Reduction of Harmonics using Active Filter for Power Quality Improvement

Abdul Wadood, Chang Hwan Kim, Saied Gholami Farkoush, Tahir Khurshaid, Kumail Hassan Kharal, Sang-Bong Rhee

Abstract - To transmit an accurate, reliable and flexible power without any distortion to consumer is a serious issue and challenging to industry especially for engineer. During transmission, a lot of power problem occur which affect the power system operation and efficiency. There are several issues regarding power quality of which harmonics affect the power system operation and their extenuation should be given preeminent importance. Among different types of harmonic filters, active power is examined as very much profitable and economical solution. This paper presents the simulation of active power filter for reduction of harmonics using mitigation techniques MATLAB/Simulink software.

Keywords: Active power filter, PI controller, RL load power quality, Total harmonic distortion (THD).

I. Introduction

In recent years power quality problem was seriously addressed and considered by power engineers. Power quality problem is not the name of a single problem occur in electric power system there are various power quality problems which exist in any transmission and distribution network like reactive power balance, voltage sag, voltage swell, voltage interruption, transients, and harmonics out of all these problems harmonics is one of the major hurdle in power system which creates a lot of interruptions. In this respect community and industry deals with this problem i.e. PQ (power quality), due to their awareness how to maintain the standard of power grid, so industries try to train the new generation to handle the power quality issues. Harmonics can be defined as those components which are present in the fundamental waveform or signal of voltage and current and they are integer multiples of fundamental frequency component. Harmonics creates an unwanted trouble in load operation as well as reduces the efficiency and performance of the equipment [1]. In power system nonlinear loads are the main designer of harmonics that injects harmonic currents in A.C system and results in an increase of reactive power supplied by Equivalent Load [2]. This increase in nonlinear in nonlinear electronic base load leads to harmonic pollution

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Which will affect the operation of power system and the required result will not achieved successfully due to Harmonics [3]. To eliminate the harmonics from the power system there is the urge of harmonic filter to be utilized in transmission network having the good configuration and the parameters to control harmonics [4]. There are three main types of harmonic filters namely passive, active and hybrid harmonic filters [5]. Presently used filter were of passive type which consist of inductor and capacitors. But later it was inaugurated that active power filters have more advantages as compared to passive harmonic filters [2] [6]. Thus the occurrence of technology is the brick way for the development of active power filter [7].

II. Objective and Principal of Operation

The objective of active power filter (APF) is to sort out that issues in a prominent way rather than using those components whose ratings are predetermined with reduced ratings unlike bulky passive components [2]. Active power filter can be implemented according to the nature of problem in power system. APF filter have three basic topologies i.e. Shunt type, series type and a combination of both shunt & series active filters [8]. The basic topology of shunt active power filter with a voltage source or a DC capacitor are similar to that of STATCOM used for reactive power compensation in electric power transmission network [9]. The concept and idea of APF is slightly old but their practical achievement was made possible with the new evolution in power electronics, control strategies as well as with discount in worth of electronic components [3]. Although the fast response of power electronic switching, Active power filter originate current or voltage components which remove the harmonic components of the nonlinear loads. The shunt active filter reimburse load current harmonics by inserting equal but opposite harmonic current [4] [9]. In this manner, the operation of shunt power filter is same like current source which inserts the harmonic components initiated by the load giving a phase difference of 180 .The series active power filter performs like a voltage regulator and also acts like a harmonic insulator between load and the utility system [10]. In the SCF (series connected filter) a coupling transformer is used to connect the filter to the system. The compensation voltage, VC, is used to cancel the load voltage harmonics caused due to nonlinear load like diode rectifiers with capacitive load in the DC side that can reduce imperfect supply voltage quality this type of methodology is especially assign for voltage sag, interruption and for unbalances in AC transmission system because at fundamental frequency the filter is designed to offer a very low impedance therefore allowing a fundamental current with negligible voltage drop and losses In addition this filter must be designed to carry fully rated load current with overcurrent protection. Moreover at fundamental frequency these consume lagging reactive power result in further voltage drop. The figure 1 & 2 shown below illustrate the adjustment of shunt active power filter in electrical network.

