ISTANBUL UNIVERSITY –
JOURNAL OF ELECTRICAL & ELECTRONICS ENGINEERING
YEAR : 2009 (801-807)
VOLUME : 9
NUMBER : 1

SENSITIVITY ASSESSMENT OF PQ THEORY AND SYNCHRONOUS DETECTION IDENTIFICATION METHODS OF CURRENT HARMONICS UNDER NON-SINUSOIDAL CONDITION FOR SHUNT ACTIVE FILTER

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ABSTRACT

This paper presents a comparative study between two commands of the shunt active filter under non-sinusoidal condition. In fact: 1) theory PQ. 2) Synchronous detection theory. The principal objective of this work is to test the sensitivity and robustness of the identification methods of the currents references, by calculating the THD. Interesting results are presented and analyzed below.

Keywords: *Active Power Filter, Instantaneous Power theory (PQ), Synchronous Detection Algorithm, non-sinusoidal voltage, THD.*

1. INTRODUCTION

The majority of power consumption has been drawn by linear loads. Modern loads typically contain power electronic devices. The current drawn by these modern devices is non-sinusoidal and therefore contain harmonics.

Shunt active filters were proposed as a means of removing harmonic current. In an active power filter, a controller determines the harmonics that are to be eliminated. The output of this controller is the reference of three-phase current controlled inverter. The Figure 1 illustrates the principle of a shunt active filter [3]. The nonlinear load is connected to the power system and is supplied by the non- sinusoidal current i_L. The active power filter is connected in parallel to the mains, on the point of common coupling (PCC), and supplies the current harmonics need to maintain the sinusoidal current source. Traditionally active power filters are studied under sinusoidal and symmetrically voltage conditions.

This paper compares control methods to obtain the compensating current under non-sinusoidal conditions. The main objective of this paper is to test the sensitivity of commands and to determine the real of THD value under non-sinusoidal condition.

Received Date: 12.05.2006
Accepted Date: 05.01.2009

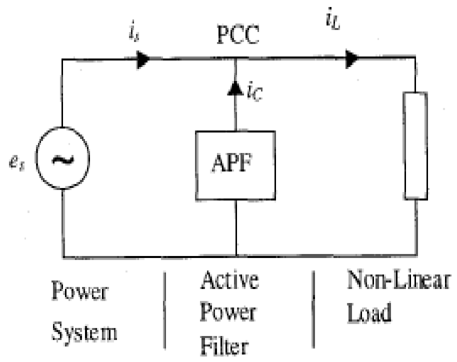


Figure 1. Principle of an active power.

2. ACTIVE POWER FILTER (APF)

Figure 2 shows basic APF block diagram including non-linear load on three-phase supply condition. In this study, three-phase uncontrolled diode bridge rectifier with resistive loading are considered as a non-linear load on three phase ac mains. This load draws non-sinusoidal currents from ac mains.

APF overcome the drawbacks of passive filters by using the switching mode power converter to perform the harmonic current elimination. Shunt active power filters are developed to suppress the harmonic currents and compensate reactive power simultaneously. The shunt active power filters are operated as a current source parallel with the nonlinear load. The power converter of active power filter is controlled to generate a compensation current, which is equal but opposite to the harmonic and reactive currents generated from the nonlinear load. In this situation, the main currents are sinusoidal and in phase with main voltages.

3. ALGORITHM OF THE INSTANTANEOUS ACTIVE AND REACTIVE POWER THEORY

The ***pq*** theory [l], also known as the instantaneous active and reactive power theory.

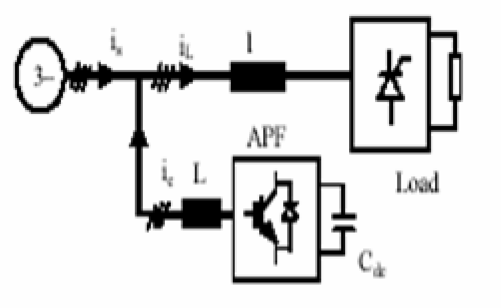


Figure 2. Block diagram of APF.

