Removing the Fundamental Component in MCSA Using the Synchronous Reference Frame Approach

Erik L. Bonaldi[1], Levy E. de L. de Oliveira[1], Member, IEEE, Luiz E. B. da SILVA[1], Member, IEEE, and Germano L. TORRES[1], Member, IEEE

[1]IEE, UNIFEI, Av. BPS, 1303, Pinheirinho, Itajubá - MG, Brazil, e-mail : (erik, levy, leborges, germano)@iee.efei.br

Abstract—**The *Predictive Maintenance* applied to three-phase-induction motors through the *Motor Current Signature Analysis* is the highlight of the moment. Removing the fundamental component of the stator current signal is an important task in this approach. With this component extracted it is possible to improve the dynamic range of the A/D converter in order to get a more precise digitized signal and improve the failure detection. In general, notch filters are utilized to accomplish this task, but they present problems such as attenuation of some important frequencies located very close to the fundamental component which have information about a specific failure. This paper introduces the *Synchronous Reference Frame* approach, generally applied to active power filters, to solve the presented problem.**

***Index Terms*—predictive maintenance, motor current signature analysis, synchronous reference frame, A/D dynamic range.**

I. Introduction

Nowadays there is a great concern about the reliability of the productive process in order to reduce production costs and increase productivity in the industrial area. This fact makes maintenance techniques a very important issue. The highlights of the moment are predictive maintenance techniques. Inside this area, Motor Current Signature Analysis (MCSA) is one of the most interesting techniques.

MCSA is a noninvasive technique diagnosing of problems in induction motors. It consists of utilizing the results of spectral analysis of the stator one-phase current signal. When a failure is present, the frequency spectrum of the line current becomes different from that of a non-faulted one. Such a fault modulates the air-gap and produces rotating frequency harmonics in the self and mutual inductances of the machine. Since the flux linkages oscillate at only the electric supply frequency, these harmonic inductances result in stator current harmonic at rotating frequency sidebands of the line frequency [1].

A problem related to the process is the necessity of an accurate and precise acquisition of the stator current signal. Since this signal is digitized and the fundamental component amplitude is extremely high if compared to the other components, smaller but important signals will get buried in the quantization noise. This way, changes in the amplitude of some components related to the failure can not be noticed while the failure is getting worse.

This paper introduces the Synchronous Reference Frame

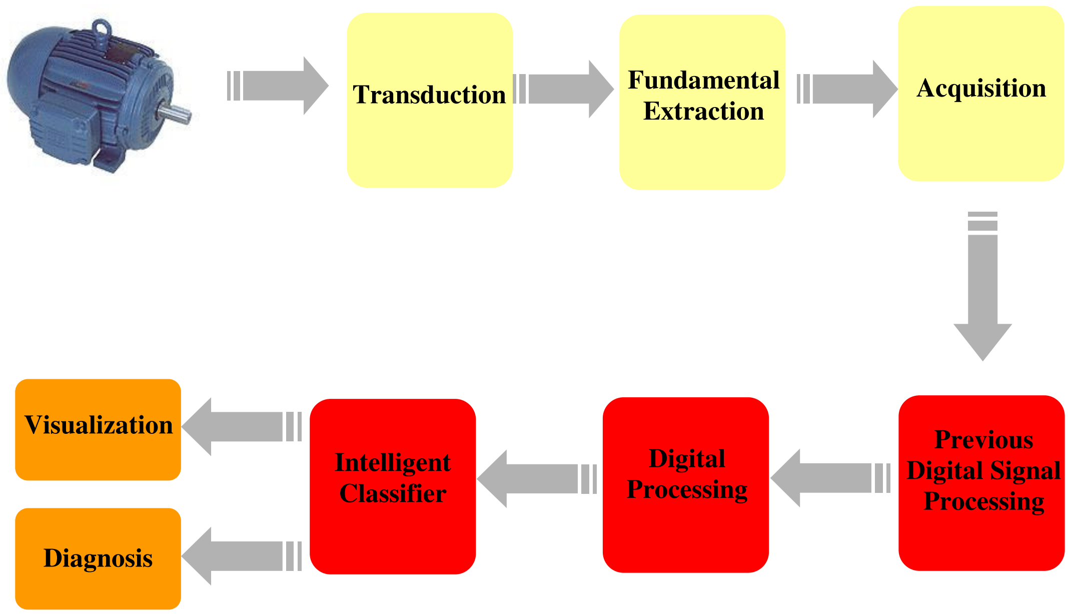


Figure 1: Predictive Maintenance System based on MCSA

Approach (SRFA), generally applied to actives power filters, to solve the presented problem.

