HYSTERESIS CONTROL FOR CURRENT HARMONICS SUPPRESSION USING SHUNT ACTIVE FILTER

Rajesh Kr. Ahuja[1], Aasha Chauhan[2], Sachin Sharma[3]

Rajesh Kr. Ahuja
Faculty, Electrical & Electronics Engineering Dept. YMCAUS&T,
Faridabad, Haryana
rajeshkrahuja@gmail.com

Aasha Chauhan
Student, Electrical & Electronics Engineering Dept. YMCAUS&T,
Faridabad, Haryana
aashachauhan07@gmail.com

Sachin Sharma
Student, Electrical & Electronics Engineering Dept. YMCAUS&T,
Faridabad, Haryana
ersachinshastri@gmail.com

ABSTRACT— Recently wide spread of power electronic equipment has caused an increase of the harmonic disturbances in the power systems. The nonlinear loads draw harmonic and reactive power components of current from ac mains. Current harmonics generated by nonlinear loads such as adjustable speed drives, static power supplies and UPS. Thus a perfect compensator is required to avoid the consequences due to harmonics. To overcome problems due to harmonics, Shunt Active Power Filter (SAPF) has been considered extensively. SAPF has better harmonic compensation than the other approaches used for solving the harmonic related problems. The performance of the SAPF depends upon different control strategies. This paper presents the performance analysis of SAPF under most important control strategy namely instantaneous real active and reactive power method (p-q) for extracting reference currents of shunt active filters under unbalanced load condition. Detailed simulations have been carried out considering this control strategy and adequate results were presented. In this paper, harmonic control strategy is applied to compensate the current harmonics in the system. A detailed study about the harmonic control method has been used using shunt active filter technique.

KEYWORDS—Harmonic Suppression, Hysteresis Current control, Instantaneous power (p–q) theory, PI Controller, Power System, Shunt Active Power Filter.

I. INTRODUCTION

Harmonics contamination is a serious and a harmful problem in Electric Power System. With the development of power electronics, the converters are widely used in the power supply devices and control application. These Non-linear loads draw currents that are non-sinusoidal and thus create voltage drops in distribution conductors. Typical non-linear loads based on solid-state converters are like UPS, SMPS etc Active Power filtering constitutes one of the most effective proposed solutions. Active power filter (APF) can solve problems of harmonic and reactive power simultaneously.

The quality of electric power is deteriorating mainly due to current and voltage harmonics, zero and negative sequence components, voltage sag, voltage swell, flicker, voltage interruption, etc. Hysteresis current control method is the most popular one in terms of quick current controllability, versatility and easy implementation [1].

Shunt active filter (SAF) is one among the various types of custom power devices proposed to improve the power quality [2]. Harmonic extraction is the process in which, reference current is generated by using the distorted waveform. Many theories have been developed such as p-q theory (instantaneous reactive power theory), d-q theory, PLL with fuzzy logic controller, neural network etc..

Out of these theories, more than 60% research works consider using p-q theory and d-q theory due to their accuracy, robustness and easy calculation. The main sources of voltage and current harmonics are due to control and energy conversion techniques involved in the power electronic devices such as chopper, rectifier, cyclo converter etc [3].

The hysteresis band is used to control the supply current and determine the switching signals for inverters gates. When the supply current exceeds the upper band, the comparators generate control signals in such a way to decrease the supply current and keep it between the bands [4]. In this paper, a further and substantial improvement of the hysteresis control is proposed, which is characterized by a very simple and robust implementation. It offers all the advantages of the hysteresis technique.

In this paper, we have used the shunt active filter technique for power filtering and then we have studied about the compensation principle used for current harmonics suppression and harmonic control method is applied as it provides a quick and easy response in the system.

