

# Comparative Study between Different Control Strategies for Shunt Active Power Filter

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**Abstract-** Power filters are widely used in modern electrical distribution system to eliminate the harmonics associated with it. The active power filter (APF) is one of power filters which have better dynamic performance. The APF needs an accurate control algorithm that provides robust performance under source and load unbalances. The control methods are responsible for generating the reference currents which used to trigger the Voltage Source Inverters (VSI). Thus, the performance of compensation of harmonics of source current largely depend on the algorithm adopted. This paper presents a comparative study of three different control schemes to eliminate odd harmonics present in the source current. The studied system is modeled and simulated in MATLAB-Simulink environment for effectiveness of the study.

**Index Terms**—shunt active power filter (SAPF), Voltage Source Inverter (VSI), harmonics, proportional integral (PI) controller, total harmonic distortion (THD).

## I. INTRODUCTION

In modern electrical distribution system, due to the wide use of non-linear loads such as uninterrupted power suppliers (UPS), adjustable speed drives (ASD), furnaces and single phase computer power supply etc has resulted serious power quality problems. Most of these non-linear loads cause harmonic injection into the power system and degrade the system performances and lower the system efficiency. The current harmonics cause overheating of transformers, excessive neutral current, distortion of feeder voltage, low power factor, damages to power devices and malfunction of sensitive equipment [1]. To eliminate the harmonics in the power system, harmonic filters are installed at PCC. Between the different technical options available to improve the power quality, shunt active power filters have proved to be vital and effective solution to compensate current and voltage disturbances in the power distribution system. By installation of harmonic filter, harmonic pollution as well as low power factor can be improved. Shunt APF is simple in construction, a VSI shunted with a large dc-link capacitor. The shunt APF has been an effective solution to mitigate the harmonics, and therefore improving the power quality. Moreover, the performance of an APF system largely depends on the applied current control strategy for generating reference current. For the shunt APF to work satisfactorily, it should compensate harmonics under both balanced and unbalanced conditions. Some control methods discussed in [2]-[6] works

good only for balanced condition but the reduction of harmonics under source and load unbalances is not satisfactory. The new method discussed in [7]-[9] solves this problem. This paper focuses on the analysis of three control schemes and their responses for shunt APF system. The studied system is modeled and simulated in MATLAB-Simulink environment for effectiveness of the study.

This paper is organized as follows: section II describes harmonic compensation schemes and different types of filter. Section III presents the control strategy based on different algorithms with detailed analysis and section IV reveals the results and discussions followed by the conclusions in the section V.

## II. HARMONIC COMPENSATION SCHEMES

The harmonic filter connected to power system has two objectives:

1. To reduce the harmonic voltage and current in the power system below acceptable level.
2. To compensate the reactive power.

Two type of filters used for this purposes are:

- Passive filter
- Active filter

### A. Passive Filters

Passive filters are used as harmonic improvement devices in the power distribution system [5] but their performances are not satisfactory due to following reasons:

(i) Passive filter must be designed in considering with current provided by nonlinear load and Source impedance affects the compensation characteristics of LC filters. (ii) When the content of harmonics in the AC line increases, the filter will be loaded. (iii) Frequency variation of AC source and tolerances in the filter components will affect the compensation characteristics of LC filters. If the system frequency variation is large, components required for attaining tuned frequency become impractical. With the above mentioned disadvantages the passive filter are less frequently used compared to active power filter.

### B. Active Filters

The use of the active power filter is the future trend of harmonic improvement in distribution power system because

of its excellent dynamic characteristics. A flexible and versatile solution to harmonic problem is offered by active power filters. Currently they are base on PWM converters and connect to low and medium voltage distribution system in shunt or series. Shunt active power filter operates as a controllable current source and series active power filter operates as a controllable voltage source. Both schemes are implemented preferably with voltage source PWM inverter with DC link capacitor. Shunt active power filter compensate current harmonic by injecting complementary current that of produced by non-linear load. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shift by 180. Moreover with an appropriate control scheme, the active power filter an also improve load power factor. The current compensation characteristics of shunt active power filter is shown in Fig.1.