Figure 1 presents the whole system where the SRFA will be applied to. The process is composed of three main parts: signal acquisition (transduction, fundamental extraction and A/D conversion), digital processing and classification. A very good acquisition will assure a very precise failure classification.

II. Proposed Solution: Synchronous Reference Frame Method

Figure 2 presents the block diagram for the fundamental current extraction process with the synchronous reference frame method (SRFM).

The SRFM [2]-[6] is based on the determination of the instantaneous active and reactive currents (id and iq). The SRFM creates a reference frame of orthogonal axes that rotates at the supply frequency (d-q system), that is, a synchronous reference. This synchronism with the supply can be achieved by a phase locked loop (PLL) [7]-[8] connected to the supply voltages or currents. In some situations only the supply frequency is necessary for applying the SRFM, so that, the supply phase is not needed [6].

In this rotating reference, the fundamental stator current becomes dc values in the id-iq currents that can be determined by some kind of low-pass filter, like: butterworth or moving average [4]-[6].

In order to calculate the id and iq currents, the invariant power Clarke transformation is applied to the stator currents, followed by the Park transformation, so that, the stator currents at the a-b-c system are transformed to the α-β-0 system and from the α-β-0 system to the d-q-0 system. Equations (1) and (2) show the Park and the invariant power Clarke transformations, respectively.

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}, \quad (1)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos\theta & sen\theta \\ -sen\theta & \cos\theta \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}, \quad (2)$$

where θ is the phase angle of the phase a voltage; and the fundamental frequency unit vectors, sin(θ) and cos(θ), are determined by the PLL.

The id and iq components can be both divided into alternating (ac) and constant parts (dc), as shown in equation (3).

$$i_d = i_d^{-} + i_d^{\sim}; \qquad i_q = i_q^{-} + i_q^{\sim}. \quad (3)$$

After the Park transformation the fundamental stator currents becomes the dc parts of the id and iq currents (id^{-} and iq^{-}) and all the rest of the harmonics become the ac parts of them ($id^{\sim}$ and $iq^{\sim}$) with a frequency offset equal to the supply frequency [4]-[6].

Therefore, eliminating the ac parts of id and iq, that is, $id^{\sim}$ and $iq^{\sim}$, the fundamental currents at the d-q-0 system, that is, id^{-} and iq^{-}, will last and so, after the transformation to the a-b-c system, they can be subtracted from the stator current transducer outputs before the A/D conversion.

The elimination of the ac parts of id and iq can be done by some kind of low-pass filter, as shown in Fig. 3.

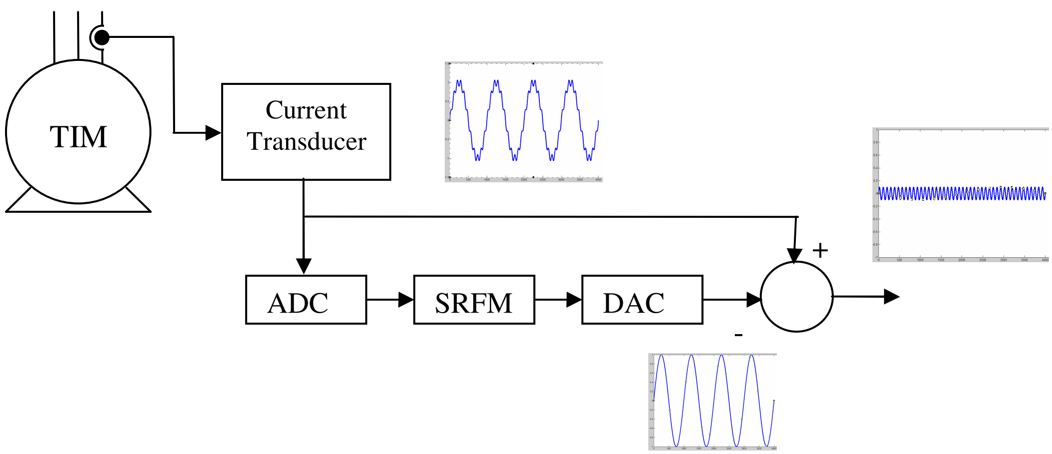


Figure 2 – Fundamental current extraction process

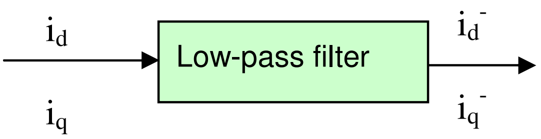


Figure 3 – Low-pass filter for eliminating the ac parts of id and iq.