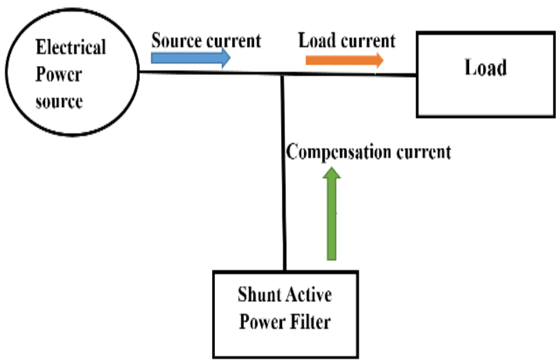

Figure 1. Active Power Filter Installation

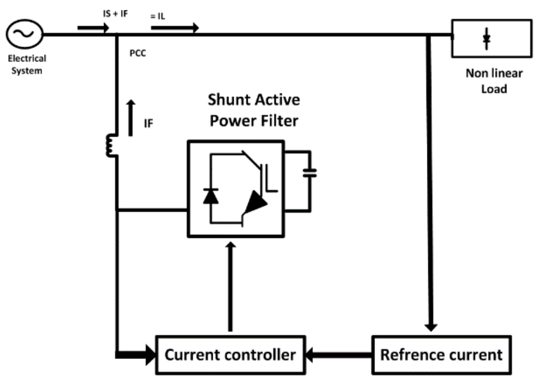

Figure 2. APF schematic

During operation the compensation current obtained will be $I_{C\,(t)}$ equal to error obtained from signal. If this properly output is given to source side in phase opposition this lead to the phase cancellation of harmonic components Although voltage is the output of VSI and can be converted to current source when RL is connected in series .Accordance with the magnitude of compensating current the value of RL branch can be determined. The steps involve in the process of active harmonic filter are given below.

The extraction of harmonic components Inverter operates compensating current control.

A. Harmonic Extraction Method

Various method are used for extraction of harmonic component from fundamental component .Although it is done in order to isolate the harmonic from supply signal or waveform mathematically [11].some of the method used for harmonic extraction [3] [8] are given below

Synchronous reference frame method, synchronous detection method, Modified power quality theory, Sine multiplication method.

B. Voltage Source Inverter (VSI)

The voltage source inverter is very reliable in operation and can operate in all four quadrants that is supply and absorb real as well as reactive power. Most of the topologies nowadays used in active power filter use a voltage source inverter for their operation. In VSI the phenomenon of self-commutation is possible due to IGBTs and MOSFETs. The advantages of voltage source converter are given below:

1. Fast control of both power i.e. Active & reactive Power, Provide a good and high level of Power.
2. Low power (<250MW)
3. STATCOM and SVC
4. Active power filter and VAR computation [9]

Self-commutating switches which can be controlled according to our desire (e.g. GTOs, IGBTs). In comparison to the conventional CSCs which are operate with line commuted thermistors switches [9]. The phenomena of commutation in a force commutated voltage source converter can occur many times regarding per cycle as in a line commuted Current source converter it happen only once per cycle. This quality allows the voltage and current to generate a nearly sinusoidal output and able to control the power factor as well. So VSI is an accessible choice for the implementation of active filters [9].

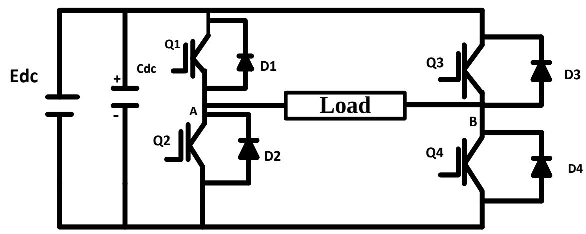

Figure 3. Single phase VSI Topology

The topology shown in the figure shows the conversion of DC voltage into an AC voltage by properly gathering the power semiconductor switches. Voltage source converters are preferred over current source converters due to its high efficiency and lower initial cost as compared to current source converters.

C. Pulse generation for Active Power Filter

The most important process in the operation of active power filters for gathering of pulse generation there are various techniques listed below.

