International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:8, No:8, 2014

# A Comparison of Shunt Active Power Filter Control Methods under Non-Sinusoidal and Unbalanced Voltage Conditions

H. Abaali, M. T. Lamchich, M. Raoufi

***Abstract*—**There are a variety of reference current identification methods, for the shunt active power filter (*SAPF*), such as the instantaneous active and reactive power, the instantaneous active and reactive current and the synchronous detection method are evaluated and compared under ideal, non sinusoidal and unbalanced voltage conditions. The *SAPF* performances, for the investigated identification methods, are tested for a non linear load. The simulation results, using Matlab Power System Blockset Toolbox from a complete structure, are presented and discussed.

***Keywords*—**Shunt active power filter, Current perturbation, Non sinusoidal and unbalanced voltage conditions.

## I. Introduction

THE wide use of high-power switching devices increased the deterioration of electric power quality. These last years, the Shunt Active Power Filter (*SAPF*) is recognized as a valid solution to improve the power electric quality. The *SAPF* state of the art is well described and documented in the literature; hundreds of works are reviewed in [1], [2].

The time domain methods are most widely used to generate the reference current for *SAPF*. The principals time domain current identification methods used in the literature are the instantaneous active and reactive power (*pq*) [4]-[6] and [12], the synchronous detection method (*SD*) [3] and [7], [8], and the instantaneous active and reactive current (*dq*) [7], [8]. This three methods assume that the three phase voltage source is balanced and do not contain harmonic components. However, the voltage source may be perturbed. Consequently, the evoked methods may lose their generality. A combination of these methods with the positive sequence voltage detection [4] and [13] is an efficient solution to generate the reference current for all voltage conditions.

In this paper, the *pq*, *dq* and *SD* methods are evaluated and compared under ideal, non sinusoidal and unbalanced voltage conditions. The *SAPF* performances, for the investigated identification methods, are tested for a non linear load (three-phase diode rectifier). The simulation results, using Matlab Power System Blockset Toolbox from a complete structure, are presented and qualitatively discussed.

H. Abaali is with the Moulay Ismaïl University, Faculty of Sciences and techniques, BP 509 Boutalamine, Errachidia, Morocco (corresponding author: phone : +212 5 35 57 44 97; fax : +212 5 35 57 47 14; e-mail: habaali@gmail.com)

M. T. Lamchich and M. Raoufi are with the Cadi Ayyad University, Faculty of Sciences Semlalia, Marrakech, Morocco.

This paper is organized as following: after the introduction and short description of general structure, we present in the third section a brief mathematical recall of the suggested current identification methods. The fourth section gives a description of the block diagram of the positive sequence voltage detector. The fifth section shows a brief exposition of the Average Current Mode Control (*ACMC)* method. In the sixth section, the simulation results are presented. Finally, these results are discussed and commented in seventh section.

## II. General Structure

The *SAPF* generate and inject the compensation current at the Point of Common Connection (*PCC*). The injected current is equivalent to the load current perturbations. Thus, the resulting total current drawn from the ac mains is sinusoidal.

The main circuit is given in Fig. 1 and the simulation parameters are:

- Three wires of the power network ($R_s$ $L_s$, $V_{rms}$)= ($0.25m\Omega$, $19.4mH$, $220V$) ;
- The Non linear load: three-phase diode rectifier feeding *RL* load at its *dc* side: (*R, L*)= ($150\Omega$, $1mH$);
- The Voltage source inverter (*VSI*) with a capacitor in its *dc* side, ($V_{dc}$, $C$)= ($740V$, $5.10^{-3}$ $F$);
- The Output filter (*L, r*)= ($3.10^{-3}$ $H$, $1\Omega$).

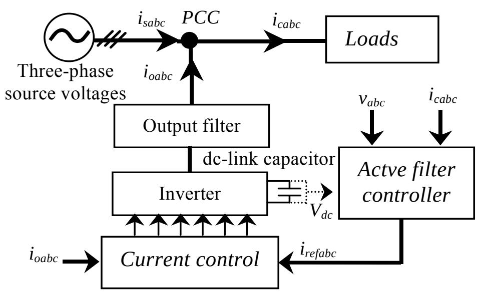



Fig. 1 General structure of the *SAPF* control

The passive output filter is used to connect the inverter to the *PCC* and to reduce the harmonic current caused by switching operation of the power transistors. The first order passive filter design is given in [11].

