Single Phase Shunt Active Power Filter for Harmonic Mitigation and Power Factor Correction

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Abstract:

used non-linear electrical devices in office equipments, industries and residential home include as power converters, power sources, Uninterruptible Power Supply (UPS) units, and fluorescent lamps. etc, All of these loads inject harmonic currents and reactive power into the power system . This paper is focusing on the application of A Single Phase Shunt Active Power Filter (1Ø SAPF) with Hysteresis Current Control (HCC) in treating the harmonics distortion in the distribution system by determining low Total Harmonic Distortion (THD) value and improving the system's Power Factor (PF). To obtain result for this *paper, the MATLAB / Simulink was used as a simulation tool. The presented system is able to compensate current harmonics, reactive power of non linear loads. The total harmonic distortion is calculated for deferent loads before and after filtering. The achieved results are within the recommended IEEE-519 standard and also the power factor of the system to almost euery.*

***KEY WORDS**: non-linear, hysteresis current control, Single Phase Shunt Active Power Filter, current source, reactive power, Harmonic, MATLAB simulink.*

1.Introduction

The non-linear loads are ever increasing in today's electrical and electronics equipment, because of increased use of power electronic components in them. Power electronic converters have tremendous advantage and beneficial in power conversion efficiency over conventional approaches [1]. But as non-linear loads, these converters draw harmonic and reactive power component of current from ac main supply. For a customer, deterioration in Power Quality (PQ) is a concern because it affects the sensitive loads connected to the grid such as communication equipment, computers and sensitive equipment. Earlier Passive filters were used for harmonic mitigation but they have many demerits such as sizing of the filter which depends upon the harmonic spectre and impedance of the grid, Also any modification in a grid result, results in deviation of designed passive filter. Also, there is an increased risk of resonance between the grid and passive filter frequencies. These problems make the use of passive filters difficult in many cases [2]. These lead to the development of shunt active filter, which takes care of the current harmonics mitigation dynamically. The Active Power Filters (APF) can be easily installed and instantaneously compensate the current harmonics and the power factor [3]. In this paper, hysteresis band current control method is used because implementation of this control is not expensive and the dynamic answer is excellent. It allows a fast current control. Unfortunately, in this control it is not possible to fix the commutation frequency. However, this disadvantage is not ever critical and current controllers based on this method are now standard in most Active Power Filter (APF) control schemes. The technique is simulated by using MATLAB/Simulink software.

Ii. Active Power Filter

Active Power Filters (APFs) that have been explored in shunt, series and combination of shunt and series configurations to compensate for current and voltage based distortions. It will play an important role for better quality solutions. Conventional power quality mitigation equipment is proving to be inadequate for many applications, and this fact has attracted the attention of power engineers to develop dynamic and adjustable solutions to power quality problems. Thus, between the different technical options available to improve power quality, Active Power Filters (APFs) have proved to be an important alternative to minimize the financial impacts of PQ problems [4].

a. Basic Principle of Shunt Active Filter

Single phase shunt active Power filter concept uses power electronics switches to produce harmonic current components which are 180° phase shift to the harmonic current components present in the non-linear loads [4]. Figure 1 shows the diagram of an active filter connected in parallel with the grid, it is most often controlled as a current generator. The structure of a shunt active power filter decomposes into two units, power unit and control unit. The power unit consists of a voltage inverter based on power switches, controlled in priming and in blocking *Gate Turn-Off Thyristor* (GTO) and Insulated Gate Bipolar Transistor (IGBT)...etc. An output filter and of a passive element that works as an energy storage circuit, often it is a capacitor [5].

