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Enhancement of Power Quality with Shunt Active Power Filter using Fuzzy Adaptive Hysteresis Controller

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***Abstract*— Wide use of power electronic devices has led to harmonic pollution thus affecting the power quality. The use of active power filters is widely accepted and implemented as a solution to the power quality problems in utility and industry applications. The main aim of this paper is to maintain total harmonic distortion (THD) of the system within the specified limits (below 5%). Fuzzy logic controlled shunt active power filter is used to compensate the harmonics. Fuzzy control does not require mathematical model of a system. The performance of a shunt active power filter is compared by using conventional hysteresis controller, adaptive hysteresis current controller and fuzzy adaptive controller for a nonlinear load. The comparison of the simulation results shows the effectiveness of the proposed controller. The behaviour of the fuzzy adaptive logic controller is found to be better to reduce the harmonics. Reference current generation is done by using the synchronous reference frame based algorithm.**

Index Terms*— Shunt Active Power Filter; Fuzzy Controller; Adaptive Control; Power Quality; Total Harmonic Distortion.

I. INTRODUCTION

The Power Quality issue is defined as "any occurrence manifested in voltage, current, or frequency deviations that results in breakdown, upset, failure, or misoperation of end-use equipment." Power electronic devices are highly nonlinear though efficient, cheap and very flexible. From the supply they absorb reactive power and harmonic currents[10]. Waveform distortions will occur because of power quality pollutions. Waveform distortions results in power loss, poor system efficiency, interference with communication lines, over heating of distribution transformers, increased rms value of supply current [3].

Passive filters and active filters are the devices used for controlling harmonic distortion. Passive filters are effective and very cheap for the elimination of harmonics. But it has a drawback of resonance, fixed compensation and they are large in size also [10]. Active power filters (APF) has a remarkable progress on analysis and design and cost effective solution. Active power filters are liable to harmonic and reactive power compensation. These are more flexible, smaller in size and have a better dynamic performance than passive filters. Different order harmonics are suppressed by the active power filters simultaneously [6],[3]. The major parts of the active power filters are a controller that generates compensating signals and three phase inverter for injecting the compensating currents [2]. Most of the pollution issues created in power systems are due to the non-linear characteristics and fast switching of power electronic equipment. Efficiency and cost are considered today almost at the same level. Active power filters have been used over the years to solve these problems to improve power quality [10]. Depending on the required application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or shunt-series type filters. These filters can also be combined with passive filters to create hybrid power filters. Among which shunt active power filter is used to eliminate load current harmonics and reactive power compensation.

Generation of reference currents are accomplished in many ways like frequency domain and in time domain. For the reference signal generation synchronous reference frame based algorithm is used [11]. And for the gating signals of the inverter reference currents and the actual filter currents are compared [5].

Harmonic distortion is one of the major problem frequently encountered. The power quality problems in the power supply are caused by the highly non-linear characteristic based loads. Hence, there is a need to reduce the total harmonic distortion below 5% as specified in IEEE 519-1992 harmonic standard [10]. To compensate the dominant current harmonics shunt active power filters are preferable. The shunt active power filter, with a self-controlled dc bus, has a similar topology like a static compensator (STATCOM) used for reactive power compensation in power systems. Shunt active power filters injects compensating currents equal but opposite to the load currents to compensate the load current harmonics. The shunt APF acts as a current source injecting the harmonic components generated by the load. Fuzzy adaptive controlled shunt active power filter is the efficient approach for the harmonics and reactive power compensation of a nonlinear load.

Wide acceptance of fuzzy logic controllers owe to easy implementation and fast response [4]. The advantage of fuzzy control is that it is based on linguistic variables and does not require a mathematical model of the system. The main focus of this paper is to reduce the THD as low as possible that is below 5%. The work is simulated in MATLAB/SIMULINK. Total Harmonic Distortion is calculated using FFT analysis on source current.

II. SHUNT ACTIVE POWER FILTER

Shunt active filters are widely accepted and dominant filter of choice in most industrial processes. The shunt APF structure is an attractive solution to harmonic current problems based on Voltage Source Inverter (VSI). The APF is connected at the point of common coupling in parallel and is fed from the mains [10]. The focus of the shunt active filter is to supply opposing harmonic current to the nonlinear load results in a net content. Then the supply signals remain purely fundamental [7]. Shunt active power filters also have the benefit of contributing to reactive power and balancing of three-phase currents. Several shunt active filters can be combined together for an increased power ratings to withstand higher currents.

