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# Harmonic Mitigation Using Inverter Based Hybrid Shunt Active Power Filter

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## Abstract

With the rapid developments and use of non linear loads, the controlling over the harmonic current to get and maintain power quality is becoming more important. Active power filters has been used to compensate the harmonic pollution in our power system. This paper presents a efficient model to compensate the current harmonics using the inverter based Shunt Active Power Filter, Passive Power Filter, and the combination of both. Synchronous Reference Frame Theory (SRF) with phase lock loop (PLL) also called instantaneous current component based compensation is developed by sensing the load current contains harmonics, which is required for harmonic and reactive power compensation due to non linear loads. In this paper, shunt active power filter using inverter can be seen as an ideal current source and injects the compensating current the system, to cancel out the line current harmonics. The proposed system is developed and simulated using MATLAB/SIMULINK power system toolbox. Simulation results are shown and comparison between passive, active and hybrid filter topology is given.

***Keywords--:*** Hysteresis Current controller, Hybrid Filter, MATLAB/SIMULINK, PI controller, Shunt active filter, Total Harmonic Distortion, Synchronous reference frame (SRF) Controller, Voltage source inverter.

## Introduction

The growing use of electronic equipment produces a large amount of harmonics in the power distribution systems because of non-sinusoidal currents consumed by non-linear loads. Some of the examples for non-linear loads are diode-rectifiers, thyristor converters, adjustable speed drives, furnaces, computer power supplies, uninterruptible power supplies, etc. These devices are much economical, flexible and energy efficient, but they are responsible for degrade power quality by producing harmonic current and consuming excessive reactive power. Which results in many problems such as resonance, excessive neutral currents, and low power factor etc. They have many unwanted negative impact on power system equipment such as additional losses in overhead and underground cables, transformers and rotating electric machines, problem in the operation of the protection systems, over voltage and shunt capacitor, error of measuring instruments, and malfunction of low efficiency of customer sensitive loads. Traditionally passive filters have been used for mitigation of distortion due to harmonic current in industrial power systems. They did not become popular because they have many drawbacks such as resonance problem, performance depend on the system impedance, absorption of harmonics current of nonlinear load, which could lead to further harmonic propagation through the power system. [1] To overcome the problems associated with the passive filter active power filters were introduced. They inject harmonic voltage or current with appropriate magnitudes and phase angle into the system and cancel harmonics of nonlinear loads. But it has also some drawbacks like high initial cost and high power losses due to which it limits there wide application, especially with high power rating system. [2].

To minimize these limitations, hybrid power filter have been introduced and implemented in practical system applications [3]-[7]. Shunt hybrid filter is consists of an active filter which is connected with the passive filter and with a three phase PWM inverter. This filter effectively mitigates the problem of a passive and active filter. It provides cost effective harmonic compensation, particularly for high power nonlinear load. In 1979, FBD (Fryze-Buchholz-Dpenbrock) method is used in time domain and real time for compensating current harmonics.[8] In 1984, H.Akagi [9] introduced instantaneous active and reactive power theory method that is quite efficient for balanced three-phase loads, being later worked by Watanabe and Aredes for three-phase four wires power systems[9], zero-sequence currents was later proposed by F.Z.Peng [10]. In 1995, Bhattacharya proposed the calculation of the d-q components of the instantaneous three phase currents and this method creates a synchronous reference frame concept [11].

In this paper SRF method is used which consists of abc-dqo transformation and a phase locked loop (PLL) circuit and a hysteresis current controller. It is a simple algorithm and good dynamic responses. The SRF is ability to compensate harmonics and reactive-power component from the distortion load currents. A novel synchronous reference frame controller based hybrid shunt active power filter for the harmonics and reactive power mitigation of the non-linear loads. The PI-controller is used to maintain the capacitance voltage of the inverter constant. The hysteresis current controller compares the reference current with measured load current and generate switching pulses based on error function. The shunt APLC system is validated through extensive simulation and investigated under steady state and transient non-linear loads that is three phase rectifier system.