In [4]-[6], it is reported the application of moving average filters to the determination of id⁻ and iq⁻. The moving average filters are simpler and faster than the butterworth ones when applied to accomplish this specific task.

Once the id⁻ and iq⁻ currents were determined, they must be transformed to the α-β-0 system by the inverse Park transformation in equation (4).

$$\begin{bmatrix} i_\alpha^- \\ i_\beta^- \end{bmatrix} = \begin{bmatrix} \cos\theta & -sen\theta \\ sen\theta & \cos\theta \end{bmatrix} . \begin{bmatrix} i_d^- \\ i_q^- \end{bmatrix}, \quad (4)$$

And, so, to the a-b-c system by the inverse invariant power Clarke transformation in equation (5).

$$\begin{bmatrix} i_a^- \\ i_b^- \\ i_c^- \end{bmatrix} = \sqrt{\frac{2}{3}} . \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} . \begin{bmatrix} i_0 \\ i_\alpha^- \\ i_\beta^- \end{bmatrix} . \quad (5)$$

It is important to notice that if only one stator current is being analyzed, the SRFM is still valid. In this particular situation, the other two currents must be generated by 120 and 240 degree delays applied to the stator current measured.

III. SIMULATIONS

The proposed algorithm was implemented in a Simulink® model and the results are presented below.

Fig. 4 is the Simulink® model used for the algorithm simulation.

Fig. 5.a presents the results of the narrow band-pass filter approach and the proposed algorithm running over a square signal and Fig. 5.b presents the results of the two approaches running over an actual motor signal, previously acquired. The simulations were performed with a 1638.4 Hz sample frequency.

The fft of important signals are presented in Fig. 6(a) and (b).

The narrow band-pass filter used was an 8 (eight) order one with 58.9 and 60.9 Hz cut-off frequencies and the low-pass filter used in the synchronous reference frame approach was an 8 (eight) order one with a 1 Hz cut-off frequency.

For the square signal, the attenuation of the fundamental component (59.9 Hz) achieved by the synchronous reference frame approach was around 36 times while the attenuation achieved by the narrow band-pass filter was around 18 times. The important components next to the 59.9 Hz component were not affected in both approaches.