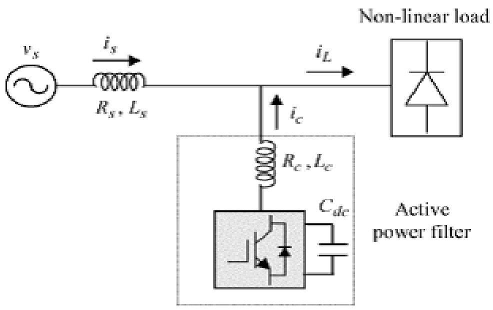

Fig 1: Shunt Active Power Filter

The APF consists of a DC link capacitor, power electronic devices. Due to nonlinear loads shunt APF acts as a current source for compensating the harmonic currents . This is achieved by "shaping" the compensation current waveform, using the Current Controlled voltage source inverter. The compensating currents are obtained by measuring the load current and subtracting from a sinusoidal reference. The main aim of shunt active power filter is to obtain a sinusoidal source current [11].

III. ESTIMATION OF REFERENCE CURRENT

There are two major approaches that are used for the harmonic detection, namely, time domain and the frequency domain methods. The frequency domain methods include Fast Fourier Transform method. The frequency domain methods require computation power, large memory and the results provided during the transient condition may be imprecise. Another approach, the time domain methods are widely followed for computing the reference current and require less calculation [2]. The two mostly used time domain methods are instantaneous real-reactive power (p-q) theory and synchronous reference (d-q-0) theory [1]. Synchronous reference frame based algorithm is followed in this work because in p-q theory it doesn't provide appropriate values in nonlinear load conditions and is frequency variant.

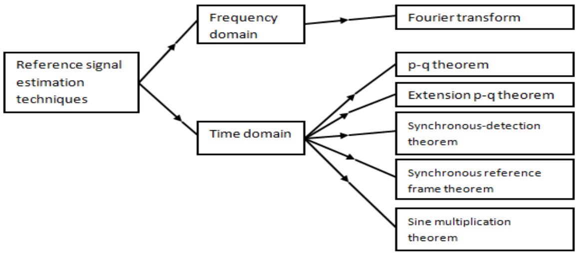

Fig 2: Reference Signal Estimation Techniques

Synchronous reference frame(SRF) theory implements a transformation from three phase to two phase with the same angular velocity as sinusoidal quantity. This theory uses Park transformation here. According to the Synchronous reference frame theory d and q components has a balanced, distortion free and constant magnitude, only o component will be zero .As per Synchronous reference frame theory, it employs abc to dqo transformation for generating the reference currents. SRF theory ensures proper controlling of converters [5]. The desired load currents are transformed to d,q,0 coordinates using park's transformation. and by using inverse park transformation the generated components are allowed to pass through the filter for cancelling out the harmonic currents [11]. The unit vectors(sinwt, coswt) are generated by the Phase Locked Loop(PLL). PLL also helps in synchronization with the supply voltage signals. The reference signals along with sensed load current are feeding to the controller . The output from the controller is the set of switching signals for the voltage source inverter [12]. Hence the shunt active power filter can be able to control the current related problems.

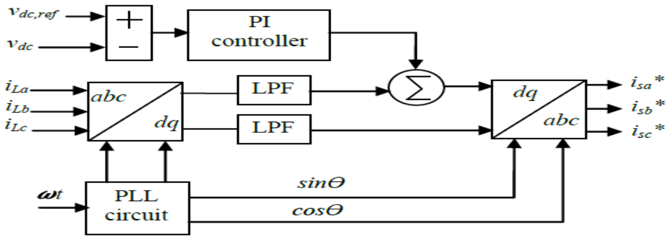

Fig 3: Block Diagram of SRF theory

The transformation from three phase load currents to synchronously rotating d-q-o frame is done by using the equation (1) given below

$$\begin{bmatrix} i_d \\ i_q \\ i_o \end{bmatrix} = \sqrt{2/3}\begin{bmatrix} \cos(wt) & \cos\left(wt-\frac{2\pi}{3}\right) & \cos\left(wt+\frac{2\pi}{3}\right) \\ -\sin(wt) & -\sin\left(wt-\frac{2\pi}{3}\right) & -\sin\left(wt+\frac{2\pi}{3}\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