**Design of shunt APLC system**

The shunt APLC system contains a voltage source inverter, a synchronous reference frame controller also called compensation controller and hysteresis band current controller for switching signal generation as shown in Fig 1.

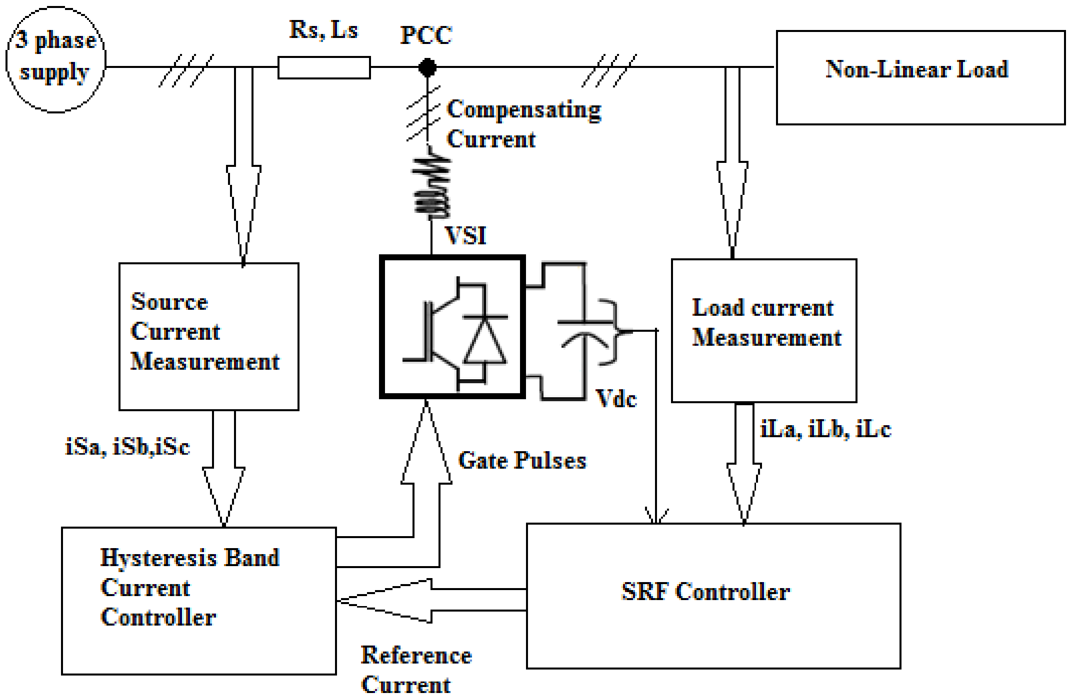


**Fig.1.** Shunt Active Power Line Conditioners system

Three phase supply source connected with the non-linear load. The nonlinear load current should contain fundamental component and harmonic current components. For harmonic compensation, the active filter must provide the compensation current $i_c(t) = i_L(t) - i_s(t)$. At that time, source current will be in phase with the utility voltage and become sinusoidal.

## PROPOSED CONTROL Strategy

The proposed control system consists of reference current control strategy using SRF method

### *SRF Control strategy:*

The synchronous reference frame theory is developed in time domain based reference current generation techniques. The SRF is performing the operation in steady-state or transient state as well as for generic voltage and current; it's capable of controlling the active power filters in real-time system. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The block diagram of the synchronous reference frame controller is shown in Fig 2.

