INVESTIGATION OF HARMONIC DETECTION TECHNIQUES FOR SHUNT ACTIVE POWER FILTER

C.S.Subash Kumar[1] and Dr. V. Gopalakrishnan[2]

[1] *Assistant Professor, Kathir College of Engineering,* [2] *Associate Professor, Government College of Technology*

ABSTRACT

Active power filters are used to eliminate current harmonics of non-linear loads. This paper evaluates three different methods of determining the compensating current for a shunt active filter that is working under non-symmetrical conditions. The paper compares the instantaneous reactive power theory, the synchronous reference frame theory and fast Fourier transform techniques. The comparison is based on simulation results. For unbalanced and non-sinusoidal source voltage conditions, the results obtained by the methods referenced are quite different. The instantaneous reactive power theory method had shown the best choice for all situations studied in this paper.

Keywords : *Shunt Active Filter, PQ Theory, SRF Theory.*

I. INTRODUCTION

The wide usage of non-linear loads, such as personal computers, variable speed drives, UPS systems, and the other electronic equipments produce harmonics which is a major problem in industrial and commercial power systems. The current harmonics are widely spread in industrial systems. These harmonics interact with system impedances and lead to current harmonics which badly affect sensitive loads. There are many methods for harmonic extraction such as Discrete Fourier Transform, Fast Fourier Transform [2-3], synchronous reference frame (dq) theory [4] and instantaneous power (pq) theory [5]. Harmonic extraction using Fourier Transform is a useful method for specific harmonic component compensation. However, Fourier Transform requires one more cycle of the voltage waveform data and corresponding time such that the delayed harmonic canceling can be occurred [6]. The dq technique which is widely used for voltage sag extraction does not respond fast or does not give accurate results to the voltage harmonics because the inaccuracy which is associated with the PLL and passive filters used in this technique [8].There are some potential problems for pq method in harmonic extraction[7].

II. CONTROL TECHNIQUES

A. FFT Computation

The basic operational principle of an active power filter requires extracting harmonics to be compensated (or minimized) from the entire current waveform. FFT is a powerful tool for harmonic analysis in active power filters.FFT is an operation to convert the time domain signal to the frequency domain spectrum.

The closed loop scheme of shunt active power filter using FFT reference current generation is shown in Fig.1. The amplitude and phase information of the harmonic series in a periodic signal can be calculated by using the fourier analyzer block shown in Fig.2 [4,5]. Dominant harmonics have been detected by running the m-file scripts in embedded matlab function block. The detected line current dominant harmonic has been phase shifted to 180° to generate the reference currents as shown in Fig.2. Thus the active power filter acts as a harmonic current source, injecting into the line harmonic with the same amplitude and opposite phase.

B. Synchronous Reference Frame Method

The closed loop control scheme for extracting the reference current using synchronous reference frame method is depicted in Fig. 3. The function of the harmonic detection block is separately highlighted in Fig. 4. The SRF method[5] is based on Park's transformation whereby the 3-phaseline currents are transformed into 2-phase quantities using Park's transformation. There are mainly two blocks corresponding to positive and negative sequence components. The positive sequence component of load current is transformed to de–qe axes by generating positive sequence phase information +θ from PLL circuit. The details of mathematical implementation of PLL software in the synchronization of three-phase system is given in [6] and its application in Matlab simulations can be found in package program. AC quantities in positive sequence waveform include all harmonic components while dc quantity is fundamental component of load current.
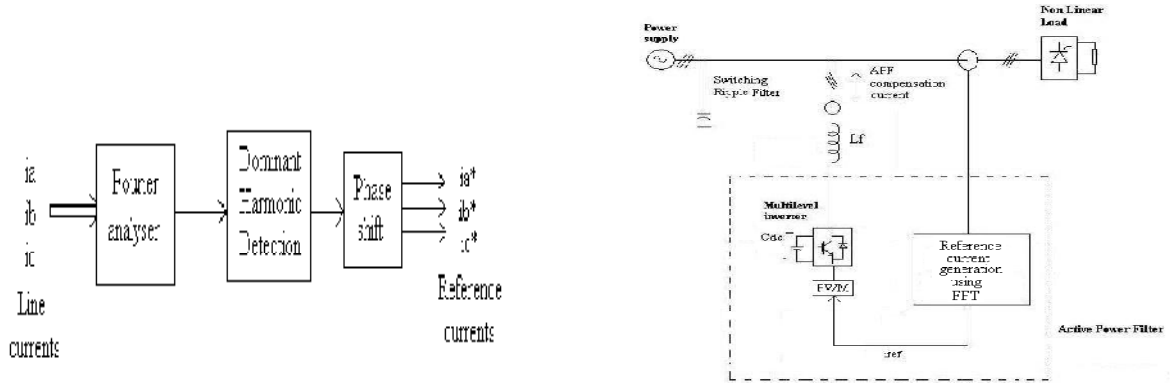
Fig.1.Shunt active power filter circuit using FFT method   Fig.2.Reference current generation by FFT method