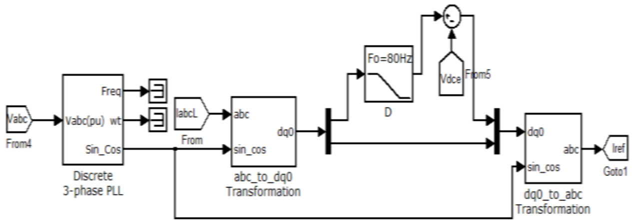

Fig 4: SIMULINK Model For Reference Signal Generation

IV. ROLE OF DC SIDE CAPACITOR

The DC side capacitor serves two main purposes: (i) it maintains a DC voltage with small ripple in steady state, and (ii) serves as an energy storage element to supply real power difference between load and source during the transient period. Thus, the DC capacitor voltage can be maintained at a reference value.

However, when the load condition changes the real power balance between the mains and the load will be disturbed. This real power difference is to be compensated by the DC capacitor [4]. This changes the DC capacitor voltage away from the reference voltage. In order to keep satisfactory operation or the active filter, the peak value of the reference current must be adjusted to proportionally change the real power drawn from the source. This real power charged/discharged by the capacitor compensates the real power consumed by the load. If the DC capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again.

V. CONVENTIONAL HYSTERESIS CURRENT CONTROLLER

The conventional hysteresis-band current control method is popularly used because of its simplicity of implementation, among the various PWM techniques. Besides fast-response current loop and inherent-peak current limiting capability, robustness to load parameter variations. The switching logic for inverter control is formulated as follows: If $i_c < (i_c^* - HB)$ upper switch is OFF and lower switch is ON If $i_c > (i_c^* + HB)$ upper switch is ON and lower switch is OFF where i_c is the filter current and i_c^* is the reference current and HB is the hysteresis band width. However, the current control with a fixed hysteresis band has the disadvantage that the switching frequency varies with in a band because peak-to-peak current ripple is required to be controlled at all points of the fundamental frequency wave. Hence injecting vaste range of high frequency harmonics and acoustic noise. To avoid the variable switching frequency adaptive technique used.

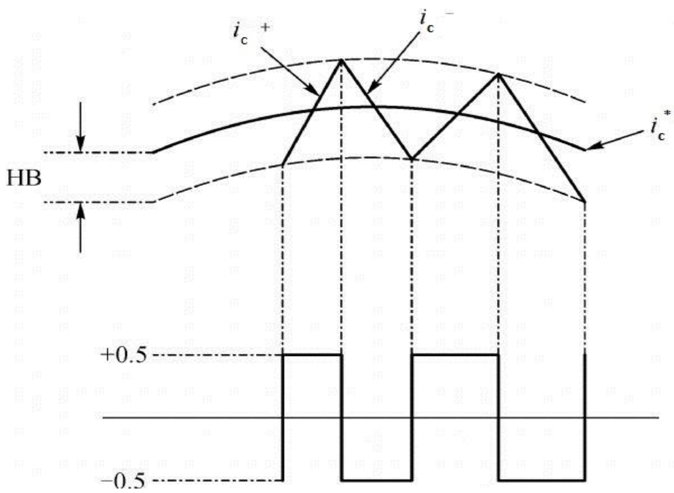

Fig 5: Conventional Hysteresis Current Control Technique

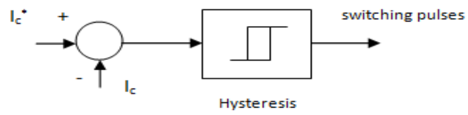

Fig 6: Block Diagram of Conventional Hysteresis Controller

VI. ADAPTIVE HYSTERESIS CURRENT CONTROLLER

This concept was first introduced by Bose(1990). Switching frequency remains constant while the value of hysteresis band(HB) varies with respect to time in Adaptive Hysteresis Current Controller [5]. In order to avoid variable switching problems Adaptive control finding applications now a days [10].

