Comparative Studies between three Techniques for Determining Active Power Filter Compensating Currents in Power System

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***Abstract*- The purpose of this paper is to evaluate three different methods of determining the compensating currents for an active power filter under balanced sinusoidal voltages system. The active power filter with voltage structure has been used in this study to the power quality improvement. This comparative study aims three methods for identification currents references such as notch filtering, synchronous reference frame and instantaneous active and reactive power theory (p-q). This work is performed to illustrate the performance and the robustness of currents references identification by calculating the harmonics distortion (THD) results and seeing its effects in reducing harmonics and power factor enhancement. This proposed comparison is carried out using MATLAB/Simulink/Sim Power Systems software.**

***Keywords* - Shunt active power filter, Harmonic compensation, Identification techniques, Harmonics distortion (THD).**

I. INTRODUCTION

In the industrialized nations where high technology is grown rapidly by using electronic equipments and power electronic devices, the currents drawn by theses non linear loads is non sinusoidal form and contains harmonics [7]. Harmonics can cause excess heating in motors and transformers and can lead to overfilling of neutral conductors in power lines in the industry [2], [4]. By tradition, passives filters have been used to eliminate the current harmonic distortion and compensate the reactive power, but can resonate with supply impedance.

A solution is known as active filters with several types of active filter topologies [10], [12]. This paper will be restricted to the shunt active power filter which is generally used to compensate the reactive power and eliminate the harmonic currents produced on the load side from the grid current, by injecting compensating currents [1], [17]. The proposed shunt active power filter system is a great tool for the compensation not only of current harmonics produced by distorting loads, but also of reactive power of non-linear loads [8].

In order to determine the reference current a number of methods are emphasized in the literature [5], [10]. This paper focuses on three domain technique known as notch filtering, synchronous reference frame and instantaneous active and reactive power theory (p-q) in the aim to improve aim to improve the compensation performances under balanced voltages conditions. We used the proportional and integrator (PI) regulator for controlling the inverter switching Fig.1.

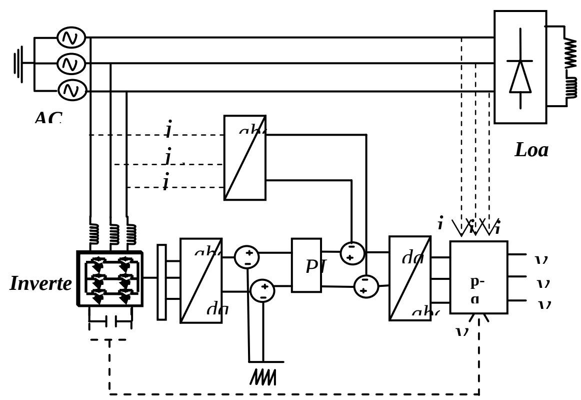

Fig.1 Diagram of power active filter

II. SHUNT ACTIVE POWER FILTER DESIGN

The main aim of the shunt active power filter is to reduce the harmonics currents, By tradition, passives filters have been used to eliminate the current harmonic distortion and compensate the reactive power, the control strategy for a shunt active power filter generates the reference current that must be provided by the power filter to compensate reactive power and harmonics currents demanded by the load [13]. This implies a set of source current in the phase domain that will be tracked generating the switching signals applied to the electronic converter by means of the suitable closed-loop switching control technique. The reference current is fed through a controller as shown in Fig. 2 and then the switching signal is generated to switch the power switching devices of the active filter such that the active filter will indeed produce the harmonics required by the load [14]. Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.

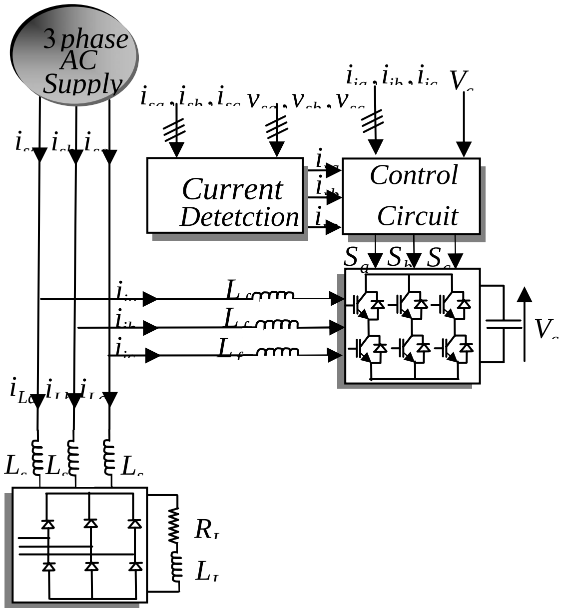

Fig .2 Equivalent schematic of shunt APF

Three control strategies for the extraction of the reference currents for an active power filter connected to the source that supply to a nonlinear load have been studied.