1. Sine PWM
2. Space vector PWM
3. Triangular PWM [7].

Triangular pulse width modulation is the most commonly technique applied to a voltage source inverter consist of chopping the DC bus voltage to generate an AC voltage of an arbitrary waveform. There are various PWM techniques available to integrate the sinusoidal pattern, the phenomenon over which this technique work is known as triangular carrier technique .In this technique the output voltage is forced over a switching cycle determined by the carrier period to be equal to the average amplitude of the modulating wave known as **V_{ref}** .As for APF implementation is concerned this methodology compares the output current error with a fixed amplitude and triangular wave carrier. Thus the compensating current produced for a shunt active power filter. The schematic representation of PWM technique is given in figure 4.

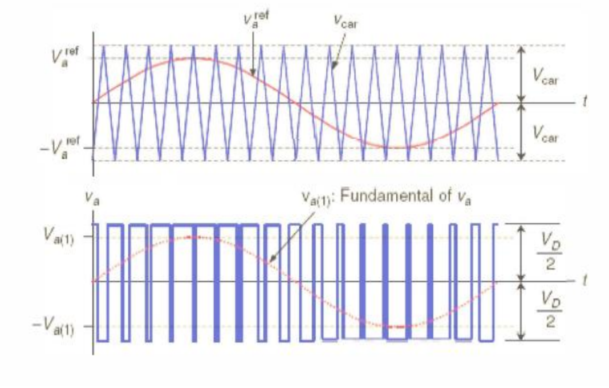

Figure 4. Triangular PWM Technique

III. Proposed Modelling of active power System

The basic shunt power filter have the advantages of giving advanced and effective result. A diode rectifier with smoothing DC capacitor acts as a nonlinear load which creates significant current distortion current. The current harmonic amplitude is significantly affected due to Ac side or source impedance .Passive filter have been extensively used in power system to mitigate these harmonic distortions chiefly due to their low cost. In the given paper current harmonics caused due to non-linear load having an RL load has been taken for Analysis as a test system. Shunt active power filter is used to inject the compensating currents in order to have purely sinusoidal source current at unity power factor.it consist of a voltage source inverter having a voltage source at the DC bus, which typically is an energy storage device like a capacitor as shown in figure 5.

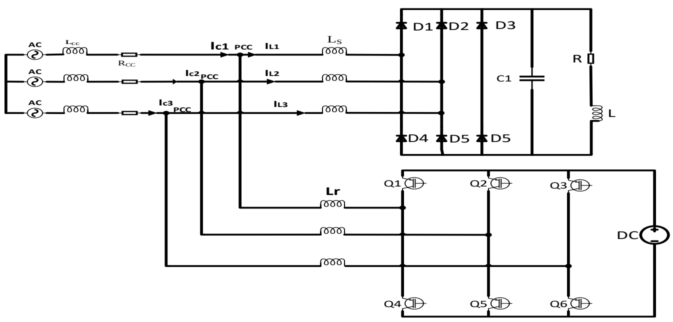

Figure 5 single line diagram of shunt active power filter

Figure 5 show the basic compensation principal of a shunt active power filter in which the compensation current **Ic** cancels the current harmonics on AC side. From figure1 the instantaneous source currents can be written as

$$I_S(t) = I_L(t) - I_C(t) \qquad (1)$$

Source voltage is given by

$$V_S(t) = V_m \sin(\omega t) \qquad (2)$$

For a nonlinear load the load current will have a fundamental component and the harmonic component, which can be further given by.

$$I_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \varphi_n) = I_1 \sin(n\omega t + \vartheta_1) + \sum_{n=2}^{\infty} I_n + \sin(n\omega t + \varphi_n) \qquad (3)$$

Instantaneous load power can be given as

$$P_L(t) = V_S(t) * I_L(t) = V_m I_1 \sin^2 \omega t * \cos\varphi_1 + V_m I_1 \sin\omega t * \cos\omega t * \sin\varphi_1$$

$$+ V_m \sin\omega t + \sum_{n=2}^{\infty} I_n + \sin(n\omega t + \varphi_n) \qquad (4)$$

$$= p_f(t) + p_r(t) + P_h(t) \qquad (5)$$

From (4), real (fundamental) power drawn by the load

$$p_r(t) = V_m I_1 \sin^2 \omega t * \cos\varphi_1 = V_s(t) * I_s(t) \qquad (6)$$

Form (6) source current supplied by the source after compensation

$$I_s(t) = p_r(t) / V_s(t) = I_1 \sin\omega t * \cos\varphi_1 \qquad (7)$$

Where

$$I_{sm} = I_1 \cos\varphi_1 \qquad (8)$$

Hence total peak current supplied by the source

$$I_{sp} = I_{sm} + I_{SL} \qquad (9)$$

Where I_{SL} represents the PWM converter switching loss. In case active power filter provides the total reactive and harmonic power, then I_S (t) will be in phase with the service voltage and will be entirely sinusoidal.at this stage of time compensation current is:

$$I_C(t) = I_L(t) - I_S(t) \qquad (10)$$

Thus it is important to compute I_S (t) for precise and instantaneous compensation of reactive and harmonic power.