There are mainly two blocks corresponding to positive and negative sequence components. The positive sequence component of load current is transformed to de–qe axes by generating positive sequence phase information +θ from PLL circuit. The details of mathematical implementation of PLL software in the synchronization of three-phase system is given in [6] and its application in Matlab simulations can be found in package program. AC quantities in positive sequence waveform include all harmonic components while dc quantity is fundamental component of load current. The negative sequence component of the current is also transformed to de–qe axes by generating negative sequence phase information −θ from the PLL. If voltages and currents in the three-phase system are balanced, the output of this block will be zero. Thus the dominant harmonic component is obtained by comparing the positive and negative sequence controller outputs.

The component which is in 2-phase form is converted into 3-phase using inverse transformation. This dominant harmonic component of the current is compared with the reference current derived from the dc voltage controller block For the active power filter to operate effectively, it is important to maintain the dc capacitor voltage at a constant value. The dc capacitor voltage is directly affected by the real power transferred across the active filter [6]. To keep the voltage constant, ideally, no real power should be transferred. However, due to losses in the switching devices and other components, a small amount of real power is needed. The actual dc input voltage of multilevel inverter has been compared with the reference voltage as shown in Fig.3. The capacitor voltage regulation is then handled by a simple proportional-integral (PI) controller. The actual filter current is then compared with the reference filter current obtained by comparing the harmonic current (ihd) detected from SRF method and the current obtained from the voltage controller(ihd,ref). This output has been regulated by the current controller (PI) and hence the reference current will be obtained. This reference current has been given as a reference waveform to the pulse width modulator circuit (PWM) of the multi level inverter. Hence the multilevel inverter generates the desired harmonic compensating current into the line which enables the reduction of dominant harmonic component in the line current.
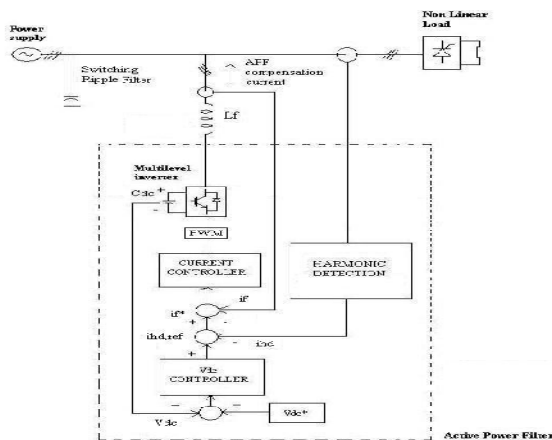

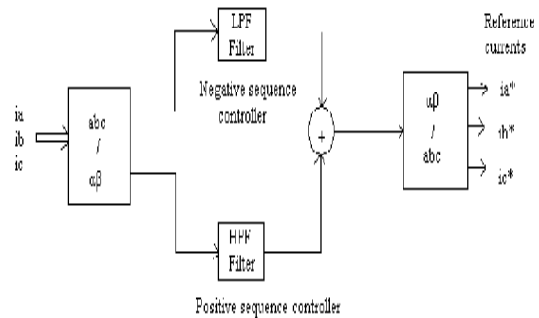Fig. 3.Closed loop circuit of shunt active power filter   Fig. 4.Harmonic detection by SRF method

using SRF method

C. Instantaneous Active and Reactive Theory

The three voltages Va, Vb and Vc from the voltage transducers are given to the controller, which converts them to Vo, Vα and Vβ using the following equations.