The three policies that have been compared are:

- Instantaneous active and reactive p-q power theory
- Notch filtering
- Synchronous Reference Frame

III. ALGORITHM OF THE INSTANTANEOUS ACTIVE AND REACTIVE P-Q POWER THEORY

The identification theory that we have used on shunt active power filter (SAPF) is known as instantaneous power theory, or p-q theory. It is based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady-state or transitory operations, as well as for generic voltage and current waveforms.

Inputs :

Vector of tension: va (t), vb (t) and vc (t)

Vector of current: ia (t), ib (t) and ic(t)

The PQ theory consists of an algebraic transformation (Clarke transformation) of the three phase voltages and current in the abc coordinates to the αβ coordinates [9].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad (1)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \qquad (2)$$

The instantaneous power is calculated as:

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

The harmonic component of the total power can be extracted as:

$$p_L = \overline{p}_L + \widetilde{p}_L \qquad (4)$$

Where,

$\overline{p}_L$: The DC component

$\widetilde{p}_L$: Harmonic component

Similarly,

$$q_L = \overline{q}_L + \widetilde{q}_L \qquad (5)$$

Finally, reference current can be calculated as:

$$\begin{bmatrix} i^*_{fa} \\ i^*_{fb} \\ i^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad (6)$$

Here,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \widetilde{p} \\ \widetilde{q} \end{bmatrix} \qquad (7)$$

The instantaneous p-q power theory has the following features [16].

- It is a theory inherent phase systems.
- It can be applied to any type of three-phase systems (balanced or unbalanced).
- It is based on instantaneous values, which gives it a good time dynamic response.
- The number of compensated harmonics depends on the bandwidth of semiconductor inverter.

IV. ALGORITHM OF NOTCH FILTERING

In this type of control the load current is filtered by a notch filter, which eliminates the component fundamental while leaving the harmonic components. A simple notch filter with bandwidth of 40 HZ has good isolating qualities [11].

The filter can considerably reduce the total harmonic distortion (THD) and recover from step change transient in 10 fundamental cycles. The transfer function for the realization of notch filter is:

$$T(s) = \frac{s^2 + w^2}{s^2 + s\frac{w_0}{Q} + w_0^2} \qquad (8)$$

The block diagram for an active power filter that uses a notch filter is shown in fig.3. The harmonic currents are subtracted from the load current by injecting into the power line with a 180° phase shift.

The notch algorithm theory has the following features:

- It applies easily to single phase systems, two phases or three phase, balanced or not.
- Has a good response time during transient.
- The number of compensated harmonics depends on the bandwidth of semiconductor inverter.

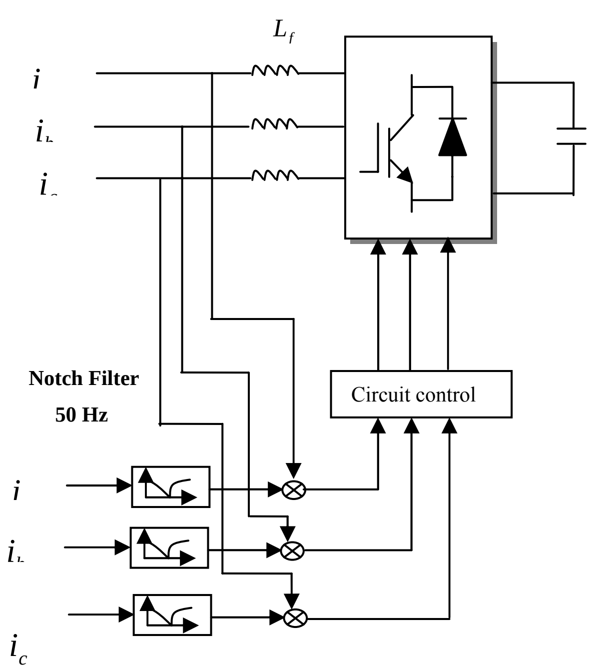

Fig. 3 Shunt APF controlled by notch filter

In Fig 3: ia, ib and ic are the line current and Lf is the value of inductance.