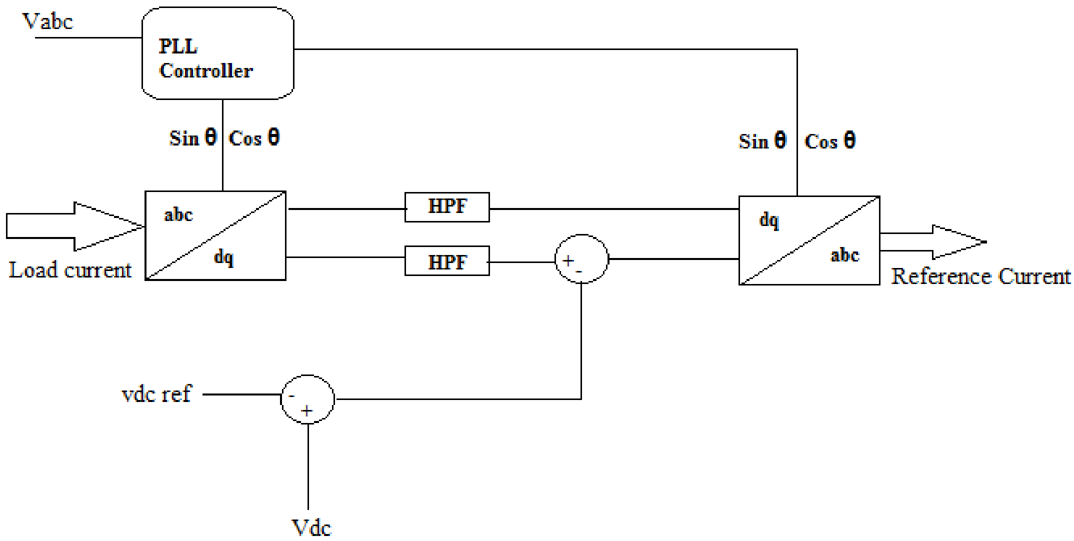


**Fig.2.** Synchronous reference frame controller

Basic structure of SRF methods consists of direct (d-q) and inverse $(d-q)^{-1}$ park transformations, which allow the evaluation of a specific harmonic component of the input signals. The reference frame transformation is formulated from a three-phase $a-b-c$ stationery system to the two phase direct axis *(d)* – quadratic axis *(q)* rotating coordinate system. In a-b-c stationary axes are fixed on the same plane and separated from each other by $120^0$. These three phase space vectors stationary coordinates are easily transformed into two axis d-q rotating reference frame. This proposed algorithm derivate from a three-phase stationary coordinate load current $i_{la}, i_{lb}, i_{lc}$ are convert to $i_{d-}i_q$ rotating coordinate current, as follows

$$i_d = \frac{2}{3}[i_{la}\sin(\omega t) + i_{lb}\sin\left(\omega t - \frac{2\pi}{3}\right) + i_{lc}\sin(\omega t + \frac{2\pi}{3})] \quad (1)$$

$$i_q = \frac{2}{3}\left[i_{la}\cos(\omega t) + i_{lb}\cos(\omega t - \frac{2\pi}{3}\right) + i_{lc}\cos(\omega t + \frac{2\pi}{3})] \quad (2)$$

The d-q transformation output signals depend on the load currents (fundamental and harmonic frequency components) and the performance of the phase locked loop. The PLL circuit of rotation speed (rad/sec) of the rotating reference frame ωt set as fundamental frequency component. The PLL circuit is providing $sin\Theta$ and $cos\Theta$ for synchronization. The id-iq current passed through low pass filter (LPF) for filtered the harmonic components and allows only the fundamental frequency components. The LPF design is based on Butterworth method and the filter order is 2. The band edge frequency is selected the fundamental of 50 Hz for eliminate the higher order harmonic components. Proportional Integral (PI) controller is used to eliminate the steady state error of the DC-component of the inverter and maintains the dc-side capacitor voltage constant. The dc capacitor voltage is sensed and compared with reference voltage for calculate the error voltage. These error voltage involved the P-I gain (KP=0.1 and KI=1) for regulate the capacitance voltage in the dynamic conditions. In accordance to the PI controller output is subtracted from the direct axis (d axis) of harmonic component for eliminate the steady state error. The algorithm is further developed to the desired reference current signals in d-q rotating frame is converted back into $a - b - c$ stationery frame. The inverse transformation from $d - q$ rotating frame to $a - b - c$ stationery frame is achieved by the following equations-