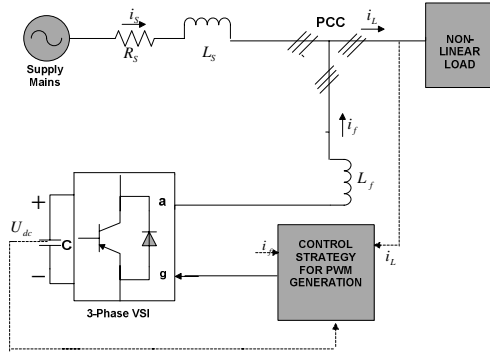


Fig.1 Basic diagram of shunt APF for current harmonic compensation

### III. CONTROL ALGORITHMS

#### A. Synchronous Detection Method

Synchronous theory can work effectively under balanced as well as unbalanced source and load condition because the compensating current are calculated taking into account the magnitude of per phase voltage. The equal current distribution method of synchronous detection theory is used to calculate the three phase compensating current to be provided by the active filter as shown in Fig. 2. Two assumptions made in calculating three phase reference currents are :

Source voltage is not distorted and Peak values of source currents are balanced after compensation as given in (1)

$$I_{rs} = I_{ys} = I_{bs} \quad (1)$$

Where  $I_{rs}$ ,  $I_{ys}$  and  $I_{bs}$  are the amplitudes of three phase source current after compensating. The real power consumed by the load can be calculated as (2)

$$p = [v_r \quad v_y \quad v_b] \cdot \begin{bmatrix} i_{Lr} \\ i_{Ly} \\ i_{Lb} \end{bmatrix} \quad (2)$$

Where  $v_r$ ,  $v_y$  and  $v_b$  are load voltages and  $i_{Lr}$ ,  $i_{Ly}$  and  $i_{Lb}$  are load current. The active power  $p$  is sent through a low pass

filter to obtain its average value  $P_{dc}$ . Then the active power is split into three phases as follows (3)

$$\left. \begin{aligned} P_r &= \frac{P_{dc} \cdot E_r}{E} \\ P_y &= \frac{P_{dc} \cdot E_y}{E} \\ P_b &= \frac{P_{dc} \cdot E_b}{E} \end{aligned} \right\} \quad (3)$$

Where  $E_r$ ,  $E_y$  and  $E_b$  are the amplitudes of the source voltages  $e_r$ ,  $e_y$  and  $e_b$ .  $E$  is the algebraic sum of  $E_r$ ,  $E_y$  and  $E_b$ . The desired source current can be calculated as (4)

$$\left. \begin{aligned} I_{rl}^* &= \frac{2 \cdot e_r \cdot P_r}{E_r^2} \\ I_{yl}^* &= \frac{2 \cdot e_y \cdot P_y}{E_y^2} \\ I_{bl}^* &= \frac{2 \cdot e_b \cdot P_b}{E_b^2} \end{aligned} \right\} \quad (4)$$

The reference signal for generating compensation current can be calculated as below (5)

$$\left. \begin{aligned} I_{rc}^* &= I_{rl}^* - I_{rL} \\ I_{yc}^* &= I_{yl}^* - I_{yL} \\ I_{bc}^* &= I_{bl}^* - I_{bL} \end{aligned} \right\} \quad (5)$$

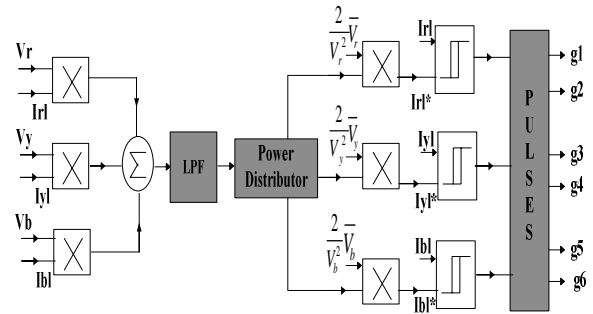


Fig.2 Block diagram for synchronous-detection method

#### B. Instantaneous Reactive Power Theory

This control algorithm gives an elementary way to find the reference currents for the Shunt APF system. The theory is based on the park transformation [6]; it transfers the three - phase axis mains voltage and currents to  $d-q$  axis. The transformation can be written in the equations (6) and (7).