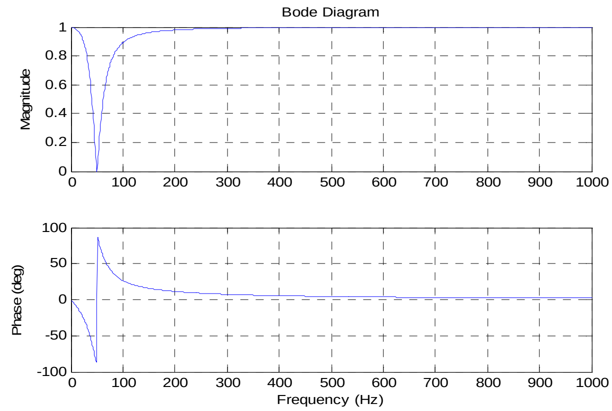

Fig .4 Notch filter response

V. ALGORITHM OF THE REFERENCE SYNCHRONOUS FRAME

This strategy for filtering is to transform current coordinates (abc) in current coordinates (dq) by using the park transform equation.1 proposed by Bhattacharya [11], which changes the three conventional rotating phase vectors into direct (d), quadrature (q) and zero (0) vectors. The frequency is set in synchronism with the network frequency.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin(wt) & \sin(wt - \frac{2\pi}{3}) & \sin(wt + \frac{2\pi}{3}) \\ \cos(wt) & \cos(wt - \frac{2\pi}{3}) & \cos(wt + \frac{2\pi}{3}) \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \qquad (9)$$

The synchronized park transformed to the network frequency in which the current flows has a very effect to fundamental current component transformation. In the other hand, the harmonic current components go through a lag frequency spectrum. The DC component is accomplished by adding a high-pass filter (HPF). The reference current is obtained by using the inversed park transform in synchronized with network frequency.

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin(wt) & \cos(wt) \\ \sin(wt - \frac{2\pi}{3}) & \cos(wt - \frac{2\pi}{3}) \\ \sin(wt + \frac{2\pi}{3}) & \cos(wt + \frac{2\pi}{3}) \end{bmatrix}\begin{bmatrix} i_d \\ i_q \end{bmatrix} \qquad (10)$$

The Reference synchronous frame has the following features [6].

- Like instantaneous power method, this method is inherent phase systems.
- It can be applied to both balanced three-phase systems as phase systems with neutral, unbalanced.
- It is based on instantaneous values, which gives it a good time dynamic response.
- Net decoupling between the fundamental and harmonic components.

VI. SIMULATION RESULTS

The proposed methods of current identification applied on shunt active power filter were set in Matlab Simulink environment to envisage its performance. The shunt active power filter (SAPF) model parameters are shown in the following Table I.

A number of simulation results were developed with different cases. The SAPF is connected in parallel with nonlinear load. Firstly, the following figures represent the polluted waveforms current created by nonlinear load and the frequency spectrum of current input. This simulation is carried out without using active power filter.

TABLE.I
SAPF PARAMETERS

Supply phase voltage "U"	220 V
Supply frequency "fs"	50 HZ
Filter inductor "Lf"	1mH
Dc link capacitor "Cf"	4.4 mF
Smoothing inductor "ls"	0.1 mH
Sample time "Ts"	4 µs

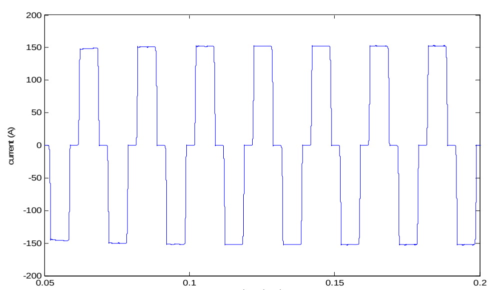

Fig.5 Current waveforms of nonlinear load

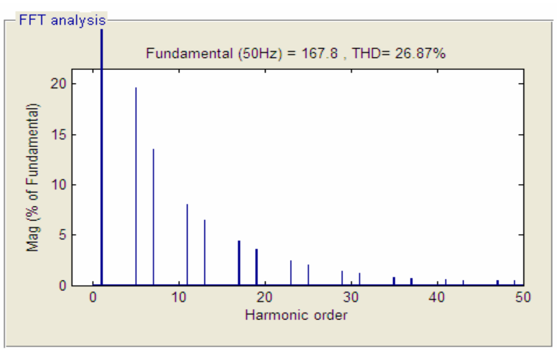

Fig.6 Frequency spectrum of input current

In order to demonstrate the validity of the proposed system shunt active power filter using harmonic identification techniques, the instantaneous active and reactive p-q power algorithm adapted with APF is simulated with the simulation parameters shown in table1. The simulation results of SAPF using p-q power theory are shown in Figure 8 and Figure 9. The total harmonic distortion (THD) is about 0.92% which proves the efficiency of the proposed SAPF controlled by the instantaneous active and reactive p-q power theory.