$$i_{sa}^* = i_d \sin(\omega t) + i_q \cos(\omega t) \quad (3)$$

$$i_{sb}^* = i_d \sin(\omega t - \frac{2\pi}{3}) + i_q \cos(\omega t - \frac{2\pi}{3}) \quad (4)$$

$$i_{sc}^* = i_d \sin(\omega t + \frac{2\pi}{3}) + i_q \cos(\omega t + \frac{2\pi}{3}) \quad (5)$$

**Simulation results and analysis**

The simulation results are compared with the control method of Passive Power Filter, Active Power Filter and the combination of Passive Power Filter and Active Power Filter.

**RESULTS FOR PASSIVE POWER FILTER**

The simulation diagram with Passive Power Filter is shown in Fig.3. The diagram consists of the source, non-linear load and Passive Power Filter.

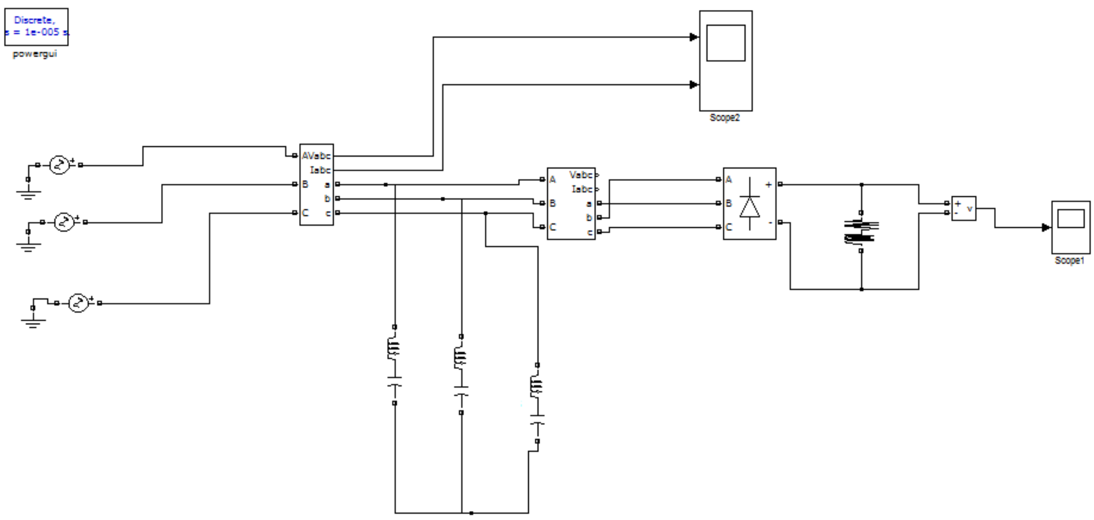


**Fig.3** Simulation diagram with PPF

Fig.4 shows the waveform of supply current before compensation. It consists of fundamental current as well as the harmonic current due to the non-linear load.