IV. Recommended Approach & Strategy

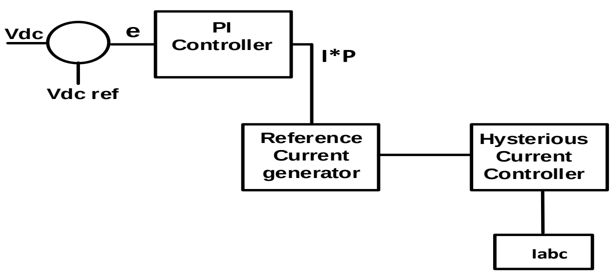

Figure 6. Block diagram of shunt active power filter

The control block diagram of SAPF consist of a Three phase shunt active power filter have a voltage source inverter (VSI) having IGBT switches and an energy storage capacitor on DC bus. The control block consists of the PI controller and the Hysteresis current controller (HCC). The work of PI controller is the evaluation of reference current from the measured DC bus voltage. The job of HCC is to generate the switching pulses for the VSI. HCC comprises of the following components.

D. Unit vector Template Formation

The input source voltage at point of common coupling (PCC) consists of fundamental and distorted component. In order to get unit vector templates of voltage, the input voltage is sensed and multiplied by gain which is equal to 1/VM, where VM represents the peak amplitude of fundamental input voltage. These unit vector templates are then given to a multiplication block for synchronization of signals. The unit vector templates for three phases are obtained as follows.

$$v_{sa} = \sin \omega t \quad (11)$$

$$v_{sa} = \sin(\omega t - 120^\circ) \quad (12)$$

$$v_{sa} = \sin(\omega t + 120^\circ) \quad (13)$$

E. Reference Source Current

The peak value of the reference current ISP can be determined by controlling the DC side capacitor voltage. The best compensation requires the mains current to be sinusoidal and in phase with the source voltage irrespective nature of load current. The desired source current after compensation is given by:

$$I^*_{sa} = I_{sp} \sin \omega t \quad (14)$$

$$I^*_{sb} = I_{sp} \sin(\omega t - 120^\circ) \quad (15)$$

$$I^*_{sc} = I_{sp} \sin(\omega t + 120^\circ) \quad (16)$$

Here $I_{sp} = I_1 \cos(\varphi_1) + I_{sL}$ is the amplitude of the desired source current, while the phase angles can be obtained from the source voltage. Thus, the waveform and phases of the source currents are known, just the magnitude of the source currents needs to be determined. Peak value of the reference current has been obtained by regulating the dc side capacitor voltage of PWM converter. This capacitor voltage is compared with the reference value and the error is processed in a PI controller. The output of PI controller is the amplitude of the desired source current and the reference currents are estimated by multiplying this peak value with the unit sine vector templates in phase with the source voltages.

F. Control strategy used in HCC

Hysteresis Current Control (HCC) technique is basically an instantaneous feedback current control method of pulse width modulation (PWM) where the actual current continually tracks the command current within a hysteresis band. The actual source currents I_{sa}, I_{sb} and I_{sc} are compared in hysteresis current controller in order to generate the control pulses for switches of VSI in such a way so that the actual source current follows the reference currents closely inside the narrow hysteresis band. This makes source currents almost sinusoidal and in phase with source voltages, thus giving unity power factor.Figure.7 shows the basic principle of HCC

