Simulation of Fuzzy Logic Based Shunt Hybrid Active Filter for Power Quality Improvement

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Abstract— This paper deals with the implementation of fuzzy logic based Shunt Hybrid Active Filter (SHAF) with non-linear load to minimize the source current harmonics and provide reactive power compensation. Comparison with Proportional Integral (PI) based SHAF is also analyzed. Shunt Hybrid Active Filter is constituted by Active Filter connected in shunt and shunt connected three phase single tuned LC filter for 5th harmonic frequency with rectifier load. The Active Filtering System is based on Synchronous Reference Frame. The proposed fuzzy logic based control strategy improves active filter operation and reduces the selective harmonic contents. The control strategies are demonstrated through MATLAB Simulated Environment.

Index Terms— Hybrid Active Filter, Total Harmonic Reduction, Power Quality, Fuzzy Logic Control

I. Introduction

The design ramification and immense cost of losses of the conventional passive filters, as well as their restricted potential to minimize inter-harmonics and non-characteristic harmonics, has encouraged the advancement of harmonic compensation by means of power electronic devices commonly referred to as Active Power Filters. The Active Power Filter (APF) is implemented using self-supported dc bus with three phase Voltage Source Inverter(VSI).The operating principle of APFs is primarily canceling the distorting harmonic current by analyzing them and generating a harmonic current spectrum in phase opposition to the measured current.

Passive filters were traditionally preferred because of low cost and simple robust structure as they used to absorb harmonic currents. But they offer fixed compensation and generate system resonance [1]–[5]. The shunt active filters can provide compensation of harmonics, reactive power and/or neutral current in ac networks, regulation of terminal voltage, suppression of the voltage flicker, and improve voltage balance in three-phase system [6], [7], [8]. Then next topology shunt hybrid power filter named transformerless hybrid filter was proposed which uses a single LC passive filter for each phase and a small rated voltage source converter based active power filter [9]

The hybrid filter consists of a three-phase LC filter tuned at the 5th harmonic frequency and a small-rated three-phase voltage-source inverter. The compensating current of the hybrid shunt active filter consists of a fundamental component and harmonic components and they are determined by the impedance of the LC filter and are controlled by the active filter.

The paper is organized as follows.In section II Design of shunt hybrid Active Filters are explained .The details of the control scheme used is explained in section III. Section IV outlines the MATLAB implementation and simulation results for the proposed configuration. Finally conclusion is presented in Section V

II. Design of Shunt Hybrid Active Filters

Fig 1 shows the proposed shunt hybrid active filters with nonlinear load drawing non-sinusoidal current. The system consists of active filter in shunt with passive filter. The shunt hybrid active filter works such that ac mains current is created to have only fundamental frequency component, by absorbing harmonics all the way through passive filters. The active filter performs as a harmonic voltage source, compensates voltage drop in passive filter at harmonic frequencies at PCC,

