

Comparative study of two control strategies for Shunt Active Power Filter (SAPF) in 3-ph, 3-wire system using PI controller

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Abstract: Due to large amount of non-linear power electronic equipment's impact and fluctuating loads, problems of power quality have become more and more serious with each passing day. Active power filtering has gained much more importance in the power quality arena as it gives the best solution for all power quality issues. Shunt active filtering is effective and the performance of such units largely depends upon the control strategies used for reference current generation. This paper presents the comparative evaluation of the performance of two control techniques to determine the reference current for the three phase three wire SAPF in order to improve the power quality using PI controller. The first one is based on the Instantaneous real and reactive power (p-q) method and second one is the Instantaneous active and reactive current (I_d - I_q) method. Both control techniques are based on time domain simulated with Matlab/Simulink. Different simulation results are presented with and without SAPF under balanced condition in this paper.

I. Introduction

An increase in power quality problems in the electric power networks are due to the increased use of non-linear loads, such as switch mode power supply (SMPS) in computers, rectifier devices in TV's, telecommunication power supplies and commercial lighting systems, etc. Harmonic pollution is an important power quality problem. In this increasing global competition, modern industries have to make their production process more efficient in order to compete. To do this, advanced technologies have to be used. With the proliferation of static power converters or non-linear loads in industrial application and distribution systems, the compensation of harmonics is becoming a significant concern. Static power converters have a current source, injecting harmonics into the supply network. This causes the problem of power system harmonics, leads to the voltage distortion the power system, at point of common coupling (PCC). When power converters inject a distorted current in the supply network, a harmonic voltage is developed across the source impedance. The voltage at PCC, being the difference of the source voltage and voltage across the source impedance, will distort [1]. Several power quality standards are defined in order to keep the harmonic distortion within the limits like IEEE-519-1992/IEC 61000 [2]. Traditionally, passive LC filters have been used to eliminate the current harmonics and to improve the power factor. However, these passive second order filters presents many disadvantages such as aging and tuning problems, series and parallel resonance, and the requirement to implement one filter per frequency harmonics that need to be eliminated. In order to overcome these problems, different kinds of active power filters, based on forced commutated devices, have been researched and developed. In recent years, shunt active power filters based on current controlled PWM converters have been widely investigated and organised as viable solutions [3-5]. Though several control strategies have been developed but still two control theories, Instantaneous real and reactive power (p-q) method and Instantaneous active and reactive current (I_d - I_q) method [6,7] are always dominant. Present paper mainly focuses on these two control strategies using PI controller. To validate current observations, extensive simulations are carried out with PI controller for both p-q and I_d - I_q methods for balanced conditions.

II. Control strategies

System description

The control techniques are implemented for a common system that is represented in figure (1). Here a three phase supply is used to feed a non-linear load consisting of a diode bridge rectifier feeding RL load at its DC side. At PCC, a current controlled voltage source inverter (CCVSI) is acting as SAPF. The DC side capacitor and AC side inductance of this VSI acts as filter components. The gate pulses to the inverter are generated by an hysteresis type pulse generator. The heart of APF is the reference current generator block. This unit takes voltage and/or current from the supply and/or load to generate the reference current depending upon the type of control strategy used.