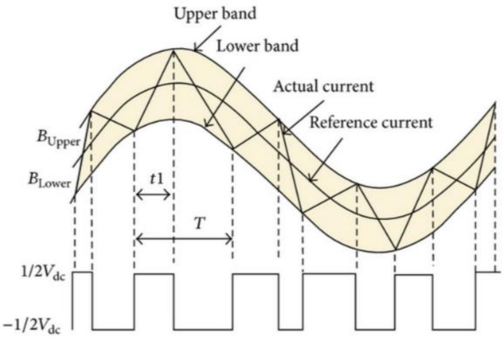

Figure 7. Hysteresis Current Control Technique

Hysteresis band (HB) is the potential boundary of the compensating current. This current deviates between upper and lower hysteresis limits. For example in phase *a*, if *Isa* is equal or over than the upper hysteresis limit (*Isa** + HB/2) then the comparator output is 0 (S1=0, S2=1). As a result, current starts to decay [5]. On the other hand, if *Isa* is equal or less than the lower hysteresis limit (*Isa** - HB/2) then the comparator output is 1 (S1=1, S2=0). As a result current gets back into the hysteresis band. From this operation, the *Isa* can deviate inside the hysteresis band following the reference current *Isa**. The key benefit of hysteresis current control method is its outstanding dynamic response, effortless implementation and economical.

The switching frequency of hysteresis current control approach described above depends mainly on how fast the current changes from upper to lower boundary of hysteresis band and inversely. As a result, the switching frequency does not remain constant all the way through the switching operation but changes along with the current waveform. Figure 8 represents the basic plan for generation of six pulses so as to drive the six switches of inverter of the shunt active power filter. In this method the actual output current generated by inverter is compared with reference current generated with the help of PI controller and unit sine vectors. Hysteresis current controller will produce pulses in such a way that inverter output current follows the reference current.

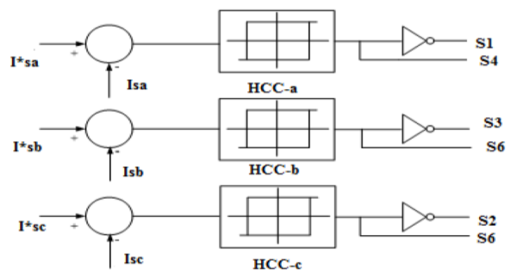

Figure 8. Pulse Generation Using Hysteresis Current Control Technique

V. PI controller

The work of PI controller is the evaluation of reference current from the measured DC bus voltage. Proportional Integral (PI) controller has been extensively used for DC bus voltage regulation in shunt active power filters. It is effortless to implement and achieves excellent results. The control scheme of a shunt active power filter should calculate the reference current waveform for each of the three phase of the inverter, maintain the dc link voltage constant, and generate the inverter gating pulses. PI controller consists of a proportional term i.e. KP and an integral term i.e. Ki. Proportional value is used determines the response to the current error; similarly the Integral part is used to determine the response based on the sum of recent errors. The transfer function of the PI controller is given by

$$H(s) = K_p + K_I / s \quad (17)$$

Here the proportional and integral gains are selected either heuristically or mathematically. The integral term causes the steady-state error to trim down to zero; however it is not the case for proportional-only control. PI controllers are commonly used than Proportional Integral Derivative (PID) controllers because the derivative action is very sensitive to noise, in this manner making PI system steadier in the Steady state in the case of a noisy environment.

VI. Simulation and Results

The proposed system is simulated using MATLAB/Simulink and Sim Power Systems software to validate the performance of proposed method. The system parameters are presented in Table-I.

Serial No.	Parameter	value
1.	Source voltage	230V(r.m.s)
2.	Source frequency	50Hz
3.	DC bus voltage	600V
4.	DC bus capacitor	3.5μF
5.	DC link inductance	10mH
6.	Hysteresis Band	± 5
7.	Load resistance	60Ω
8.	Load inductance	10mH
9.	Sample time	0.2μseconds

Table-I: System Parameters

The system is first simulated without filter in order to the system is first simulated without filter in order to investigate the effect of non- linear loads in power systems. Figure 9 shows the three phase source current drawn by non-linear load in absence of active power filter. The result shows that the current drawn is not sinusoidal and is not in phase with the source voltage.

