Direct Current Control Based Harmonic Compensation

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Abstract - **A Control strategy for single phase shunt active power filter is proposed. Shunt APF is connected in parallel with load. The control strategy is based on Direct Current Control Scheme; so that the current waveform is injected at the point of common coupling by shunt active filter is able to compensate the current harmonics and also the reactive power. The proposed algorithm also regulates the terminal voltage. Simulations have been carried out on MATLAB-simulink platform.**

Index Terms - **Shunt Active Filter, Sinusoidal Pulse Width Modulation, Voltage Source Inverter, Harmonics, Hysteresis Current Controller, Point of Common Coupling.**

I.INTRODUCTION

The proliferation use of power-electronics equipment in recent years has increased the number of non-linear loads which draw harmonic currents from the source can have several drawbacks including low power factor, low efficiency and electromagnetic interference. Power quality is a significant measure of an electrical power system. The word power quality means to retain purely sinusoidal current in phase with a purely sinusoidal voltage. The power generated at the generating station is purely sinusoidal in nature. The quality of electric power is weakening mainly due to current and voltage harmonics [1].

Conventional compensation methods such as passive filter and active filter [8],[12],[16] were engaged to develop the power quality. The passive LC filters are used to improve the power factor and to manage current harmonics. One of the most important disadvantages of passive filters is non variable compensation characteristics. Huge evolution has been made in the field of shunt active power filter (APFs) based on voltage source inverter (VSI) is most familiar one because of its efficiency and it is a really functional device for eliminating harmonic pollution in power systems to respond quickly and work with high control accuracy in current tracking, especially with the introduction of control techniques and topologies to overcome such problems [9].

Various control methods have been applied, such as adaptive signal processing [3],[10], neural-network theory [13], sliding mode control [14], hysteresis current control [12] and synchronous reference frame strategy[7].

Among these methods the Hysteresis current control has proven to be the most suitable solution for all the applications of current controlled voltage source inverters where performance requirements are more demanding, such as active filters [9] and high performance AC power conditioners. As it is well known, the hysteresis control is characterized by unconditioned stability, very fast response and good accuracy. It regulates the current produced by the inverter, which allow direct current control [10].

II. SHUNT ACTIVE POWER FILTER

A. Basic Principle of Operation

The basic principle of shunt active power filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the point of coupling thereby forcing the source current to be pure sinusoidal. The fig.1illustrates the concept of harmonic current cancellation so that the current being Supplied from the source is to be sinusoidal in nature.

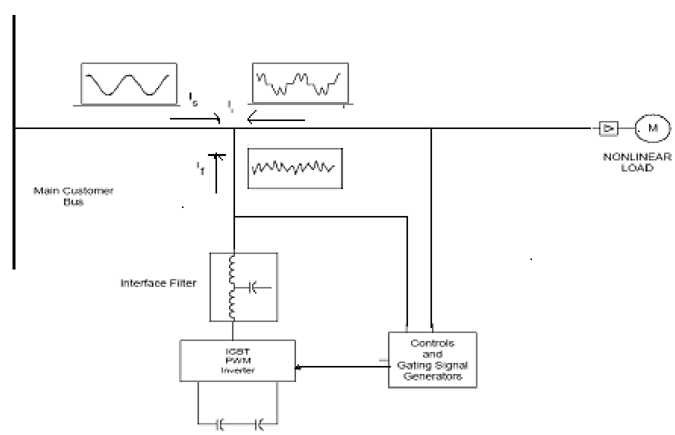

Figure 1. Block diagram of Shunt Active filtering

The voltage source inverter used in the active filter makes the harmonic control possible. This inverter uses dc capacitors as the supply and can switch at a high frequency to generate a signal that will cancel the harmonics from the non-linear load. The active filter does not need to provide any real power to cancel harmonic currents from the load. The harmonic currents to be cancelled show up as reactive power.

Reduction the harmonic voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Therefore the dc capacitors and the filter components must be rated based on the reactive power associated with the harmonics to be cancelled and on the actual current waveform that must be generated to achieve the cancellation.

The current waveform for cancelling harmonics is achieved with the voltage source inverter in the current control mode and an interfacing filter. The filter provides smoothing and isolation for high frequency components. The desired current waveform is obtained by accurately controlling the switching of the insulated gate bipolar transistor in the inverter. Control of the current wave shape is limited by the switching frequency of the inverter and by the available driving voltage across the interfacing inductance.

The driving voltage across the interfacing inductance determines the maximum di/dt that can be achieved by the filter. This is important because relatively high values of di/dt may be needed to cancel higher order harmonic components. Therefore, there is a trade off involved in the sizing of interfacing inductor.

A large inductor is better for isolation from the power system and protection from transient disturbances. However, the large inductor limits the ability of the active filter to cancel higher order harmonics.