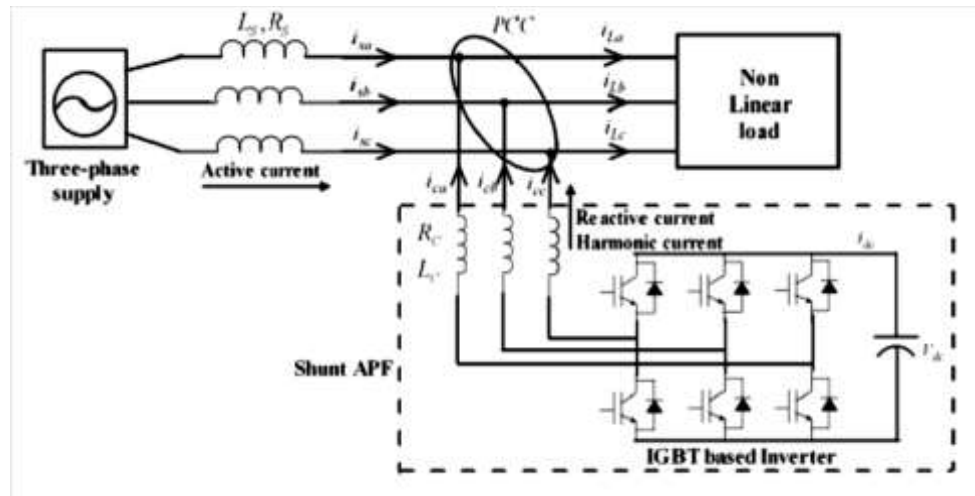


Fig.1.The three-phase, three-wire SAPF

A. Instantaneous real and reactive power (p-q) method:

Akagi et al. [8] proposed a concept based on the theory of instantaneous reactive power in the $\alpha\beta$ reference frame; this theory stimulates the realization of three phase, three-wire APFs. In this theory, the instantaneous source voltage and current signals in $a-b-c$ coordinates are transformed into two-phases i.e. $\alpha\beta$ orthogonal coordinates as follows.

$$\begin{bmatrix} V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (1)$$

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

For simplicity, the zero-phase sequence component voltage and current signals are eliminated in (1) and (2). The instantaneous active power (p) and the instantaneous imaginary power (q) in a three-phase circuit are defined in (3).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (3)$$

Using (3) load current in $\alpha\beta$ frame can be calculated as

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

The block diagram of this method is as shown in figure (2). The reference compensating current can be calculated in such a way that it supplies the instantaneous reactive power (q) and the harmonic component of the instantaneous active power (p). The reference compensating current (i_c^*) can be obtained as:

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ -V_{s\beta} & V_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

The compensating current signals in $\alpha\beta$ frame can be transferred to $a-b-c$ frame using inverse Clark's transformation as:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (6)$$



This method does not take into account the zero sequence components, and hence, the effect of unbalanced voltages and currents. The instantaneous reactive power ($p-q$) theory is widely used for three-phase balanced non-linear loads, such as rectifiers.

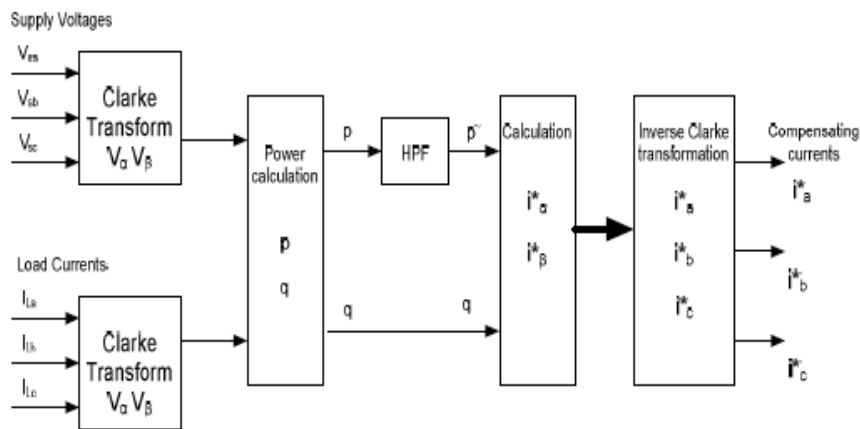


Figure.2.Block diagram of instantaneous active and reactive power theory (p-q)

B. Instantaneous active and reactive current control strategy (I_d-I_q):

The active power filter control algorithm, based on Instantaneous active and reactive current control strategy (I_d-I_q) [9], as shown in figure(3). In this method, the load current signals are first transformed into synchronous reference ($dq0$) frame. The fundamental component of the load current after transformation is a DC value and the harmonics appear like a ripple over this DC offset. A low pass filter is used to separate harmonic components from the load current. The active power loss component is subtracted from this current to get the reference d and q component of filter currents. Then reference current in abc frame is obtained using inverse transformation. The reference current is compared with actual filter current and the error current is used by the hysteresis controller to generate the pulses. In general the rotating frame dq0 is obtained from abc quantities by the following transformation as mentioned in [10].

$$\begin{bmatrix} x_o \\ x_d \\ x_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \cos \theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ \sin \theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix}$$