II. SHUNT ACTIVE POWER FILTER

The shunt active power filter (APF) is a device that is connected in parallel to and cancels the reactive and harmonic currents from a nonlinear load. The resulting total current drawn from the ac main is sinusoidal. Ideally, the APF needs to generate just enough reactive and harmonic current to compensate the nonlinear loads in the line. In an APF depicted in Fig. 1, a current controlled voltage source inverter is used to generate the compensating current (ic) and is injected into the utility power source grid. This cancels the harmonic components drawn by the nonlinear load and keeps the utility line current (is) sinusoidal.

One of the most popular Active Power Filters (APF) used for compensating reactive power and harmonics is the shunt active filter that is shown in figure 1. The simple shunt active filter arrangement with non-linear load is considered.

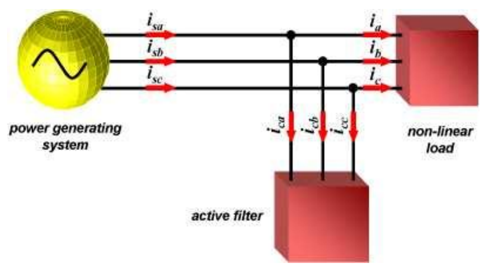


Figure.1 Shunt Active Power Filter

Shunt active power filter compensate current harmonics by injecting equal but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic Components generated by the load but phase shifted by 180^o.

III. INSTANTANEOUS REAL AND REACTIVE POWER THEORY

In 1983, Akagi et al. [1, 2] have proposed the "The Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as instantaneous power theory , or p-q theory. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the a-b-c coordinates to the α-β-0 coordinates, followed by the calculation of the p-q theory instantaneous power components.

The clarkes transformation is shown in figure 2 below:

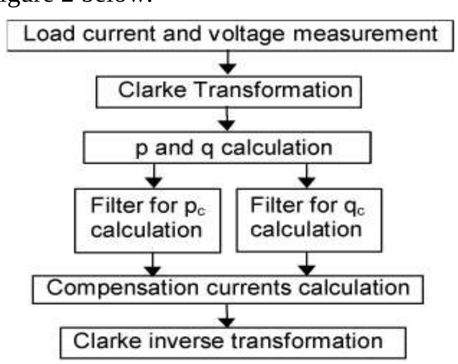


Figure.2 Clarke transformation

The relation of the transformation between each component of the three phase power system and the orthogonal coordinates are expressed in space vectors shown by the following equations in terms of voltage and current as shown in euation 1.

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{………} (1)$$

The three phase coordinates a-b-c is mutually orthogonal. As a result, the conventional power for three phase circuits can be derived by using the above equations. The instantaneous active power of the three phase circuit, p, can be calculated as shown in equation 2.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{……….}(2)$$

and the instantaneous real power is defined as follows in equation 3.

$$p = v_a i_a + v_b i_b + v_c i_c \quad \text{………}(3)$$

From these equations, the instantaneous power can be rewritten as shown in euation 4.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad \text{………..}(4)$$

As the compensator will only compensate the instantaneous reactive power, the real power is always set to zero. The instantaneous reactive power is set into opposite vectors in order to cancel the reactive component in the line current. From the equation 2 & 3, yields equation 5.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix} \quad \text{……..}(5)$$

By deriving from these equation, the compensating reactive power can be identified. The compensating current of each phase can be derived by using the inverse orthogonal transformations as shown below in equation 6.

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{cb} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \quad \text{……..}(6)$$

This instantaneous reactive theorem performs instantaneously as the reactive power is detected based on the instantaneous voltages and currents of the three phase circuits. This will provide better harmonics compensations as the response of the harmonics detection phase is in small delay.

The current control strategy plays an important role in fast response current controlled inverters such as the active power filters. There are several types of current controllers such as three independent hysteresis controllers, three dependent hysteresis controllers, ramp comparison controllers and predictive controllers. However, the hysteresis current control method is the most commonly proposed control method in time domain. This method provides instantaneous current corrective response, good accuracy and unconditioned stability to the system. Besides that, this technique is said to be the most suitable solution for current controlled inverters [5], [6].