B. *General Structure of Shunt Active Filter*

Shunt active filter works as current sources which when properly designed and controlled, produces harmonic currents having opposite phase than those harmonic current produced by the non linear load. When such a shunt active filter is connected parallel with a non-linear load its harmonic currents are compensated. This type of filter is known as **CURRENT INJECTION TYPE APF.**

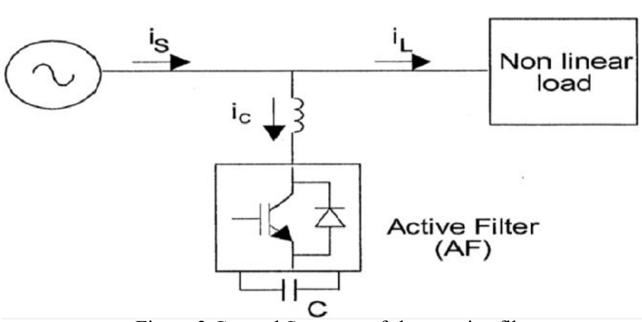

Figure.2 General Structure of shunt active filter

The active conditioner shown in fig. 2 is connected in parallel with the AC line and constantly injects currents that precisely correspond to the harmonic components drawn by the load. The result is that the current supplied by the power source remains sinusoidal [17]. Thus the characteristics of active filter can be explained as:

Let us consider:

I_S=Source Current

I_L=Load Current

I_F=Fundamental load current

I_H=Harmonic Current

I_C=compensating harmonic current

According to the fundamental concept

$$I_L=I_F+I_H \quad (1)$$

Active power filter produced compensating current of I_C, which is in equal but opposite to the harmonic current I_H produced by the load.

$$I_C=I_H \quad \text{(Opposite phase)} \quad (2)$$

Also $I_L=I_S+I_C$ (3)

$$I_F+I_H=I_S+I_C$$

$$=I_S+I_H$$

$$I_S=I_F \quad \text{(Source supplied Fundamental current only)} \quad (4)$$

The normal power source provides the fundamental current and the harmonic current required by the load is supplied by the active harmonic conditioner.

C. *Scheme of the System*

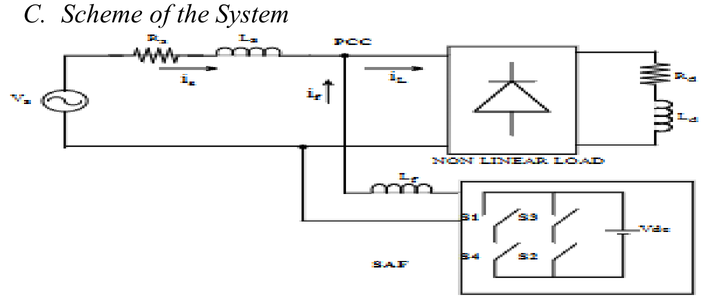

Figure 3.Scheme of the System under Study

The Fig 3 consist of single phase shunt active diode bridge rectifier[15] and single phase active power filter. In order to obtain harmonic free supply current flowing in source.The shunt active filter control algorithm are implemented to compensate the current harmonics.

III. COMPENSATOR CONTROL STRATEGY

A. *Compensation Technique*

The control algorithm computes the reference for the compensation current to be injected by the shunt active filter.The control method has an objective to guarantee balanced and sinusoidal source current .The idea can be easily realized if active filter part of the fundamental component of the current is accurately determined. [2] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles. [5] discussed about principles of Semiconductors which forms the basis of Electronic Devices and Components.

B. Hysteresis Current Control

The block diagram representation of hysteresis Current control loop is shown in fig.4. It regulate the current produced by the inverter ,which allow direct current control[6][20].

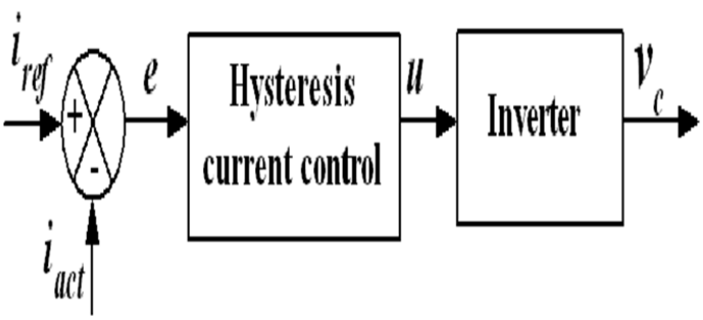

Figure 4.Block Diagram of Hysteresis Current Control

It is one of the simplest technique used to control the magnitude and phase angle of current injected by shunt active filter. It is a most popular one in terms of quick current controllability. In this controller, the main switch is switched on when the inductor current goes below a certain value , and it is switched off when the inductor current goes above a specified maximum value[19].Thus the amplitude of the current becomes bounded between these two limits.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_{act}.

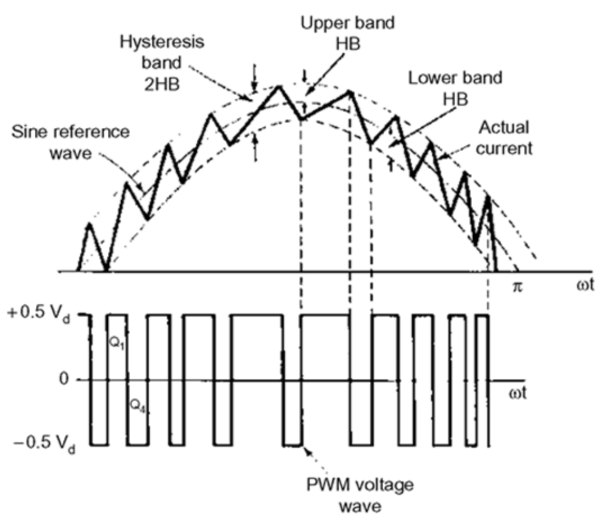

Figure 5. Current Control Block Diagram

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 shown in Fig.5.