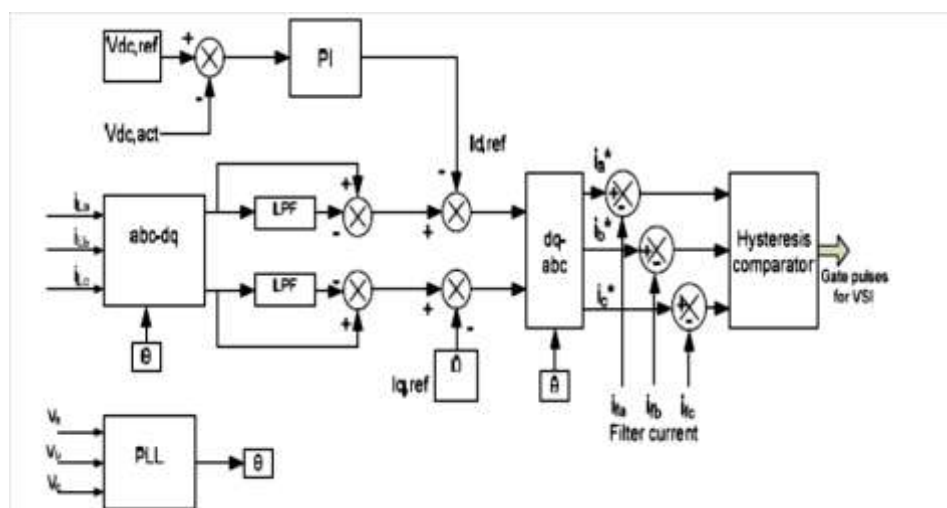


Figure 3. block diagram of Instantaneous active and reactive current control strategy, (I_d-I_q) method.

For synchronization a PLL is used which derives phase angle θ the AC supply voltage.



III. Modelling and simulation of the system

To simulate the two control techniques, two models are developed in MATLAB/SIMULINK™ environment using Sim Power System blockset.

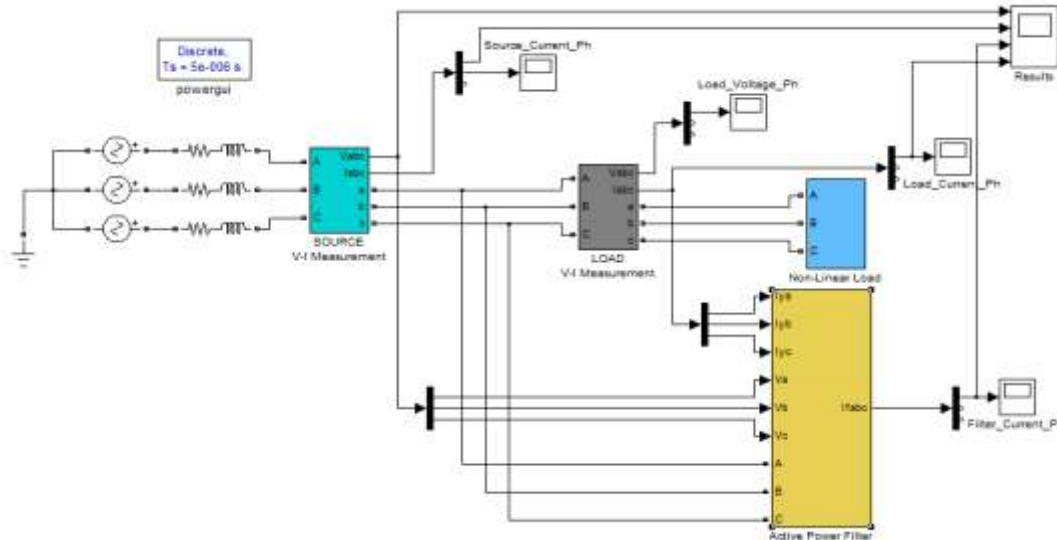


Fig.4.Simulation Block Diagram

The above fig. shows the simulation block diagram for both methods used in this study. The complete active filter system for the both techniques is composed mainly of a three phase source, a non-linear load which is a three phase rectifier feeding RL load, a PWM voltage source inverter and a control block. The only difference is localized in the nature of the signals to measure.

Following are the simulation parameters:

$$V_s = 220\sqrt{2} \text{ V}, R_s = 0.0000001 \Omega, L_s = 0.1 \text{e-}4, R_f = 0.1 \Omega, L_f = 1 \text{e-}3, V_{dc} = 800 \text{ V}, C_{dc} = 0.12 \text{ F}, K_p = 0.6, K_i = 30$$

At first, fig.5 and 5.1 presents the results of simulation before connecting the filter to the network polluted by the non-linear load and FFT analysis. The source current presents a high harmonic distortion (THD=30.44%), caused by the presence of non-linear load.