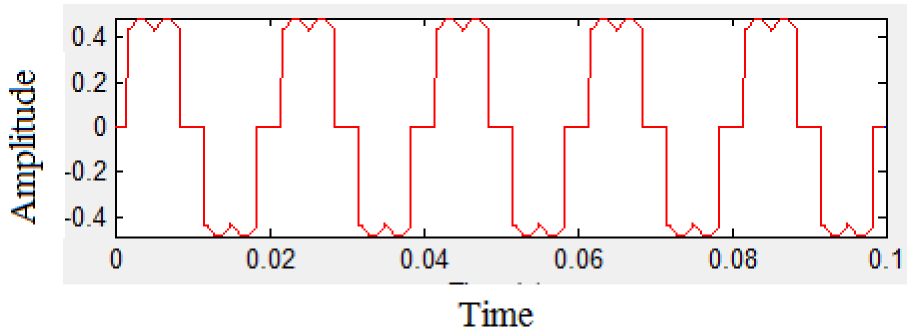


**Fig.4.** Supply current waveform –before compensation

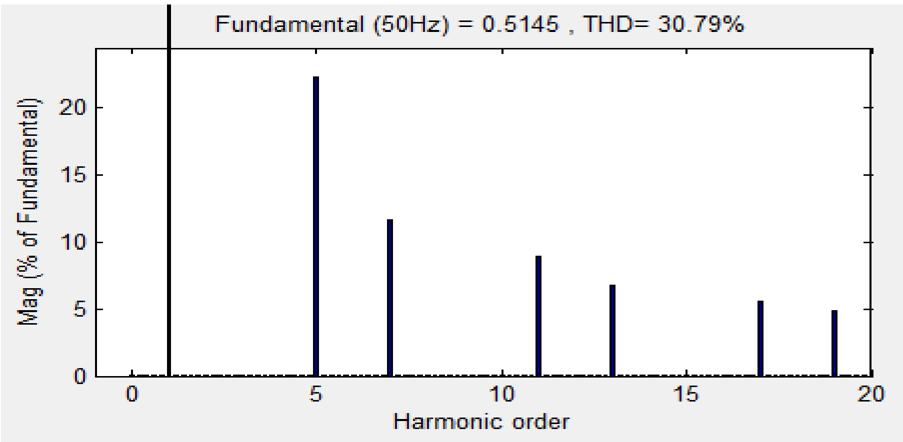


**Fig.5.** Spectrum analysis of supply current-Before compensation

Fig.5 shows the spectrum analysis of supply current before compensation. The Total Harmonic Distortion of the supply current present is 30.79%. The harmonic current present in the supply current is eliminated by using the Passive Power Filter.

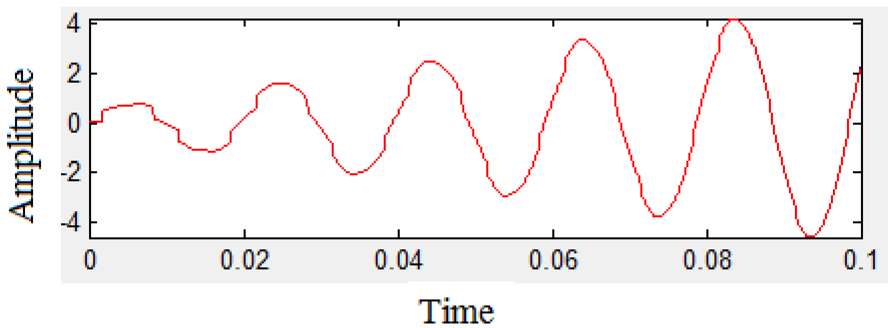


**Fig. 6.** Supply current waveform –after compensation using PPF

Fig.6 shows the waveform of supply current after compensation. It consists of fundamental current only. The harmonic current present in the supply current is eliminated by using the Passive Power Filter.

