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Comparative Analysis of Types of Shunt Hybrid Power Filter Using Instantaneous Power Theory

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ABSTRACT: The use of nonlinear load led to the injection of harmonics into the power system. In this paper, the performance of two topologies of shunt hybrid power filters for compensating voltage and current harmonics in the distributed power generation (DPG) system has been compared. The control algorithm used in this paper is the p-q theory for the harmonics compensation. The performance of these topologies are verified through MATLAB/Simulink for RL load. The THD of the power system is reduced to minimum tolerance level (< 5%) by the use of both hybrid filters. The THD of the power system is reduced from 30.26% to 5.05% and 4.57 % with the use of hybrid filter with parallel connected active and passive filters and with series connected active and passive filter respectively.

KEYWORDS: Shunt hybrid power filter, Instantaneous power theory, harmonics, THD

I. INTRODUCTION

A good power quality is an important factor for the reliable operation of electrical loads. In recent years, high penetration of nonlinear loads such as compact fluorescent lamps, light-emitting diode lamps and switching mode power suppliers give rise to serious challenges in power quality for distribution systems. Harmonic distortion produced by nonlinear loads causes several problems such as increased power losses in customer equipment, power transformers and power lines, flicker, shorter life of organic insulation etc. The installation of DPG to the distribution system may have a significant impact on power quality. This impact may be positive or negative. It depends on the distribution system and DPG unit characteristics. Positive impacts includes improved reliability, voltage support, reduction of transmission and distribution losses. However, in some cases inverter-based DPG units can increase the current and voltage distortions in the system to which they are connected. Between the different technical options available to power quality improving active power filters (APF) have proved to be an important alternative to compensate for current and voltage disturbances in power distribution systems. In recent years active power filters have been widely investigated for the compensation of harmonic currents.

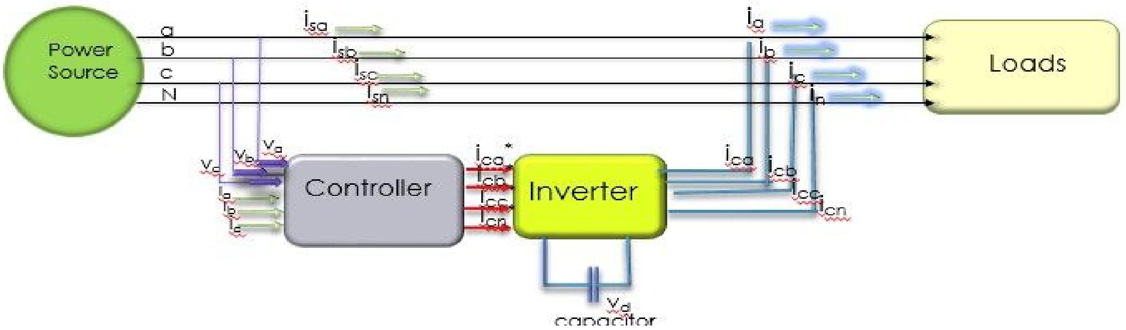


Fig 1: Block diagram of shunt connected compensation system

The shunt active filter for a single-phase DPG system is considered in [2]. However, in many cases installation of pure active filters is not cost effective solution because their ratings are close to load. The hybrid power filters (HPF) seem to be more attractive solution for current and voltage disturbance mitigation

II. SYSTEM CONFIGURATION

The two topologies of HPF comprising of a series combination of active and passive filters and a parallel combination of active and passive filters are shown in the fig. 2 and 3 respectively, connected to the power system feeding the non-linear load. The active filter in both topologies is a voltage source inverter (VSI) with a DC-link capacitance (C_{dc}) at the DC side and a filter inductor (L_c) to attenuate the ripple of the converter current caused by the switching of the converter[8]. Two single tuned low pass filter tuned to 7thharmonics are used with the activefilter.