Inputs:
Vector of tension: $v_a(t)$, $v_b(t)$ et $v_c(t)$
Vector of current: $i_a(t)$, $i_b(t)$ et $i_c(t)$

Algorithm processes:

1) Park transformation

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} va \\ vb \\ vc \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \qquad (2)$$

2) Calculation of the instantaneous power:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v\alpha & v\beta \\ -v\beta & v\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \qquad (3)$$

$$p = \overline{P} + \tilde{P} \qquad (4)$$

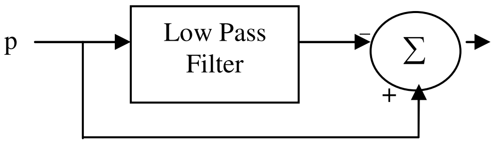


Figure 3. Extraction of the polluted component.

The LPF give better characteristic than HPL in other hand less residual current, [09]

4) Adding P_{av} power (the input of PI regulator) to the extracted power $\tilde{P}$.

$$P(t) = \tilde{P}(t) + P_{av}(t) \tag{5}$$

5) Calculation of reference current

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha^{'} \\ i_\beta^{'} \end{bmatrix} \tag{6}$$

where

$$\begin{bmatrix} i_\alpha^{'} \\ i_\beta^{'} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \tag{7}$$

4. ALGORITHM OF SYNCHRONOUS DETECTION THEORY

Inputs:

Vector of tension: $v_a(t),\, v_b(t)\ et\ v_c(t)$ (8)

Vector of current: $i_a(t),\, i_b(t)\ et\ i_c(t)$

Algorithm processes:

1) Calculation of the instantaneous power:

$$\begin{cases} p_a(t) = v_a(t) * i_a(t) \\ p_b(t) = v_b(t) * i_b(t) \\ p_c(t) = v_c(t) * i_c(t) \end{cases} \tag{9}$$

2) Total power:

$$p(t)_{TOTAL} = p_a(t) + p_b(t) + p_c(t) \tag{10}$$

3) Extraction of the polluted component of the total power absorptive by the load.

We filter the total power by a low passes filter from such kind that the signal obtained presents the harmonic component of the active power.

$$p(t) = \bar{p}(t) + \tilde{p}(t) \tag{11}$$

4) Add P_{av} power (the output of PI regulator) to the extracted power $\tilde{P}$.

$$P(t) = \bar{p}(t) + p_{av}(t) \tag{12}$$

5) Calculation of voltage amplitude:

$$\begin{cases} Va = \sqrt{2}.|Va| \\ Vb = \sqrt{2}.|Vb| \\ Vc = \sqrt{2}.|Vc| \end{cases} \tag{13}$$

Where V is the sum of mains voltage

$$V = Va + Vb + Vc \tag{14}$$

6) Calculation of the harmonic powers

$$\begin{cases} P_{ah} = \dfrac{P(t)Va}{V} \\ P_{bh} = \dfrac{P(t)Vb}{V} \\ P_{ch} = \dfrac{P(t)Vc}{V} \end{cases} \tag{15}$$

7) Calculation of the current reference

$$\begin{cases} i_a^* = \dfrac{2v_a(t).P_{ah}}{(Va)^2} \\ i_b^* = \dfrac{2v_b(t).P_{bh}}{(Vb)^2} \\ i_c^* = \dfrac{2v_c(t).P_{ch}}{(Vc)^2} \end{cases} \tag{16}$$

5. SIMULATION RESULTS

We suppose that voltage supply is definition by the following equations:

$$\begin{aligned} v_a &= 50 + \sqrt{2}\ 220\ \sin(wt) + \frac{\sqrt{2}\ 220}{7}\ \sin(7wt) \\ v_b &= 50 + \sqrt{2}\ 220\ \sin(wt - \frac{2\pi}{3}) + \frac{\sqrt{2}\ 220}{7}\ \sin(7wt - \frac{2\pi}{3}) \quad (14) \\ v_c &= 50 + \sqrt{2}\ 220\ \sin(wt + \frac{2\pi}{3}) + \frac{\sqrt{2}\ 220}{7}\ \sin(7wt + \frac{2\pi}{3}) \end{aligned}$$

Where *f* = 50 Hz.