The switching logic is formulated as follows:

If $i_{act} < (i_{ref} - HB)$ S1, S2 ON & S3,S4 OFF

If $i_{act} > (i_{ref} + HB)$ S1, S2 OFF & S3, S4 ON

The switching frequency of the hysteresis current control method described above depends on how fast the current changes from upper limit to lower limit of the hysteresis band, or vice versa. Therefore the switching frequency does not remain constant throughout the switching operation, but varies along with the current waveform. Furthermore, the filter inductance value of the active filter is the main parameter determining the rate of change of active filter current.

III. SIMULATION OF SHUNT ACTIVE FILTER

The simulation study on a single phase system feeding a single phase diode rectifier has been carried out in MATLAB 7.8. The simulink model of the system is shown below for two loads i.e. for linear and non linear load.

Fig .6 shows that the linear load which is connected to the source of the power system. Hence the sinusoidal source voltage and current is obtained.

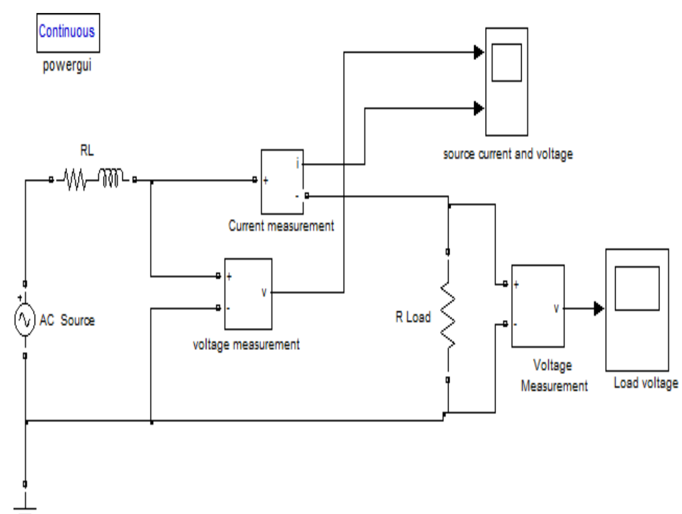

Figure 6.For Linear Load

Fig 7.shows that the source to be connected with the non linear load (diode rectifier). Such that the harmonic distortion produced by this load can be affect the source current and also the voltage.

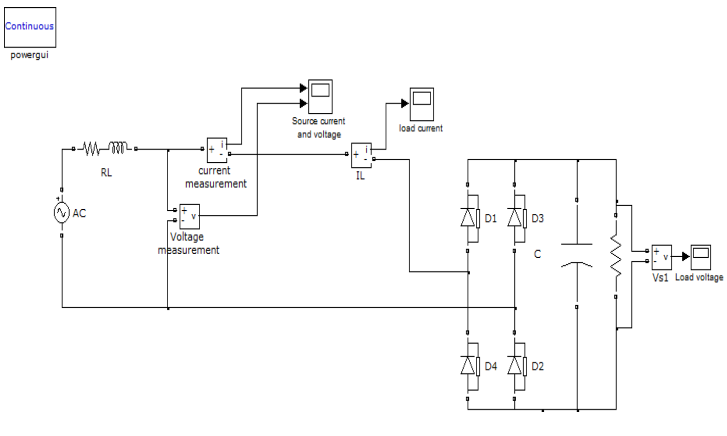

Figure 7.For Non Linear Load

In Fig .8, Extraction of harmonic current [4] from the load side, the harmonic and fundamental current is separated.

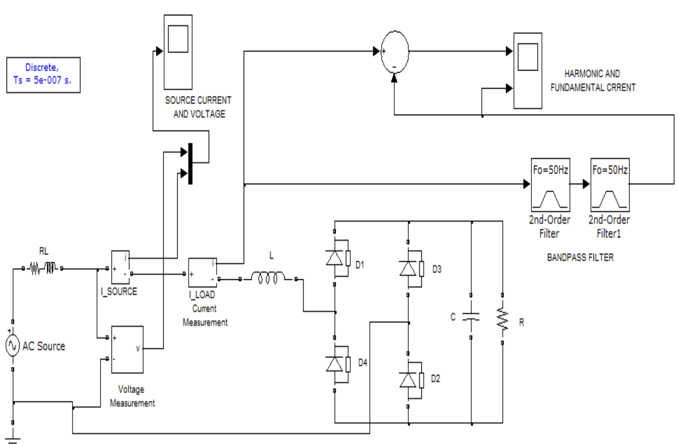

Figure 8. Extraction of Harmonic Current

Fig 9.shows that the single phase full bridge inverter used as shunt active active power filter.In Fig.10, The module "Subsystem" is a Sinusoidal PWM, the pulse width is a sinusoidal function of the angular position of the pulse in a cycle.For realizing SPWM, a high frequency triangular carrier wave Vc is compared with a sinusoidal reference wave Vr of the desired frequency, the intersection of Vc and Vr waves determines the switching instants and commutation of the modulated pulse. The carrier and reference waves are mixed in a comparator, when sinusoidal wave has magnitude higher than the triangular wave, the comparator output is high, otherwise it is low[18].