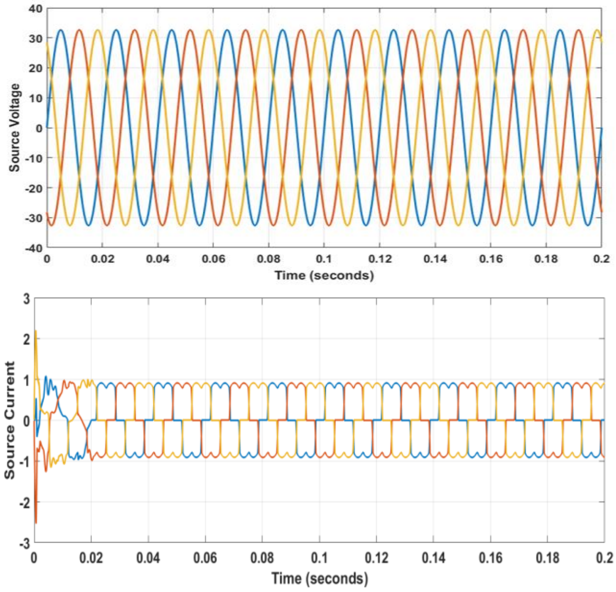

Figure 9. Source current without Shunt Active Power Filter

G. FFT Analysis

When filter is not used THD is also high due to nonlinear load. Figure 10 shows THD due to nonlinear load in absence of filter. The source current is highly distorted with a THD of 28.38% as shown in Figure 10. The source current THD is much greater than the acceptable limit of 5% set by IEEE-519-1992 standard.

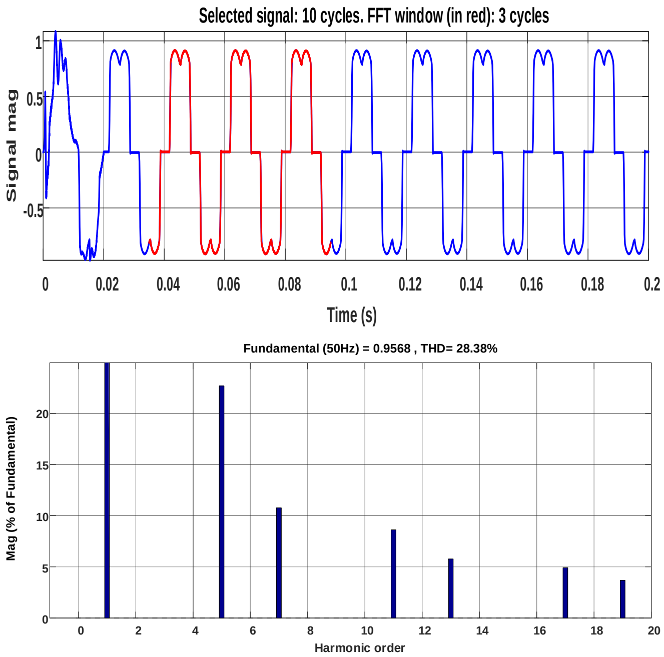

Figure 10. THD due to nonlinear load without filter

Now a shunt active power filter is used for harmonics and reactive power compensation. The result shows that the current drawn is sinusoidal and is in phase with the source voltage Figure 11 shows the source current has become near sinusoidal after using shunt active power filter thus improving the power factor and reducing THD from 28.38 to 2.08 as shown in figure 12 and Table-II