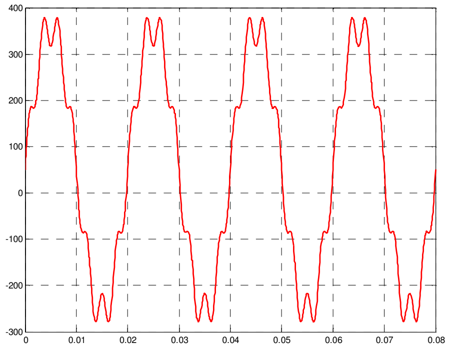


Figure 4. Main voltage waveforms.

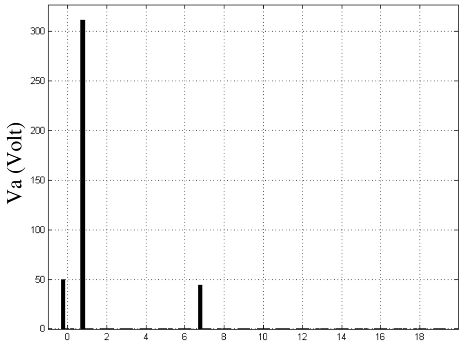


Figure 5. Frequency spectrum of input voltage.

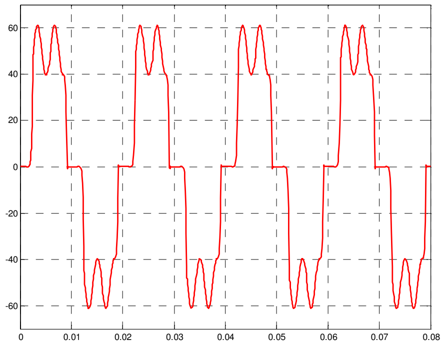


Figure 6. Current waveform of nonlinear load.

Figures 4 and 6 respectively represent the polluted waveforms voltage and required current by a nonlinear load. According to figures 5 and 7, one notice the voltage is polluted by a harmonic row 7 plus a continuous component.

The THD for each harmonic is present as follows.

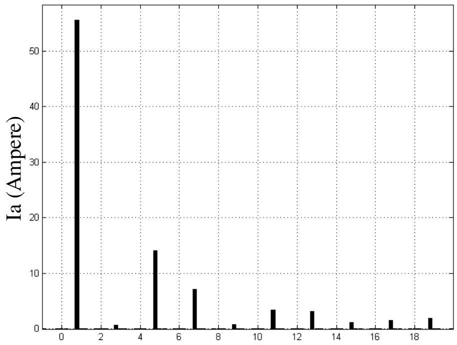


Figure 7. Frequency spectrum of input current.

Table 1.

Harmonic Row	*THD (%)*
5	*25.4*
7	*12.77*
9	*1.5*
11	*6.22*

The THD voltage equals to 26.84 % and for the THD current equals to 31.28 %.

6. FILTERING

The APF is controlled by tow mentioned methods above under non-sinusoidal conditions however results of simulation are illustrated fellow.