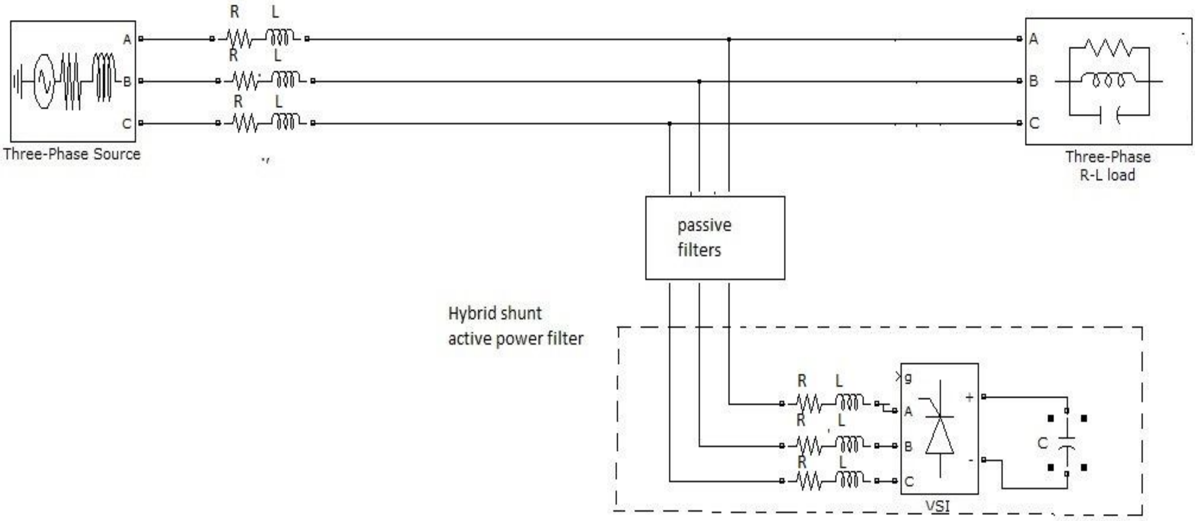


Fig 2: Schematic diagram for a hybrid active power filter with series combination of active and passive filters

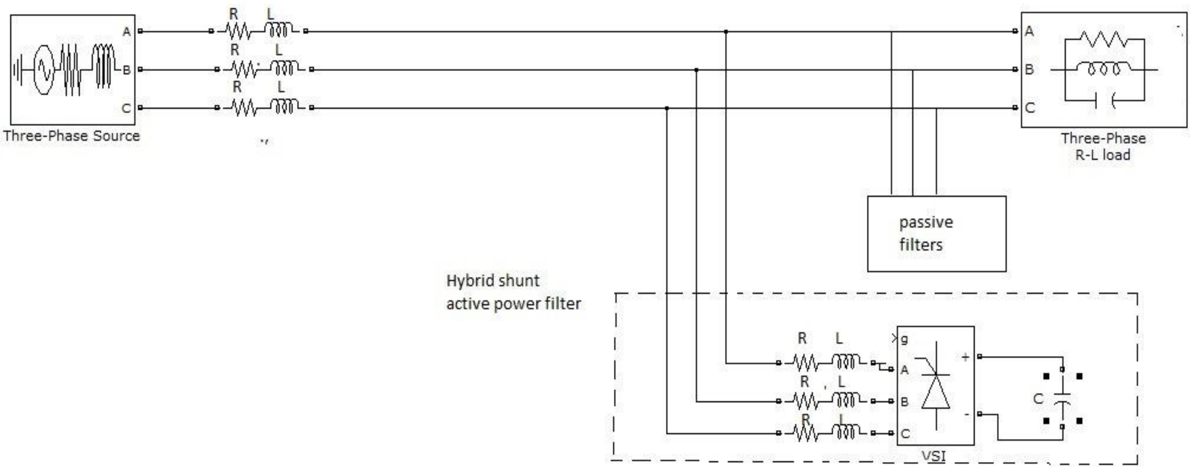


Fig 3: Schematic diagram for a hybrid active power filter with parallel combination of active and passive filters

III. CONTROL STRATEGY

The control strategy proposed here aims at making the compensated line current to be sinusoidal and balanced. Therefore the objectives include a sinusoidal reference current calculation and a current control technique for generating switching pulses to the VSI for a sinusoidal and a balanced line current.The control strategy used here is based on the p-q theory introduced by Akagi [3] and expanded to three-phase four-wire systems by Aredes. It applies an algebraic transformation (Clarke transform) of the three-phase system voltages and load currents in the a-b-c coordinates to the α-β-0 coordinates. After the transformation,[11] the p-q theory components are achieved by the expressions (3)-(4), where p is the instantaneous real power and q is the instantaneous imaginary power.