IV. HARMONIC CURRENT CONTROL METHOD

Hysteresis current control is a method of generating the required triggering pulses by comparing the error signal with that of the hysteresis band and it is used for controlling the voltage source inverter so that the output current is generated from the filter will follow the reference current waveform is shown in Figure 3.

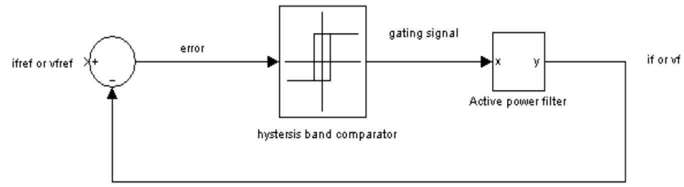


Figure.3 Hysteresis Control

This method controls the switches of the voltage source inverter asynchronously to ramp the current through the inductor up and down, so that it follows the reference current. Hysteresis current control is the easiest control method to implement in the real time.

Figure 4 illustrates the ramping of the current between the two limits where the upper hysteresis limit is the sum of the reference current and the maximum error or the difference between the upper limit and the reference current and for the lower hysteresis limit, it is the subtraction of the reference current and the minimum error. Supposing the value for the minimum and maximum error should be the same. As a result, the hysteresis bandwidth is equal to two times of error [7].

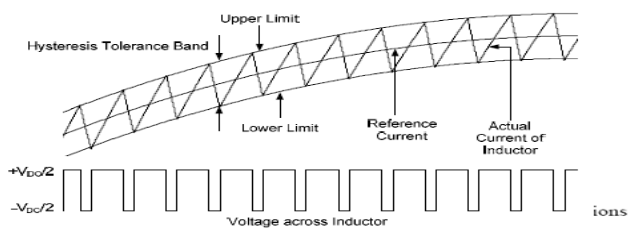


Figure.4 Hysteresis Band

According to the operating principle of the inverter, the output voltages of each phase are significant to the switching pulses of the switches in each leg. As a result, the switching gates for the active power filter can be obtained. The voltage across the inductors show the frequency of the switching and the frequency can be altered by adjusting the width of the hysteresis tolerance band.

V. SIMULATION RESULT

In order to verify the results, the simulation is done in a **MATLAB/SIMULINK** environment. The\model of proposed method is shown in Figure 5 and corresponding waveforms are obtained. The system parameters are given below.