$$V_0 = \frac{1}{\sqrt{3}}(V_a + V_b + V_c) \tag{1}$$

$$V_\alpha = \sqrt{\frac{2}{3}}(V_a + \frac{V_b}{2} + \frac{V_c}{2}) \tag{2}$$

$$V_\beta = \sqrt{\frac{2}{3}}\left(\frac{\sqrt{3}}{2}V_b - \frac{\sqrt{3}}{2}V_c\right) \tag{3}$$

Similarly, the controller is fed with current signals from the current transducers, which are converted to i0, iα and iβ using the following equations

$$I_0 = \frac{1}{\sqrt{3}}(I_0 + I_0 + I_0) \tag{4}$$

$$I_\alpha = \sqrt{\frac{2}{3}}(I_0 + \frac{I_0}{2} + \frac{I_0}{2}) \tag{5}$$

$$I_\beta = \sqrt{\frac{2}{3}}(\frac{\sqrt{3}}{2}I_0 - \frac{\sqrt{3}}{2}I_0) \tag{6}$$

The real and reactive powers are obtained from the following equations

$$P_0 = V_0 I_0 \tag{7}$$
$$p = V_\alpha I_\alpha + V_\beta I_\beta \tag{8}$$
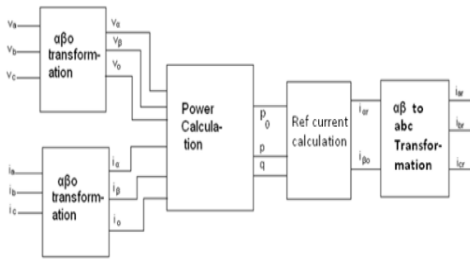$$q = -V_\beta I_\alpha + V_\alpha I_\beta \tag{9}$$

Fig.5. Block diagram representation of calculation
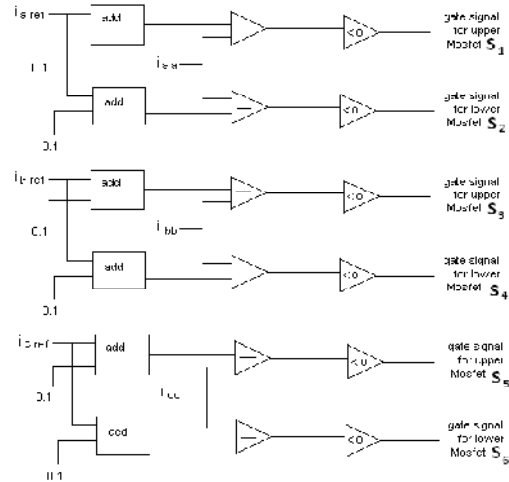of reference currents

Fig. 6 Generation of Gating Signals

This calculation is represented diagrammatically in Fig. 5. The active power signal **p** has a steady component and a fluctuating component. The steady component only should be drawn from the grid, whereas the fluctuating component should be drawn from the active power filter. If this can be done, the grid will not be affected by harmonic currents. If **q** can be supplied entirely from the active power filter, the power factor will also be improved. If reference currents can be calculated with this in view, the shunt active power filter will contribute in a great way to improve the power quality. The power signal **p** is passed through a high pass filter. A diagrammatic representation of this scheme is shown in Fig.6.

P_0 (zero sequence power signal) is passed through low pass filter and the active power signal is passed through high pass filter. The output of low pass filter is steady component of zero sequence power. In high pass filter, output is fluctuating component of power as shown in Fig.6. This difference is $P_0 - \tilde{p}$ is used to calculate the reference currents using the following expressions.

$$I_{caref} = \frac{1}{V_\alpha^2 + V_\beta^2}[V_\alpha(P_0 - \tilde{p}) + V_\beta q] \tag{10}$$

$$I_{c\beta ref} = \frac{1}{V_\alpha^2 + V_\beta^2}[V_\beta(P_0 - \tilde{p}) + V_\alpha q] \tag{11}$$

These reference currents in the α-β frame are converted to a-b-c frame, using the reverse transformation given below.