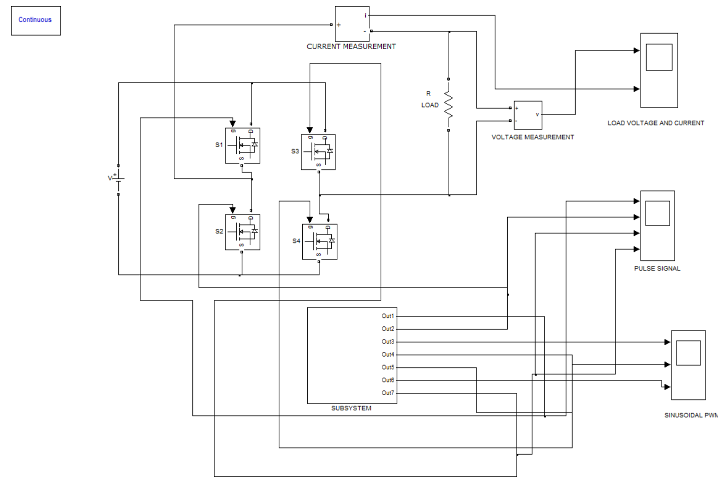

Figure 9.Single Phase Full Bridge Inverter

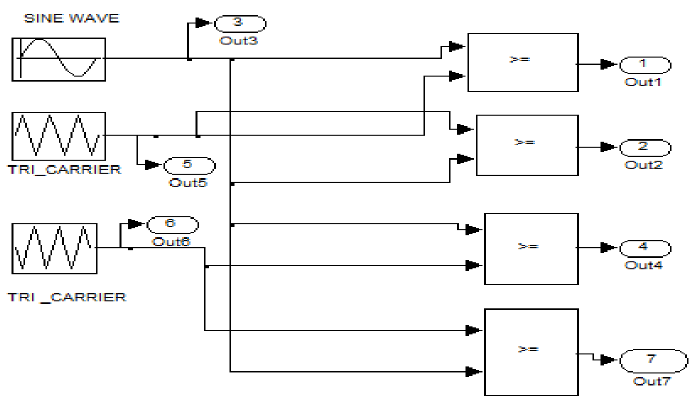

Figure 10.Subsystem of Single Phase Full Bridge Inverter

Fig 11.shows the schematic block diagrams of the shunt active filter .In order to simplify the diagram the "subsystem 1" in Fig 12. is a hysteresis current control, it which control the shunt active filter, such that the reference current is taken from the load side. It is compared with the actual current of the inverter produces the error so the hysteresis controller regulate the current from the inverter produces the equal and opposite current waveform (harmonic component) at the point of common coupling to the load. The current waveform from the shunt active filter cancels the opposite harmonic component waveform of the load side thereby forcing the source to be pure sinusoidal. Fig 13.shows that the subsystem of the subsystem 1which it consider of band pass filter which has the combination of the low pass and high pass filter. It is also called second order filter which it gives the quality power.