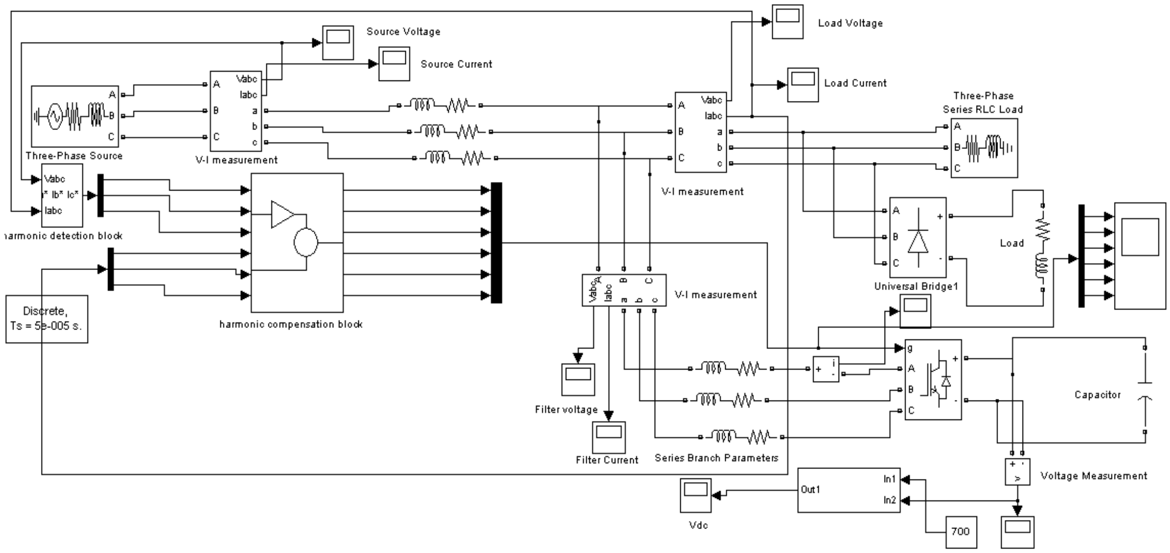


Figure.5 Simulation Model of Hysteresis Current Control

Specification of the design

Simulation is performed on **Three phase Balanced Non –Linear Load** as shown below:

- **System Parameters**

Source Voltage	400
System Frequency	50 Hz

- **Active Power Filter(APF)**

Dc-link voltage	600V
Dc side capacitance	$2000x10^{-6}$
Ac side inductance	8mH
Ac side resistance	0.002 Ω
Load side resistance	10 Ω
Load side inductance	1Mh

The various waveforms for the hysteresis control method are shown in Figure 6 -11. Figure 6 shows AC source voltage, while Figure 7 shows the load voltage and current waveforms. In order to reduce the harmonic level in the system, within the standard, the proposed algorithm based SAF is introduced in the system. Figur8 shows the distorted line currents produced by the algorithm for the filtering purpose and the actual filter current is shown in the Figure9.

By injecting the required amount of current to the system the source current become sinusoidal as shown in Figure 10. With the proposed control algorithm the source current improves with the THD of 2.09% which is well within the standard. In order to perform the above task the capacitor voltage should have to be maintained, and must be regulated by the algorithm. The proposed algorithm can properly regulate the capacitor voltage as shown in Figure 11.

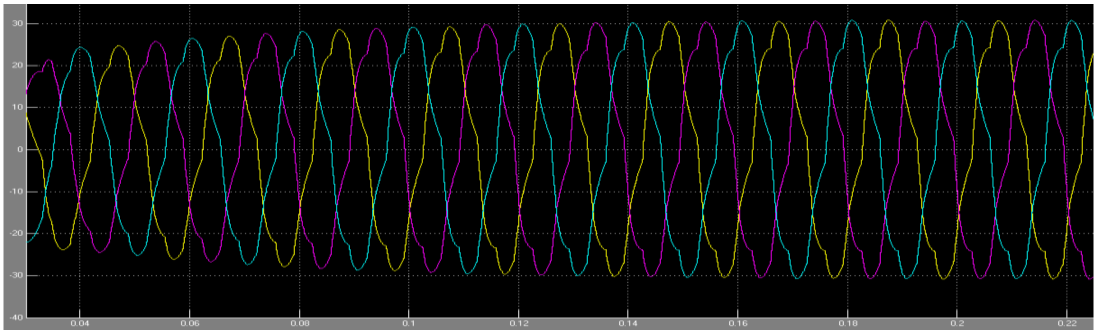
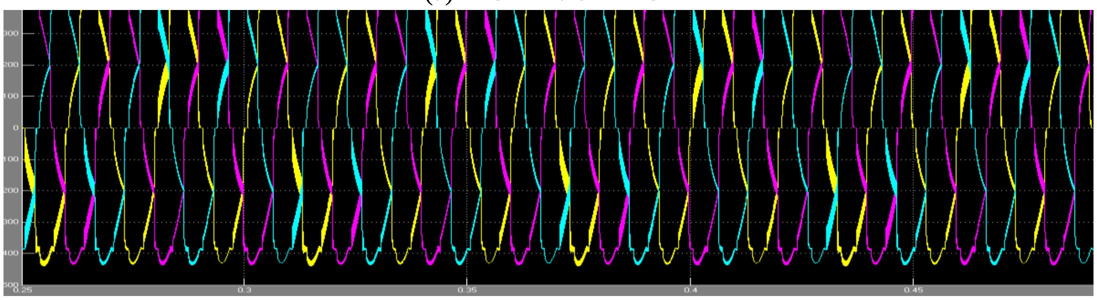