$$I_{caref} = \sqrt{\frac{2}{3}}[\frac{(-i_0)}{\sqrt{2}} + I_{caref}] \tag{12}$$

$$I_{c\beta ref} = \sqrt{\frac{2}{3}}[\frac{(-i_0)}{\sqrt{2}} - \frac{1}{2}I_{caref} + \frac{\sqrt{3}}{2}I_{c\beta ref}] \tag{13}$$

$$I_{ccref} = \sqrt{\frac{2}{3}} \left[\frac{(-i_0)}{\sqrt{2}} - \frac{1}{2} I_{caref} - \frac{\sqrt{3}}{2} I_{ca\beta ref} \right] \qquad (14)$$

This scheme involves selection of two levels of current. First one is slightly above the reference current and other slightly below the reference current. Feedback signal from the actual current is taken. When the actual current is below lower value, the MOSFETs are switched on, and when the current crosses the upper value, the MOSFETs are switched off. As a result, the actual current remains within the upper and lower bands of the current reference. The scheme is explained diagrammatically in Fig. 6.

SIMULATIONS

The block diagram shown in fig.7 presents the piecewise blocks of the voltage source instantaneous power control technique. Due to the application of non-linear load, harmonics are present. The three-phase voltages and line currents are taken as inputs for the P-Q theory and reference currents are generated. These reference currents are utilized to generate the PWM pulses which are used to trigger the IGBT's of the active filter. The capacitor is charged or discharged based on the reference currents by triggering the IGBT's. A resistor is connected across the capacitor in order to decrease the discharging time and keep the voltage across the capacitor constant.
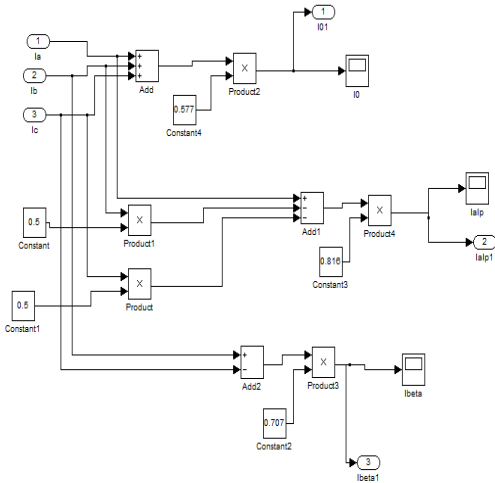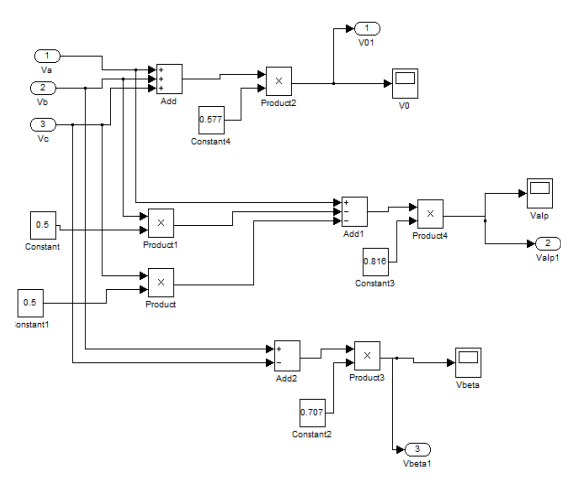

Fig. 7 Instantaneous Current Control

Fig.8 Instantaneous Voltage Control

The block implements the following equations:

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = T \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} = T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \qquad (15)$$

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & \sqrt{3}/2 \end{bmatrix} \qquad (16)$$

The Voltage Source Instantaneous Power Control Technique implementation used by the active filter controller is shown in the Fig 8.
The block in Fig.10 implements the following equations:

$$\begin{bmatrix} P_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} V_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} \qquad (17)$$

The oscillation and steady state components are separated by implementing the following equations

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \widetilde{P_0} + \Delta \bar{P}_{loss} \\ q \end{bmatrix} \qquad (18)$$