The instantaneous power p-q is based on time domain transformation from a,b,c phases to three orthogonal axes i.e. α-β-0 transformation. This can be applied to three-phase system with or without neutral. The p-q theory uses α-β-0 or Clarke transformation given by eq. (1) & (2). Ifv$_o$ and i$_o$ are neglected, instantaneous power vectors are given as eq. (3) & (4). The (α-p,q) (β-p,q) components can be defined in eq. (5).

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} (1)$$

$$\begin{bmatrix} I_0 \\ I_\alpha \\ \boldsymbol{I_\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} (2)$$

$$p = V_\alpha I_\alpha + V_{\boldsymbol{\beta}} I_{\boldsymbol{\beta}} = \tilde{p} + \bar{p} \qquad (3)$$

$$q = V_\beta I_\alpha - V_\alpha I_{\boldsymbol{\beta}} = \tilde{q} + \bar{q} \qquad (4)$$

$$\begin{bmatrix} I_{C\alpha} \\ I_{C\beta} \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P_c^* \\ Q_c^* \end{bmatrix} (5)$$

$$\begin{bmatrix} I_{ca}^* \\ I_{cb}^* \\ I_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{c0}^* \\ I_{ca}^* \\ I_{cb}^* \end{bmatrix} (6)$$

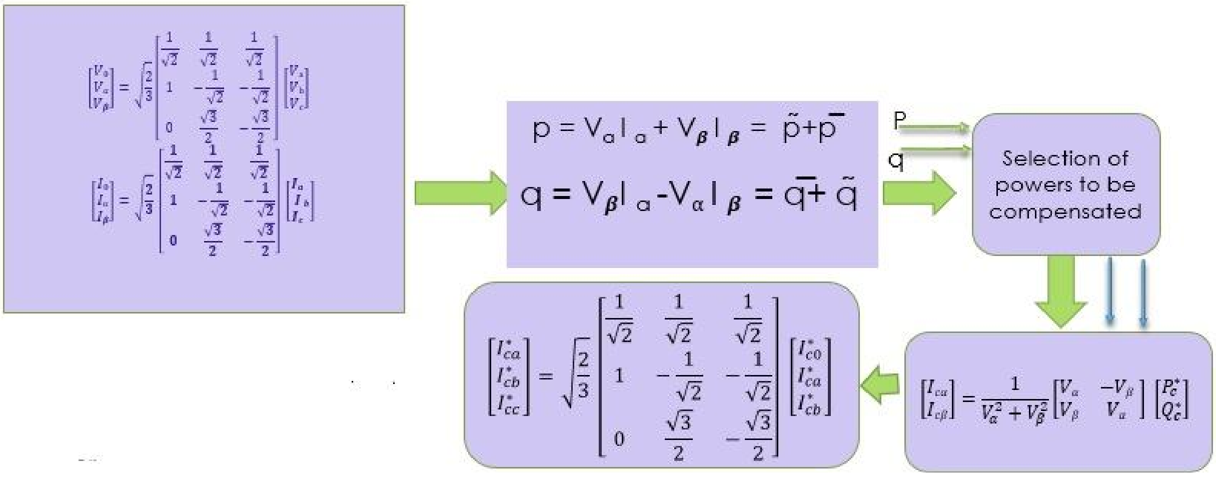


Fig 4: Block diagram of calculation of reference signal from p-q theory

The p and q components of voltage, current, active power can be separated by using above equations, which further decides the compensation methodology to be applied to a particular system. The p-q theory has selecting the component independently. This can be understood clearly from the block diagram shown in fig. 4. The α, β components of voltage and current are used for calculating instantaneous real and reactive power. Among this the harmonic real power component and the entire reactive power are used for the compensation current calculation. This compensation current is injected to the power system to nullify the harmonic components in the system.