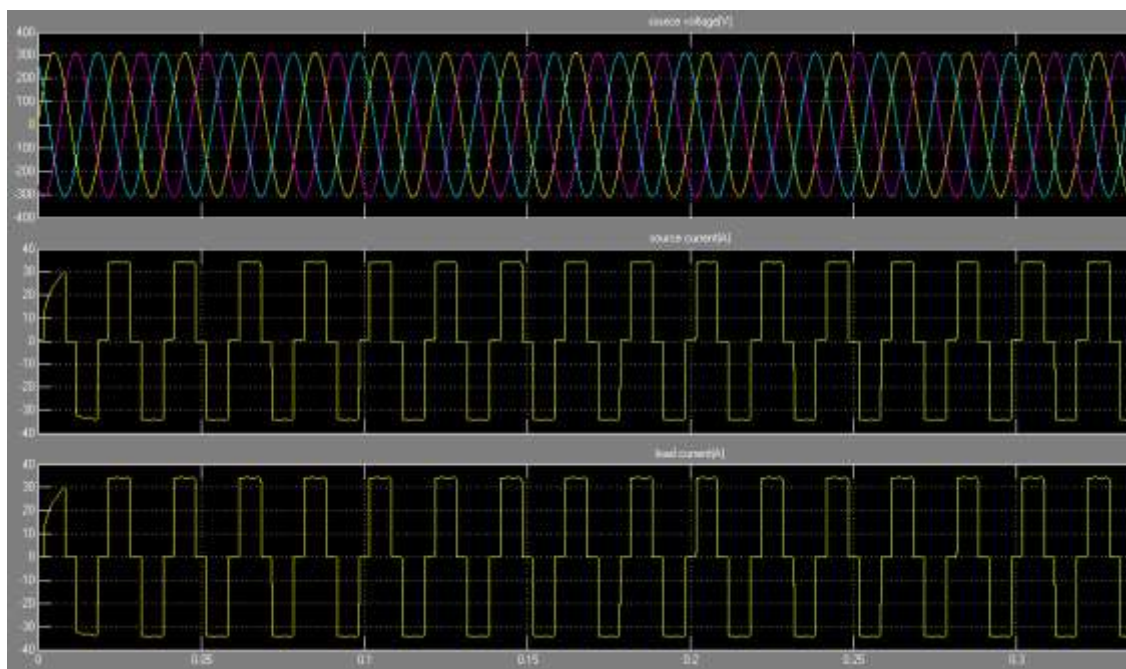


Fig.5. Simulation results before connecting the SAPF



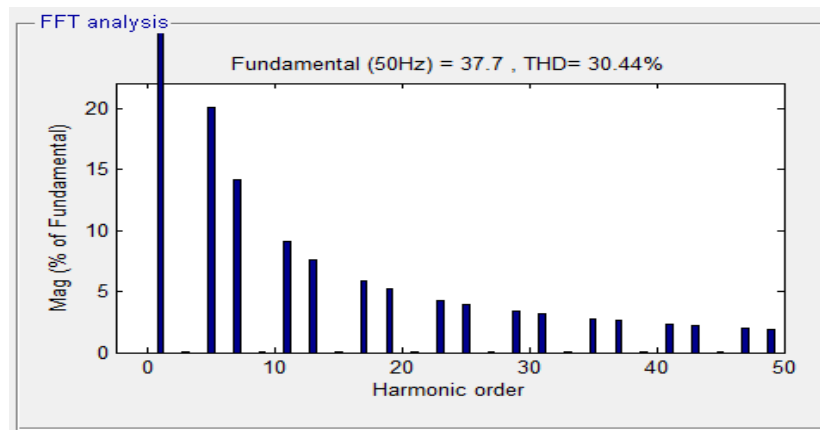


Fig.5.1. %THD without using SAPF

In this section, fig.6 and 6.1 presents the results of simulation after connecting the filter to the network polluted by the non-linear load using (p-q) method and its FFT analysis. The source current presents a Total Harmonic Distortion (THD=3.64%).