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{rL} \\ v_{yL} \\ v_{bL} \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{rL} \\ i_{yL} \\ i_{bL} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (8)$$

The Instantaneous reactive power algorithm, also known as  $p$ - $q$  theory, defines the active, reactive powers as in equation (8), where  $p$  and  $q$  can be decomposed as combination of mean and alternating part as in equation (9).

$$p = \bar{p} + \tilde{p} \quad (9)$$

$$q = \bar{q} + \tilde{q}$$

$$\begin{bmatrix} i_{r\alpha}^* \\ i_{r\beta}^* \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} \bar{p} \\ q \end{bmatrix} \quad (10)$$

$$\begin{bmatrix} I_{rl}^* \\ I_{yl}^* \\ I_{bl}^* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1 & \frac{\sqrt{3}}{2} \\ 2 & 2 \\ -1 & -\sqrt{3} \\ 2 & 2 \end{bmatrix} \begin{bmatrix} i_{r\alpha}^* \\ i_{r\beta}^* \end{bmatrix} \quad (11)$$

The component  $\tilde{p}$  represents the alternating part of real power and it does not involve any energy transfer from source to load so it must be compensated. Similarly the reactive power involved with the load must be compensated by the APF. Hence the reference signal of compensation current in the  $d$ - $q$  axes can be given as in (10). And using the inverse park transformation we get the reference currents back to three-phase system (11). The block diagram for this algorithm is shown in Fig.3

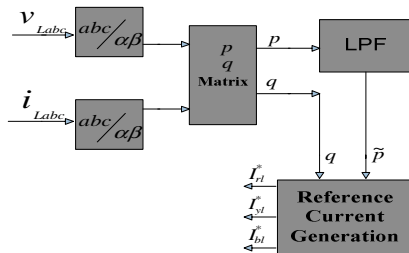


Fig.3 Block diagram for instantaneous reactive power method

### C. DC Link Voltage PI Controller Method

In this method magnitude of the mains current is determined by the power balance of the mains, the power converter and

the load. The capacitor which is located on the DC bus of VSI is used as energy storage element for regulating voltage and supplying reactive power to the load. In the normal operating condition the power supplied from mains must be equal to the real power demanded by the load. For a lossless active power system no power passes through the power converter. Hence the average voltage of dc capacitor can be maintained at constant value. During power unbalance, the error power is injected by the power converter, which causes voltage fluctuation of the dc link capacitor. From above it is cleared that the real power flow information can be obtained from the average of the dc capacitor voltage. Fig.4 shows the internal structure of the control circuit. The control scheme consists of PI controller and three phase sine wave generator for reference current generation and phase generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a PI controller, which contributes to zero steady error in tracking the reference current signal. The output of the PI controller is considered as peak value of the supply current ( $I_s$ ), which is composed of two components: (1) fundamental active power component of load current and (2) loss component of APF; to maintain the average capacitor voltage to a constant value. Peak value of the current ( $I_s$ ) obtained from the PI controller is multiplied by the unit sine vectors in phase with the respective source voltages to obtain the reference compensating currents. These estimated reference currents ( $I_{rs}^*, I_{ys}^*, I_{bs}^*$ ) and sensed actual currents ( $I_{rs}, I_{ys}, I_{bs}$ ) are compared at a hysteresis band, which gives the error signal for the modulation technique. This error signal decides the operation of the converter switches. In this current control circuit configuration, the source/supply currents ( $I_{sryb}$ ) are made to follow the sinusoidal reference current ( $I_{sryb}^*$ ) within a fixed hysteretic band. The width of hysteresis window determines the source current pattern, its harmonic spectrum and the switching frequency of the devices.

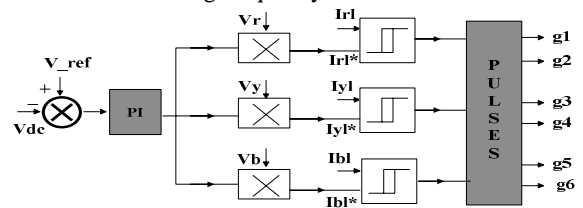


Fig.4 Block diagram for DC Link Voltage Controller Method

## IV. SIMULATION RESULTS AND DISCUSSIONS

This section presents the Matlab based simulation results of above discussed control scheme for APF system. The various parameter used for simulation study is given in Table-I. The source voltage applied to system is shown in fig-5.

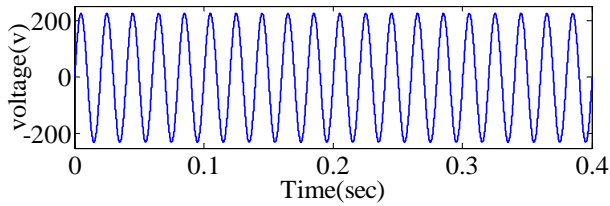


Fig.5 Source voltage

TABLE I  
SIMULATION PARAMETERS

Parameters	Values
$V_S$	415 V rms line, 50Hz
$R_S; L_S$	0.1 $\Omega$ ; 0.15mH
$R_f; L_f$	0.1 $\Omega$ ; 0.6mH
Load	Diode rectifier shunted with R=10 $\Omega$
Reference DC Link $U_{dc}$	350V

A. AC Current Analysis

Figure 6, 7 and 8 shows the simulation result obtained for source current ( $I_s$ ), load current ( $I_L$ ) and filter compensating current ( $I_f$ ) for the synchronous, IRPT and PI controller algorithms respectively. The SAPF is switched to the system at 0.1 sec. The responses before and after switching can be easily distinguished from the waveform and THD values given in the table II .