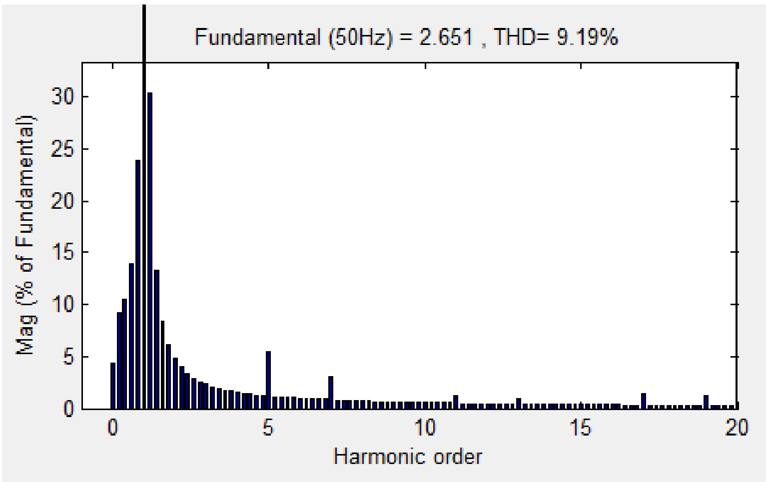


**Fig.7.** Spectrum analysis of supply current-after compensation using PPF

Fig.7 shows the spectrum analysis of supply current after compensation. The Total Harmonic Distortion of the supply current is reduced to 9.19% from 30.79%.

## RESULTS FOR SHUNT ACTIVE POWER FILTER

The simulation diagram with shunt Active Power Filter is shown in Fig.8. The diagram consists of the source, non-linear load, shunt Active Power Filter and its control circuit.

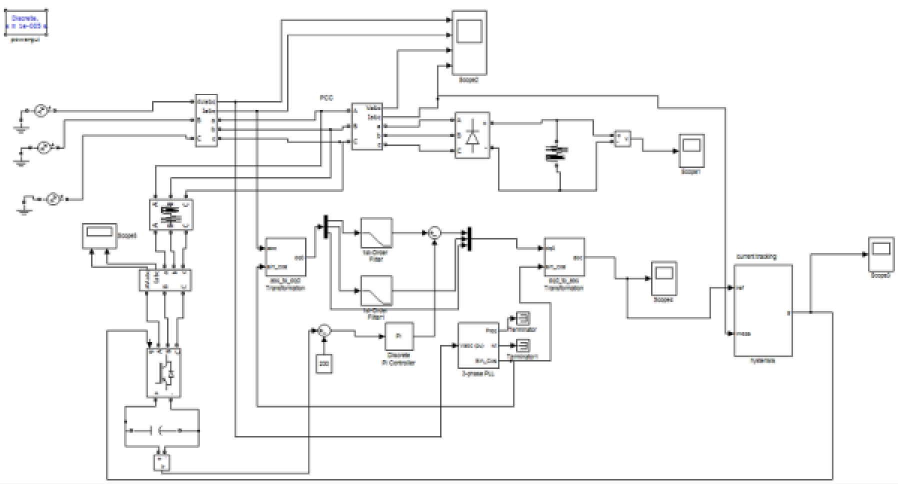

**Fig. 8.** Simulation diagram with SAPF

Fig. 9 shows the waveform of supply current after compensation. It consists of fundamental current only. The harmonic current present in the supply current is eliminated by using the Shunt Active Power Filter. The distortion present in the supply current is reduced when compared to PPF compensation.