## III. Disturbing Current Identification Methods

The mathematical recall of the *pq*, *SD* and *dq* methods are given below.

*A. Instantaneous Active and Reactive Power (pq)*

The *pq* method, described in [4]-[6] and [12], is used to calculate instantaneously the reference current. This method is based on the instantaneous voltage and current on the load side expressed in a stationary reference $\alpha$-$\beta$ as given by (1) and (2) respectively. For simplicity a null value for zero sequences voltage and current are considered.

$$[v]_{\alpha\beta} = C_{32}\,[v]_{abc} \tag{1}$$

$$[i]_{\alpha\beta} = C_{32}\,[i]_{abc} \tag{2}$$

$C_{32}$ : Concordia transformation.

The instantaneous real power given by (3) in three phase circuit is defined in [6].

$$p = v_a i_a + v_b i_b + v_c i_c = v_\alpha i_\alpha + v_\beta i_\beta \tag{3}$$

The conventional instantaneous reactive power in the three phase system introduces the instantaneous imaginary power space vector expressed by (4) which is defined in [6].

$$q = v_\alpha \wedge i_\beta + v_\beta \wedge i_\alpha \tag{4}$$

Both powers are decomposed into oscillatory component (perturbation power) and average component (fundamental active and reactive power). The conventional instantaneous active and reactive powers are then expressed by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \bar{p} \\ \bar{q} \end{bmatrix} + \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{5}$$

To reach a sinusoidal current with unity power factor the oscillating term of $p$ and all terms of $q$ have to be removed. In our case, only harmonics compensation is considered. Consequently, the powers to be compensated are:

$$p_c = -\,\tilde{p}, \qquad q_c = -\,\tilde{q} \tag{6}$$

For the harmonic compensation, the filters introduces some harmonics that are not present in the load current [5]. To prevent this phenomenon the gains of the low-pass filters given in Fig. 2 used to eliminate the average component of real and reactive power must be the same.

The *dc*-link capacitor voltage can be controlled by trimming the instantaneous real power $p_{av}$. The compensation current in $\alpha$-$\beta$ quantities is given by:

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + p_{av} \\ -\tilde{q} \end{bmatrix} \tag{7}$$

By performing the inverse transformation, the three phase compensation current is obtained by:

$$[i^*_c]_{abc} = C_{32}^T\,[i^*_c]_{\alpha\beta} \tag{8}$$

Under non-ideal voltage conditions $v^2_\alpha + v^2_\beta$ is not constant. Therefore, the calculation of reference current is affected and undesirable harmonic components will appear in the line current after compensation.

The diagram of the modified *pq* method (*Mpq*), corresponding to a combination of a standard *pq* with a *PSVD* is given in Fig. 2.

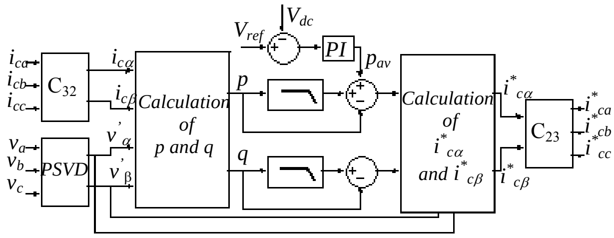



Fig. 2 Block diagram of the instantaneous active and reactive power

*B. Synchronous Detection Method (SD)*

For the *SD* [3] and [7], [8], the three phase main current is assumed to be balanced after compensation. Thus:

$$I_{ma} = I_{mb} = I_{mc} \tag{9}$$

where $I_{ma}$ , $I_{mb}$ and $I_{mc}$ are the amplitudes of the three phase main current after compensation. The real power consumed by the load can be represented as:

$$P = \begin{bmatrix} v_a & v_b & v_c \end{bmatrix} \begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} \tag{10}$$

$v_k$ and $i_{ck}$ , where *k=(a, b, c)* are the voltage source and load current respectively. The modified *SD* diagram (*MSD*), is given in Fig. 3.