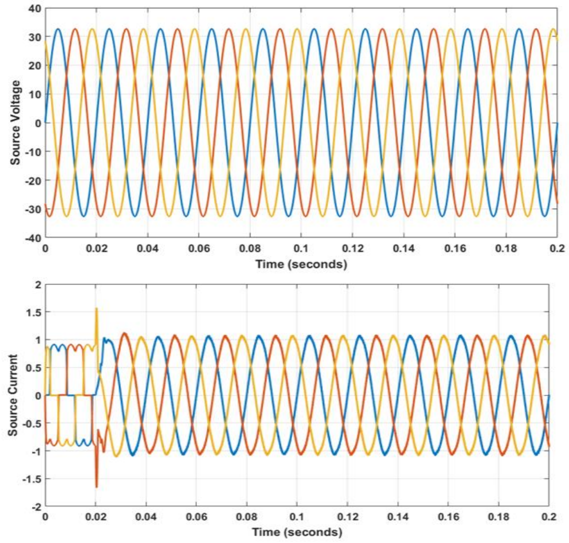

Figure 11. source current with shunt active filter

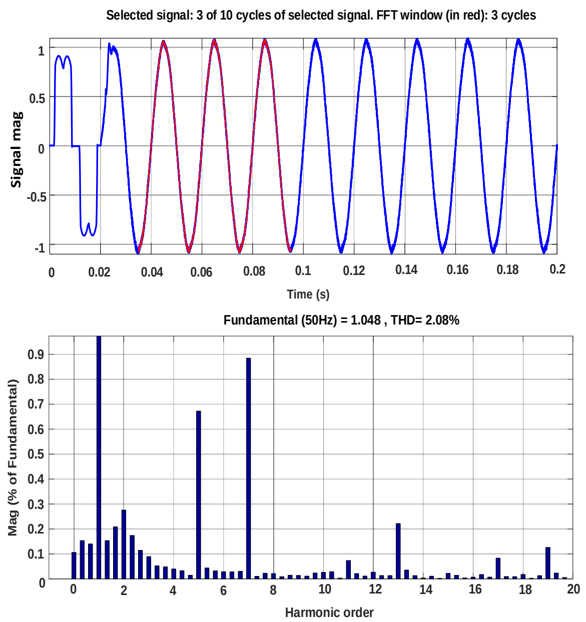

Figure 12. THD due to nonlinear load with filter

Table 2 shows the comparative analysis of Shunt active power Filter to reduce the THD

Filter	THD
Without shunt active power filter	28.38
With shunt active power filter	2.08

Table-II THD With and without shunt active power filter

VII. Conclusion

This chapter intents at studying the Performance of shunt hybrid active power filter to the three phase system and the concussion and role of shunt active power filters in mitigation of Harmonics. The concept of shunt hybrid active power filters requires different harmonic extraction and different control methods which can be surveyed to suggest a better solution. A shunt active filter has the quality of dynamism, robustness and doesn't cause electrical resonance or isn't made up of large or bulky equipment's. Hybrid filters topologies help in damping resonances occurring between line impedances and passive filters and provide cost-effective, superior efficiency, improved reliability and better solutions for harmonic compensation with an extremely small-rated inverter as compared to active. Power filter topologies and other options of power quality improvement. Thus it could be an economical solution to deal with current harmonics issues. Moreover, this design requires compact size of shunt active power filter

VIII. References

[1] Akagi, H. "New trends in active filters for Power conditioning", *IEEE Transactions on Industrial Applications* **Volume.** 32(6): 1312-1322, 1996

[2] Akagi. H, "Modern active filters and Traditional passive filters", Bulletin of the Polish Academy of Sciences, Technical Sciences 54(3), 255-269, 2006.

[3] K-L. Areerak and K-N. Areerak, "The Comparison Study of Harmonic Detection Methods for Shunt Active Power Filters", World Academy of Science, Engineering and Technology 46 2010 pg. 243-248

[4] Bhim Singh, Kamal AI-Haddad & Ambrish Chandra, "A Review of Active Filters for Power Quality Improvement", *IEEE Transactions on Industrial Electronics*, **Volume**. 46, No. 5, pp 960-970, Oct. 1999.

[5] S.Khalid & Bharti Dwivedi "Power Quality Issues, Problems, standards & their effects in industry with corrective means", *International Journal of Advances In Engineering & Technology*, May 2011.

[6] L. Moran, J. Dixon, J. Espinoza, & R.Wallace, "Using Active Power Filters to Improve Power Quality", 5th Brasilian Power Electronics Conference, COBEP'99.

[7] Muhammad H. Rashid, "Power electronics -circuits, devices and APPLICATIONSTHIRD EDITION", Pearson, New Jersey, USA.

[8] Vedat M. Karsh, Mehmet Tumay, Berrin SOslOoglu, "An evaluation of time domain techniques for compensating currents of SHUNT ACTIVE POWER FILTERS".

[9] Vijay K Sood, "HVDC and FACTS controllers- Applications of Static Converters in power systems Kluwer Academic Publishers, 2004.

[10] Zainal Salam, Tan Perng Cheng and Awang Jusoh, "Harmonics Mitigation Using Active Power Filter: A Technological Review" ELEKTRIKA.

[11] Anzari M, Rejil Chandran and ArunKumar R, "Single-Phase Shunt Active Power Filter Using Indirect Control Method" Advance in Electronic and Electric Engineering ISSN 2231-1297, Volume 3, Number 1 (2013), pp. 81-90