thereby creating a short circuit across passive filter at   harmonic frequency. [10]
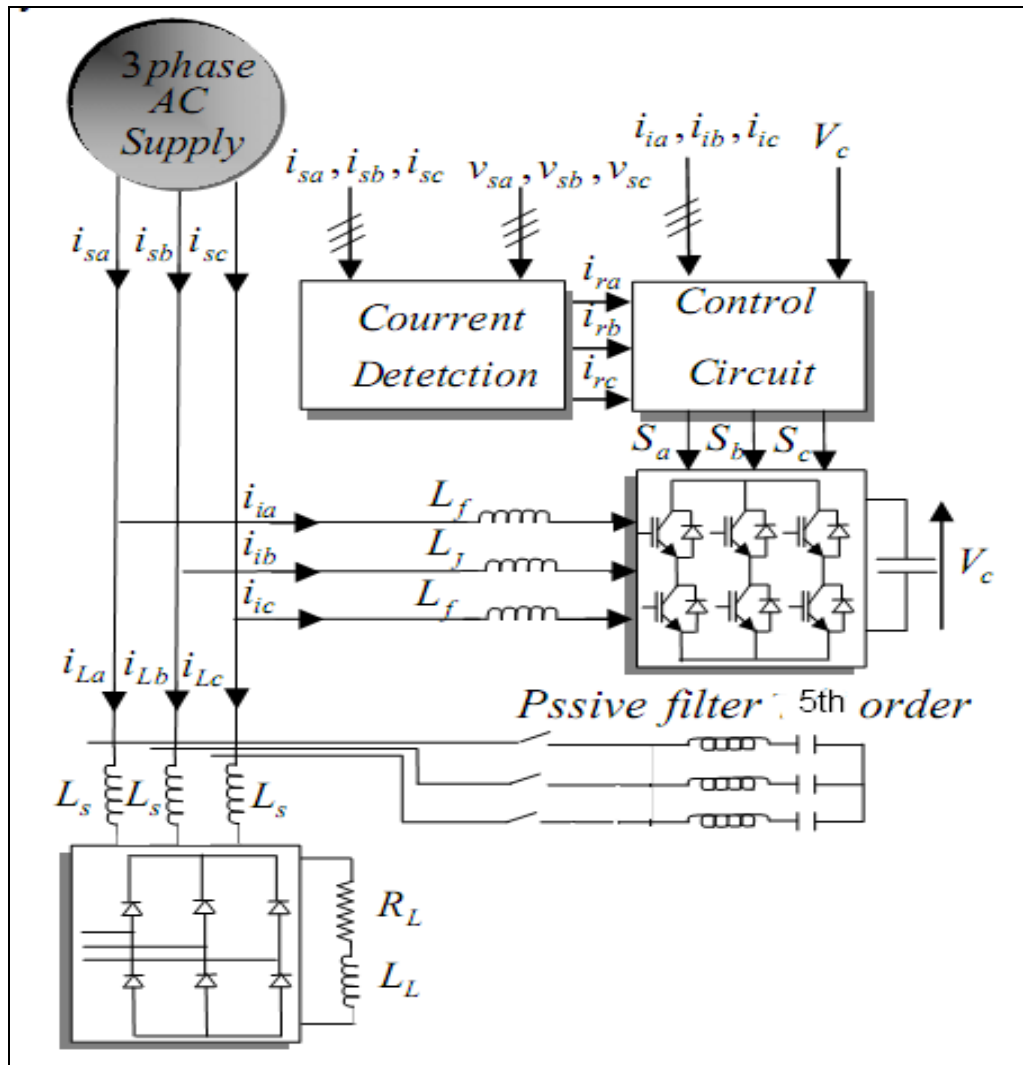

Fig. 1: Circuit Diagram for Shunt Hybrid Active Filter

The fundamental shunt passive filtering law is to catch the selective harmonic currents in LC circuits, tuned up to the harmonic filtering frequency to be eliminated from power system. In single-tuned filter, the reactance of inductor is equal to that of capacitor at resonant frequency f.

$$f = \frac{1}{2\pi \sqrt{L_f C_f}} \qquad (1)$$

The primary step to design a single tuned filter is to first define the size of the capacitor with a reasonable power factor at the operating line voltage.

$$X_c = \frac{V_{L-L}^2}{kVAR.filter} \qquad (2)$$

Once the size of the capacitor is defined with a realistic power factor at the operating line voltage, the

reactance value can be calculated by using (2) where filter kVAR signifies the reactive power capacity of the filter and V_{L-L} stands for the line to line rated voltage of the filter. Other parameter included in filter design is resistance value of filter R which can be determined by defining the sharpness of filter Q, also termed as Quality factor.

$$Q = \frac{\sqrt{L_f C_f}}{R} \qquad (3)$$

III. Control Scheme

In Voltage Source Converter type Active Power Filter the circuit has Dc link capacitor and no additional DC supply is required for DC link side; because a small amount of current at fundamental frequency is drained from the supply to meet the filter losses so that DC link

voltage is kept stable. Thus Synchronous Reference Frame Theory was introduced in [11] is used to generate the pulses for the semiconductor switches which support the maximum filter current introduced to the main side. The three phase currents (i_a, i_b, i_c) , load currents (i_{La}, i_{Lb}, i_{Lc}), the PCC voltages (v_{sa}, v_{sb}, v_{sc}) and