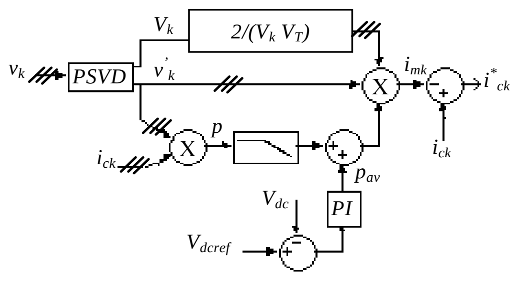



Fig. 3 *MSD* Current identification block diagram

The *dc*-link capacitor voltage can be controlled by trimming the instantaneous real power $p_{av}$. The low-pass filter is used to extract the average value $\overline{P}$ of the real power $P$, which is added to the $p_{av}$. The real power is then split into three phases of the mains supply:

$$P_k = (\overline{P} + P_{av})V_k \;/V_T \tag{11}$$

where $V_k$ is the amplitude of each main voltage and $V_T = \sum_K V_K$. The desired main current can be calculated as:

$$i_{mk} = \frac{2v_k}{V_k^2} P_k \tag{12}$$

The reference current is given by:

$$i_{ck}^* = i_{ck} - i_{mk} \tag{13}$$

*C. Instantaneous Active and Reactive Current $i_d i_q$ (dq)*

This method [7], [8], is based on a synchronous rotating frame derived from the voltage without using a Phase Looked Loop (*PLL*) circuit. In this theory, the active filter current is obtained from the instantaneous active and reactive current components ($i_{cd}$ and $i_{cq}$) of nonlinear load.

The load current in the *a-b-c* reference frame is transformed to the α-β reference frame according to (2). In the second step, these stationary reference frame quantities are then transformed into synchronous reference frame quantities based on the Park transformation given by (15).

The direct and quadratic current components can be written in complex form, as:

$$i_{cdq} = i_{cd} + j i_{cq} \tag{14}$$

which may also be written in matrix form as :

$$\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix}$$

where

$$\theta = \tan^{-1}\left(\frac{v_\beta}{v_\alpha}\right) \tag{15}$$

Using the simple geometry, (15) is written in terms of the stationary reference frame load voltage vectors as:

$$\begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \tag{16}$$

In the nonlinear load case, the instantaneous active and reactive load current can also be decomposed into oscillatory and average terms. Since the *d* and *q* axes rotate at the angular frequency $\omega=2\pi f$ fundamental in the $\alpha$-$\beta$ plane, the first harmonic positive sequence current is transformed to *dc* quantity, and other current components constitute the oscillatory parts. After removal of the *dc*-component of $i_{cdq}$ a using low-pass filter, the compensation current in $\alpha$-$\beta$ reference is obtained by (17).

A *PI* with anti-windup performs the voltage regulation on the *VSI dc* side. Its input is the capacitor voltage error ($V_{ref}$-$V_{dc}$). Through regulation of the first harmonic direct current of positive sequence $i_{dch1}^+$, it is possible to control the active power flow in the *VSI* and thus the *dc*-link capacitor voltage $V_{dc}$. The reactive power may be controlled by the first harmonic quadratic current of positive sequence $i_{qch1}^+$. However, considering that the primary end of the active filter is simply the elimination of current harmonics caused by nonlinear loads, the current $i_{qch1}^+$ is set to zero.

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{i}_{cd} + i_{dch1}^+ \\ -\tilde{i}_{cq} + i_{qch1}^+ \end{bmatrix} \tag{17}$$

The three-phase compensation current is obtained by (8). The diagram of the modified *dq* method, given in Fig. 4, shows the control circuit of the compensator.