A. *Passive Filter Design*

At the harmonic frequency n , the filter impedance

$$X_F = X_{FL;} + X_{FC} = n\omega L + \frac{1}{n\omega C} \quad (7)$$

Where X_{FL} and X_{FC} are filter impedances due to inductance and capacitance
Therefore the current injected into the line is, neglecting resistance

$$I_i = jX_F I_n / j(X_{F+}X_{t+}x_l) = I_n \left\{ \frac{n\omega L - \frac{1}{n\omega C}}{n(Xt + X\ l + n\omega L - \frac{1}{n\omega C})} \right\} \quad (8)$$

Here all the quantities are referred to the same voltage level

$$\eta = I_l / I_n \ * 10 = \%\ I_l \quad (9)$$

then the required value of the capacitor can be found out for a set limit η[12].
The passive filter used in the topology is tuned for eliminating 7 th harmonics. The passive filter parameters are L= 0.4μF and C= 3.3Mh
.

IV. SIMULATION DIAGRAM AND RESULTS

The two topologies of Hybrid filters are simulated using MATLAB/ SIMULINK. The simulation of p-q theory is carried out for the compensating current calculation of the three-phase voltage source supplying thyristor rectifier with RL load(18 Ω, 10mH) . The p-q theory provides complete analysis of different power components for analysis and compensation. The time-domain calculation allows deciding about the exact instant and amount of compensation to be provided for elimination. The rms value of the fundamental component being 400V. The active filter parameters are L=3.35mH, R=0.4 ohms, DC link capacitance = 40mF , DC link reference voltage $V_{dc.ref}$=800V. The passive filter is tuned for eliminating 7th harmonics and the parameters are L= 0.4μF and C= 3.3mH.

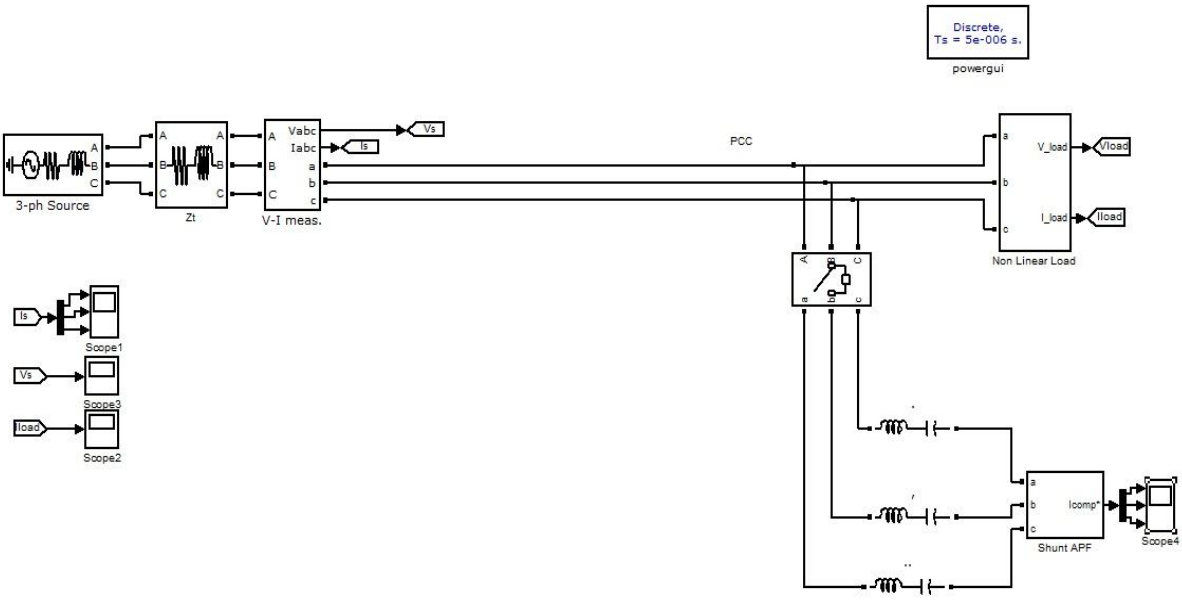


Fig 5: Simulink diagram for a hybrid active power filter with series combination of active and passive filters