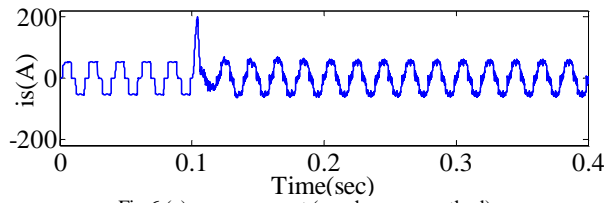


Fig.6 (a) source current (synchronous method)

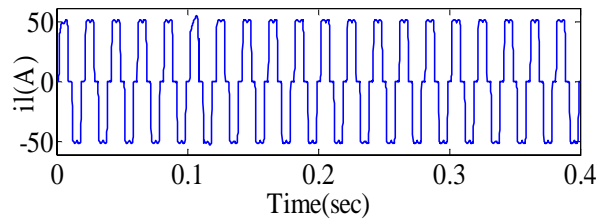


Fig.6 (b) load current (synchronous method)

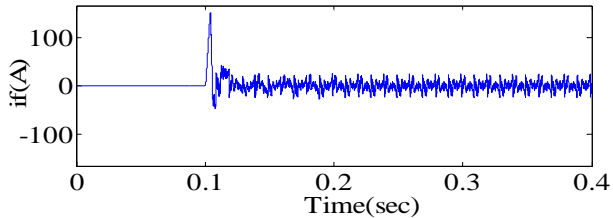


Fig.6 (c) filter compensating current (synchronous method)

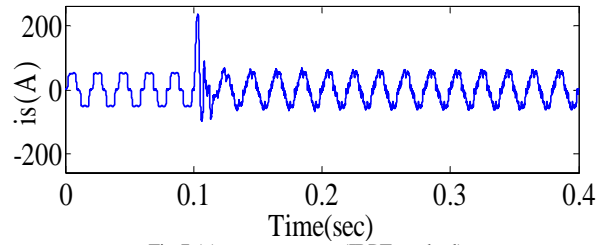


Fig.7 (a) source current (IRPT method)

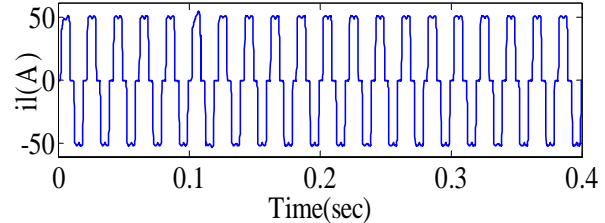


Fig.7 (b) load current (IRPT method)

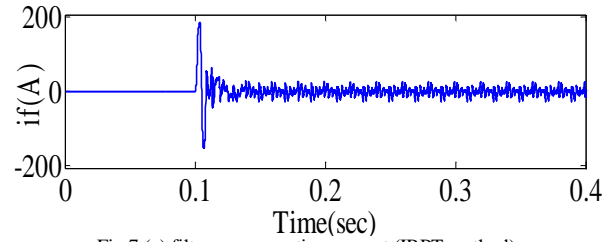


Fig.7 (c) filter compensating current (IRPT method)

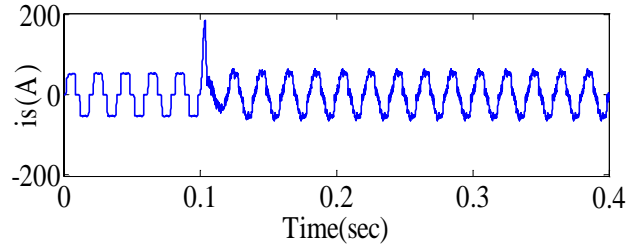


Fig.8 (a) source current (PI controller algorithm)

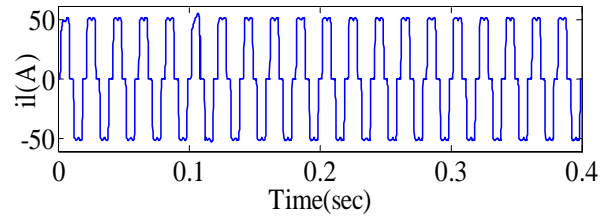


Fig.8 (b) load current (PI controller algorithm)