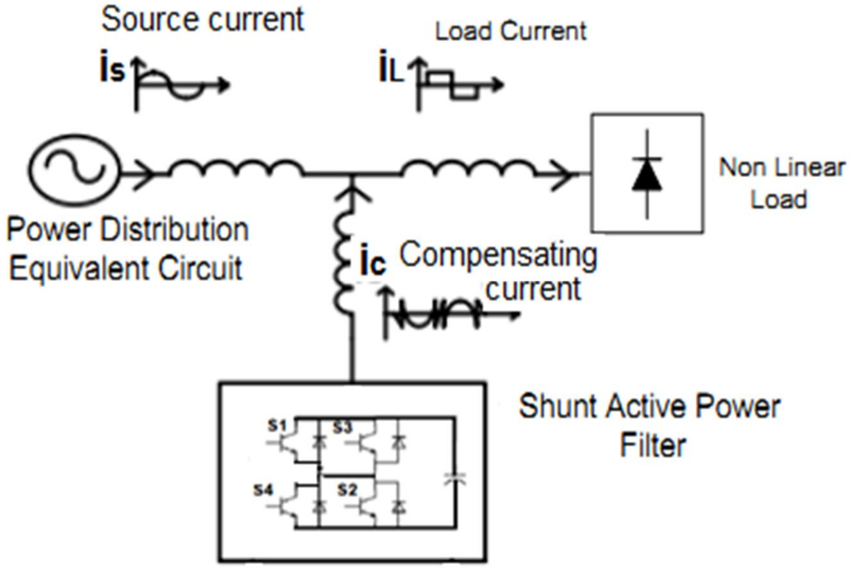


Fig.1 Schematic diagram of Shunt Active Power Filter.

Single phase active power filter is based on injection of harmonic currents into the AC system of the same magnitude but opposite in phase to that of the load harmonic currents. So in effect the harmonic components will be cancelled at the Point of Common Coupling (PCC), to prevent from flowing into the grid. This is achieved by shaping the compensation current waveform (i_c), using the Voltage Source Inverter (VSI) switches. The shape of compensation current is obtained by measuring the load current (i_L) and subtracting it from a sinusoidal reference[6,7]. Figure1 shows the working of a general (1Ø SAPF) to obtain a sinusoidal source current (i_S) using the relationship :

$$i_S = i_L - i_C \tag{1}$$

Suppose the nonlinear load current can be written as the sum of the Fundamental Current Component ($i_{L,C}$) and the Current Harmonics ($i_{L,h}$) according to

Active filter current is expressed as:

$$i_L = \mathrm{i}_{L,C} + \mathrm{i}_{L,h} \tag{2}$$

then the injected compensation current by shunt APF should be

$$i_C = i_{L,h} \tag{3}$$

the resulting source current is

$$i_S = i_L - i_C = \mathrm{i}_{L,C} \tag{4}$$

Equation (4) theoretically shows that with a 1Ø SAPF the supply current harmonics can be compensated completely [5,6].

B. Compensation Technique

The control algorithm computes the reference for the compensation current to be injected by the shunt active filter [5,7]. The choice of the control algorithm therefore decides the accuracy and response time of the filter. The calculation steps involved in the control technique have to be minimal to make the control circuit compact. The control strategy has an objective to guarantee balanced and sinusoidal source current at almost unity power factor. This objective can be easily realized if the active part of the fundamental component of the load current is accurately and instantaneously determined [7, 8].

C. Hysteresis Current Control

The Hysteresis Current Control (HCC) scheme used for the control of shunt active filter is shown in Figure 2. The reference for compensation current to be injected by the active filter is referred to as i_{ref} and the actual current of the active filter is referred to as i_{inj} . The control scheme decides the switching pattern of active filter in such a way to maintain the actual injected current of the filter to remain within a desired Hysteresis Band (HB) as indicated in Figure 2 [6,8]. The switching logic is formulated as follows:

If $i_{inj} < (i_{ref} - HB)$ S_1, S_2 ON & S_3, S_4 OFF.

If $i_{inj} > (i_{ref} + HB)$ S_1, S_2 OFF & S_3, S_4 ON.