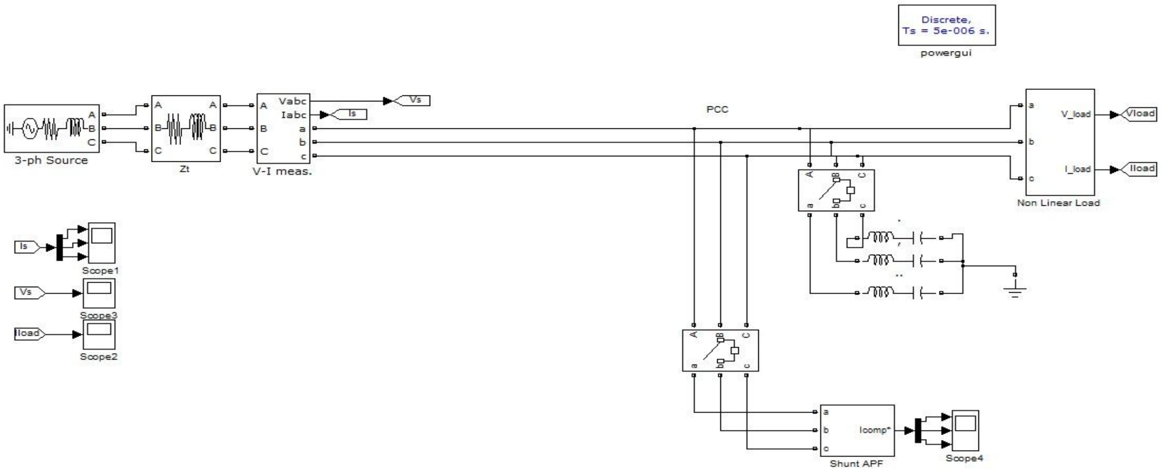


Fig 6: Simulink diagram for a hybrid active power filter with series combination of active and passive filters