Table.II shows the harmonic row (5, 7, 11, 13 and 17) values which are reduced compared with the other methods Notch filtering algorithm and reference synchronous frame algorithm. In other hand, the injected current produced by this control strategy has good performance on harmonic reference injection compared to the other following method as shown in Fig. 7.

TABLE.2
HARMONIC ROW USING ACTIVE AND REACTIVE P-Q ALGORITHM

Harmonic Row	THD_i (%)
5	0.18
7	0.31
11	0.23
13	0.20
17	0.21

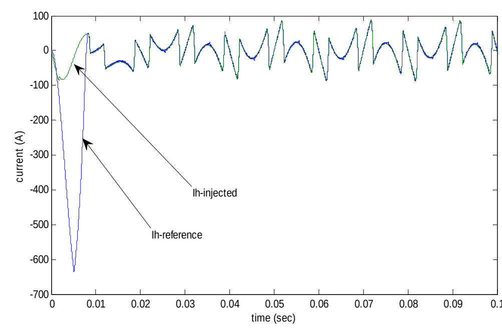

Fig .7 Current waveforms of injected current by power p-q algorithm

The active filter controlled by the algorithm of instantaneous power required two filters low pass butteworth second order to eliminate components of average power. The cut off frequency of theses filters has been adjusted to 30 Hz. For this algorithm approach, the cut off frequency of the three notch filters used for generate the current reference was adjusted to 50 Hz and its depreciation coefficient at 1.5. The simulation results are shown in Fig 10 and Fig 12.

Contrary to the control based on instantaneous power strategy, the identification method based on reference synchronous frame required two pass-filters in order to eliminate fundamental component. The cut off frequency for theses filters has been adjusted to 12 Hz and its depreciation coefficient at 0.7. The simulation results are shown in Fig 13 and Fig 15.