dc bus voltage (v_{dc}) of active filter are sensed as feedback signals. Load currents are transformed into synchronously rotating reference frame d axis and q axis by using $\cos\theta$ and $\sin\theta$ where θ is derived from three phase PLL circuit.
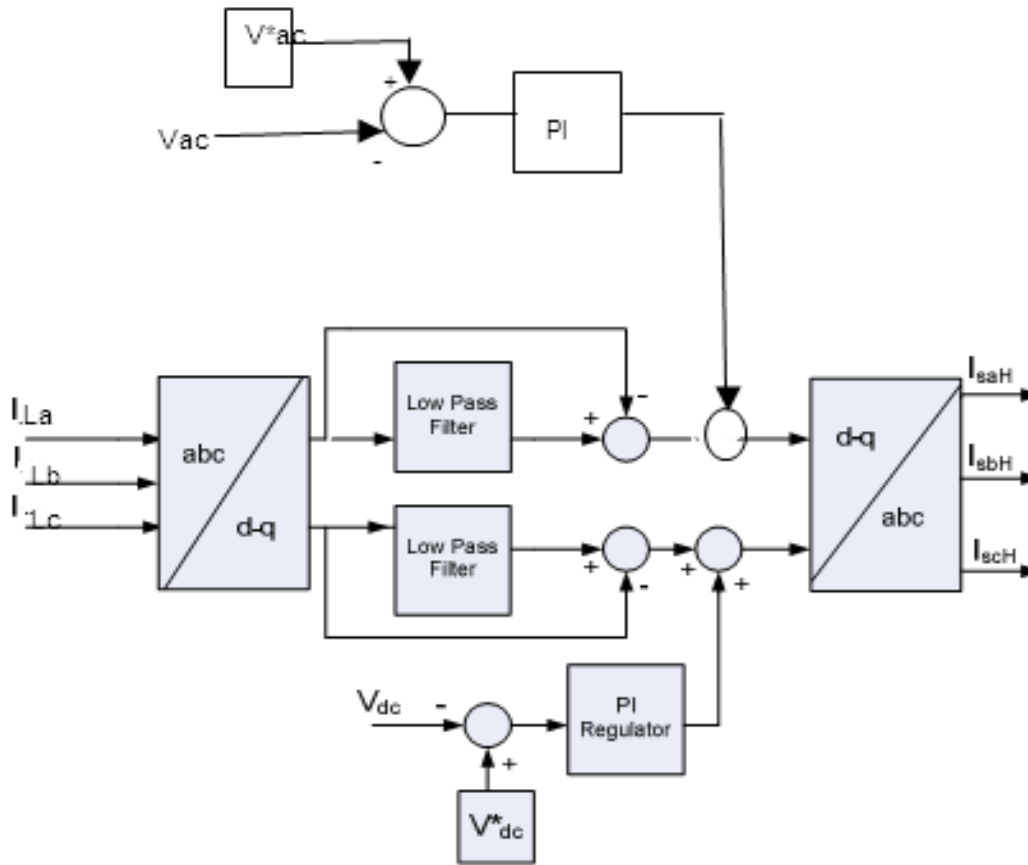

Fig. 2: Synchronous Reference Frame Method

The d-axis and q-axis currents consist of fundamental and harmonic components as

$$i_{Ld} = i_{dd} + i_{da} \tag{4}$$

$$i_{Lq} = i_{qd} + i_{qa} \tag{5}$$

3.1 PI Controller

The PI controller consists of proportional term and integral term. Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. The reference currents for the control of active filter are generated according to the equation (6). The output of PI controller at the dc bus voltage of active filter is considered as the current (i_{loss}) for meeting its losses.

$$i_{loss(n)} = i_{loss(n-1)} + k_{pd}(v_{de(n)} - v_{de(n-1)}) + k_{id} v_{de(n)} \tag{6}$$

where, $v_{de} - v_{de(n-1)}$ is the error between the reference$(v_{dc}*)$ and sensed (v_{dc}) dc voltage at the nth sampling instant. K_{pd} and K_{id} are the proportional and the integral gains of the dc bus voltage PI controller.

The reference source current is therefore expressed as,

$$i_d^* = i_{dd} + i_{loss} \tag{7}$$

Similarly PI controller is used to regulate reactive power

$$i_{qr(n)} = i_{qrs(n-1)} + k_{pq}(v_{te(n)} - v_{te(n-1)}) + k_{iq} v_{te(n)} \tag{8}$$

The reference supply quadrature axis current is as

$$i_q^* = i_{qd} + i_{qr} \tag{9}$$

where, $v_{te(n)} = v_s^* - v_{(n)}$ denotes the error between reference (v_s^*) and actual$(v_{s(n)})$ terminal voltage amplitudes at the n sampling instant. K_{pq} and K_{iq} are the proportional and the integral gains of the PI controller.