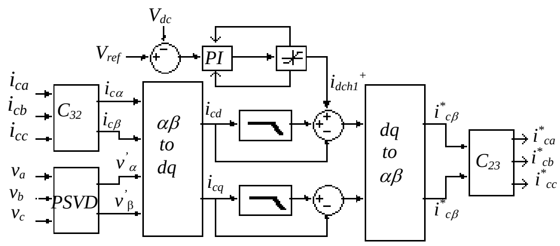



Fig. 4 Control circuit block diagram of the modified *dq*

## IV. Positive Sequence Voltage Detection

The positive sequence voltage detection uses a *PLL* circuit locked to the fundamental frequency of the system voltage [4] and [13]. The output of the *PLL* circuit corresponds to the $\alpha$-$\beta$ ($i'_\alpha = \sin(\omega_1 t)$ and $i'_\beta = -\cos(\omega_1 t)$) transformation of some auxiliary fundamental positive sequence current, considering only the fundamental positive sequence components. There are used in the main circuit of the positive sequence voltage detector as auxiliary current source $i'_\alpha$ and $i'_\beta$. The voltage source transformed into the $\alpha$-$\beta$ axis, given by (1), are used together with auxiliary current source $i'_\alpha$ and $i'_\beta$ to calculate the auxiliary powers $p'$ and $q'$ (5). The influence of the fundamental negative sequence and the harmonics will appear only in the high frequency components of the $p'$ and $q'$. Two $5^{th}$ order Butterworth low-pass filters are used to obtain the average values or the real $\overline{p}'$ and imaginary $\overline{q}'$ powers. According to the (18) $v'_\alpha$ and $v'_\beta$ are calculated, which correspond to the fundamental positive sequence components of the system voltage transformed into the α-β axis.

$$\begin{bmatrix} v'_\alpha \\ v'_\beta \end{bmatrix} = \frac{1}{i'^2_\alpha + i'^2_\beta} \begin{bmatrix} i'_\alpha & i'_\beta \\ i'_\beta & -i'_\alpha \end{bmatrix} \begin{bmatrix} \overline{p} \\ \overline{q} \end{bmatrix} \quad (18)$$

Finally, the three phase voltage source $v'_a$, $v'_b$ and $v'_c$ can be calculated applying the inverse transformation given by (8). The diagram of the positive sequence voltage detection is represented in Fig. 5.

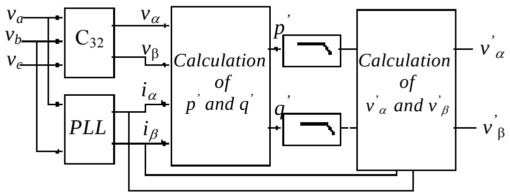



Fig. 5 Positive sequence voltage detector diagram (*PSVD*)

## V. Current Control Loop

The output current of the converter must track the reference current produced by the identification method. Thereupon, a regulation block is required and must be designed. The reference current is often regulated by a *PI* regulator. But, the output current can track the reference current with an amplitude error or phase delay [12]. In this paper, we propose the Average Current Mode Control (*ACMC*) [10] instead of classical regulator. In fact, the *ACMC* is a current control technique that has an almost switching frequency and produces a user-defined current waveform. It has a fast response time and is capable of supporting a wide range of power circuit topologies. *ACMC* uses an integrating filter to produce an average current error that is compared to a triangular waveform to produce the required Pulse Width Modulation (*PWM*) signal ($f_s$=10KHz) [9]. The control circuit topology is shown in Fig. 6.

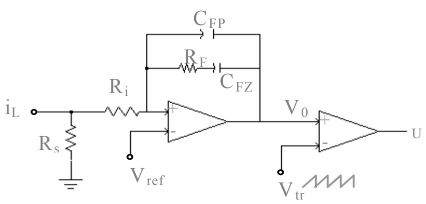



Fig. 6 *ACMC* circuit block

The Current control transfer function is given by:

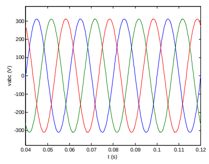
$$V_0 = V_{ref} + (V_{ref} - R_s\, i_L)\frac{1 + s(R_F C_{FZ})}{s(R_i\,(C_{FP} + C_{FZ})) + s^2(R_i\, R_F C_{FP} C_{FZ})} \quad (19)$$

## VI. Simulation Results

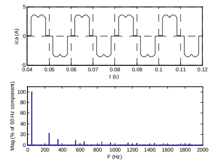
The purpose of the simulation is to show the effectiveness of the shunt active filter with proposed identification methods to maintain the current source sinusoidal when the source supplying a nonlinear load under ideal, unbalanced and non sinusoidal voltage conditions.

### A. Ideal Voltage Source Conditions (IVC)

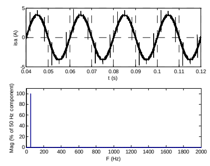
The three phase voltage source are balanced and do not contain harmonic components (Fig. 7 (a)). Fig. 7 (b) shows the line current and its spectrum before compensation. The line current and its spectrum after compensation using *pq*, *SD* and *dq* method are represented in Fig. 7 (c).