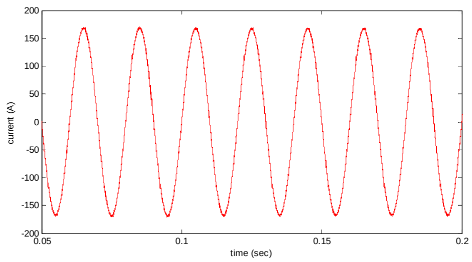

Fig.8 Current waveforms of supply current using p-q power theory

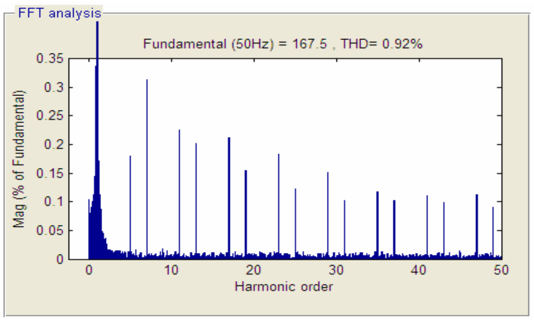

Fig.9 Frequency spectrum of input current using p-q power theory

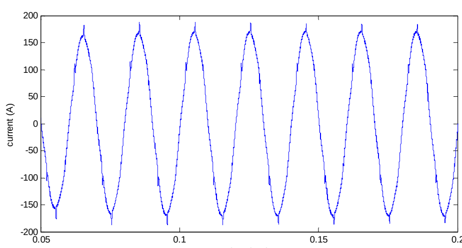

Fig.10 Current waveforms of supply current using notch filtering Algorithm

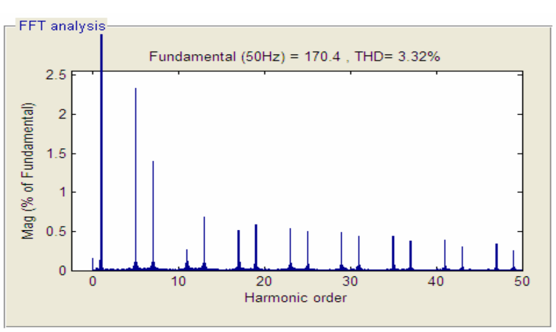

Fig.11 Frequency spectrum of input current using notch filtering Algorithm

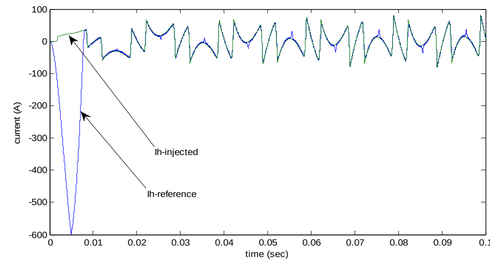

Fig.12 Injected current waveform using notch filtering Algorithm

TABLE.3
HARMONIC ROW USED NOTCH FILTERING

Harmonic Row	THD (%)
5	2.33
7	1.40
11	0.27
13	0.68
17	0.51

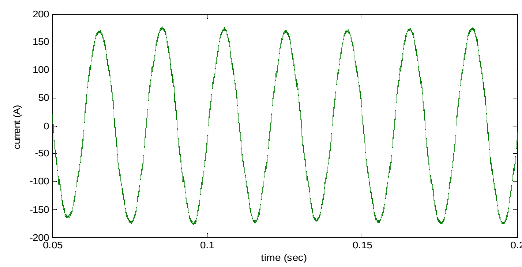

Fig.13 Current waveforms of supply current using reference synchronous frame method

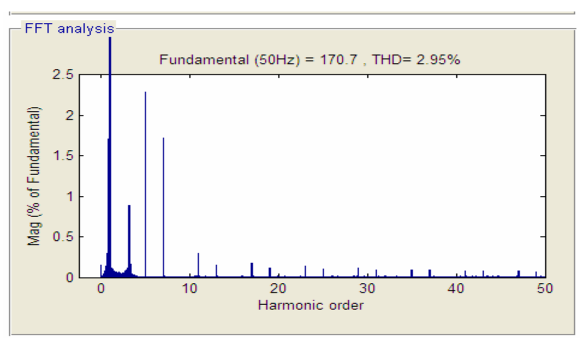

Fig.14 Frequency spectrum of input current using reference synchronous frame method

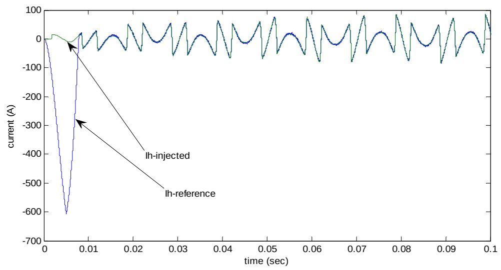

Fig.15 Injected current waveform using reference synchronous frame method

TABLE.4

HARMONIC ROW USED REFERENCE SYNCHRONOUS FRAME METHOD

Harmonic Row	THD (%)
5	2.28
7	1.71
11	0.30
13	0.16
17	0.17

VII. COMPARATIVE STUDIES

In this paper, we have presented a comparative study between three identification strategies applied on SAPF in order to notice the filter performance. The instantaneous power p-q method has improved the filtering quality (THD 0.92 %) for the shunt active power filter compared to the two other methods notch algorithm and reference synchronous frame theory which can be seen in the fig 9.

TABLE.5

COMPARATIVE THD RESULTS

	THD (%)	Harmonic Order				
		5th	7th	11th	13th	17th
Current without filtering	26.87	19.58	13.55	8.04	3.44	4.5
Current after filtering using notch theory	3.32	2.33	1.40	0.27	0.68	0.51
Current after filtering using reference synchronous	2.95	2.28	1.71	0.30	0.16	0.17
Current after filtering using p-q theory	0.92	0.18	0.31	0.23	0.20	0.21

TABLE.6

SOURCE CURRENT TOTAL HARMONIC DISTORTION: THD% AND POWER FACTOR

	Without SAPF	Notch filtering method	Reference synchronous method	Instantaneous power P-Q method
THD_i(%)	26.87	3.32	2.95	0.92
Power factor	0.68	0.85	0.89	0.94
Robustness		3.12	3.99	4.5

The harmonics analysis shows that the notch algorithm theory amplifies the 5th harmonic to 2.33 % on the contrary to the reference synchronous frame which amplifies 7th to 1.71%.

VIII. CONCLUSION

Nonlinear loads are responsible for the harmonic currents in the network; the most appropriate strategy depends on the correction objective. This paper evaluated three methods of determining the active filter compensating current for the power system. The obtained total harmonic distortion (THDi) with the proposed shunt active power filter using notch filtering algorithm, reference synchronous frame method and active reactive power p-q theory is 3.32%, 2.95% and 0.92% respectively. The THD is very less compared with the other methods techniques. Moreover, the power factor has been also increased from 0.85 and 0.89 to 0.94. The results have good conformity with the present work.

According to the previous results the proposed algorithm (Instantaneous power P-Q theory) has better dynamic performance and robustness. The algorithm (P-Q method) applied to SAPF has demonstrated good performance for harmonic elimination and reactive power compensation.

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