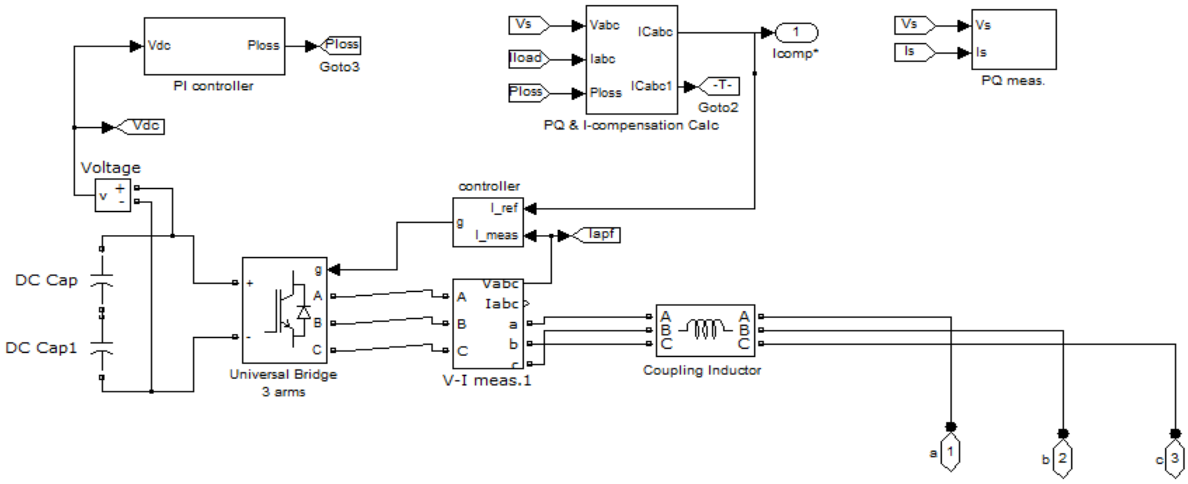


Fig 7: Simulink diagram of the Shunt APF

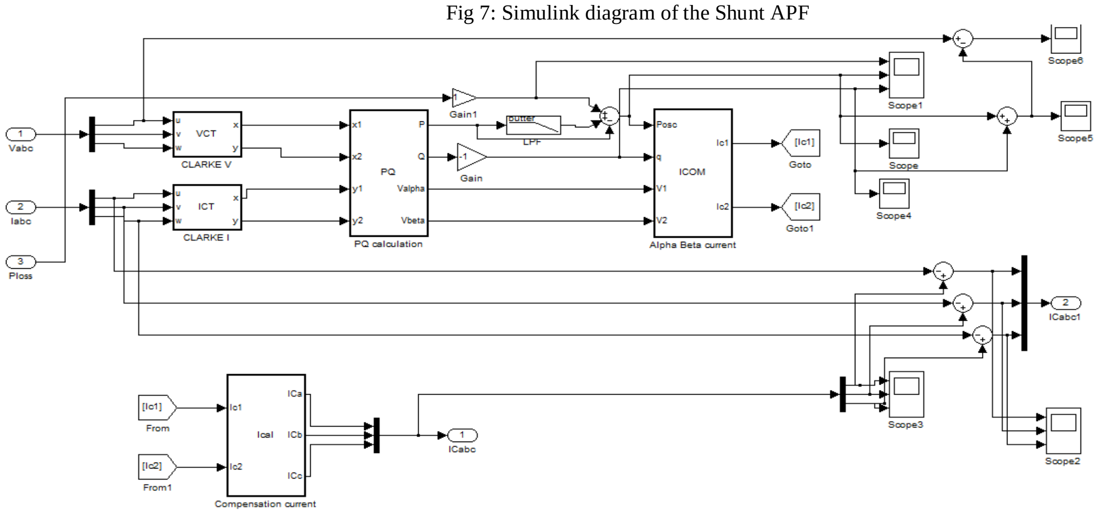
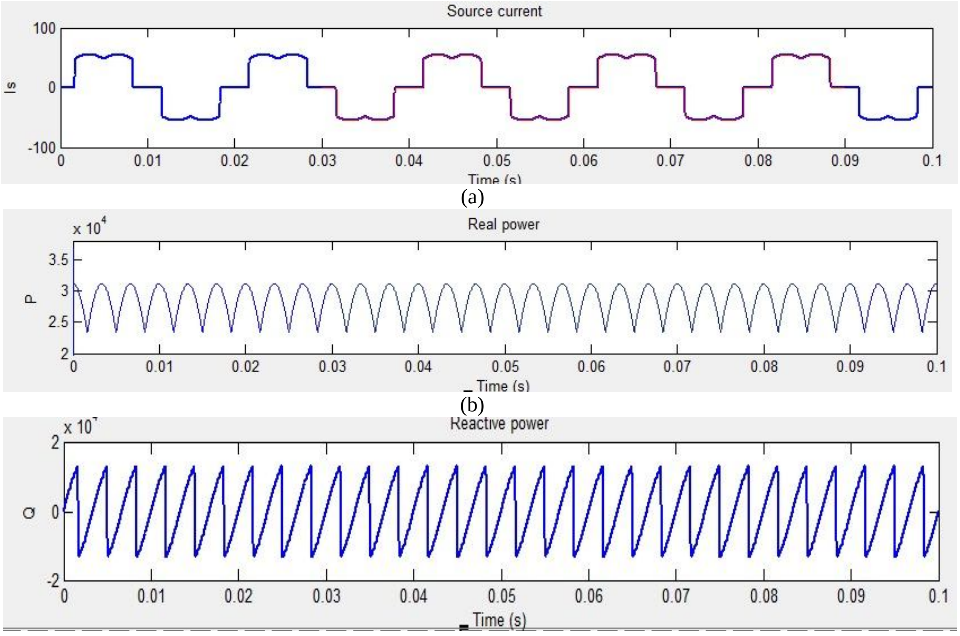


Fig 8: Simulink diagram reference current calculation circuit

Fig. 9, 10, & 11 shows the simulation results of source currents, compensated currents , real power and reactive power of power system without compensation, with series combination of passive and active filters, with parallel combination of passive and active filters respectively.