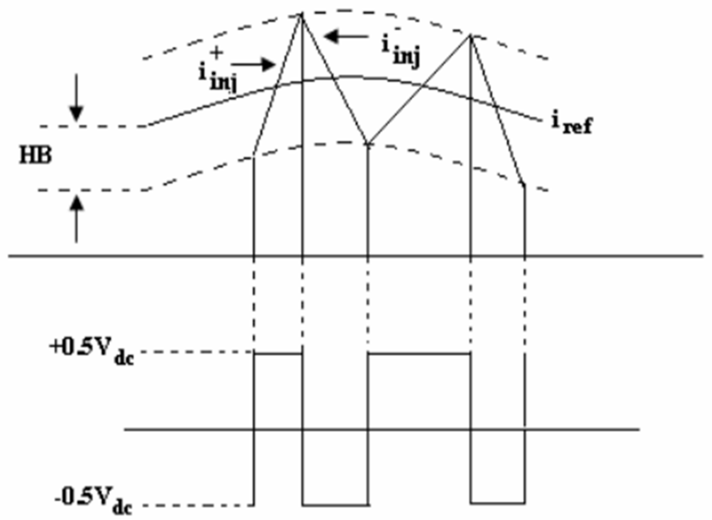


Fig.2 Hysteresis current control.

III. System description & simulation model

System presented in figure1 is used in this paper, the system consists of Single phase power system and single-phase shunt active filter with two different loads. The first load consists of a single-phase diode bridge rectifier with a R-L circuit at the dc side, and the second load is represented by a single-phase diode bridge rectifier with a R-C circuit at the dc side. Figure5 shows the model of proposed method, the parameters that are used in simulation system are listed in Table 1. In order to verify the results, the simulation is done in a **MATLAB/SIMULINK** environment, the results of both cases are presented in the following sections .

Table 1: Value of the simulation parameters.

Parameter	Symbol	Value
Source voltage	V_s	230
System Frequency	f_s	50 Hz
APF Interface inductor	L_f	10 mH
APF/ dc-side capacitance	C_f	1100 µF
Switching frequency	f_{sw}	12.5 KHZ

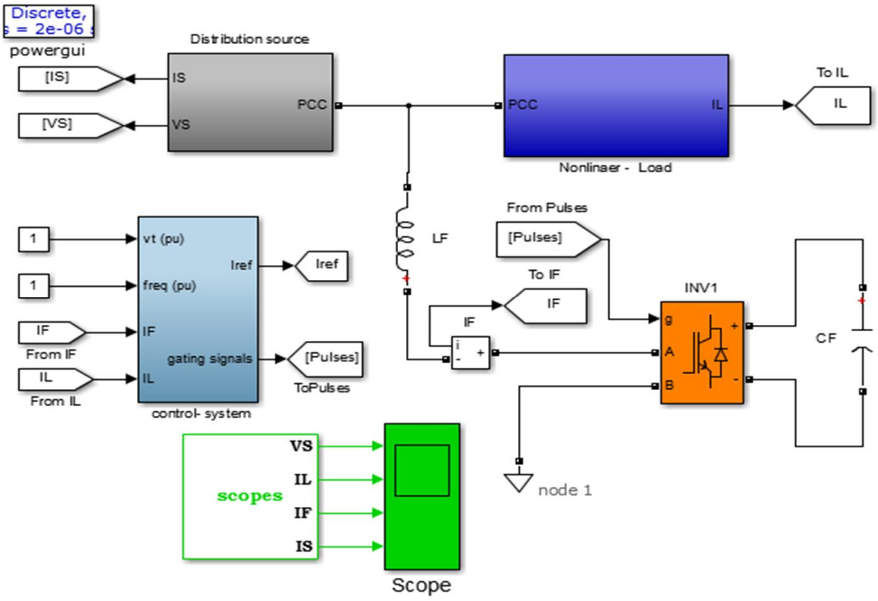
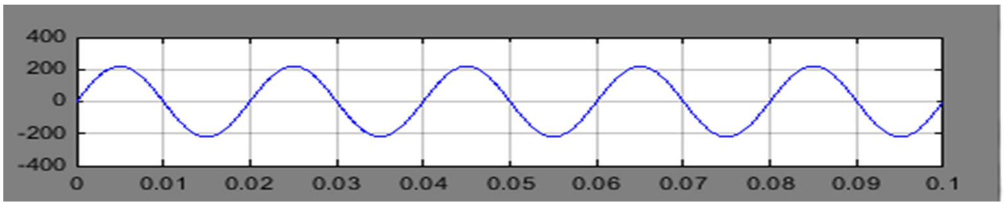


