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Simulation of Shunt Active Power Filter with Pi and Fuzzy Logic Controller

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***Abstract:** In this paper the main objective is to improve the performance of shunt active power filter using PI controller and Fuzzy logic controller. Generally shunt active power filters are used to compensate load harmonic currents and reactive power which are produced by non-linear loads by using different controllers. In PI controllers the complexity is more because it requires mathematical model whereas, Fuzzy logic controller does not require a mathematical model it is based on linguistic variables. Hence, this paper proposed control approach and analysed by simulations.*

***Keywords:** Shunt Active Power Filter, PI controller, Fuzzy logic controller, Hysteresis controller, Total Harmonic Distortion.*

I. INTRODUCTION

In present world the use of electronic equipment are widely increasing. By the usage of electronic equipment it produces a huge amount of harmonics in the power system. Harmonics are produced because of non-linear loads like controlled rectifiers such as thyristor converters and uncontrolled rectifiers like diode rectifiers, adjustable speed drives, personal computers, furnaces etc. Though these equipment are high efficient, flexible and economical while coming to the performance they degrade the power quality of the power system by creating harmonic currents and consuming high amount of reactive power [1-5].

The major problems with harmonically polluted power system are caused because of harmonic distortion. The cited problems are poor power factor, increasing losses, excessive heating in the equipment. In power systems, disturbances are encountered by the harmonics. To eliminate these harmonics, we are using filters like passive filters to mitigate harmonics, but they are ineffective to adapt the network characteristic variation and size is also large. So, as an alternative method we are using active filters in place of passive filters to reduce the harmonics. Passive filters fall into series resonance with power system, so that voltage distortion produces high amount of harmonic currents into the passive filter [6].In order to overcome this problems active filters are introduced [6]. Active filters are less expensive and they are controllable and they have quicker response, smaller in size.

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Active filters may put in series or in parallel to the loads. In shunt active power filter topology voltage source converter is connected in parallel to the non-linear load is a solution to harmonic current problems. The main objective of shunt active power filter is to inject harmonic current in the AC system which are equal in amplitude and also opposite in phase to the original harmonics.

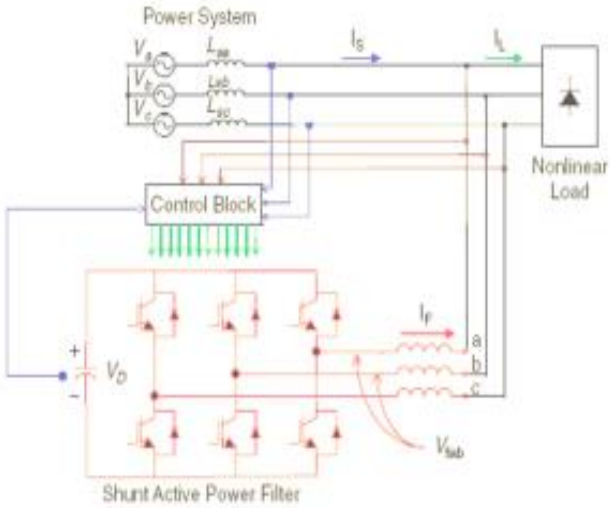

Fig1 Shunt Active Power Filter Topology

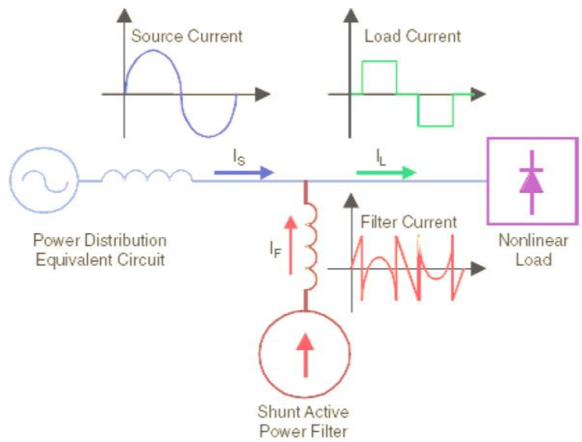

Fig 2 Filter Current Generated To Compensate Load Current Harmonics

II. BASIC COMPENSATION PRINCIPLE

The shunt active filter consists of rectifier, dc capacitor and active filter in shunt. The converter is a voltage source converter. The converter consists of series resistance and inductance. Current harmonics are reduced by injecting equal but opposite current harmonics.[7]

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A. Estimation of Reference Source Current

The instantaneous source current is given by,

$$i_s(t) = i_l(t) - i_c(t) \qquad (1)$$

Where, i_s, i_l, i_c are source current, load current and compensating current.