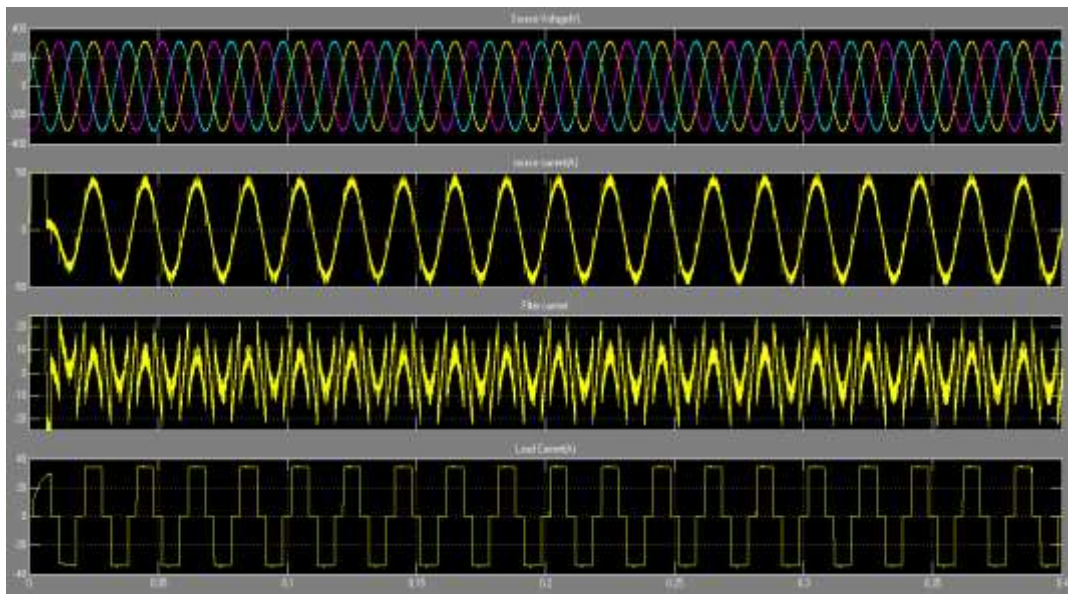


Fig.6. Simulation results after connecting the SAPF with (p-q) method

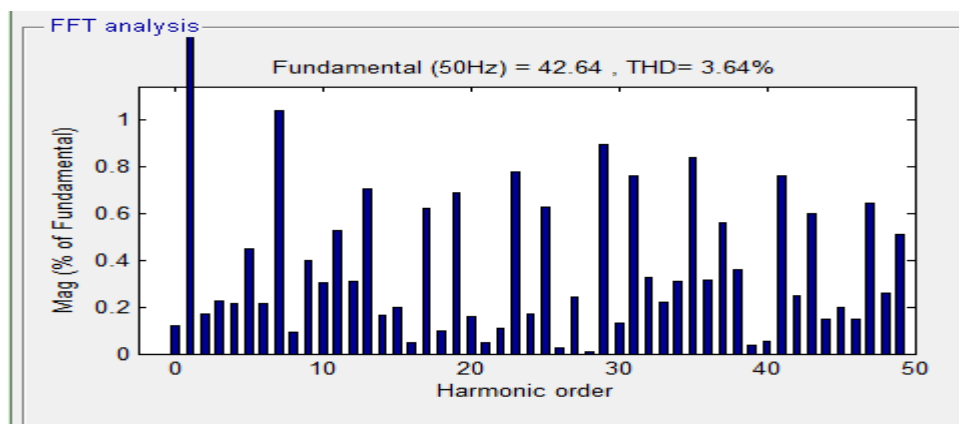


Fig.6.1. %THD using SAPF with (p-q) method



In this next section, fig.7 and 7.1 presents the results of simulation after connecting the filter to the network polluted by the non-linear load using (I_d - I_q) method and its FFT analysis. The source current presents a Total Harmonic Distortion (THD=2.90%).