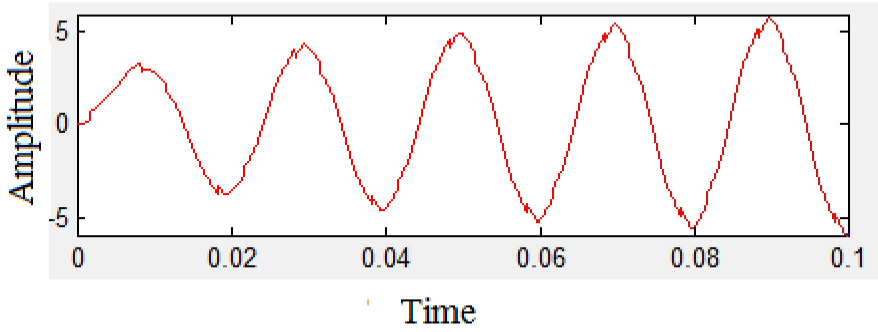


**Fig. 9** Supply current waveform –after compensation using SAPF

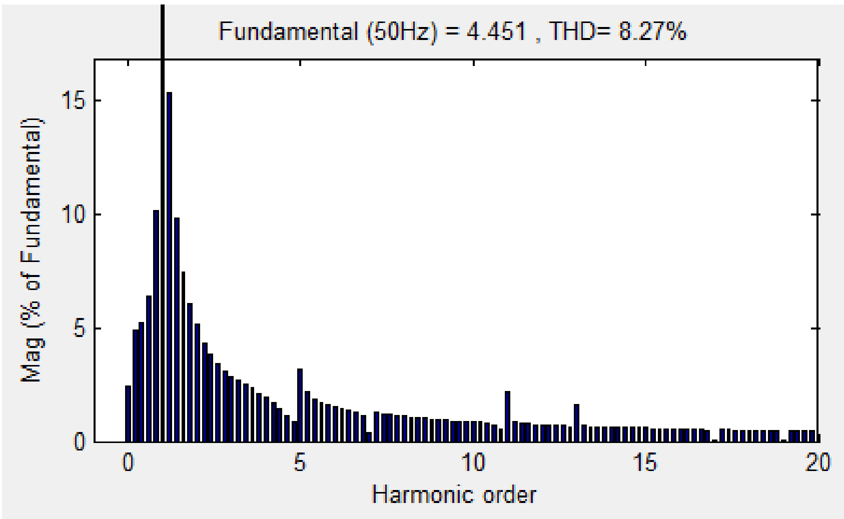


**Fig. 10.** Spectrum analysis of supply current-after compensation using SAPF

Fig. 10 shows the spectrum analysis of supply current after compensation. The Total Harmonic Distortion of the supply current is reduced to 8.27% from 30.79%.

## RESULTS FOR COMBINATION OF SHUNT ACTIVE POWER FILTER AND PASSIVE POWER FILTER

The simulation diagram with shunt Active Power Filter and PPF is shown in Fig.11. The diagram consists of the source, non-linear load, Passive Power Filter, shunt Active Power Filter and its control circuit

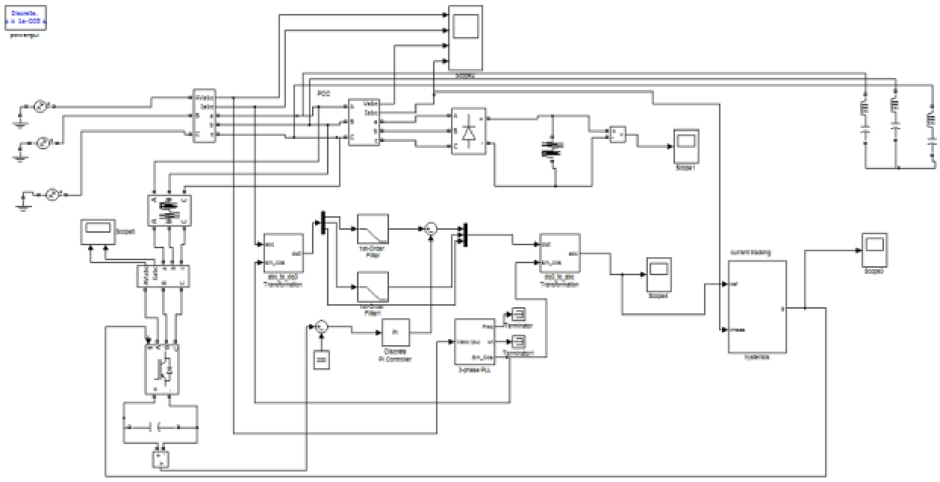

**Fig. 11** simulation diagram with SAPF and PPF

Fig. 12 shows the waveform of supply current after compensation. The waveform is more sinusoidal when compared to other two techniques.