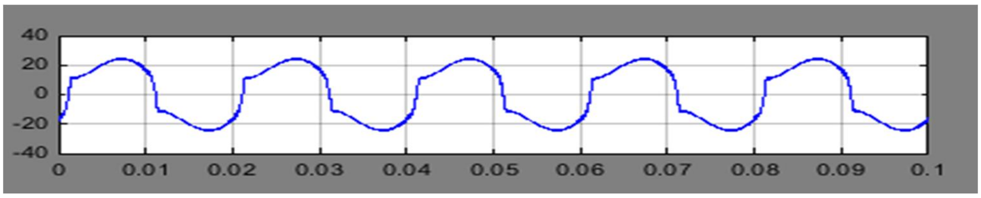
Fig.5 Simulation Model of shunt APF with Hysteresis Current Control..

A. case (I) Single-phase diode bridge rectifier supplying Inductive (R-L) Load.

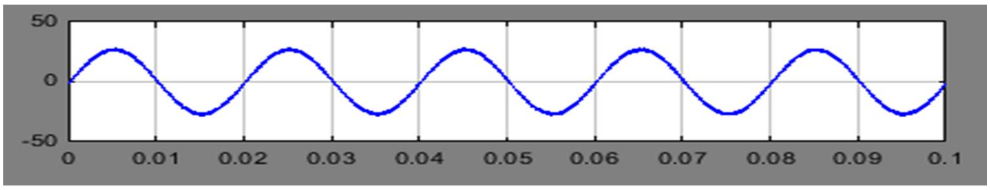
The proposed single-phase shunt active power filter using hysteresis control strategy is simulated in simpower system toolbox in MATLAB software. Here a 50Hz source is connected to the non-linear load which is a full bridge diode rectifier supplying a R-L load, R=7 Ω and L=20 mH . Figure 6 shows the simulation result waveforms before and after compensation, and Figure 7 shows the harmonic frequency analysis . Due to the non-linearity in the load, Table 2 shows the source current is distorted and the THD content is about 22.06%. When the shunt active power filter is connected in between source and load which injects the negative harmonic compensating current into the line and the source current regain its sinusoidal nature , THD content is improved to 3.91% and the Source Voltage & Current is in-Phase with SAPF, the results, power factor is correcting with shunt APF. Figure 8 shows the waveforms before and after compensation.



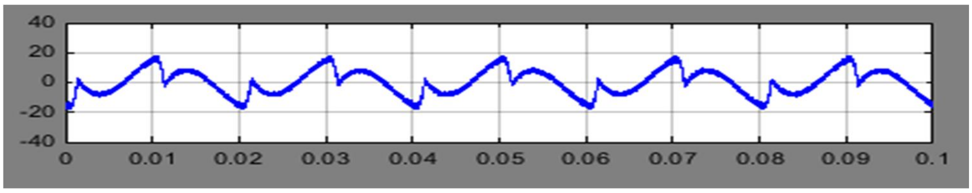
(a) ac supply voltage.



(b) source current before compensation.

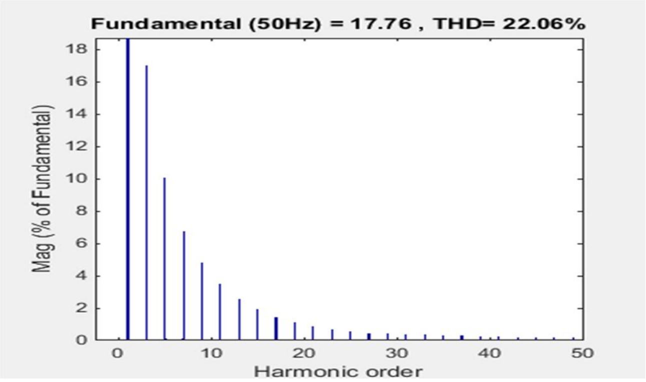


(c) source current after compensation.