(a)



(b)



(c)

Fig. 7 (a) ideal voltage source, (b) line current and its spectrum before compensation (c) line current and its spectrum after compensation using respectivly *pq*, *SD* and *dq* methods

Table I illustrates the individual amplitude of low-order harmonics, in the supply current, to individual harmonics given by the *IEC 1000-3-4* standard.

TABLE I
HARMONIC CONTENTS IN THE SUPPLY CURRENT (IVC)

| *h* | $I_h/I_1$ (%) Before Compensation (BC) | $I_h/I_1$ (%) After compensation (AC) | | | IEC 1000-3-4 $I_h/I_1$ (%) |
|---|---|---|---|---|---|
| | | *Pq* | *SD* | *dq* | |
| 5 | 22.6 | 0.4 | 0.3 | 0.4 | 9.5 |
| 7 | 11.3 | 0.4 | 0.3 | 0.4 | 6.5 |
| 11 | 9.0 | 0.4 | 0.3 | 0.3 | 3.1 |
| 13 | 6.5 | 0.3 | 0.3 | 0.3 | 2.0 |
| 17 | 5.7 | 0.4 | 0.4 | 0.4 | 1.2 |
| 19 | 4..5 | 0.3 | 0.3 | 0.3 | 1.1 |

The line current $THD_i$ is *29.6%* before compensation. It is reduced after compensation to *1.2%* using *pq* method, to *1.0%* using *SD* method and to *1.1%* using *dq* method. Then the time domain current identification methods and modified methods give the same and good results.

### *B. Unbalanced Voltage Source Conditions (UVC)*

The three phase voltage source is unbalanced, but do not contain harmonic components Fig. 8 (a). Its expression is given in (20).

$$\begin{aligned} v_a(t) &= V_1 \sin\omega t + 0.13 V_1 \sin\omega t \\ v_b(t) &= V_1 \sin(\omega t - \frac{2\pi}{3}) + 0.13 V_1 \sin(\omega t + \frac{2\pi}{3}) \\ v_b(t) &= V_1 \sin(\omega t + \frac{2\pi}{3}) + 0.13 V_1 \sin(\omega t - \frac{2\pi}{3}) \text{ where } V_1 = \sqrt{2}.220 \end{aligned} \quad (20)$$

Figs. 8 (b)-(h) show the line current and its spectrum before compensation and after compensation using *pq*, *Mpq*, *SD*, *MSD*, *dq* and *Mdq.*

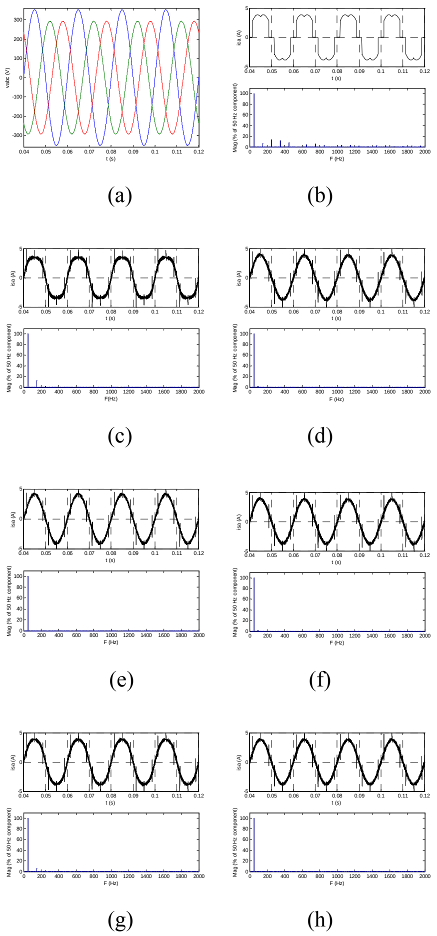



Fig. 8 (a) unbalanced voltage source, (b) line current and its spectrum before compensation. (c), (d), (e), (f), (g) and (h) line current and its spectrum after compensation using respectively, *pq, Mpq, SD, MSD, dq* and *Mdq*

The harmonic current contents repartition before and after compensation using all these methods, under unbalanced voltage conditions are resumed in Table II.