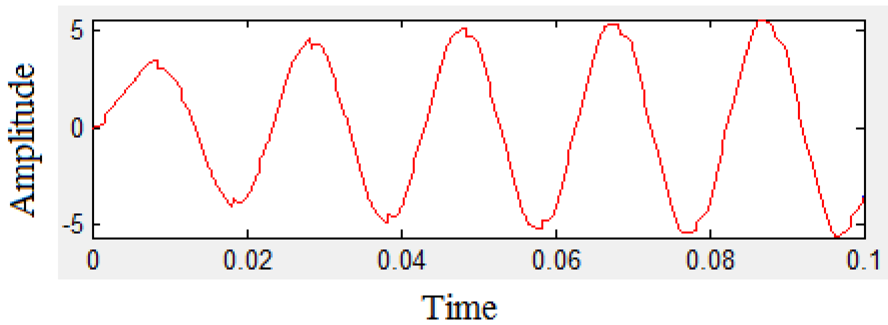


**Fig. 12** Supply current waveform –after compensation using SAPF and PP

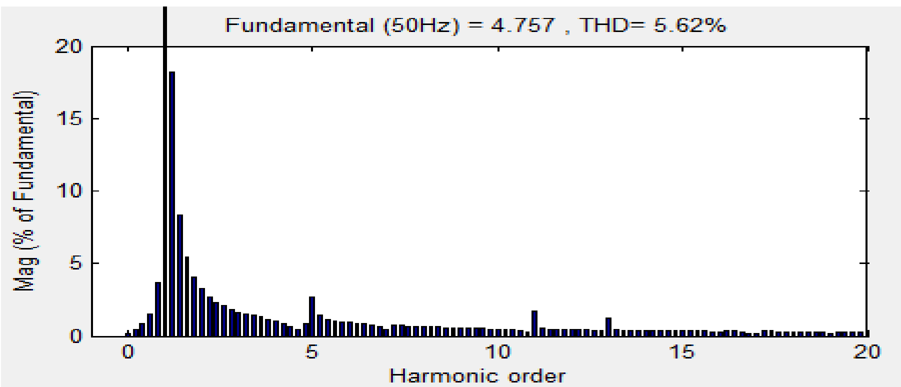


**Fig. 13** Spectrum analysis of supply current-after compensation using SAPF and PPF

Fig. 13 shows the spectrum analysis of supply current after compensation. The Total Harmonic Distortion of the supply current is reduced to 5.62% from 30.79%.

### 4.4 COMPARISON OF RESULTS

The numerical values of the harmonics are listed in table 1. The comparisons are made between before compensation, Shunt Active Filter and the combination of Shunt Active Power Filter and Shunt passive Filter.

Table 1 shows the comparison chart of harmonic order. The % of harmonics can be reduced in the combination of Shunt Active Filter and Passive Power Filter when compared to Passive Power Filter alone.

Table 2 shows the % of THD of PPF, SAPF and the combination of SAPF and PPF. When compared to all methods the % of THD can be reduced to5.62% by the combination of the two methods

**Table 1. Comparison of % of harmonics**

| Harmonic order | % of harmonics | | |
|---|---|---|---|
| | Before Compensation | SAPF | SAPF + PPF |
| 3rd | 4.79 | 0.70 | 0.35 |
| 5th | 18.91 | 3.28 | 0.96 |
| 7th | 14.24 | 2.56 | 1.10 |
| 9th | 1.16 | 0.89 | 0.74 |
| 11th | 1.66 | 1.33 | 0.11 |
| 13th | 7.75 | 1.34 | 0.45 |

**Table 2. Comparison of % of THD**

| SYSTEM | % of THD |
|---|---|
| Before compensation | 30.79 |
| Passive Power Filter | 9.19 |
| Shunt Active Power Filter | 8.27 |
| Combination of Shunt Active power Filter and Passive power Filter | 5.62 |

## Conclusions

The system of Passive power Filter, Shunt Active Power Filter and the combination of Passive power Filter and Shunt Active Power Filter is proposed in this work. When compared to the three methods the combination of Passive power Filter and Shunt Active Power Filter is efficient for harmonic suppression and power factor improvement. By this method the % of THD can be reduced to 5.62.

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