Source voltage is given by,

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

If a non-linear load is applied, load current will have a fundamental component. Current harmonics can be written as

$$i_l(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \Phi_n) = I_1 \sin(n\omega t + \Phi_1) + \sum_{n-2}^{\infty} \sin(n\omega t + \Phi_n) \qquad (3)$$

Load power can be written as

$$P_L(t) = V_s(t) * i_l(t) = V_m I_1 sin^2\omega t * \cos \Phi_1 + V_m I_1 \sin \omega t * \cos \omega t * \sin \Phi_1 + V_m \sin \omega t * \sum_{n=2}^{\infty} I_n \sin(n\omega t + \Phi_n) \qquad (4)$$

$$P_L(t) = P_f(t) + P_r(t) + P_h(t) \qquad (5)$$

Real power drawn by load can be written as

$$P_f(t) = V_m I_1 sin^2\omega t * \cos \Phi_1 = V_s(t) * i_s(t) \qquad (6)$$

Source current supplied by source after compensation is

$$i_s(t) = \frac{P_f(t)}{V_s(t)} = I_1 \cos \Phi_1 \sin \omega t = I_{sm} \sin \omega t \qquad (7)$$

Where $I_{sm} = I_1 \cos \Phi_1$

The total peak current supplied by the source is given by,

$$I_{sp} = I_{sm} + I_{s1} \qquad (8)$$

If the active filter provides active and reactive power then source current $i_s(t)$ is in phase with the utility voltage and sinusoidal. At this moment of time the active filter provides the compensating current.

$$i_c(t) = i_l(t) - i_c(t) \qquad (9)$$

The desired source current, after compensation can be written as,

$$i_{sa}^* = I_{sp} \sin \omega t \qquad (10)$$

$$I_{sb}^* = I_{sp} \sin(\omega t - 120^0) \qquad (11)$$

$$I_{sc}^* = I_{sp} \sin(\omega t + 120^0) \qquad (12)$$

B. Role of DC side Capacitor:

The DC side capacitor serves two main purposes they are it maintains steady state and it serves as an energy storage device. In steady state, real power supplied by source must be equal to real power demand and a power to compensate the losses in the filter [8]. To maintain dc voltage equal to its reference value the losses through the filter branches will be compensated by source current.

C. Design of DC side capacitor(C_{dc}):

The DC side capacitor design is based on the principle of instantaneous power flow method. The output of the rectifier is voltage that needs to be filtered by connecting the inductance to reduce the level of ripple current. In order to reduce the ripple of voltage source inverter caused by switching of power devices [8]. The design of filtering inductor is based on harmonic current reduction technique. On the dc side of filter, capacitor supplies the dc voltage. DC side capacitor C_{dc} can be written as,

$$C_{dc} = (\pi * I_{c1,rated})/(\sqrt{3}\omega V_{dc,p-p(max)}) \qquad (13)$$

D. Instantaneous active and reactive(p-q) theory:

This theory was developed by Akagi, Kanazawa and Nabae in the year 1983-84. This theory is applied to active power filter control. The calculations are simple consists of algebraic equations. It is used for reference current calculation [9]. It applies an algebraic transformation known as Clarke's Transformation. In this method voltage and load current in a-b-c co-ordinates are transformed to αβ co-ordinates [10]. The equation are given below

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{2/3} * \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (14)$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{2/3} * \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} * \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \qquad (15)$$

Instantaneous power is given by,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} * \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \qquad (16)$$

According to p-q theory real and imaginary power can be written as,

Real power: $p = \bar{p} + \tilde{p}$

Imaginary power: $q = \bar{q} + \tilde{q}$

$\bar{p}$= Mean value of instantaneous real power transferred from source to load.

$\tilde{p}$= Alternating value of instantaneous real power exchanged between source and load.

$\bar{q}$= Mean value of instantaneous imaginary power exchanged between source and load.

$\tilde{q}$= Alternating value of instantaneous imaginary power exchanged between phases and load.