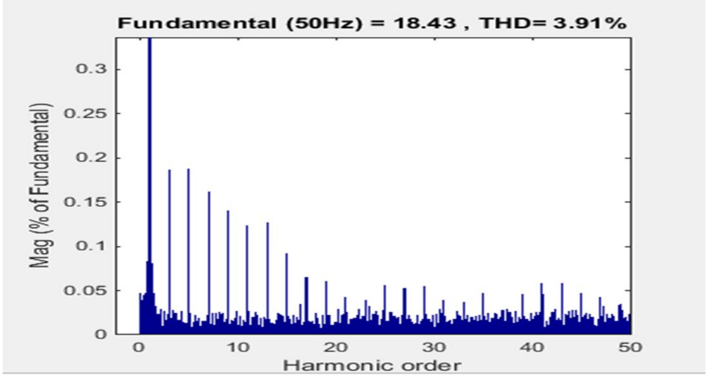


(d) compensating current fed by active filter.

Fig.6 Simulation result waveforms .



(a) FFT analysis of distorted source current.

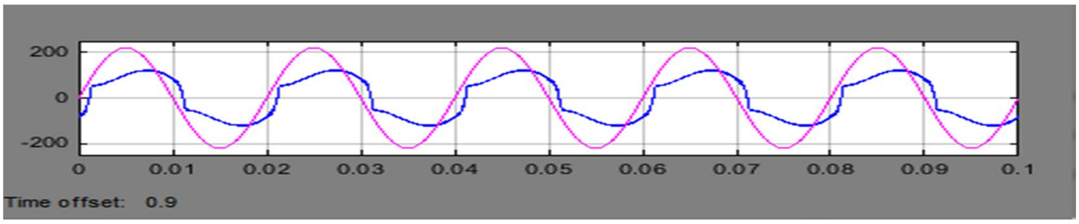


(b) FFT analysis of source current after compensation.

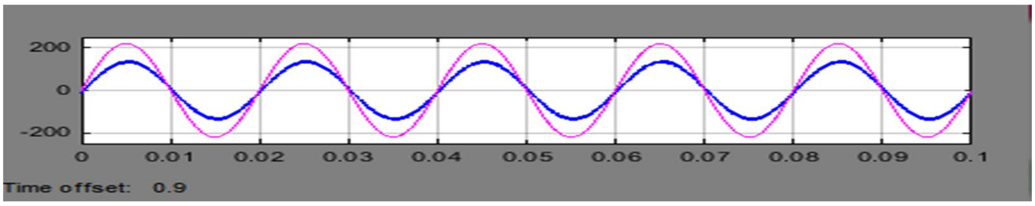
Fig.7 Harmonic spectrum of source current .

Table 2: Performance of HCC technique for 1Ø SAPF.

Condition	**THD (%) for source current(Is)**
Without Filter	22.06
With Filter	3.91



(a) Source Voltage & Current waveforms without shunt APF.

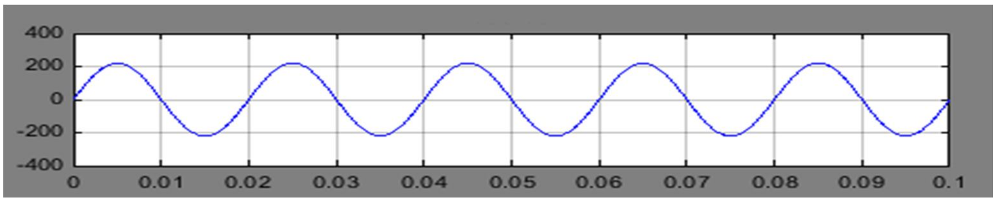


(b) Source Voltage & Current waveforms with shunt APF.