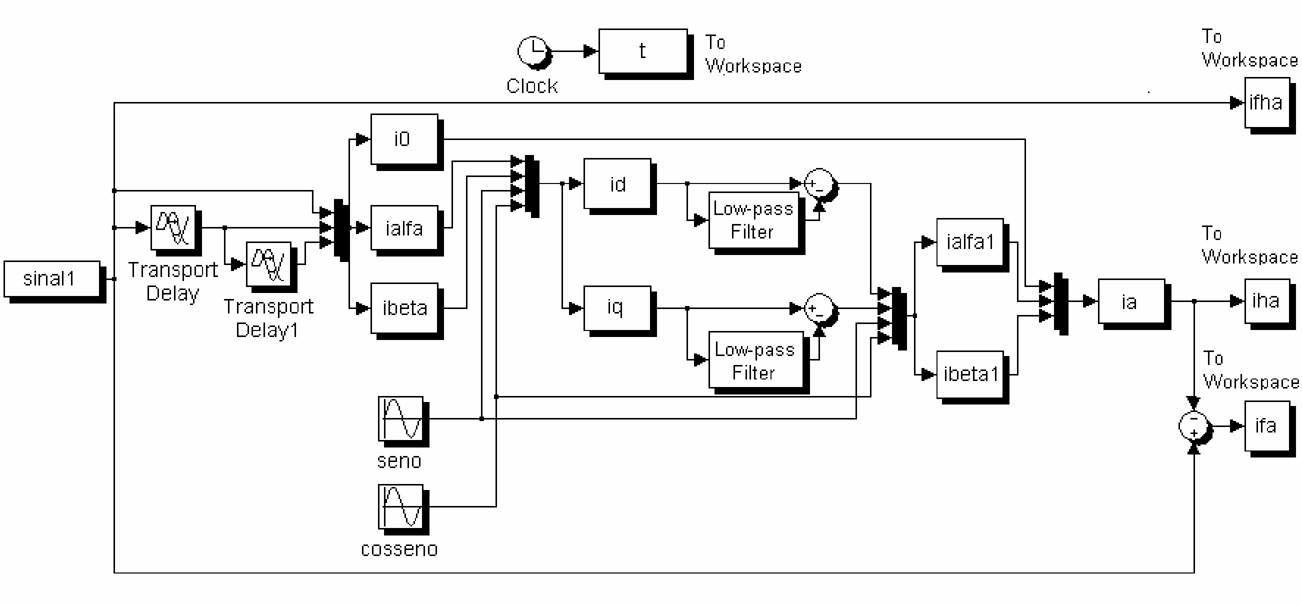
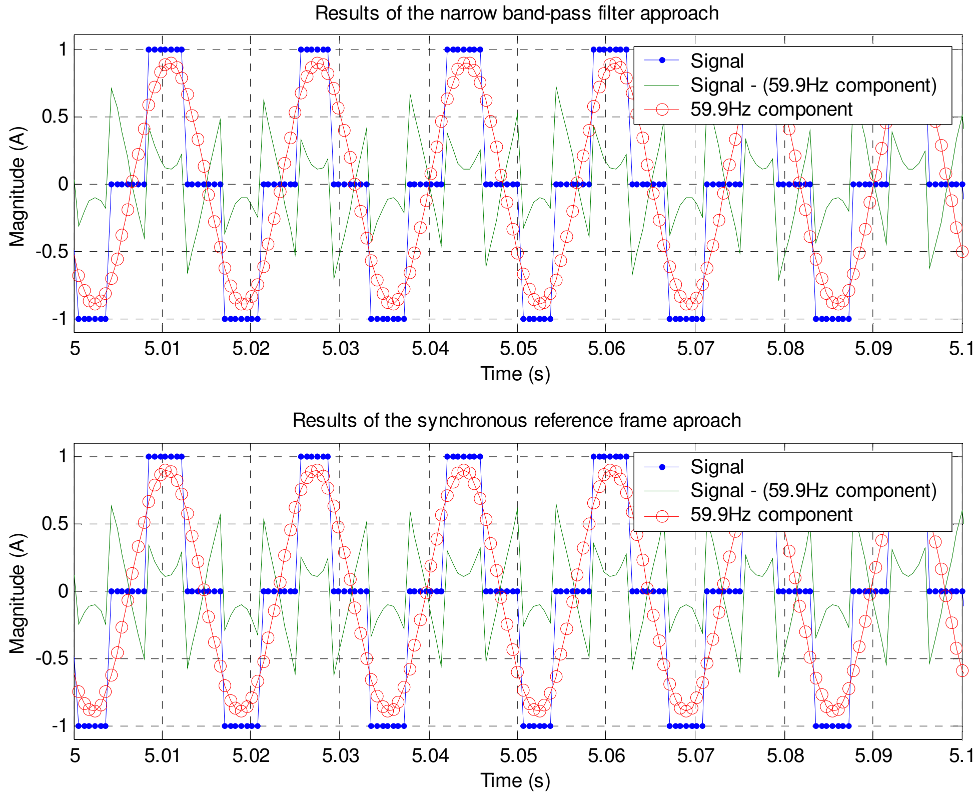


Figure 4 – Simulink® model of the proposed algorithm

(a)



(b)