Figure 6 Source Voltage Waveform (a ,b ,c)

(a) LOAD VOLTAGE



(b) LOAD CURRENT

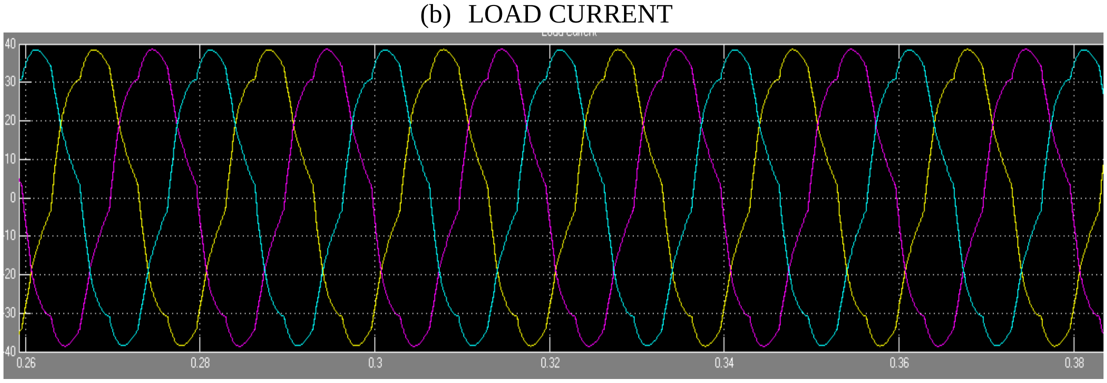


Figure 7 Load voltage and current waveform (a,b,c)