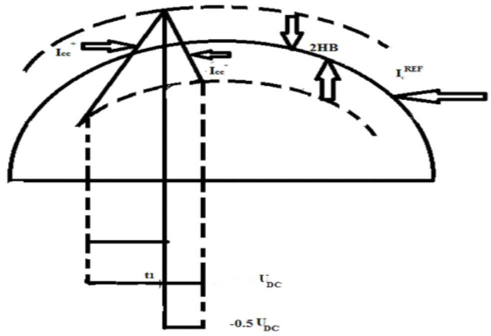

Fig 7: Concept Of Adaptive Control

The current i_{cc}^- tends to cross the lower hysteresis band at point I, where upper side IGBT of leg "c" is switched on. The linearly rising current i_{cc}^+ then touches the upper band at point 2, where the lower side IGBT of leg "c" is switched on. The equations can be written in the respective switching intervals t_1 and t_2

$$\frac{di_{cc}^+}{dt} = \frac{1}{L}(0.5U_{dc} - U_s)$$

$$\frac{di_{cc}^-}{dt} = -\frac{1}{L}(0.5U_{dc} + U_s)$$

From the geometry these equations can be written

$$\frac{di_{cc}^+}{dt}t_1 - \frac{di_c^{ref}}{dt}t_1 = 2HB$$

$$\frac{di_{cc}^-}{dt}t_2 - \frac{di_c^{ref}}{dt}t_2 = -2HB$$

$$t_1 + t_2 = t_c = 1/f_c$$

t_1 and t_2 are respective switching intervals and f_c is the switching frequency. By solving the above equations obtained hysteresis band is

$$HB = \left\{\frac{0.125U_{dc}}{f_c L}\left[1 - \frac{4L^2}{U_{dc}^2}\left(\frac{U_s}{L} + m^2\right)\right]\right\}$$

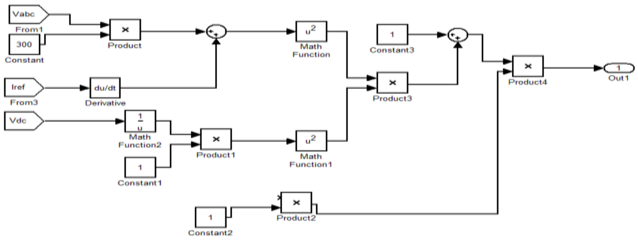

Fig 8: SIMULINK Model For The Hysteresis Band

VII. PROPOSED FUZZY SCHEME

Among the various controllers used for the power filters, the most promising is the fuzzy logic controller. Fuzzy logic controllers have generated a great deal of interest in applications. Fuzzy control is basically an adaptive, which gives robust performance. In fact, fuzzy control is the best adaptive control technique among all other techniques. Fuzzy logic unlike Boolean or crisp logic, deal with problems that have imprecision or uncertainty and uses membership functions with values varying between 0 and 1 [4]. Fuzzy logic controller uses fuzzy set theory with a specified degree of membership in which a variable is a member of one or more sets. Fuzzy logic deals with the human reasoning process in computers, quantify imprecise information, make decision. The advantages of fuzzy logic controllers are can work with imprecise inputs, robustness, no need of mathematical model, and can handle non-linearity [12].

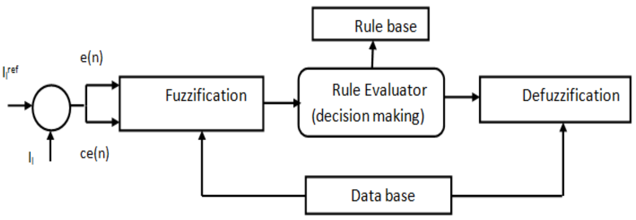

Fig 9: Block Diagram Of Fuzzy Controller

A fuzzy logic controller is conventionally based on a control rules and structure base. The desired switching signals for the filter inverter circuit are determined using Fuzzy logic controller according to the error in the filter current. The design uses centrifugal defuzzification method [8]. The two inputs are error and its derivative and one output which is the command signal to the inverter. The input and output variables are converted into linguistic variables. The two input and output uses triangle membership functions. The Fig.8, Fig.9 and Fig.10 represent the error, change in error and output. Mamdani Fuzzy system has been used in the fuzzy controller [9]. It is characterized as Seven fuzzy sets for each input and Seven fuzzy sets for the output.

Seven Fuzzy subsets are NB(Negative Big), NM(Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM(Positive Medium) and PB (Positive Big). In this paper, we have applied min-max inference method to get implied fuzzy set.