TABLE II
HARMONIC CONTENTS IN THE SUPPLY CURRENT (UVC)

| *h* | $I_h/I_1$ (%) Before Compensation (BC) | $I_h/I_1$ (%) After compensation (AC) | | | | | |
|---|---|---|---|---|---|---|---|
| | | *pq* | *Mpq* | *SD* | *MSD* | *dq* | *Mdq* |
| 3 | 6.8 | 12.5 | 0.5 | 0.8 | 0.5 | 5.9 | 0.3 |
| 5 | 13.4 | 2.2 | 0.5 | 0.5 | 0.5 | 1.0 | 0.5 |
| 7 | 11.5 | 0.3 | 0.4 | 0.3 | 0.4 | 0.3 | 0.4 |
| 9 | 7.9 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| 11 | 0.1 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 13 | 4.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| 15 | 5.9 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| 17 | 3.2 | 0.4 | 0.4 | 0.3 | 0.4 | 0.4 | 0.4 |
| 19 | 0.3 | 0.1 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |

Table II shows that significant levels of triplens harmonic current appeared before compensation, under *UVC*'s, and illustrates also the individual amplitude of low-order harmonics in the supply current as a percentage of the fundamental component.

We can note that the $3^{rd}$ harmonic is amplified in the case of *pq* method and is less reduced for *dq* method. The line current $THD_i$ is *23.2%* before compensation. It is reduced after compensation to *12.8%* using *pq* and to *1.6%* using *Mpq,* to *1.6%* using *SD* and *MSD*, and to *6.2%* using *dq* and to *1.5%* using *Mdq*.

### *C. Distorted Voltage Source Conditions (DVC)*

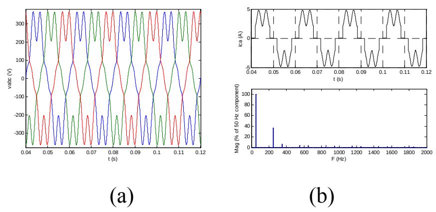
The three phase voltage source is balanced, but contains the $5^{th}$ and $7^{th}$ harmonic components Fig. 9 (a). Its expression is given in (21):

$$\begin{aligned} v_a(t) &= V_1 \sin\omega t - V_5 \sin 5\omega t + V_7 \sin 7\omega t \\ v_b(t) &= V_1 \sin(\omega t - \frac{2\pi}{3}) - V_5 \sin(5\omega t + \frac{2\pi}{3}) + V_7 \sin(7\omega t - \frac{2\pi}{3}) \\ v_c(t) &= V_1 \sin(\omega t + \frac{2\pi}{3}) - V_5 \sin(5\omega t - \frac{2\pi}{3}) + V_7 \sin(7\omega t + \frac{2\pi}{3}) \end{aligned} \quad (21)$$

where $V_5 = V_1 / 5$ and $V_7 = V_1 / 7$

Figs. 9 (b)-(h) show the line current and its spectrum before compensation and after compensation using *pq*, *Mpq*, *SD*, *MSD*, *dq* and *Mdq*

The voltage Total Harmonic Distortion ($THD_v$) in the *PCC* is *24.6%.*



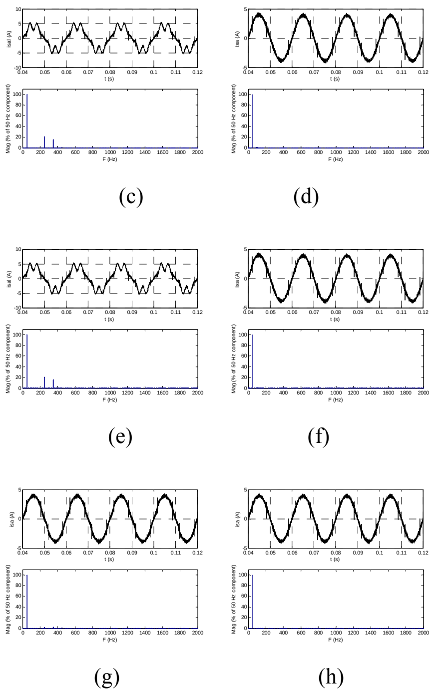



Fig. 9 (a) distorted voltage source, (b) line current and its spectrum before compensation. (c), (d), (e), (f), (g) and (h) line current and its spectrum after compensation using respectively *pq*, *Mpq, SD, MSD, dq* and *Mdq*

The harmonic contents repartition before and after compensation under *DVC*'s, are resumed in Table III.