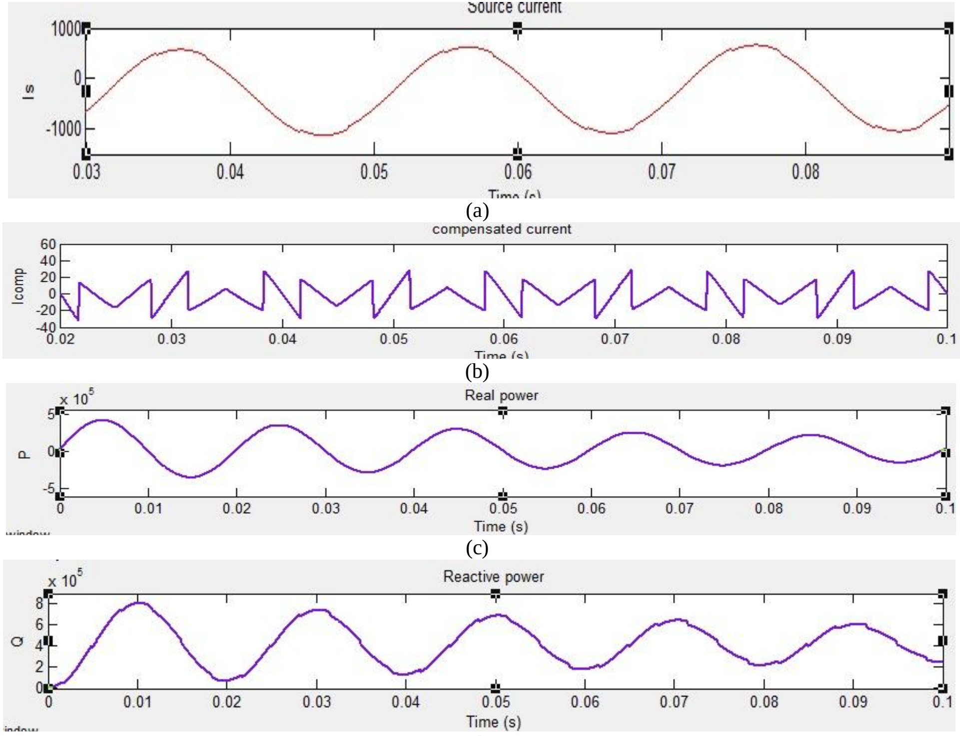


(a)

(b)

(c)

Fig 9: Simulated results of (a)source current, (b) real power and (c)reactive power of the power system without compensation



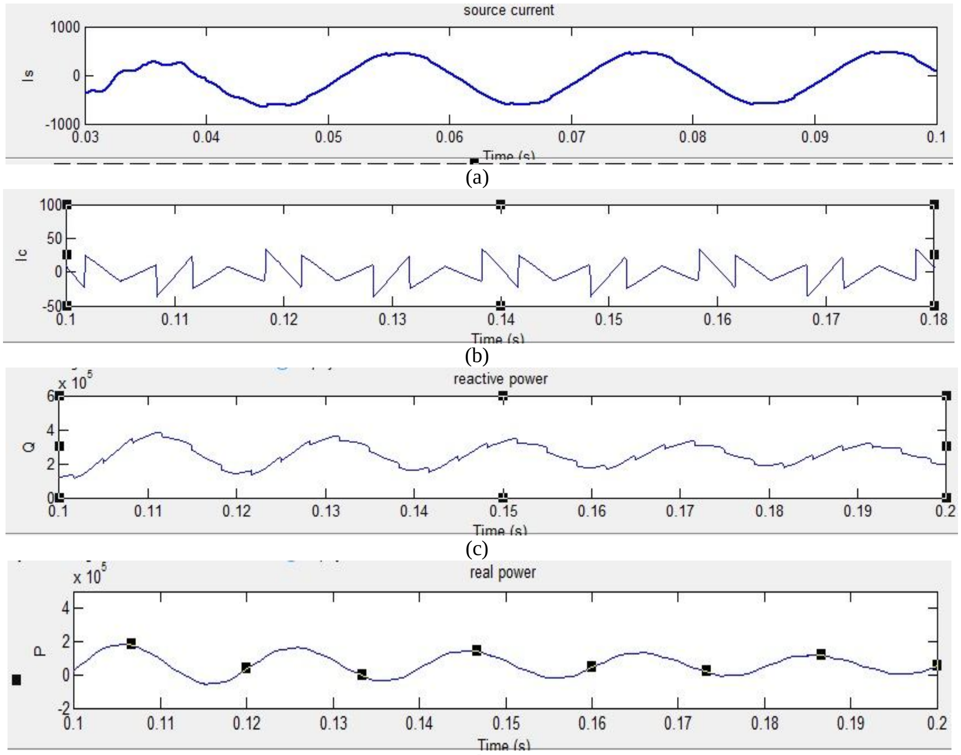
(a)

(b)

(c)

(d)

Fig 10: Simulated waveforms of (a) source current, (b)compensated current, (c)real power and (d) reactive power of the power system with series connected active and passive filter compensation



(a)