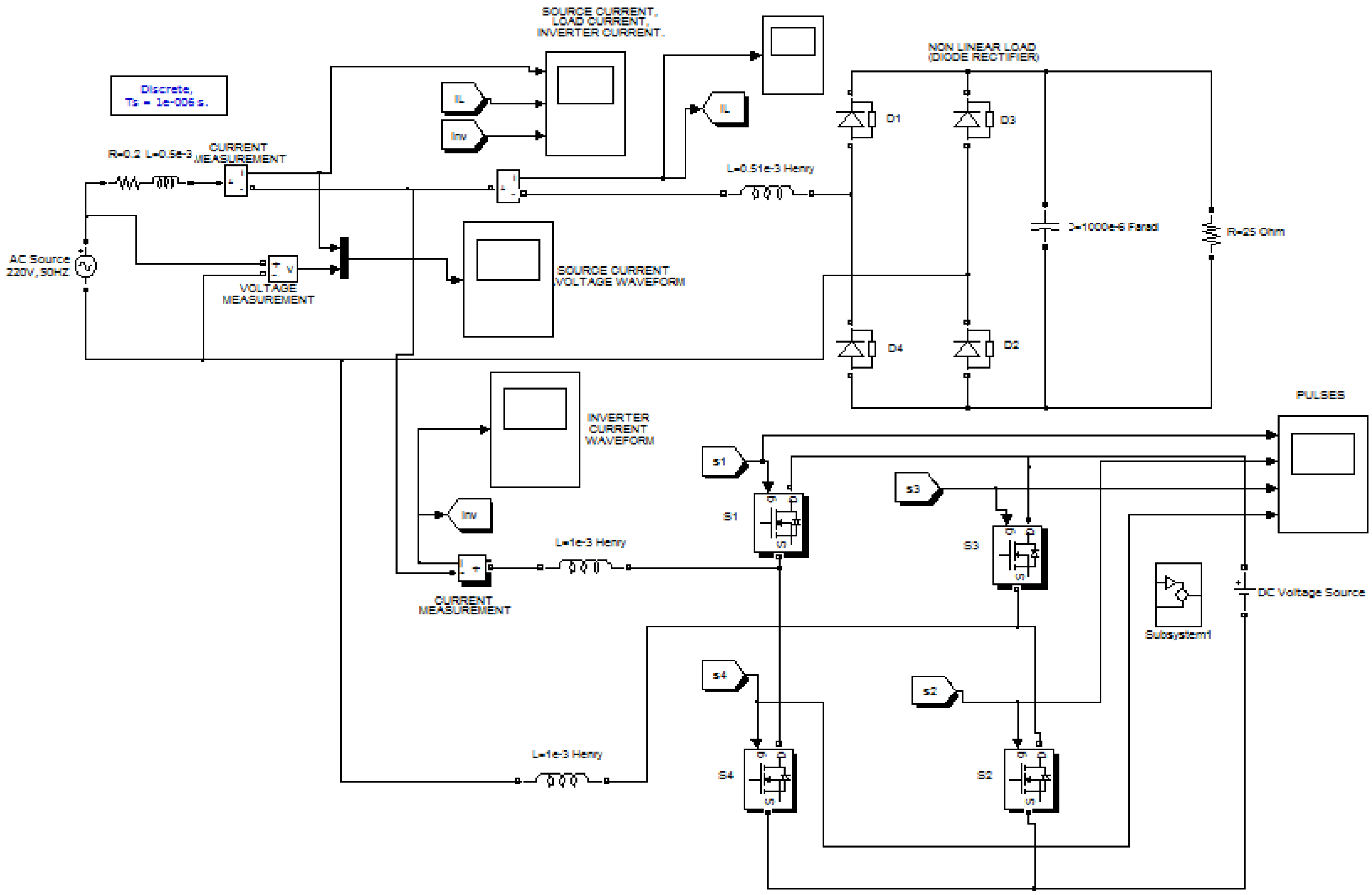

Figure 11. Simulation Block Diagram of Shunt Active Power Filter

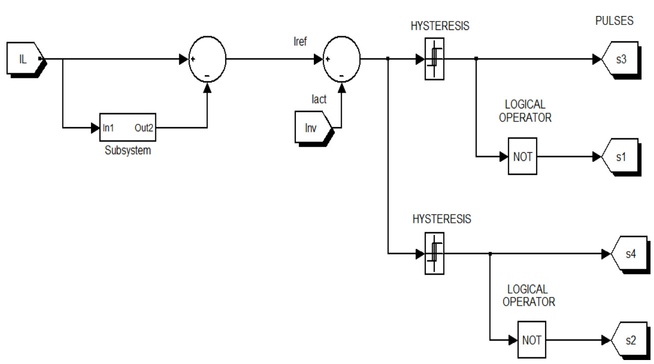

Figure.12 Subsystem 1: Hysteresis Current Control Block Diagram

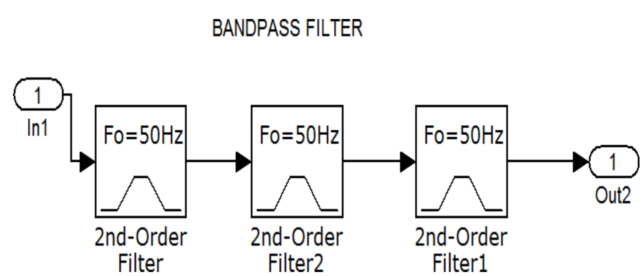

Figure .13. Subsystem

Fig 14. Shows that the source current and voltage obtained for the linear load.

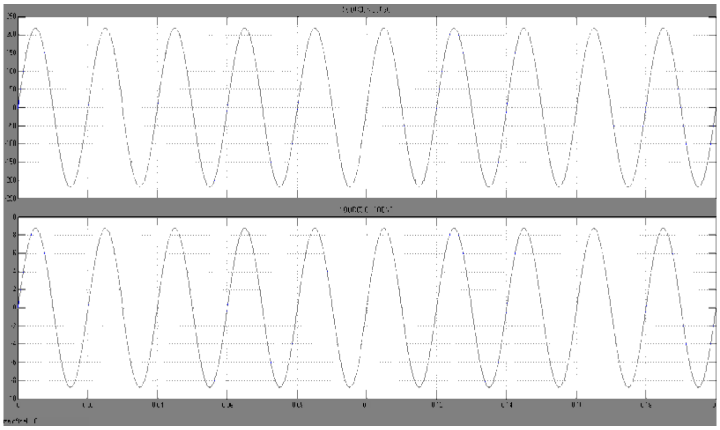

Figure 14. Simulated waveforms for Source Current and source Voltage for Linear load

Fig.15 shows that the source current and voltage is affected by the harmonic distortion for the non linear load.