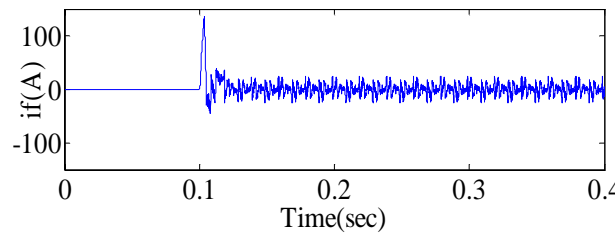


Fig.8 (c) filter compensating current (PI controller algorithm)

The simulation results obtained are summarized through Table II which presents the comparative analysis based on THD for ac currents for the discussed control schemes.

**B. DC Voltage Analysis**

Fig.9, 10 and Fig.11 depicts the dc-link response of the three methods. Table III shows magnitude of 2nd order ripple present in the dc-link voltages and harmonic spectrum of the same.

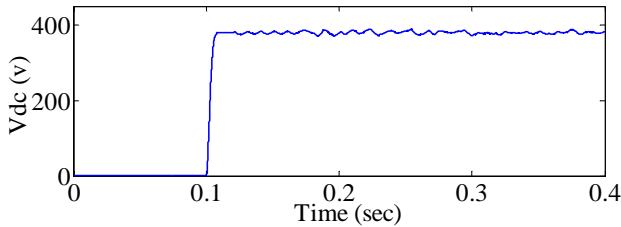


Fig.9 DC link voltage (synchronous method)

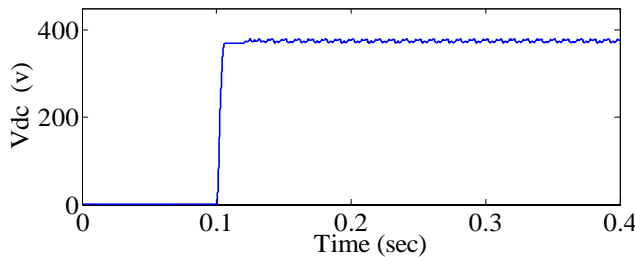


Fig.10 DC link voltage (IRPT method)

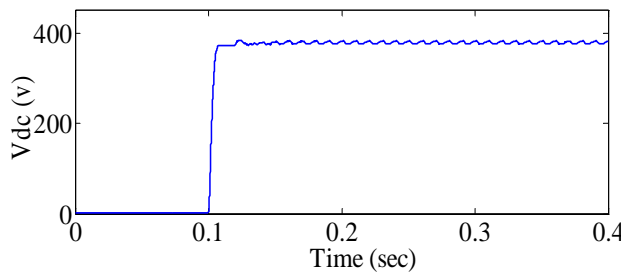


Fig.10 DC link voltage (PI controller algorithm)

**C. Comparative Analysis**

The simulation results obtained are summarized through Table II and Table III which presents the comparative analysis based on THD for ac currents and magnitude of 2<sup>nd</sup> order ripple on dc link voltage for the discussed control schemes.

TABLE II

THD OF SOURCE CURRENT OF THE THREE CONTROL SCHEMES

Source Current THD (%)	Synchronous Detection Method	Instantaneous Reactive Power Method	DC link voltage PI controller Method
Without APF	25.67	25.67	25.67
With APF	18.71	17.27	10.19

TABLE III

ORDER RIPPLE ON DC LINK VOLTAGE

MAGNITUDE OF 2<sup>ND</sup>

Control Schemes	Synchronous Detection Method	Instantaneous Reactive Power Method	DC link voltage PI controller Method
Mag. of 2 <sup>nd</sup> order ripple on dc link	5.7	5.3	2.3

**V. CONCLUSION**

The paper presents a comparative analysis of three control algorithms for shunt APF in order to eliminate harmonics present in the source current due to load unbalances. In exacting, it has been confirmed that, the performance of the PI controller method is superior to preceded methods. It is possible to obtain the acceptable THD values for source currents by using the latter method. The analysis has been assisted by the comparative tables presented in the section IV. Furthermore, the response of dc link voltage by PI controller is better than Synchronous and IRPT methods. The constant dc-link voltage enhances the life of capacitor shunted across APF, so use of PI controller is more reliable. The three algorithms has been simulated to demonstrate the feasibility and effectiveness of the study using MATLAB-SIMULINK.

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