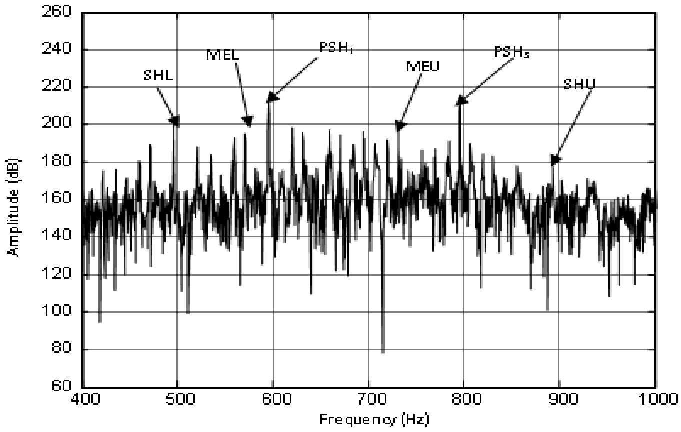

Fig.4. IPS for Mixed Eccentricity and with saturation.

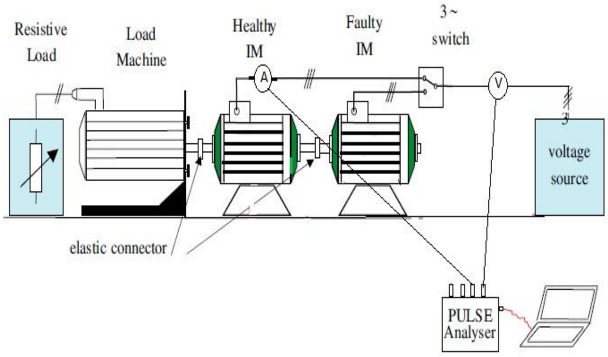

Fig. 5 Detection system scheme

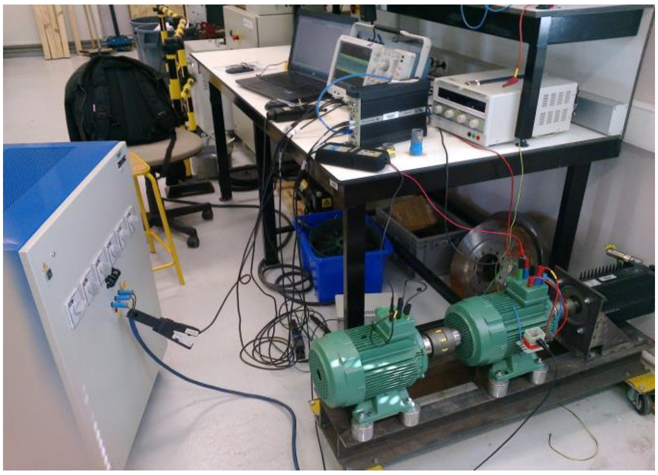

Fig. 6 Experimental bench

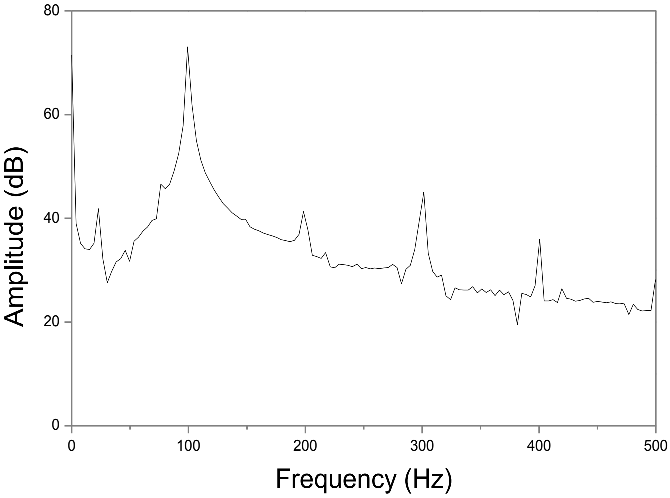

Fig. 7 IPS for healthy motor (experimental result).