6.1. Results Obtained By Pq Theory

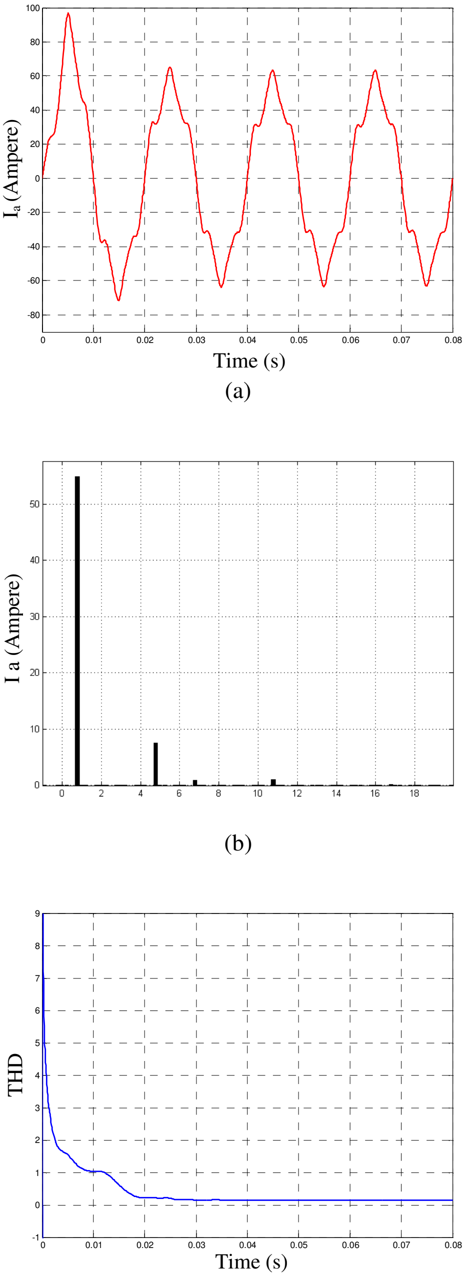
The figure 8 (a), represents the filtered current of phase (a). We notice that there is a filtering problem with the waveform, which is not sinusoidal. In other words, there are harmonics, which are represented in the figure 8 (b) such as:

Table 2.

Harmonic Row	*THD (%)*
5	*13.7*

7	***1.71***
11	***1.96***

According to the figure 8 (c), the THD of the filtered current using pq theory equals to 13.89 %.



(a)

(b)

(c)

Figure 8. - PQ theory results -

(a) Load current,
(b) Spectre of current,
(c) THD load supply current

6.2. Results Obtained By The Synchronous Detection Method

According to the figure 9 (a), we notice that the current is badly filtered. In other words, there are harmonics that are represented in the figure 9 (b), such as:

Table 3.

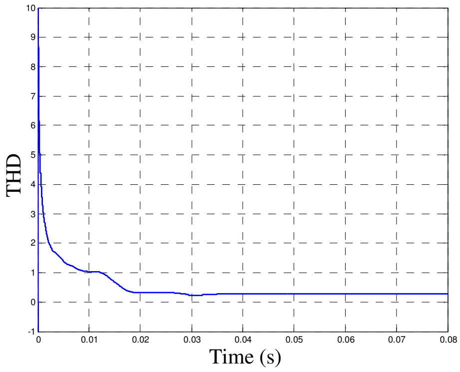
Harmonic Row	*THD (%)*
0	***16***
5	***4.37***
7	***16.29***
11	***0.6***

According to the figure 9 (c), we note the THD filtered current using the theory of synchronous detection equals to 28.29 %

The current filtered by the pq. Theory is improved with a percentage of 55.59% but in the case of the synchronous detection method it equals to 9.5 %.

The harmonics analysis shows that pq. Theory method amplifies the 5th harmonic (13.17%), on the contrary to the synchronous detection method which the amplifies 7th harmonic (16.29%).

The most remarkable task is the appearance of the continuous component in the filtered current by the synchronous detection method (Figure9 (b))



(c)

Figure 9. - Synchronous detection theory results-
(a) Load current,

(b) harmonic order,
(c) Load supply current THD

7. COMPARISON

Case 1: Under sinusoidal voltage simulation:

Table 4.

	THD (%)	*Harmonic Order*		
		3th	*5th*	*7th*
Current before filtering	*28.06*	*0.76*	*21.66*	*10.92*
Current after filtering (pq theory)	*0.746*	*0*	*0.51*	*0.51*
Current after filtering (Syn. Det. Theory)	*0.724*	*0*	*0.51*	*0.51*

Case 2: Under non-sinusoidal voltage simulation:

The following figure shows THD values measure before and after filtering using both theories:

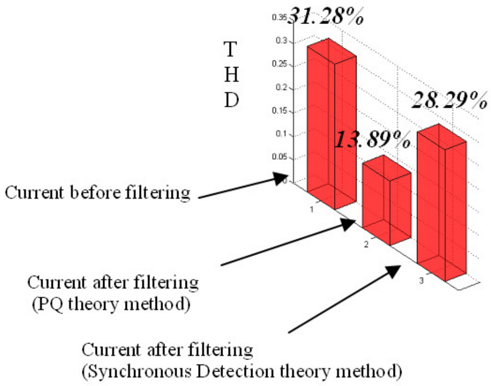


Figure 10. THD values.