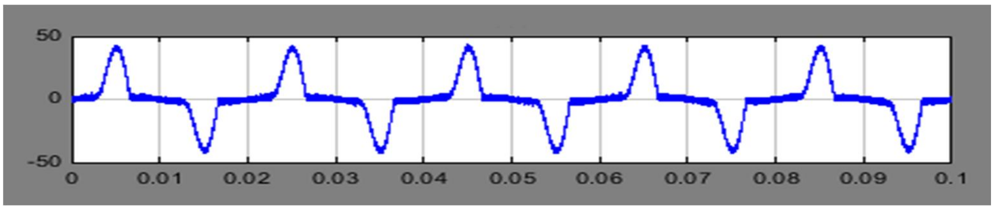
Fig.8 Phase relationship between source voltage and source current.

B. case (II) Single-phase diode bridge rectifier with resistor and Capacitive Voltage Smoothing

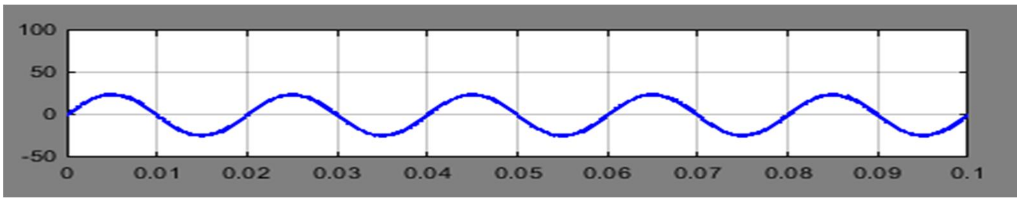
In this case, a single-phase nonlinear load consists of a full bridge diode rectifier with a R-C load, a capacitor in parallel with a resistor, R=20 Ω and C=500 µF. Figure 9 shows the waveforms obtained from simulation results performed with this type of load (source voltage, load current, source current and compensation current). Figure 10 shows the FFT analysis tool of sim-power system toolbox, Table 3 shows the value of the total harmonic distortion without filter is 85.54 %, When the shunt APF is connected THD is reduced to 5.68 %, and the waveform of source current and source voltage is in phase, the power factor is much better than with shunt APF, Figure 11 shows the Source Voltage & Current in In-Phase Condition with and without shunt APF.



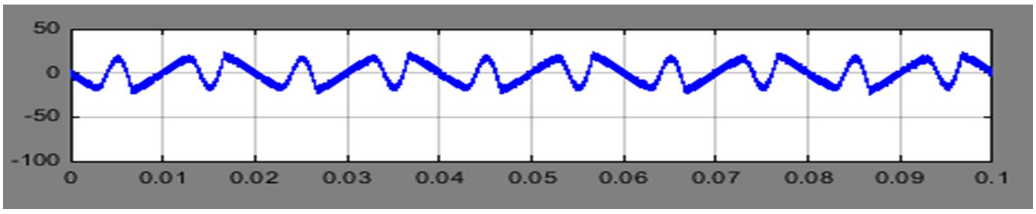
(a) ac supply voltage.



(b) source current before compensation.

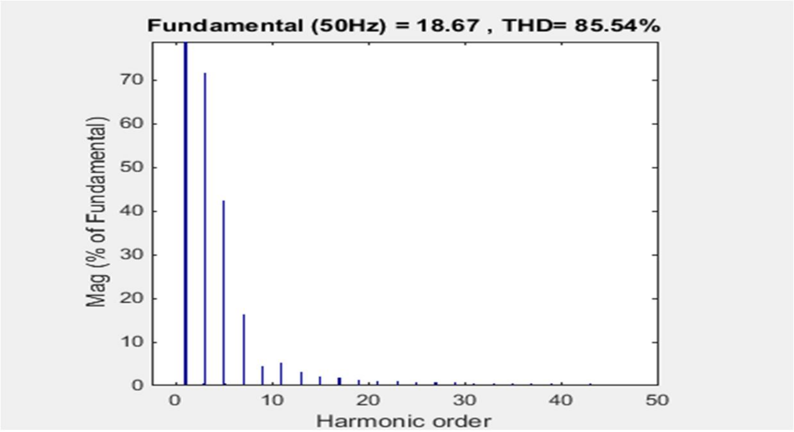


(c) source current after compensation.