3.2 Fuzzy Logic Controller

Conventionally PI controllers have been used to maintain the DC bus voltage. In this paper, the followed control strategy employs the decision making for the control of DC bus by using Fuzzy Logic controller. The concept of Fuzzy Logic Controller (FLC) was offered in 1965 by Professor Lotfi Zadeh .He proposed a way of processing data by consenting partial set membership rather than crisp set membership [12]. Thereafter, it was recognized to be an admirable choice for many control system applications as it mimics human control logic.
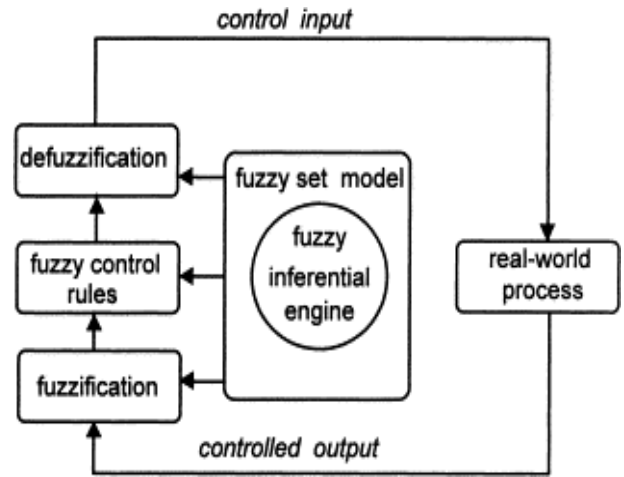

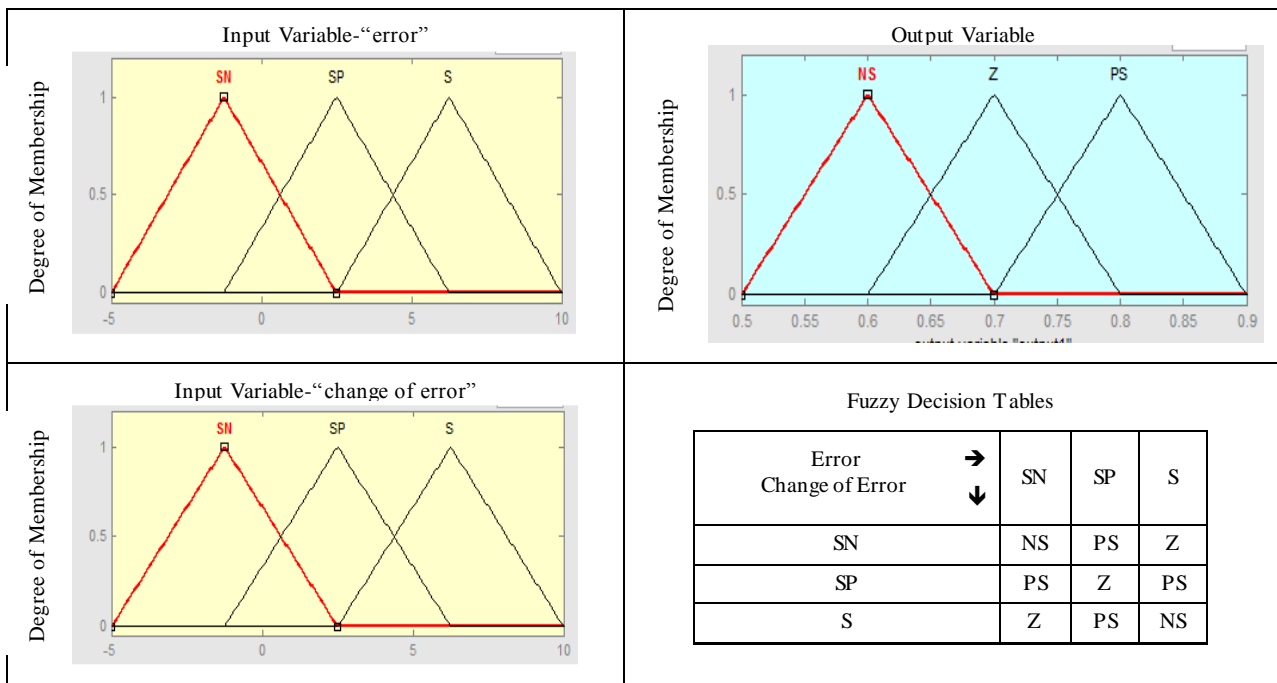Fig. 3: Architecture of Fuzzy Logic Controller