E. PI Controller:

PI controller is used to estimate the output and controls the dc voltage. The error signal passes through it, and eliminates the steady state error in dc voltage [11]. The transfer function of the PI controller is given by,

$$H(s) = K_p + \frac{K_i}{s} \qquad (17)$$

$$I_{max} = e * K_p + K_i \int e\, dt \qquad (18)$$

Where, K_p is the proportional constant which determines the dynamic response of the voltage control and K_i is the integral constant which determines the settling time.

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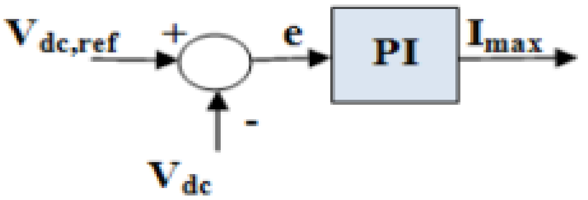

Fig 3 PI Controller Function

F. Fuzzy Logic Controller:

In order to implement control algorithm of a shunt active filter the DC side capacitor voltage must be sensed and compared with reference value. The error and change in error are two inputs for fuzzy processing. In fuzzy controller the control action is determined by sets of linguistic rules. The advantage is it does not require mathematical model and works with imprecise inputs.

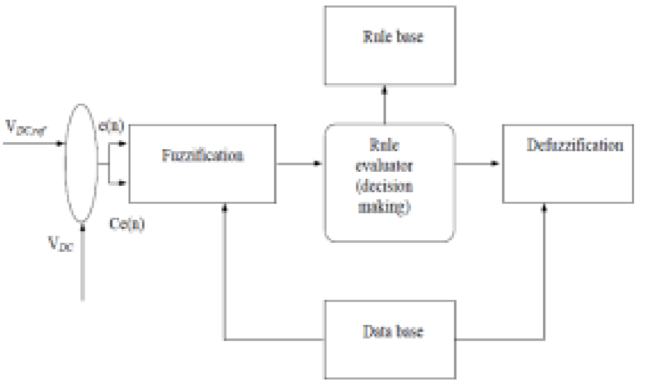

Fig 4 Block Diagram of Fuzzy Controller

- **Fuzzification:**

In Fuzzy logic control instead of numerical variables we give linguistic variables. Error between reference and output signal is assigned as Positive small (PS), Positive Medium (PM), Positive Big (PB), Negative Small (NS), Negative Medium (NM), Negative Big (NB), Zero (ZE). Triangular membership function is used for fuzzification. Fuzzification is a process which converts number variable to a linguistic variable [12].

- **Rule Elevator:**

Fuzzy logic uses linguistic variables instead of numerical variables. The fuzzy set rules to control the system are,

AND-Intersection: $\mu A \cup B = min[\mu A(X), \mu B(x)]$
OR-Union: $\mu A \cup B = max[\mu A(X), \mu B(x)]$
NOT-Complement: μA=1-μA(x)

- **Defuzzification:**

The fuzzy logic rules of generated output in linguistic variables; linguistic variables are transformed to crisp values. The selection is between accuracy and computational intensity. Consequently, one should defuzzify the fuzzy control action i.e. output inferred from fuzzy control algorithm [13].

- **Rule Base:**

Rule base stores the linguistic control rules required by rule elevator. The rules used in the controller are shown in below table.

Table 1 Fuzzy Rules

$^{e}/_{de}$	NB	NM	NS	ZE	PS	PM	PB
NB	ZE	ZE	NB	NM	NM	ZE	ZE
NM	ZE	ZE	NM	NM	NS	ZE	ZE
NS	ZE	ZE	NS	NS	ZE	ZE	ZE
ZE	ZE	ZE	NS	NM	PS	ZE	ZE
PS	ZE	ZE	ZE	PS	PS	ZE	ZE
PM	ZE	ZE	NS	PM	PB	ZE	ZE
PB	ZE	ZE	NS	PM	PB	ZE	ZE