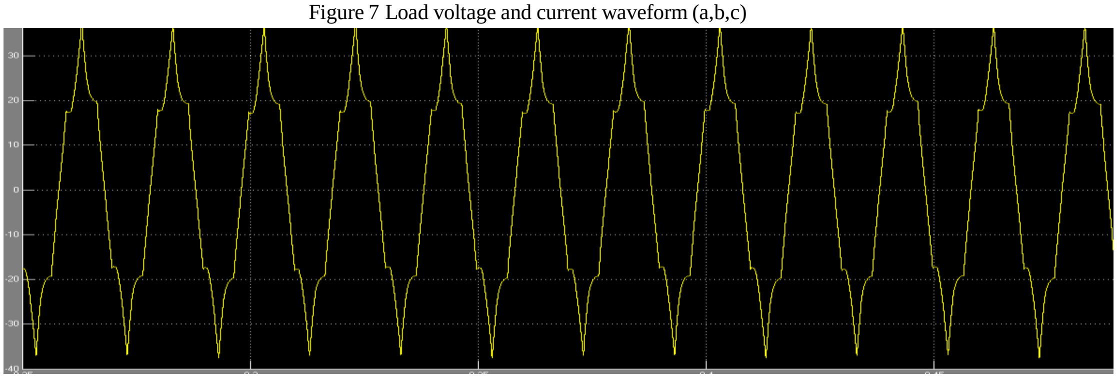


Figure 8 Distorted Line Current

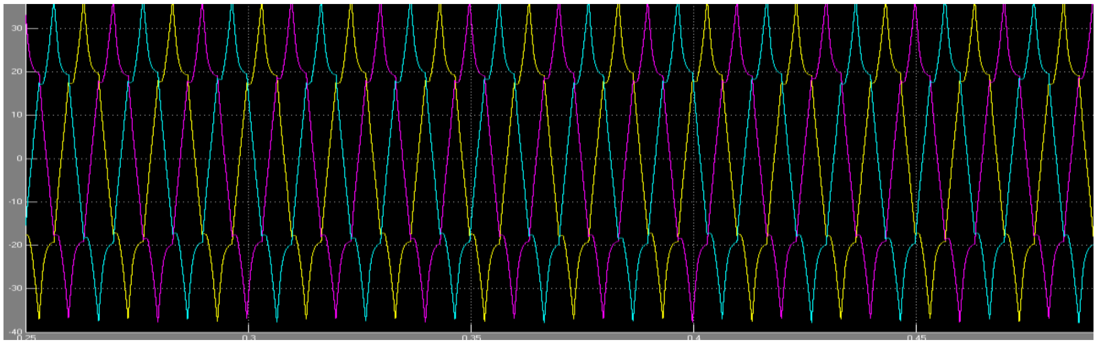


Figure 9 Filter Current

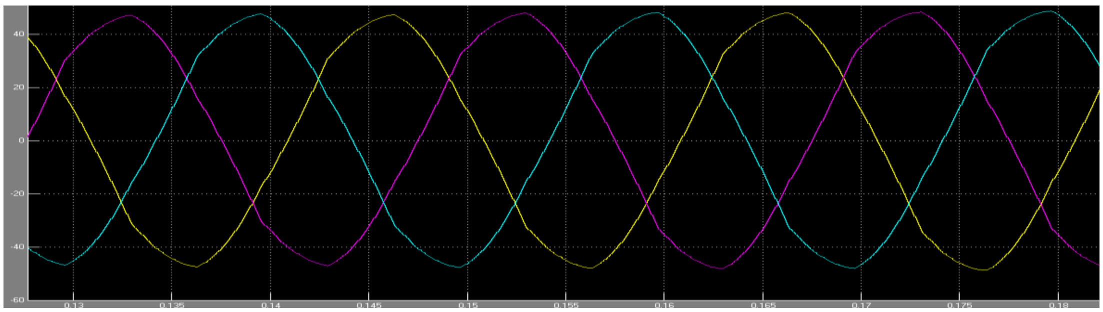


Figure 10 Sinosoidal Source Current

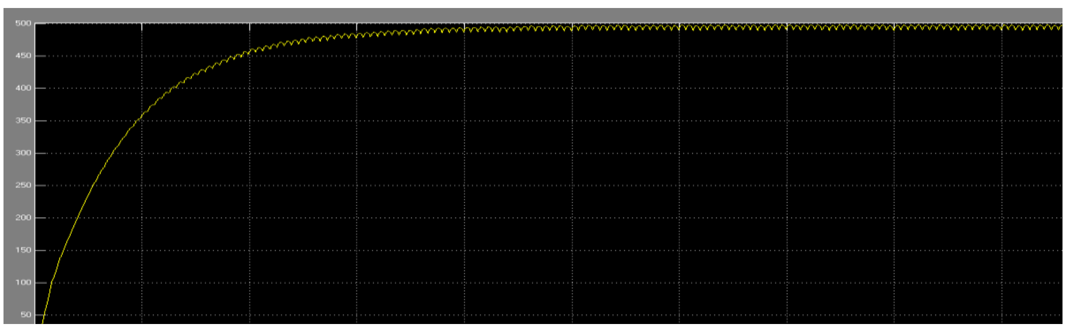


Figure11 D.C. Capacitor Voltage

The frequency of the hysteresis controller is kept 50Hz. These results show that source always remains sinusoidal and lower than the load currents. It is evident from Figure 8 that even if the load resistor is been changed, the proposed algorithm is capable of coping with the change in the load and the transient performance of the Active filter with the scheme is very good. The THD of the existing method has been reduced to 2.09%.

It is observed that the THD of the given system reduced and it can also be observed from the harmonic spectrum of currents that, the proposed algorithm is effective to meet the standard recommendations on harmonic level in unbalanced current source conditions, as well as during load variation conditions. The proposed algorithm also compensates the reactive power requirements of the load and it improves the power factor of the system.