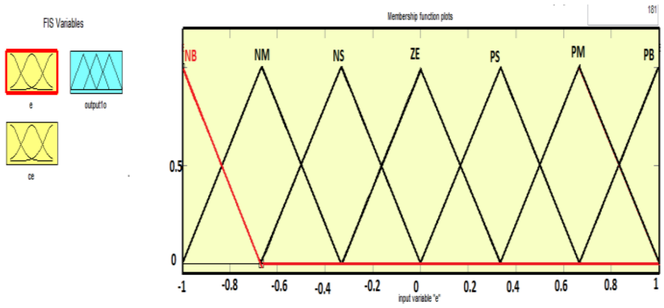

Fig 10: Input Variable 'Error'

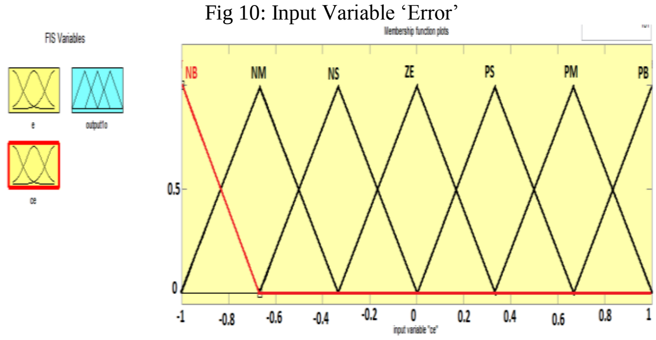

Fig 11: Input Variable 'Change In Error'