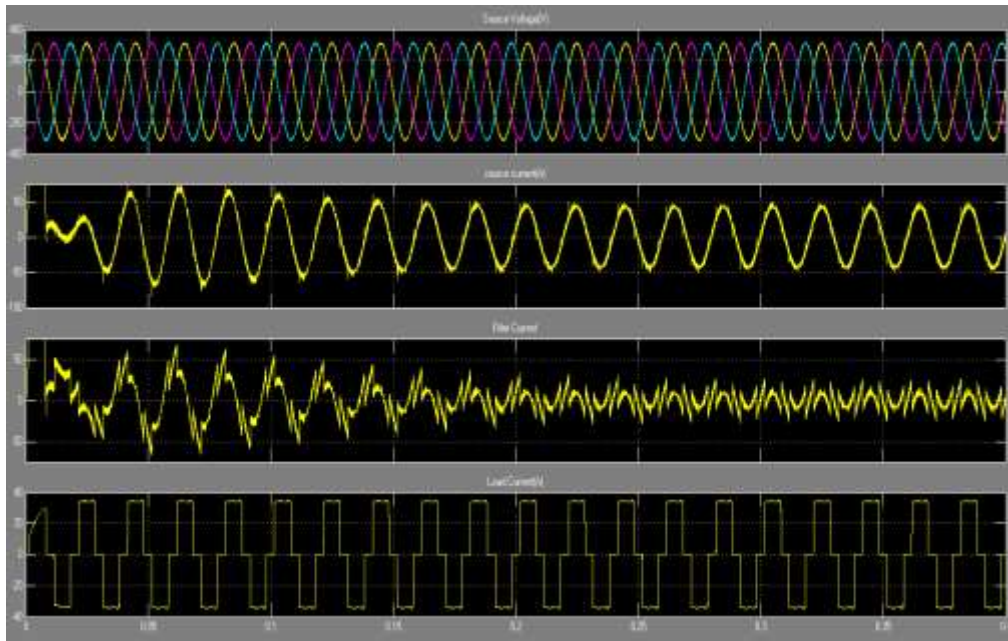


Fig.7: Simulation results after connecting the SAPF with (I_d - I_q) method

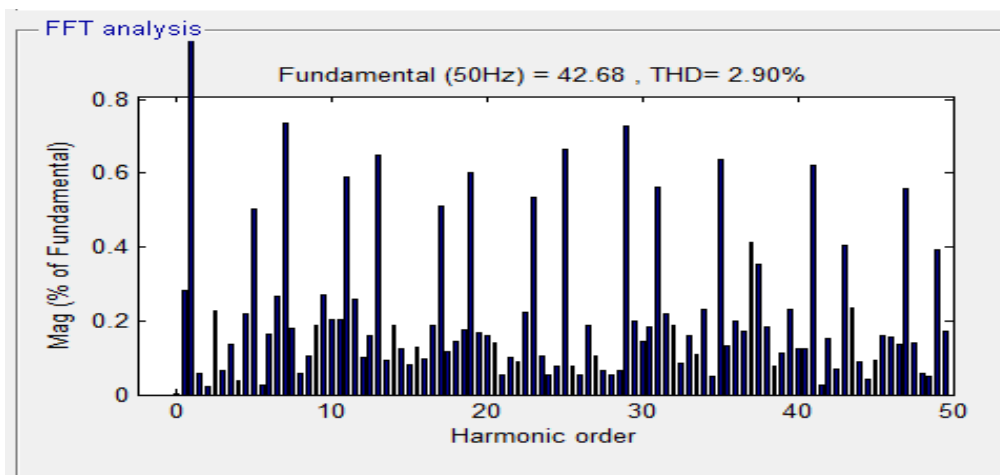


Fig.7.1. %THD using SAPF with (I_d - I_q) method

According to the given results shown above, the total harmonic distortion will be 30.44%, and after connecting shunt active power filter, the source current becomes sinusoidal and the total harmonic distortion becomes 3.64% in case of Instantaneous real and reactive power (p-q) method and 2.90% in case of Instantaneous active and reactive current control strategy (I_d - I_q) method. Furthermore, the dc capacitor voltage achieves quickly the reference value V_{dc}^* (800V) after few cycles.

Conclusion

A comparison between two control strategies has been studied in this paper, to improve power quality by compensating harmonics. The performance of control strategy based on Instantaneous real and reactive power (p-q) method has been studied and compared with another control technique using Instantaneous active and reactive current control strategy (I_d - I_q) method. It is clear from the simulation results that the compensation process for both the techniques is simple, but the control technique using Instantaneous active and reactive current control strategy (I_d - I_q) method has a better transient response as compared to another control technique. The THD of the supply current is well below, the limit imposed by IEEE-519 or CEI 61000 Standards.



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