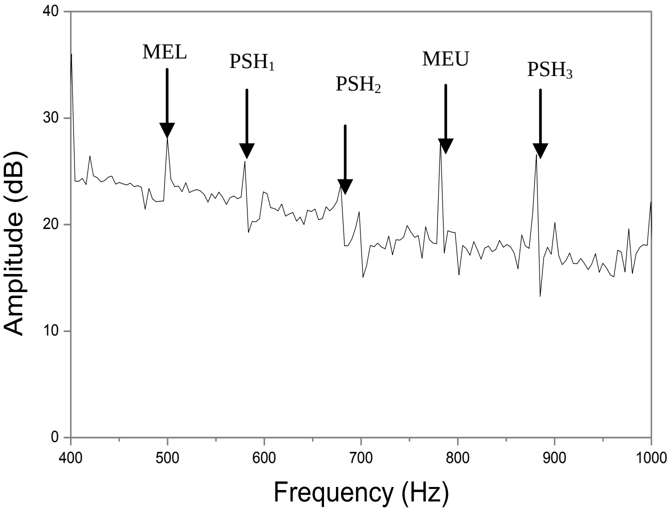

Fig. 8 IPS for faulty motor and without saturation (experimental result).

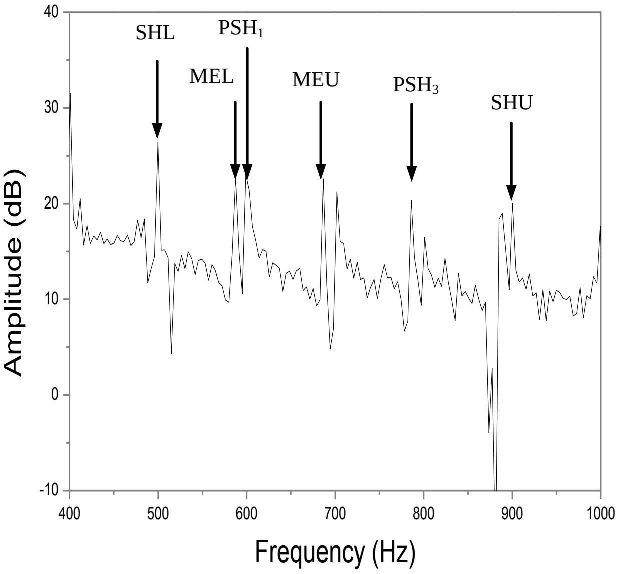

Fig. 9 IPS for faulty motor and with saturation (experimental result).

motor is shown in the Figure 7. It can be noticed, that both practical and simulation spectrum results are comparable (the principal harmonics components can be identified at 100 Hz).

Figure 8 shows the instantaneous power spectrum for faulty motor without saturation. The Low and Up mixed eccentricity harmonics (MEL and MEU) are sided band, and detected in the neighbourhood of the principal slot harmonics, this confirms the simulation results (Figure 3).

For the case of the faulty motor with saturation (Figure 9), the mixed eccentricity harmonics are in the proximity of the saturation harmonic position, which also confirms the simulation results.

IV. CONCLUSIONS

This paper presents a non-invasive method for detection of mixed eccentricity fault in saturated squirrel cage induction motor, using instantaneous power spectrum. The advantages of the proposed method compared to the others methods, are, the simplicity to implement, and to interpret, and the low cost of the set-up. It showed in the health case that the saturation harmonic is present in the neighbourhood of the PSH in agreement with the experimental results.

Likewise, simulation results shown, that the magnitude and the position of the saturation harmonic in the neighbourhood of the mixed eccentricity harmonics, will contribute in the fault motor diagnostic technique. Finally, the experimental tests realized in different operation forms of induction machine confirm our results obtained in [7].

Appendix

Machine Parameters: 7.5 Hp, 36 stator slots, 28 rotor bars,

Rs = 3.5332	Ω	stator resistance
Ls = 0.028	H	stator inductance
Lr = 0.28	µH	rotor inductance
Rr = 68.34	µΩ	rotor resistance
J = 0.02	kg.m2	rotor inertia

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