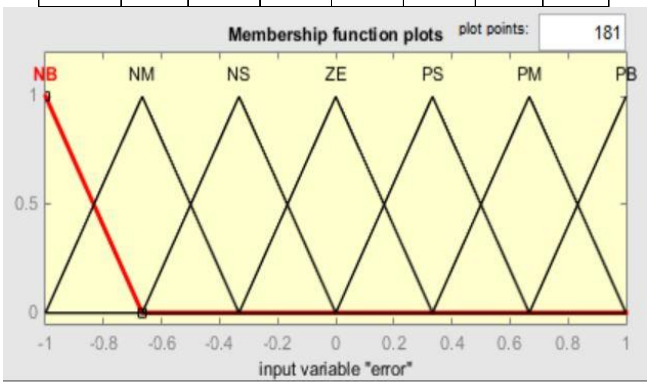

Fig 5 membership functions for input and output variables

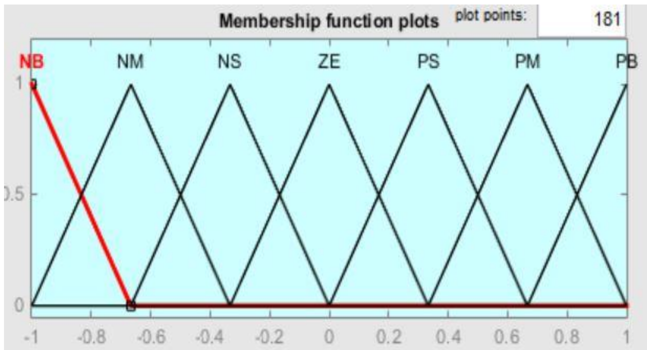

Fig 6 Membership function for output variable

G. Hysteresis Current Controller:

The implementation of hysteresis current controller is based on switching signals from comparison of current error with tolerance band i.e., comparison of actual phase current with tolerance band around the reference current with that phase. On the other hand, this type of band control is negatively affected by phase current interactions. This is due to the commutations of three phases. Depending on load conditions switching frequency may vary resulting in irregular operation of inverter. These Controllers are used in different application like motion control, active filtering. This controller provides fast and robust dynamic response and requires simple implementation in digital signal platforms[14].

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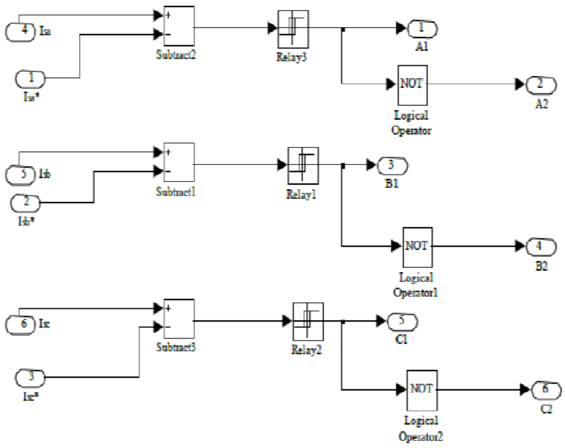

Fig 7 Simulation of hysteresis controller

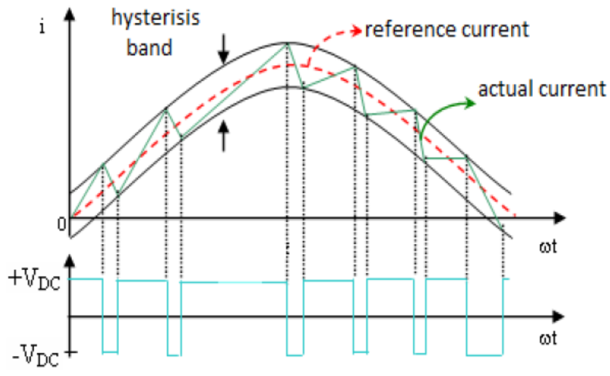

Fig 8 Pulse Generation of Hysteresis Controller

III. SIMULATION AND RESULTS

The performance of proposed PI and Fuzzy logic control strategy is evaluated through simulation using Matlab/Simulink power tools. Power devices used are IGBT's with diodes and thyristors.