TABLE III
HARMONIC CONTENTS IN THE SUPPLY CURRENT (*DVC*)

| *h* | $I_h/I_1$ (%) Before Compensation (BC) | $I_h/I_1$ (%) After compensation (AC) | | | | | |
|---|---|---|---|---|---|---|---|
| | | *pq* | *Mpq* | *SD* | *MSD* | *dq* | *Mdq* |
| 5 | 37.1 | 14.6 | 0.7 | 20.9 | 0.4 | 2.2 | 0.4 |
| 7 | 6.3 | 20.4 | 0.7 | 15.6 | 0.3 | 2.4 | 0.4 |
| 11 | 4.5 | 2.3 | 0.3 | 0.4 | 0.2 | 0.1 | 0.3 |
| 13 | 3.5 | 4.4 | 0.4 | 0.8 | 0.3 | 0.7 | 0.4 |
| 17 | 3.4 | 0.3 | 0.5 | 0.1 | 0.2 | 0.2 | 0.2 |
| 19 | 2.7 | 0.8 | 0.5 | 0.1 | 0.1 | 0.1 | 0.2 |

Table III illustrates the individual amplitude of low-order harmonics in the supply current as a percentage of the fundamental component under *DVC*'s.

We can note that only the $7^{th}$ harmonic current is amplified after compensation using *pq* and *SD* methods. The value of the line current $THD_i$ is *38.6%* before compensation. It is reduced after compensation to *25.6%* using *pq* and to *1.6%* using *Mpq,* to *26.1%* using *SD* and to 1.0*%* using *MSD*, to 3.3*%* using *dq* and to 1.0*%* using *Mdq*.

The synthesis of all these results is resumed in Table IV.

TABLE IV
SUMMARY OF THE HARMONIC ISOLATION METHODS

| *Identification methods* | | | *pq* | *Mpq* | *SD* | *MSD* | *dq* | *Mdq* |
|---|---|---|---|---|---|---|---|---|
| $THD_i$*(%)* | *IVC* | *BC* | *29.6* | | | | | |
| | | *AC* | *1.2* | | *1.0* | | *1.1* | |
| | *UVC* | *BC* | *23.2* | | | | | |
| | | *AC* | *12.8* | *1.6* | *1.6* | *1.6* | *6.2* | *1.5* |
| | *DVC* | *BC* | *38.6* | | | | | |
| | | *AC* | *25.6* | *1.6* | *26.1* | *1.0* | *3.3* | *1.0* |
| *Harmonic current orders* | $3^{th}$ | *UVC* | ++ | --- | --- | --- | - | --- |
| | $5^{th}$ | | -- | --- | --- | --- | --- | --- |
| | $5^{th}$ | *DVC* | - | --- | - | --- | -- | --- |
| | $7^{th}$ | | ++ | --- | ++ | --- | -- | --- |
| | $11^{th}$ | | - | --- | --- | ---- | --- | --- |
| | $13^{th}$ | | + | --- | --- | --- | --- | --- |
| *Number of filter stages* | | | *2* | *4* | *1* | *3* | *2* | *4* |

+: With higher number of the "+", the harmonic order is more amplified
-: With higher number of the "–", the harmonic order is more reduced.

All the compared methods are effective under ideal voltage conditions and the three modified methods are effective under all voltage conditions.

Using *pq* method, under unbalanced voltage conditions the $3^{rd}$ harmonic order is amplified, the $5^{th}$ harmonic order is slightly reduced. Under distorted voltage conditions, the $5^{th}$ and $11^{th}$ harmonic orders slightly reduced, and $7^{th}$ and $13^{th}$ harmonic orders are amplified.

The *SD* method is an acceptable solution under unbalanced voltage conditions. However it is worse under distorted voltage conditions, because the $5^{th}$ harmonic order slightly reduced, and $7^{th}$ harmonic order is amplified.

Using *dq* method, the harmonic perturbations are reduced under distorted and unbalanced voltage conditions, with lowest reduction of the $3^{rd}$ harmonic order under unbalanced voltage conditions.

## VII. CONCLUSION

This paper has described the control of shunt active power filter using an *ACMC* regulation current technique and different reference current detection methods. A positive sequence voltage detector block has been introduced to overcome the limitation of the time domain reference current detection methods under ideal, non sinusoidal and unbalanced voltage conditions.