VI. **Result and Discussion**

The objectives of this paper have been achieved by reducing the harmonic components that exist in a power system with a chosen nonlinear load. This system is able to compensate the harmonics caused by a three phase uncontrolled diode rectifier and it provides positive results by reducing the percentage of THD of the line current. The validity in terms of eliminating instantaneous reactive theory in terms of eliminating harmonics and power factor improvement is confirmed from low THD source current which is in phase with source voltage. However, the system can be improved to increase its flexibility and the robustness in compensating harmonics cause by different kinds of nonlinear loads.

VII. Future Work

As instantaneous reactive theory can be implemented in three-phase with excellent results in terms of THD, transient response, reference current generation. The work on extending use of these theory in APF is being done **[9].** Switching required in APF is very high in order of 10 kHz resulting in appreciable amount of power. Thus, one can further work on to reduce switching frequency and to switching losses. For future work, we intend to extend our study to the hybrid structure of series and shunt active power filters and the application of the fuzzy and neural networks to these structures.

VIII. Conclusion

In this paper we are able to compensate the harmonics caused by a three phase uncontrolled diode rectifier and it provides positive results by reducing the percentage of THD of the line current. In fact, the distortion of the power supply current was diminished to a satisfactory level with THD = 2.09%. As a conclusion, the objectives of this paper have been achieved by reducing the harmonic components that exist in a power system with a chosen nonlinear load.

IX. REFERENCES

[1] Akagi.H, 1996. "New Trends in Active Filters for Power Conditioning", IEEE Transaction on Industrial Applications, vol. 32, No 6, Dec., pp 1312-1322.

[2] Akagi.H, 2006. "Modern active filter and traditional passive filters", Bulletin of the polish academy of sciences technical sciences vol.54.No.3

[3] Ali Ajami and Seyed Hossein Hosseini, 2006. "Implementation of a Novel Control Strategy for Shunt Active Filter", ECTI Transactions on Electrical Eng., Electronics, And Communications Vol.4, No.1

[4] .Akagi, Hirofumi. Active Filters for Power Conditioning. In Timothy L.Skvarenina. The Power Electronics Handbook: Industrial Electronics Series. United State of America: CRC Press. Chap. 17:30-63. 2002.

[5] .Peng, F. Z., Akagi, H. and Nabae, A. A Novel Harmonics Power Filter.IEEE Transactions on Power Electronics Specialists Conference. April 11-14. PESC '88 Record: IEEE. 1988. 1151-1159.

[6] .Grady, W. M., Samotyi, M. J. and Noyola, A. H. Survey of Active Line Conditioning Methodologies. IEEE Transactions on Power Delivery.1990. 5 (3): 1536-1542.

[7] Bhattacharya S. and Divan D., "Synchronous frame based controller implementation for a hybrid series active filter system," IEEE Conf. On Industry applications, vol.4,(1995):pp. 2531–2540

[8] Lin C. E., Su W. F., Lu S. L, Chen C. L., and Huang C. L., "Operation strategy of hybrid harmonic filter in demand-side system," IEEE-IAS Annul. Meeting, Industry applications, (1995):pp. 1862–1866.

[9] Dahono P.A, "New hysteresis current controller for single-phase bridge inverters" IET journal on Power electronics, vol.2 (2009):pp. 585-594

Authors Biography

1. **Aasha Chauhan** was born in Faridabad (Haryana), India, in 1989. She received the Bachelor in **Electrical and Electronics** degree from Maharishi Dayanand University, Rohtak, in 2010 and., the Master in **Power System and Drive** degree from the University of **YMCAUST**, Faridabad (Haryana), in 2012 in Electrical engineering. Her research interests power electronics, signal processing in Electrical Drives.

2. **Sachin Sharma** was born in Yamuna nagar (Haryana), India, in 1985. He received the Bachelor in **Electrical** degree from Kurukshetra University,Kurukshetra in 2008 and the Master in **Power System and Drive** degree from the University of **YMCAUST**, Faridabad (Haryana), in 2012 in Electrical engineering. His research interests in power signal and Electrical Drives.