Table 2 System Specifications

System Parameters	Values
Source voltage, frequency	400V, 50Hz
Source Impedance (R_s, L_s)	0.01Ω, 0.001mH
Filter Impedance (R_c, L_c)	1Ω, 1.2mH
Load Impedance (R_l, L_l)	10Ω, 5mH
LC Filter	100Ω, 0.001H, 5μF
V_{dc}	850V
DC link Capacitance	20μF
K_p, K_i	0.1, 1

PI and FLC based active power filter simulation results are verified and presented. Source voltage before compensation and source current before compensation is shown below

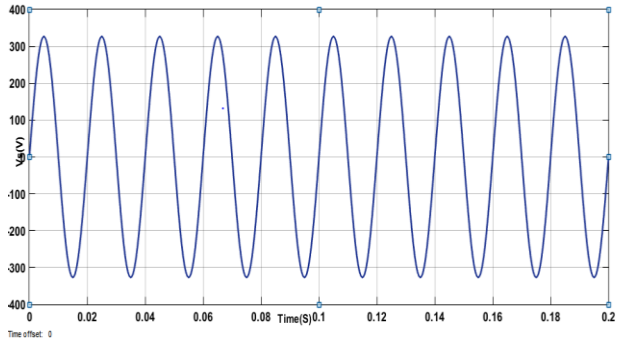

Fig 9 Source voltage without filter

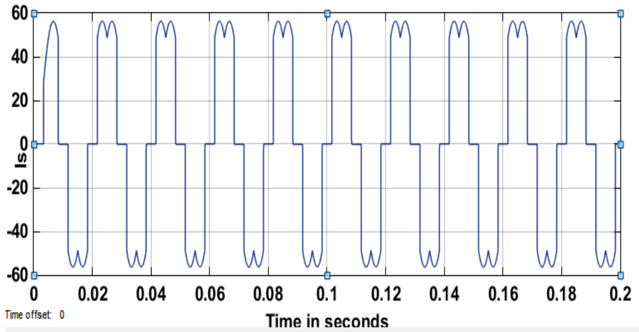

Fig 10 Source Current Without Filter

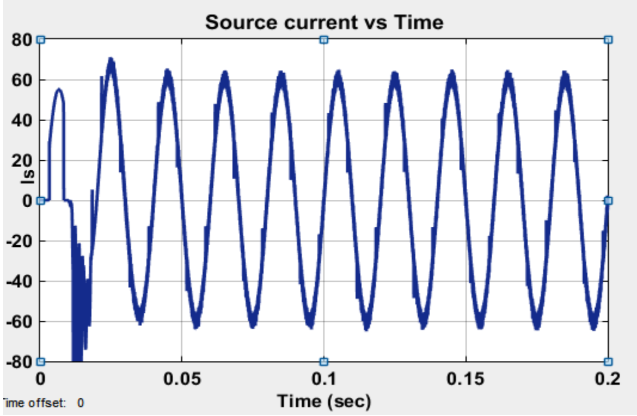

Fig 11 Source current with PI Controller

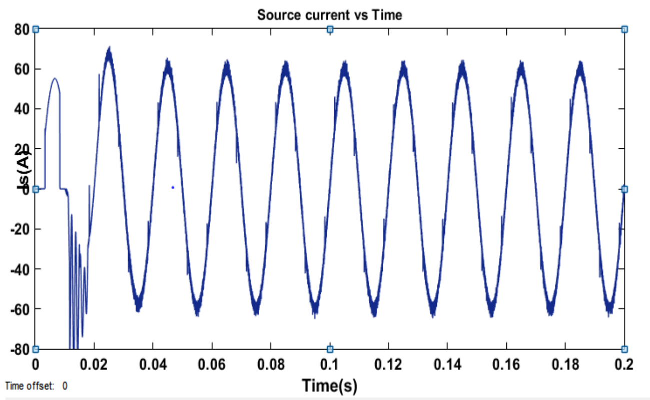

Fig 12 Source current with Fuzzy controller

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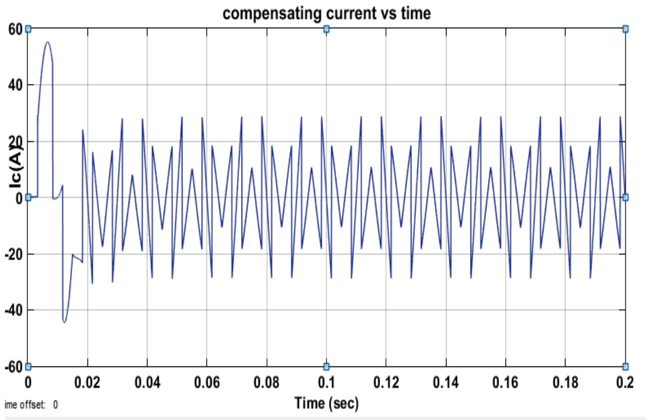