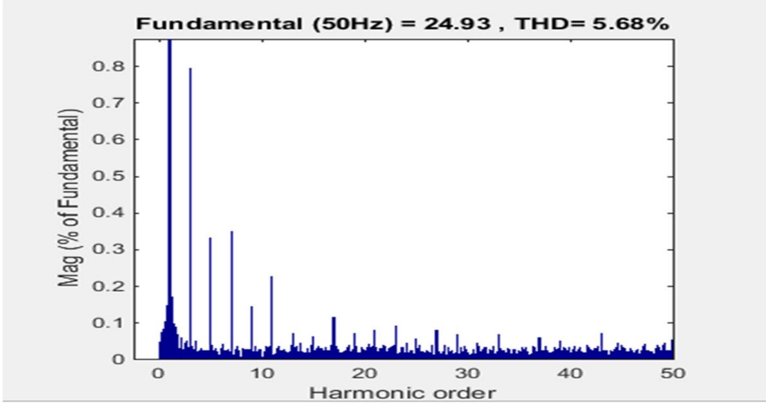


(d) compensating current fed by active filter.

Fig.9 Simulation result waveforms.



(a) FFT analysis of distorted source current.

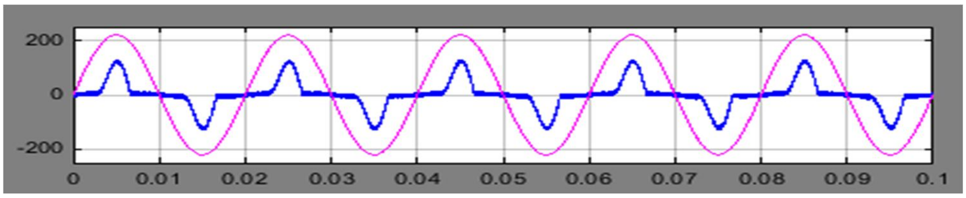


(b) FFT analysis of source current after compensation.

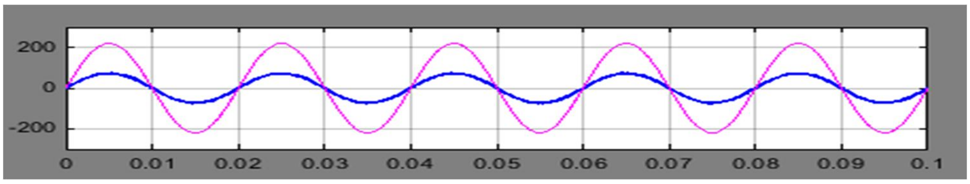
Fig.10 Harmonic spectrum.

Table 3: Performance of HCC technique for 1Ø SAPF.

Condition	**THD (%) for source current(Is)**
Without Filter	85.54
With Filter	5.68



(a) Source Voltage & Current waveforms without shunt APF.



(b) Source Voltage & Current waveforms with shunt APF.

Fig.11 Phase relationship between source voltage and source current.

Conclusions

A single phase shunt active power filter based on Hysteresis Current Controller technique is used in this paper, the shunt active power filter is found effective in injecting harmonic compensating current and thereby reducing the source current THD and improves the power factor of the line. From the simulation results it is clear that in case (I) THD has been reduced from 22.06% to 3.91% after compensation and from 85.54% to 5.68% in case (II).

It is also the source current waveform is in phase with the source voltage and free from harmonic components. In addition, the great advantage of the single-phase shunt active power filter output is verified successfully with the help of MATLAB software and is ability to compensate not only inductive power but also capacitance reactive power, which is generated by receivers and computers in an office equipments, and residential home appliances.

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