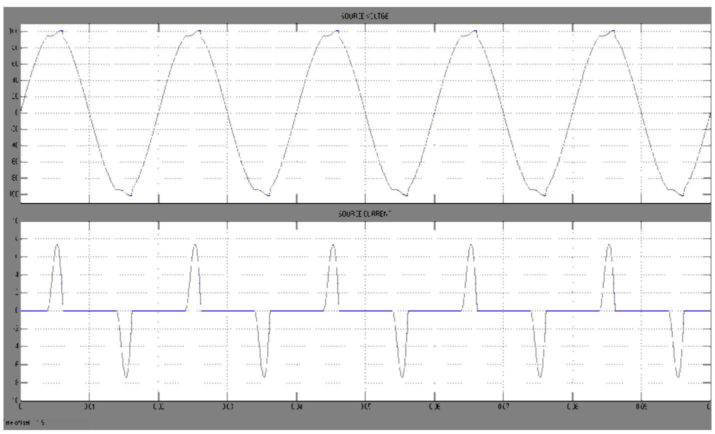

Figure 15. Source Voltage and Source Current for Non Linear Load

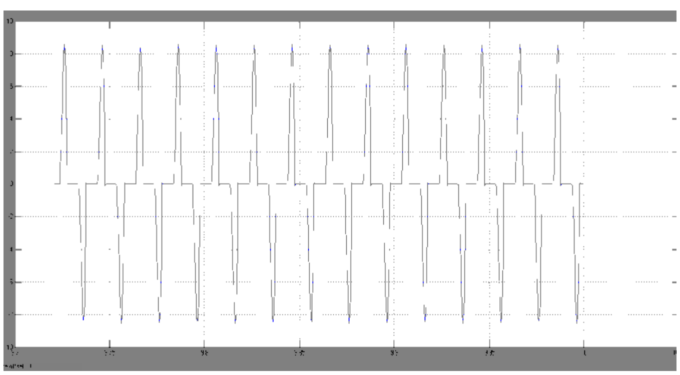

Figure 16. Load current for Non Linear Load

Fig 17.shows that the harmonic current is extracted from the load side hence from the fundamental and harmonic component is separated.

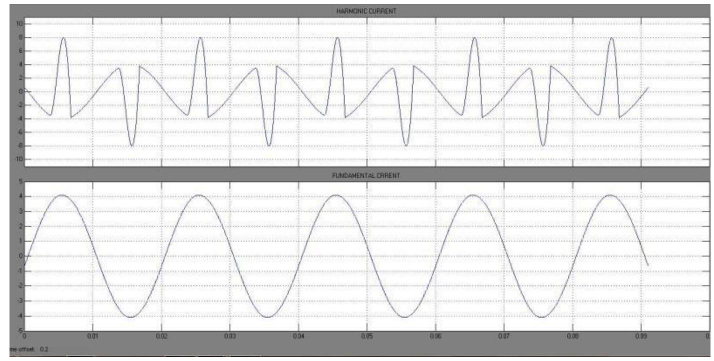

Figure 17. Extraction of Harmonic Current Component

Fig 18. Shows that the source current and voltage when the harmonic current is extracted.

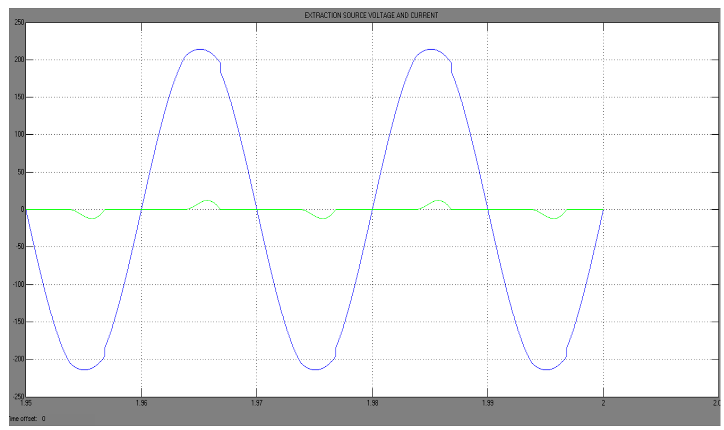

Figure 18.Wave form of source current and voltage during extraction of harmonic currrent