Fig 13 Compensating current with PI Controller

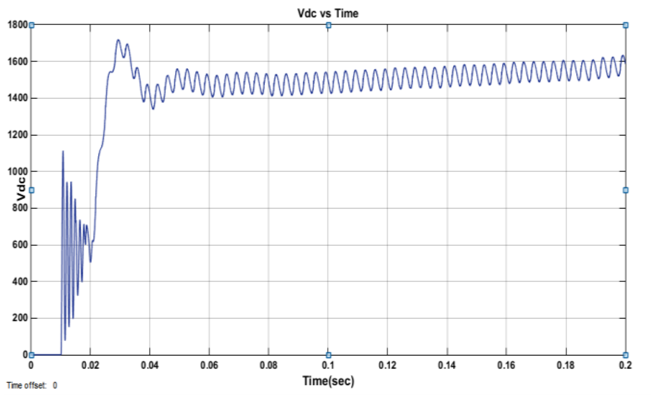

Fig 14 V_{dc} with PI Controller

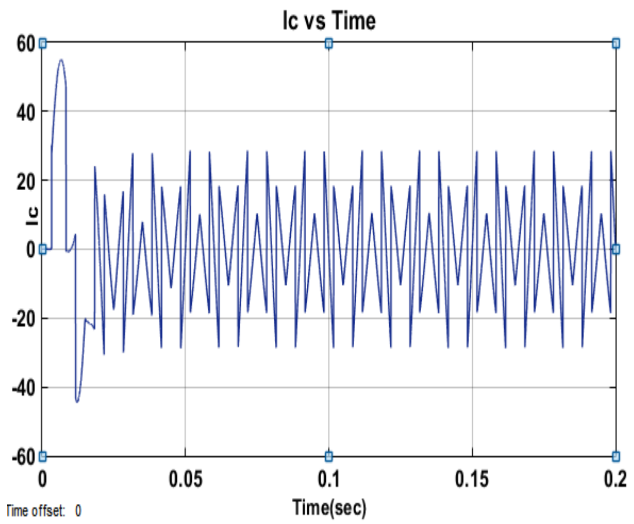

Fig 15 Compensating current with Fuzzy Controller

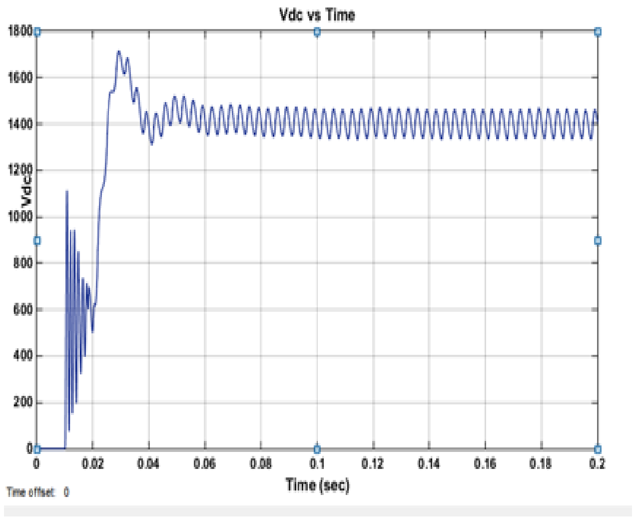

Fig 16 V_{dc} with Fuzzy controller

By using PI controller and Fuzzy logic controller, with diode rectifier total harmonic distortion (THD) has reduced from 30.26% to 4.65% and 4.63%. The THD's for different loads are shown below.

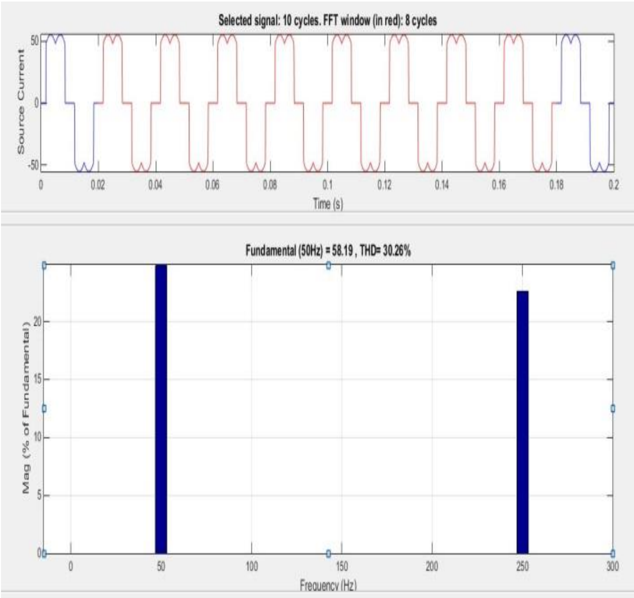

Fig 17 THD without filter (30.26%)