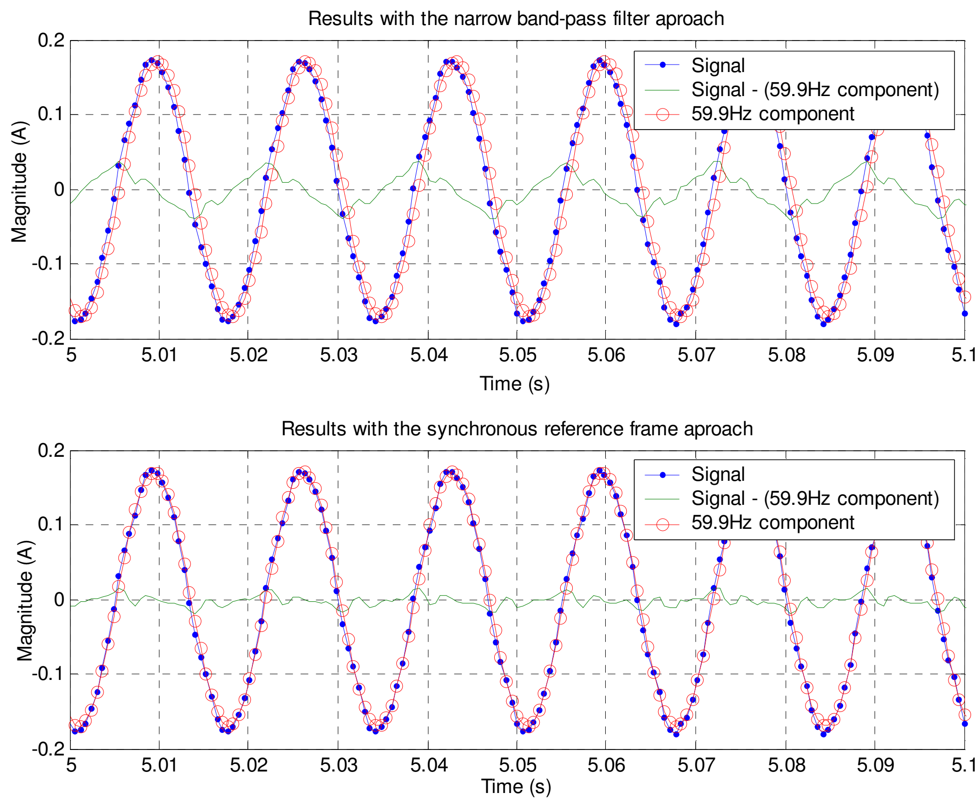
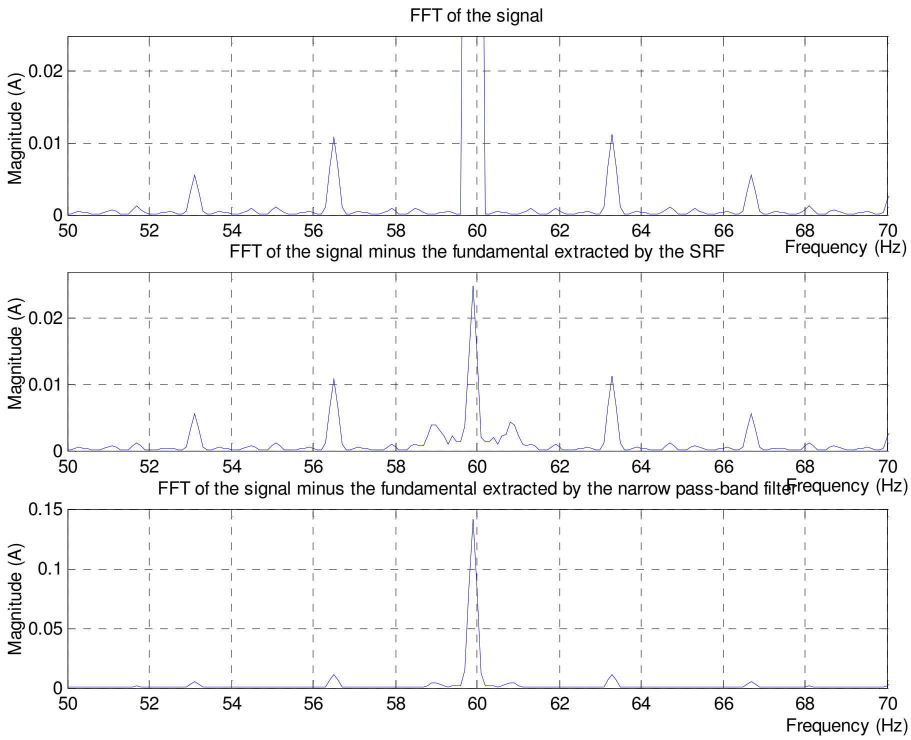


Figure 5 –Results for (a) square wave signal and (b) real motor current.