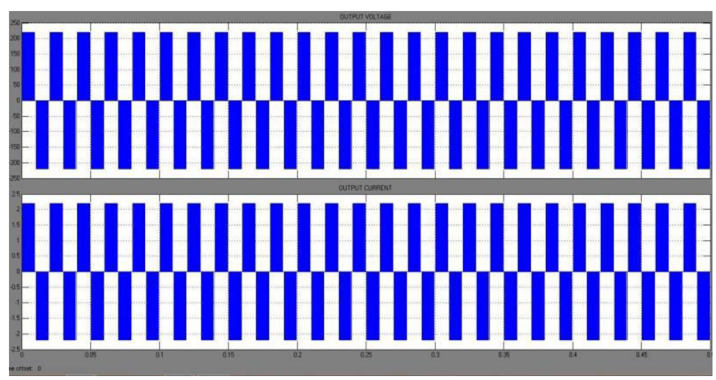

Figure 19. Output voltage and current of Inverter

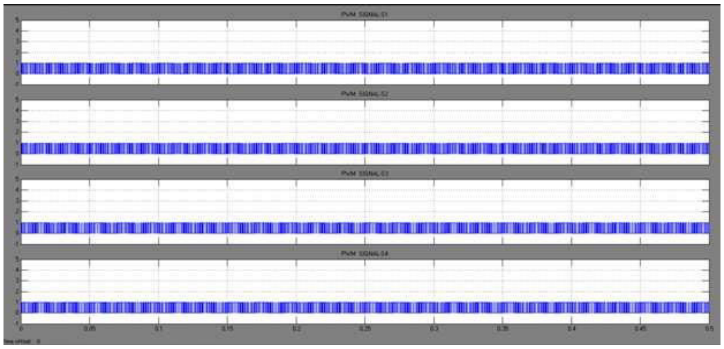

Fig 20. Generation of Pulses by Sinusoidal PWM

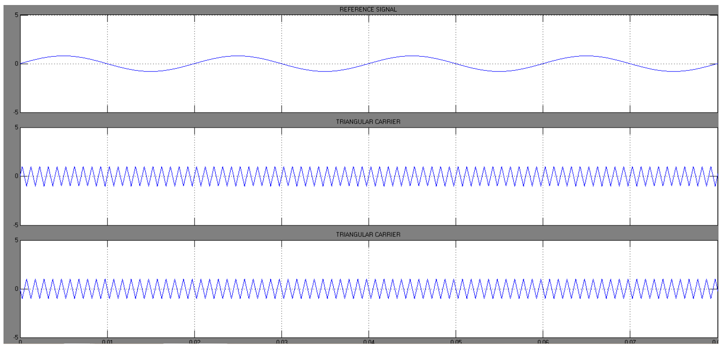

Figure 21. Reference and carrier signal of Sinusoidal PWM

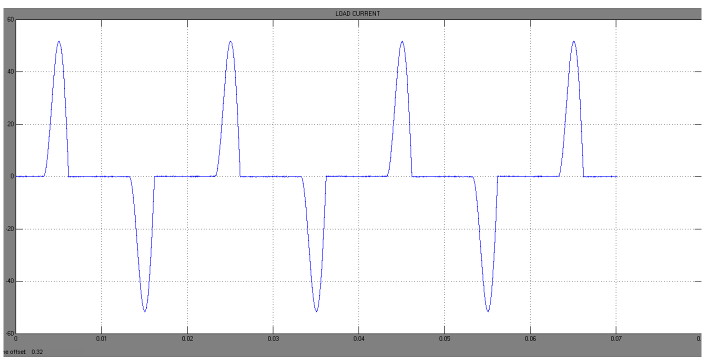

Figure 22. Load Current with SAPF

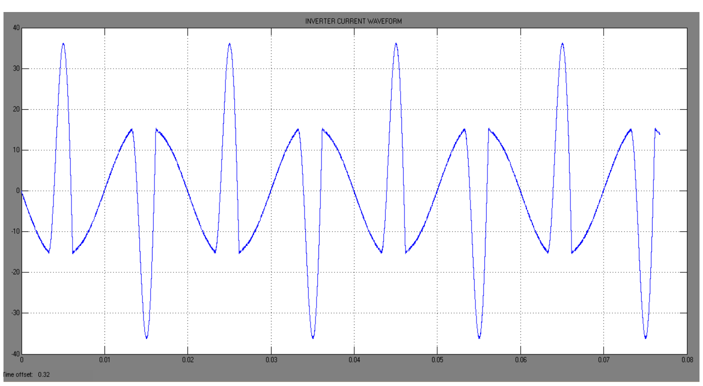

Figure 23. Inverter Current Waveform

Fig 24. Shows that the source current before compensation hence there is no sinusoidal wave in the source side because of absence of active filter,after compensation i.e.,there is a shunt active filter which is connected parallel to the load makes the source to be pure sinusoidal,as shown in the Fig 25.