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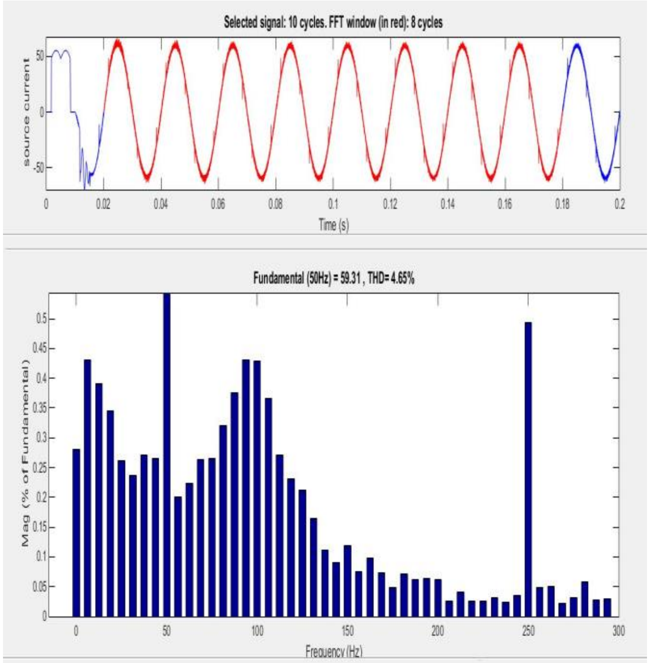

Fig 18 THD with PI controller (4.65%)

Table 3 THD Values using Diode Rectifier

Source current I_S			
Load	THD Without filter	THD With PI Controller	THD With Fuzzy logic controller
R	30.26%	4.65%	4.63%
RL	30.31%	4.75%	4.72%
LC	31.34%	26.77%	27.81%

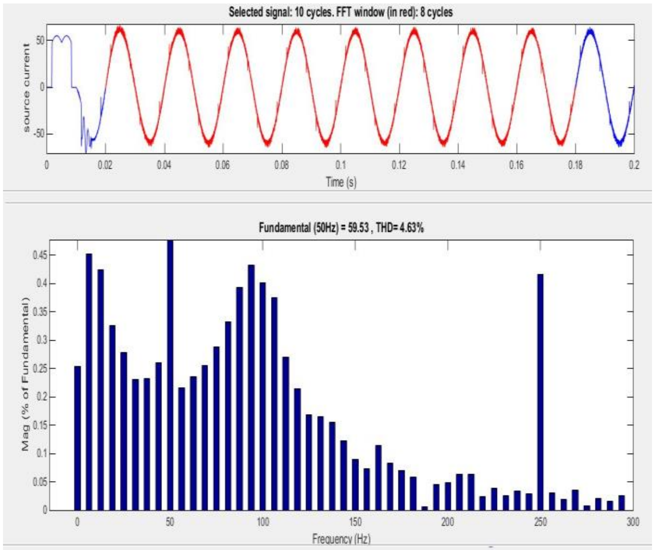

Fig 19 THD with Fuzzy Logic controller (4.63%)

By using PI Controller and Fuzzy logic controller with controlled rectifier using thyristors Total Harmonic Distortion (THD) has reduced from 30.26% to 4.90% and 4.86%. The THD's for different loads at different firing angles are shown in below table.