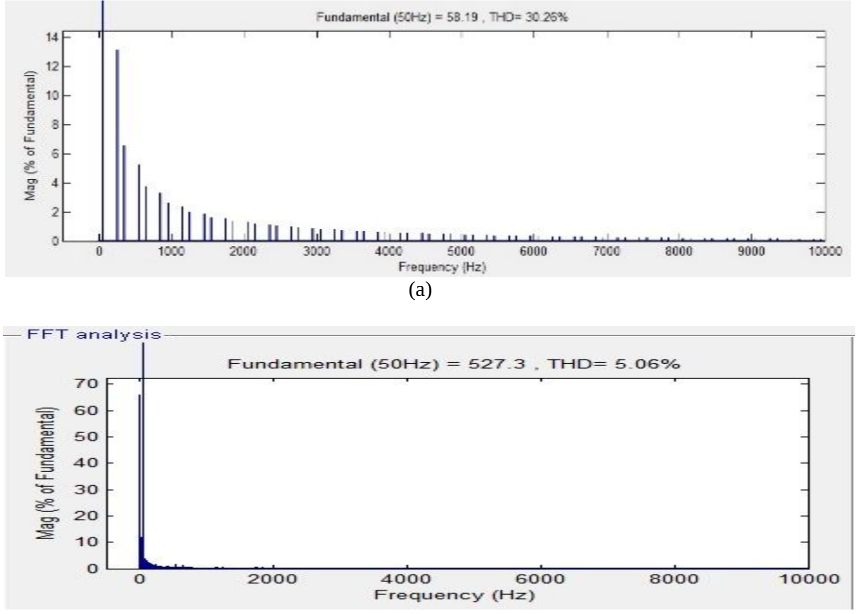
(b)

(c)

(d)

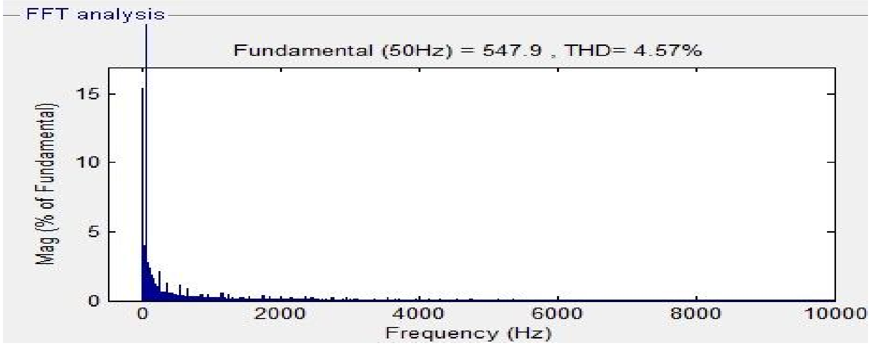
Fig 11: Simulated waveforms of (a)source current, (b)compensated current, (c)real power and (d)reactive power of the power system with parallel connected active and passive filter compensation

The THD of the power system is reduced from 30.26% to 5.05% and 4.57 % with the use of hybrid filter with parallel connected active and passive filters and with series connected active and passive filter respectively. The FFT analysis of source current without compensation, with hybrid filter having parallel connected active and passive filters and series connected active and passive filter are shown below in fig. 12



(a)

(b)



(c)

Fig 12: FFT analysis of source current (a) without compensation , (b)with hybrid filter having parallel connected active and (c)passive filters and series connected active and passive filter

V. CONCLUSION

Two types of hybrid filter topology with a series and parallel combination of active and passive filters are simulated for a three phase system. It replaces an already existing active filter to improve the harmonic compensation, power factor etc. The passive filter performance might have effected due to changes in the system parameters. This topology helps in improving the performance of passive filter and at the same time, the active filter can be used at a lower rating. Use of passive filters in parallel with an active filter reduces the load distortion bandwidth to be compensated by the active filter. The performance of the control strategy used in this paper is simple and effectively compensates the load generated harmonics and nullifies the effect of the source voltage harmonics in the line. It reshape the distorted waves to practically sinusoidal waves. The FFT analysis is done and THD of the power system is found to be reduced from 30.26% to 5.05% and 4.57 % with the use of hybrid filter with parallel connected active and passive filters and with series connected active and passive filter respectively. In the future this can be interfaced with the renewable energy sources so that it will work as compensator as well as inverter.

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