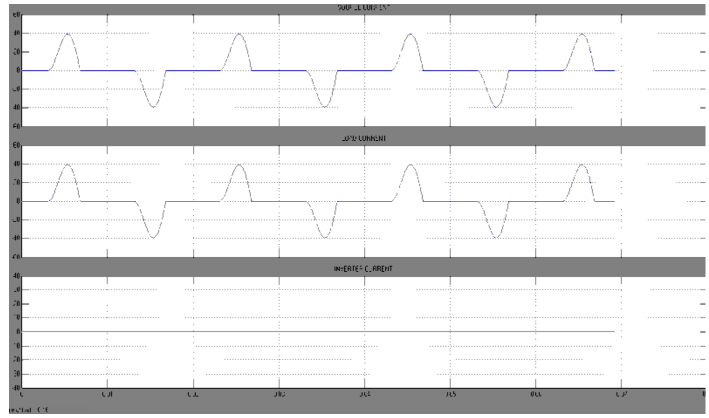

Figure 24. Source, Load,Inverter Current Before Compensation

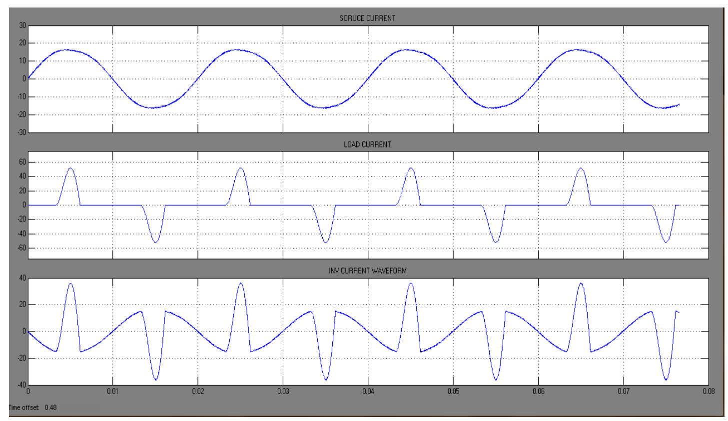

Figure 25. Source, Load, Inverter Current After Compensation

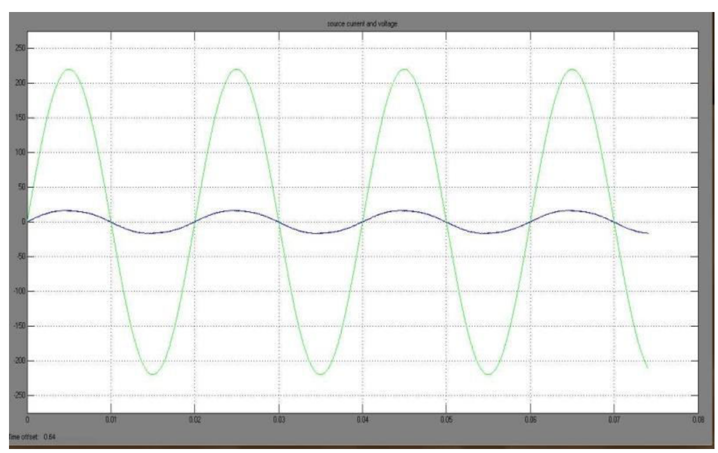

Figure 26. Sinusoidal Source Current and Voltage

IV. FFT ANALYSIS- SOURCE CURRENT BEFORE COMPENSATION

The total harmonic distortion will be calculated by using Fast Fourier tool transform it is presented in the MATLAB software.

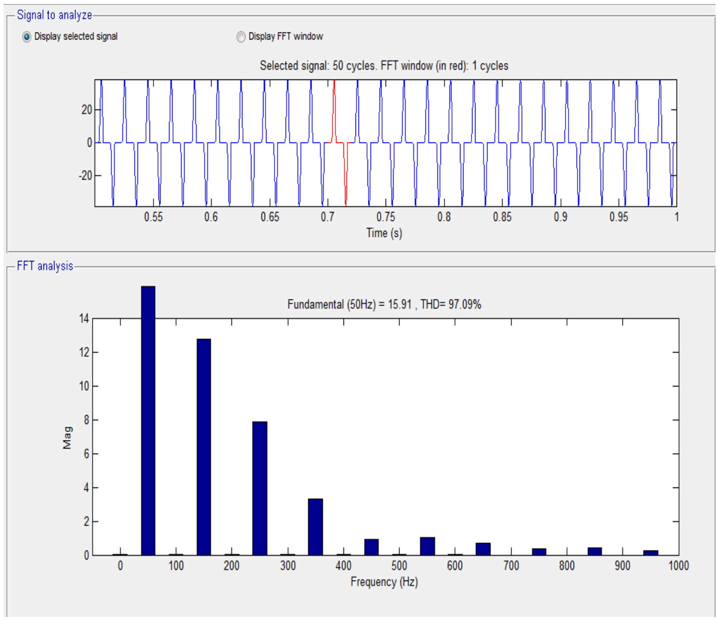

Figure 27. Harmonic Spectrum of Source Current Before Compensation

The Total Harmonic distortion in the Source Current has been calculated as 97.09% before compensation.

V. FFT ANALYSIS- SOURCE CURRENT AFTER COMPENSATION

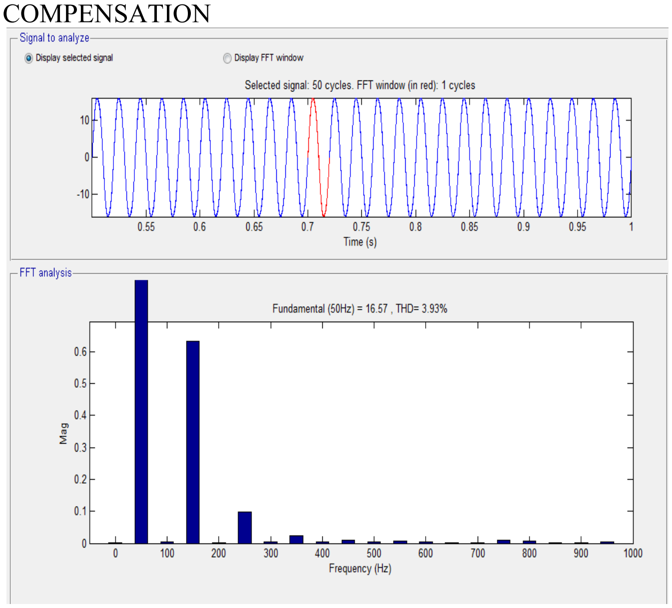

Figure 28. Harmonic Spectrum of Source Current After Compensation

The Total Harmonic distortion in the source current has been calculated as 3.93% after compensation.

TABLE I
CURRENT HARMONICS AS % OF FUNDAMENTAL (THD)

S.NO	THD of Source current before and after compensation	Total Harmonic Distortion
1.	THD of Source current before compensation	97.09%
2.	THD of Source current after compensation	3.93%

VI. CONCLUSIONS

This paper proposes the implementation of single phase active filter in shunt with the non - linear load to control the source current to be sinusoidal. From the simulation results, this system provides the sinusoidal source current. Therefore the harmonic distortion is reduced from 97.09% to 3.93% in the source side .The guidelines for harmonic reduction would be essential and effective in overcoming "Harmonic Pollution". In these paper sources and effects of harmonics, harmonic monitoring and eliminating methods are discussed in details. The use and advantages of applying active power filters for compensating harmonic present in the non-linear load has been presented. The principle of operation of shunt active power filters has been presented in this paper.

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