Compared to *IEC 1000-3-4* standard and basis of the synthesis of all results in Table IV, the presented results have proven good performances and verify the feasibility of the modified detection methods and are most effective for all voltage conditions. These results highlight also the major problem of the *pq* method under non ideal voltage conditions and the *SD* under distorted voltage conditions. The *dq* method provides acceptable results without the need of *PSVD* under all voltage conditions.

Then we can conclude that the *dq* method is one of the most effective and optimal methods, and the *SD* is more effective than *pq* under unbalanced voltage conditions.

In the future work, we will study the same problem with the neutral conductor in unbalanced load and reactive power compensation, and will try to validate the simulation results using the experimental results.

## REFERENCES

[1] B. Singh. K. Al-Haddad. A. Chandra. “A review of active filters for power quality improvement” In: IEEE Transactions On Industrial Electronics. Vol. 46. NO. 5. October 1999. p. 960-971.
[2] C. Brandao. J. Antonio. M. Lima: Edison Roberto Cabral da Silva “A revision of the state of the art in active filters” In: 5th Power Electronics Conferences. 19-23. September. Brazil 1999. p 857-862.
[3] H. Abaali. M. T. Lamchich and M. Raoufi “Shunt Power Active Filter Control under Non Ideal Voltage Conditions” World Academy of Science, Engineering and Technology Vol. 2, No. 10, pp. 1086-1091 2008
[4] H. Abaali. M. T. Lamchich and M. Raoufi “The Three phase Shunt Active Filters for the Harmonics Compensation Under Distorted and Unbalanced Mains Voltage Conditions” IEEE-ICIT’04 International Conference on Industrial Technology December 8-10, Hammamet Tunisia, 2004.
[5] E. H. Watanabe. M. Arades. H. Akagi. “The pq Theory for Active Filter Control: Some Problems and Solutions” In: 14th Conferences of Automatic, Natal – RN. 2 a 5 September, Brazil, 2002, p. 1078-1083.
[6] H. Akagi. Y. Kanazawa. A. Nabae. “Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components” In: IEEE Transactions on Industry Applications, Vol. IA-20, NO. 3, May/June 1984, p. 625-630.
[7] Vedat M. Karslı, Mehmet Tümay and Berrin Süslüoğlu, “An Evaluation of Time Domain Techniques for Compensating Current of Shunt Active Power Filters” International Conference on Electrical and Electronics Engineering Bursa, Turkey, Dec. 2003.
[8] H. –L. Jou “Performance Comparison of the three-phase Active Power Filter Algorithm” IEE Proc.Gen. Trans. Distrib, vol. 142, no.6, 1995.
[9] L. Dixon “Average current mode control of switching power supplies” Unitrode Switching Regulated Power Design Seminar Manual, SEM-700, 1990.
[10] M. Raoufi and M. T. Lamchich “Average Current Mode Control of a Voltage Source Inverter Connected to the Grid: Application to Different Filter Cells” Journal of Electrical Engineering, Vol 55, 03-04 2004, 77-82.
[11] M. Bojrup “Advanced Control of Active Filters in a Battery Charger Application” Licentiate thesis. Lund Institute of Technology, Sweden, 1999.
[12] A. Allali, “Compensateurs Actifs des Réseaux Electriques Basse Tension”. Thesis University Louis Pasteur Strasbourg. Doctoral School Sciences for Engineer. September 12. 2002.
[13] M. Aredes “Active Power Line Conditioners” From the specialist area 12 electro-technology of the technical University. Thesis. Berlin 1996 D83.

**L’Houssine Abaali** was born on 10 October, 1974 in Khanifra, Morrocco. He received his B.S. degree in 1995, the L.S. degree in 1999, the Extensive graduate diploma (DESA/Masters) from the Cady University, Faculty of Science Semlalia in 2001 and the Dr degree in Power Electronic and electrical engineering from Cady University, Faculty of Science Semlalia in 2007. From 2007 to 2009, he was a professor at the Higher Technician Certificate (BTS) at the Laayoune Centre Morocco. He is currently Professor of electrical engineering at the Moulay Ismaïl University, Faculty of sciences and techniques, Errachidia, Morocco. His research interests are Electrical Power Distribution, Operations, Planning, Management, and Simulation of Electric Energy Systems, Power System Quality.