(a)



(b)

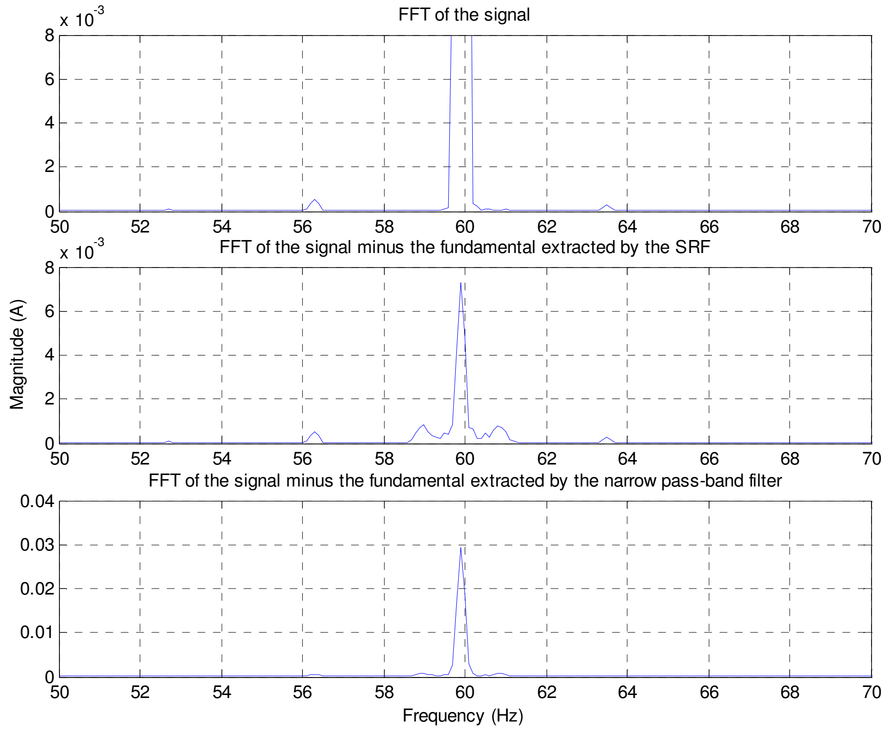


Figure 6 – Fast Fourier Transforms of some important signals in (a) Fig. 5(a) and (b) Fig. 5(b).

For the real signal, the attenuation of the fundamental component (59.9 Hz) achieved by the synchronous Reference Frame approach was around 23 times while the attenuation achieved by the narrow band-pass filter was around 6 times. The important components next to the 60 Hz component were not affected in both approaches.

IV. CONCLUSION

The dynamic range of A/D converters in a MCSA failure detection system is an important feature for improving the diagnosis sensitivity. The presence of the fundamental component in the current signal being transduced compromises the dynamic range available for the other components that actually contain the fault information and present much smaller magnitudes.

The present work presents a digital alternative to analog notch filters usually used. The digital approach proposed, in spite of its complexity, is more robust and achieves a better attenuation of the fundamental component in the analysed signal, as it was presented by the simulations.

V. BIBLIOGRAPHY

[1] R. R. Obaid, T. G. Habetler, D. J. Gritter – "A Simplified Technique for Detecting Faults using Stator Current in Small Induction Motors", In Proceedings of the 35th Annual Meeting and World Conference on Industrial Application of Electrical Energy, July 2000.

[2] Bhattacharya, S., Divan, D., "Synchronous frame based controller implementation for a hybrid series active filter system", IEEE/IAS Annual Meeting, pp 2531-2540, 1995;

[3] Soares, V., Verdelho, P., and Marques, G. D., "An instantaneous active and reactive current component method for active filters", IEEE Trans. On Power Electron., vol. 15, pp 660-669, 2000;

[4] Oliveira, L.E.L., Silva, L.E.B., Silva,V.F., Torres, G.L., Bonaldi, Erik Leandro, "Improving the dynamic response of active power filters based on the synchronous reference frame method", In Proceedings of the XVII Applied Power Electronics Conference, vol. 2, March 2002;

[5] Oliveira, L.E.L., Silva, L.E.B., Silva,V.F., Torres, G.L., Pinto, J.O.P., "Real-time determination of the best interval of calculation for moving averages used for dc value extraction in active power filter control methods", In Proceedings of the 28th IECON, vol 2, November 2002;

[6] Oliveira, L.E.L., Silva, L.E.B., Silva,V.F., Torres, G.L., Pinto, J.O.P., "Active power filter for harmonic current compensation using the id-iq control method without pll and with the best transient time", In Proceedings of the WSEAS ICOPES, october 2002;

[7] Best, R. E., "Phase Locked Loops – Theory, Design and Applications", McGraw-Hill Book, USA, 1984;

[8] Kaura, V., Blasko, V., "Operation of a phase locked loop system under distorted utility conditions", IEEE Trans. Ind. Appl., vol. 33, pp 58-63, 1997;