8. CONCLUSION

The comparison of active power filters control methods are investigated in this paper. It is obvious that under sinusoidal voltages these methods give similar results. Under non-sinusoidal conditions, all methods give different results. The synchronous detection method gives poor results; there were the pq method gives acceptable results.

The continuous component current appears only in synchronous detection method.

In conclusion, I recommend using PLL (Phase Locked Loop) to keep sinusoidal waveforms of voltage signals, to get result in accordance with THD regulation [13] .

REFERENCES

[1] Akagi H.,. Kanazawa Y., Nabae A., "Generalized Theory of the lnrtrntansour Reactive Power in Three-Phssc Circuirs," *in Pror IPEC-Tokyo'93 Int. CO"[Power Electronics,* pp. 1375-1186. Tokyo, 1983.

[2] Akagi H.,. Kanazwa Y., Narbae A.,. "lnswntanmu~ Rerclivs Powsr Compensator Comprising Switching Devices Without Energy Storage Componcntr", *IEEE Tranrocrionr on Indurtv Applicormrr*, Vol: IA-20, No. I, pp. 625-630, 1984.

[3] Marques G.D., "A Comparison of Active Power Filter Control Methods in Unbalanced and Non-sinusoidal Conditions" *IEEE Press,* pp. 444 – 449, 1998.

[4] Watanibe E.H., Stsphm R.M., Ardes M., "New Concepts of Instantaneous Active and Reactive Powers in Electrical Systems with Generic Lauds" *IEEE Tram on Power Deliver,* Vol: 8,No. 2, pp. 697-703, April, 1993.

[5] Susaki Y., Matsumura T., Genji T., Inoue J., Yoshioka K., Kohata M., "Development and proof examination result of Active Filter for Power Distribution Systems", *Trans. Inst. Elect. Eng. Jpn.*, Vol: 120-B, No. 5, pp. 746-752, 2000.

[6] Wada K., Fujita H., Akagi H. " Considerations of a Shunt Active Filter Based on on Voltage Detection for Installation on a Long Distribution Feeder" *in Proc. Conf. IEEE-IAS Ann. Meeting*, 2001, pp. 157-163.

[7] Liserre M., Blaabjerg F., Hansen S., "'Design and Control of an LCL-Filter based Active Rectifier", *Proc. Of IAS*, 2001, pp. 299-307, Sept. /Oct. 2001.

[8] Benachaiba C., Mazari B., Rahli M. "Minimisation des Courants Harmoniques par la

Technique d'Optimisation de la commutation Forcée d'un Convertisseur AC/DC", *Sciences et Technologie*, B-No. 21, juin 2004, pp. 71-74.

[9] Benachaiba C., Mazari B., "Etude de la Compatibilité entre les Courants Harmoniques dans un Système de Filtrage Actif Parallèle", *Conf. on Elect. Engin. (CEE'02)*, Univ. de Batna, Algérie.

[10] Akagi H., "New Trends in Active Filter for power conditioning", *IEEE Trans. Ind. Application*, Vol: 32, No. 6, pp. 1312-1322, 1996.

[11] Bhattacharya S., Divan D.M., Banerjee B., "Synchronous reference harmonic isolator using active series filter," *in Proc. EPE Conf.*, Florence, Italy, 1991, pp. 30–35.

[12] Soares V., Verdelho P., Marques G.D., "An instantaneous active and reactive current component method for active filters", *IEEE Trans. Power Electron.*, Vol: 15, pp. 660–669, July, 2000.

[13] Souvik C., Ramanarayanan V., "Phase-Angle Balance Control for Harmonic Filtering of a Three-Phase Shunt Active Filter System" *IEEE transactions on industry applications*, Vol: 39, No. 2, March/April, 2003, pp. 565 – 574.