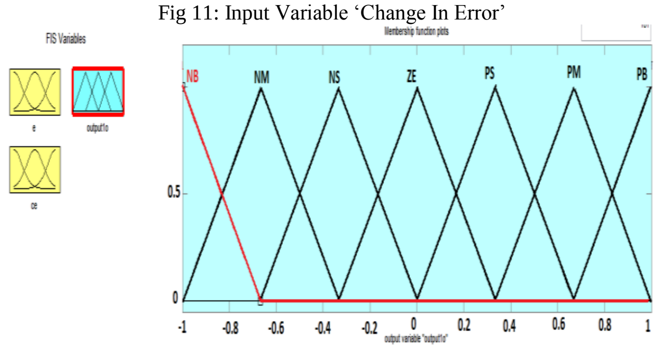

Fig 12: Output

VIII. SIMULATION RESULTS

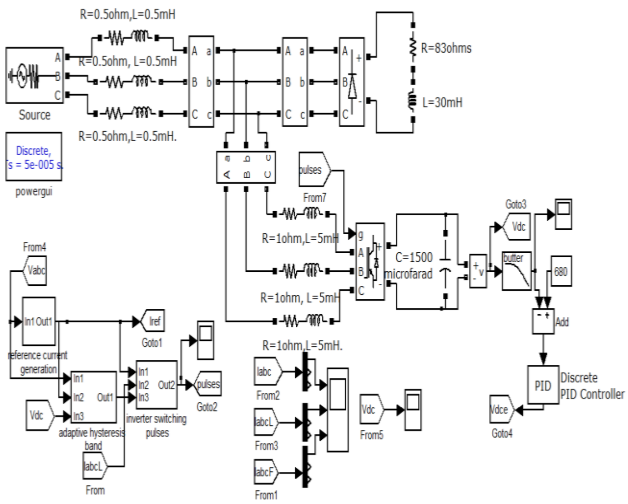

Fig 13: MATLAB Simulation

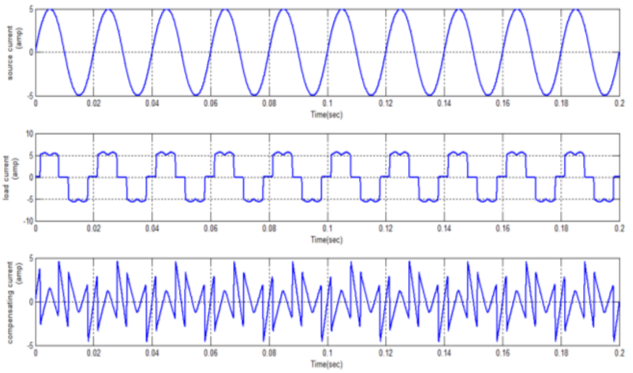

Fig 14: Compensated Source Current, Load Current And Compensating Current

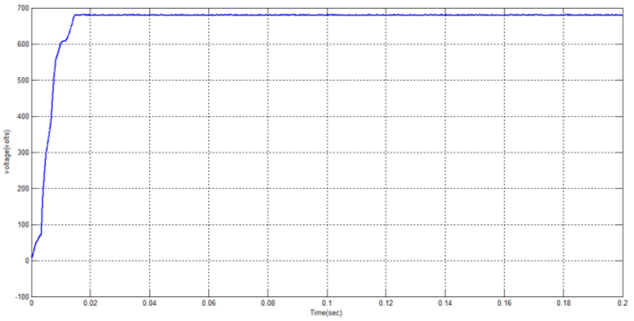

Fig 15: DC Capacitor Voltage

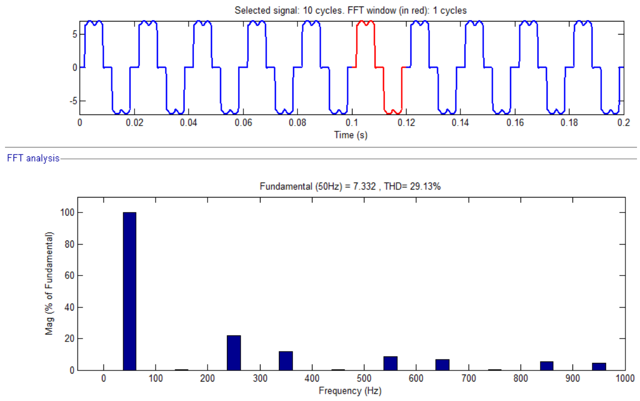

Fig 16: FFT Analysis Of Uncompensated Source Current

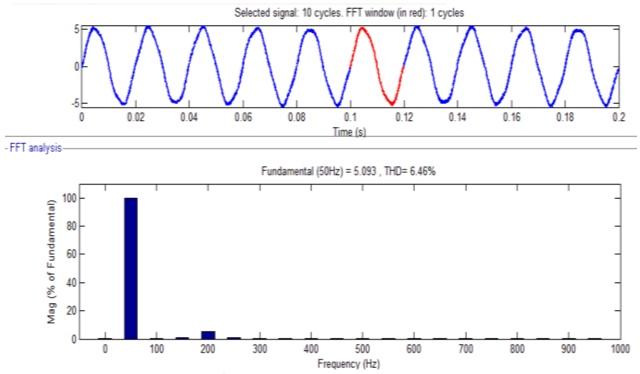

Fig 17: FFT Analysis Of Compensated Source Current Using Conventional Hysteresis Controller

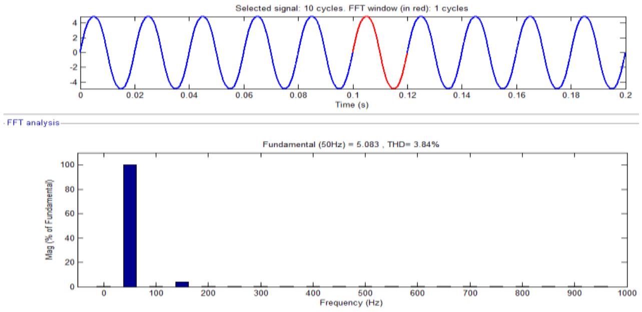

Fig 18: FFT Analysis Of Compensated Source Current Using Adaptive Hysteresis Current Controller

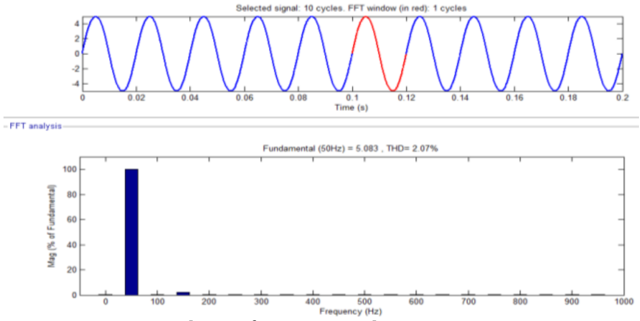

Fig 19: FFT Analysis Of Compensated Source Current Using Fuzzy Adaptive Current Controller