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71 | Page

Where,

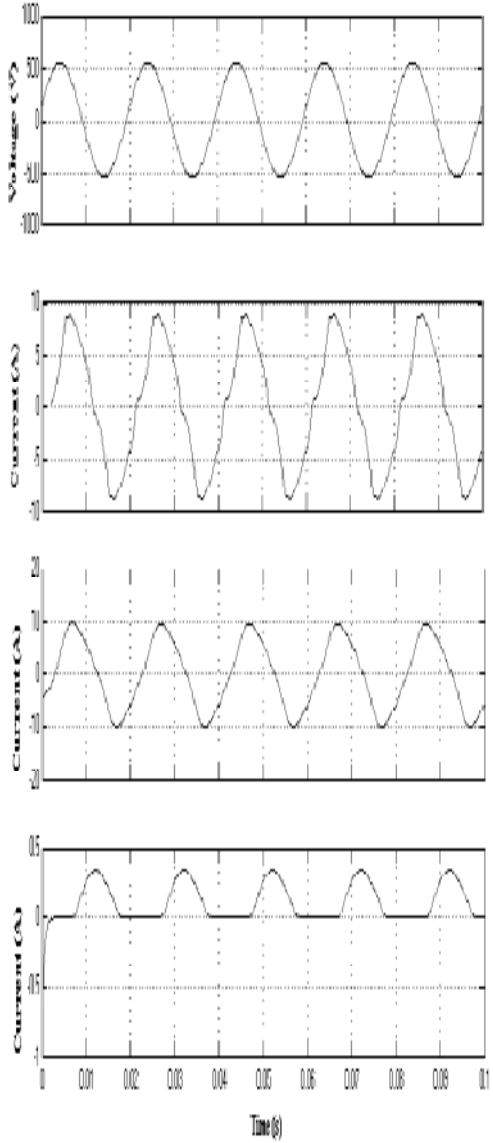$$\Delta\bar{P} = \bar{P}_0 + \bar{P}_{loss} \qquad (19)$$

Fig.9 FFT method: i) input voltage ii) Line current without filter iii) Line current with filter iv) APF current
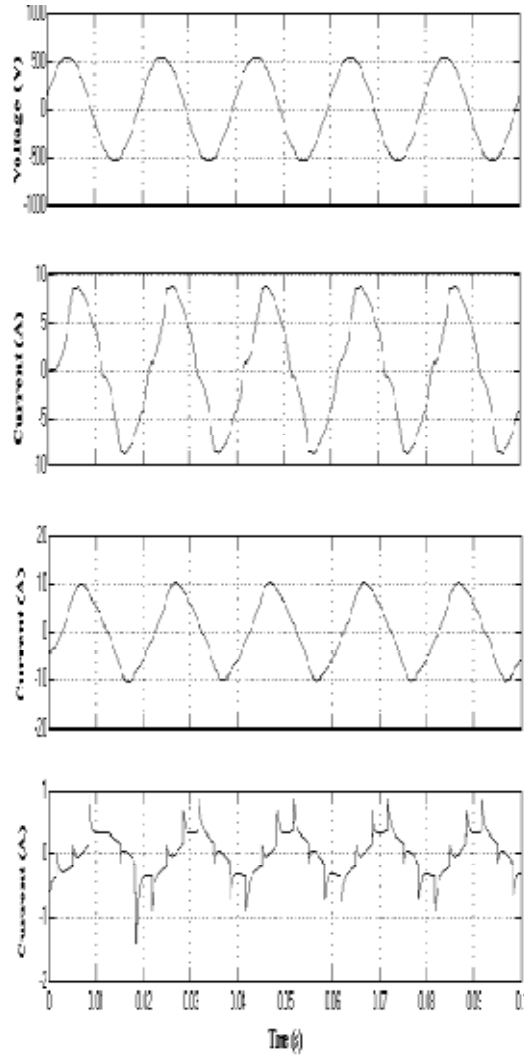
Fig 10 : PQ Method i) input voltage ii) Line current without filter iii) Line current with filter iv) APF current

CONCLUSION:

In this paper various harmonic current extraction methods are show such as Active & Reactive Theory (pqTheory) ,Synchronous Reference Frame (dq-Theory),Fast Fourier Transform. The computer simulations have been verified the effectiveness of the proposed control scheme. From the simulation results, the proposed approach was very successful and easily implemented. When the system phase voltages are unsymmetrical and distorted, because no distortion appears in the line currents. In non-ideal mains voltage condition, the source currents by the instantaneous power (p–q) theory are distorted, but the source currents by the proposed method have no distortion.

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