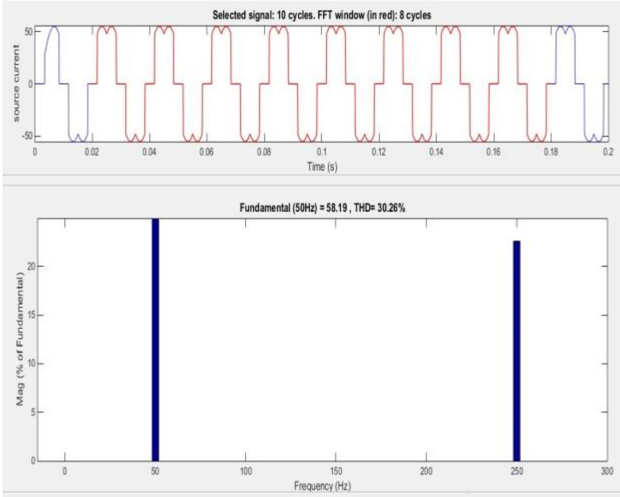

Fig 20 THD without filter using controlled rectifier (30.26%)

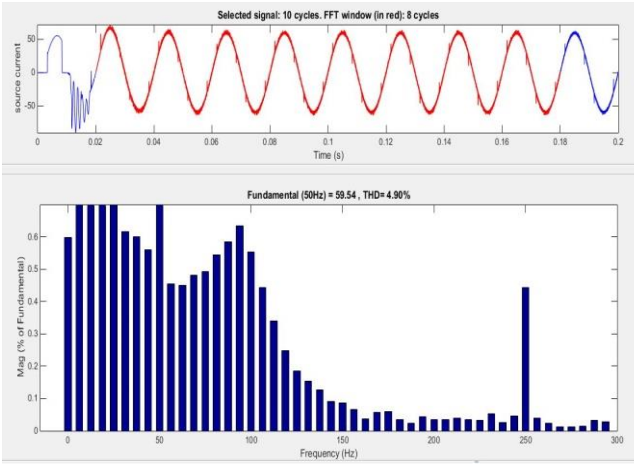

Fig 21 THD with PI controller using controlled rectifier (4.90%)

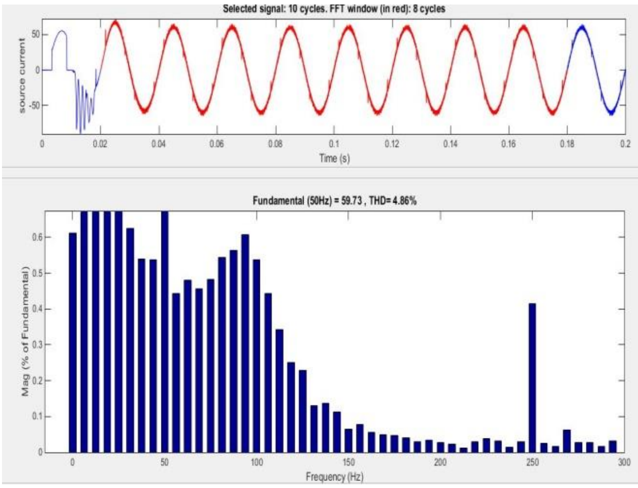

Fig 22 THD with Fuzzy controller using controlled rectifier

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Table 4 THD Values using Controlled rectifier

Source current *Is*				
Firing angle	Load	THD without Filter	THD with PI Controller	THD with Fuzzy Controller
0^0	R	30.26%	4.90%	4.86%
	RL	30.31%	5.08%	4.97%
	LC	31.34%	26.55%	25.85%
30^0	R	61.13%	30.46%	11.66%
	RL	43.46%	25.24%	29.69%
	LC	215.22%	60.83%	62.07%
60^0	R	129.74%	82.29%	83.80%
	RL	98.08%	63.02%	63.22%
	LC	388.30%	116.52%	121.79%
90^0	R	774.59%	164.53%	180.64%
	RL	750.99%	164.44%	179.55%
	LC	789.81%	164.98%	180.00%

IV. CONCLUSION

In this paper shunt active power filter has been investigated and developed using PI and Fuzzy logic controller for reduction of total harmonic reduction in the source current. It is found that shunt active power filter improves the power quality by eliminating current harmonics of the load current. Fuzzy logic controller based active power filter has a better performance when compared to PI controller. The THD values of source current for PI controller using Diode rectifier and controlled rectifier are 4.65% and 4.90% respectively. Similarly, for the Fuzzy logic controller, the THD values of source current using uncontrolled and controlled rectifiers are 4.63% and 4.86% respectively. The THD of source current is reduced to 4.63% using Fuzzy controller.

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