TABLE I. DESIGN PARAMETERS

Source voltage	415 V L-L
System frequency	50Hz
dc link voltage	680 V
dc-bus capacitance	1500µf
Interfacing inductance	5mH
ac-side resistance	0.5 ohm
Load resistance	83ohm
Bridge rectifier	Three phase diode rectifier

TABLE II. THD COMPARISON

Algorithm	Current THD%
Without compensation	29.13%
Conventional hysteresis current controller	6.46%
Adaptive hysteresis current controller	3.84%
Fuzzy adaptive controller	2.07%

IX. CONCLUSION

Harmonic compensation was done using fuzzy adaptive controller based shunt active power filter. It can be seen that total harmonic distortion reduced clearly with the fuzzy adaptive controller than the shunt active power filter with the adaptive hysteresis current controller. And it has a better dynamic performance. Hence by using fuzzy adaptive controller THD is reduced to 2.07% where as with adaptive hysteresis current controller THD is 3.84%.

X. REFERENCES

[1] Akagi H ,Yoshihira Kanazawa, Akira Nabae. Instantaneous reactive power compensation comprising switching devices without energy components. IEEE Trans.lnd. Appl 1984 ;20 :625-630.DOT : 10.11 09/TIA. I 984.4504460

[2] Grady WM, M J Samotyj, A H Noyola. Survey of active power line conditioning methodologies. IEEE Trans. Power Delivery 1990 ;5 : 1536-1542. DOT : 10.1109/61.57998.

[3] Singh ,B., AI-Haddad,K.,and Chandra,A., 1999. A review of active power filters for power quality improvement. IEEE Trans. on Industrial Electronics, Vo1.46, No.5,pp960-971. ISSN : 0278-0046 DOT : 10.1109/41.793345

[4] Jain S K, Agarwal P, Gupta HO. Fuzzy logic controlled shunt active power filter for power quality improvement. TEE proceedings on Electrical Power Application 2002; 149: 317-328. DOT : 10.1 049/ip-epa:20020511

[5] Murat Kale, Engin Ozdemir. An adaptive hysteresis band current controller for Shunt active power filter. Electric Power Systems Research 2005; 73: 113-119. DOT: I 0.1 016/j.epsr.2004.06.006.

[6] Singh B N, Singh B, Chandra A, Rastgoufard P, Al-Hadded K. An improved control algorithm for active filters. IEEE Trans. on Power Delivery 2007; 22: 1009-1020. DOT: 10.1109/TPWRD.2006.886790

[7] Gupta,N.,Dubey S.P.,Singh S.P. 2011.Neural network –based shunt active filter with direct current control for power quality conditioning. International journal of Power Electronics, vol.6, no.3, pp 597-620. DOT: 10.1504IIJPELEC.2011.042803

[8] B.Suresh Kumar, K.Ramesh Reddy, V.Lalitha.’ Pi, Fuzzy Logic Controlled Shunt Active Power Filter For Three-Phase Four-Wire Systems With Balanced, Unbalanced And Variable Loads’. Journal of Theoretical and Applied Information Technology © 2005 - 2011 JATIT & LLS.

[9] Hamza Bentria,’ A Shunt Active Power Filter Controlled By Fuzzy Logic Controller For Current Harmonic Compensation And Power Factor Improvement’. Journal of Theoretical and Applied Information Technology 15th October 2011. Vol. 32 No.1 © 2005 - 2011 JATIT & LLS.

[10] Dr.S. U Prabha, Preethi Thekkath .,2013.Adaptive Hysteresis Current Controlled Shunt Active Power Filter for Power Quality Enhancement, International Conference on Circuits, Power and Computing Technologies [ICCPCT-2013].

[11] Rejil C, AnzariM and Arun Kumar R, ‘Design and Simulation of Three Phase Shunt Active Power Filter Using SRF Theory’, Advance in Electronic and Electric Engineering. ISSN 2231-1297, Volume 3, Number 6 (2013), pp. 651-660 © Research India Publications http://www.ripublication.com/aeee.htm

[12] Monfared, Mohammad; Golestan, Saeed; Guerrero, Josep M.’ A New Synchronous Reference Frame-Based Method for Single-Phase Shunt Active Power Filters’ Journal of Power Electronics. 10.6113/JPE.2013.13.4.692, 2013.