Fig 4 input/output variables and fuzzy control rules

Error → Change of Error ↓	SN	SP	S
SN	NS	PS	Z
SP	PS	Z	PS
S	Z	PS	NS

Fig 3 shows the architecture of Fuzzy Logic Controller (FLC).The internal structure of Fuzzy controller consists of fuzzification, decision making unit, rule base, defuzzification,.The triangular shaped membership functions are considered for the input variables error 'e' ($v_{dc}^* - v_{dc}$), change in error 'ce' (de/dt) and output 'du' as shown in Figs 4.Three membership functions namely SN (small negative),S (small), SP (small positive), ZE (zero), are selected for input variables and PS (positive small), NS (negative small) and Z (zero) are chosen for output variables .Firstly all three variables are normalized with in the membership function range. In the second stage, the fuzzy variables are processed by an interface which executes 9 control rules as shown in Fig 3. In third stage as defuzzification and denormalization, the fuzzy variables are converted back to crisp variables. Fig 4 shows the shapes of input/output variables and the assignment of fuzzy control rules. The peak value of reference currents is estimated by regulating the DC link voltage using fuzzy logic controller. The error and change in error are considered as the input variables and current loss($\dot{i}_{loss}$) as output variable.

3.3 Hystersis Controller

There are several current control strategies proposed in the literature [13], namely, PI control, Average Current Mode Control (ACMC), Sliding Mode Control (SMC) and hysteresis control. Among the various current control techniques, hysteresis control is the most popular one for active power filter applications. The

fundamental of hysteresis current control says that it is basically an on-line PWM control that fixes the output voltage of the inverter instantaneously. The switching frequency can be changed by the width of the hysteresis band h_b. The upper device and the lower device in one phase leg of VSI are switched in complementary manner. If upper switch is OFF and lower switch is ON in the phase "a" leg then 0. If upper switch is ON and lower switch is OFF in the phase "a" leg then 1.Similarily switching of devices can be done for phase "b" and phase "c"

IV. Matlab Based Simulation

The proposed fuzzy logic based shunt hybrid active filter is developed in MATLAB using Power System

Block set Toolbox as shown in Fig 1. Three-phase source is supplied by a sinusoidal balanced three-phase 415 V source and 50 Hz frequency with a source inductance of 2 mH and a source resistance of 0.2Ω. The active filter consists of an IGBT three-leg bridge. One 2200 µF capacitors is connected at the dc side. The reference voltage at the capacitors is 750 V. A small-rated filter has been included to minimize the switching ripples at the inverter output. The load used in simulating the system are three phase unbalance nonlinear load. The component values for the passive filter network and other parameters of the system are given in Table 1.Passive filter arrangement provides 50 % Reactive VAR compensation at the fundamental frequency

Table 1: parameters of the system

Parameters	Values
Supply voltage	415V (L-L), 50 Hz

Loads:	(i) Linear: phase a=25Ω
	    Phase b=10 Ω and 80mH
	    Phase c =10 Ω and 80 mH
	(ii) Nonlinear: Three phase full bridge, rectifier drawing 5A

Shunt Active Filter: Interfacing Inductance	L_f = 5.5 mH, R_f= 0.25 Ω
DC bus capacitance	22000e-6F.
Referenced Dc voltage	750 V
Tuned Passive Filter	C_5=129.4e-6F ;L_5=3.1mH

V. Comparison between Different Types of Configurations

The performance of the proposed scheme is evaluated for its application to unbalanced non-linear load for different configurations of filters viz passive filters, pure shunt active filter, shunt hybrid active filter, fuzzy based shunt hybrid filter. In the present study the 5th tuned branches of passive filter are considered. Resonance problem occurs at fifth harmonic frequency when passive filter operates alone. The hybrid filter produces the resonance caused by capacitors in the passive filters with source side inductive impedance and amplification phenomenon at fifth harmonic frequency disappears However when the proposed fuzzy based

shunt hybrid active filter is curved with Synchronous Reference Frame method, the most dominant harmonics of the load are greatly reduced. Total Harmonic Distortion is reduced from14.74 % to 2.34 %

Table 2 shows the THD for all three phases for different types of filter. It can be seen from Fig 5 and Table III that proposed hybrid filter system is able to reduce the 5th harmonic of supply current to 1.47% whereas PI based shunt hybrid filter system reduce the 5th harmonic of supply current to 1.68% .The THD of the ac supply current reduces to 4.53% with passive filters alone as the major component of the load current without any filter is composed of 5th harmonic.

Table 2: THD for different phases (in percentage)

| Phase   ➜ | Phase a | Phase b | Phase c |
Type of filter ⬇			
Load current without filter	14.74	16.27	19.66
Pure shunt active filter	3.27	4.58	3.75
PI based hybrid filter	2.65	3.15	2.64
Fuzzy based shunt hybrid filter	2.34	2.64	2.27

Figure 5(a) shows the waveform of the load current and figure 5(b), 5(c) and 5(d) shows the source current

by using pure shunt active filter, shunt hybrid active filter and fuzzy based shunt hybrid active filter.
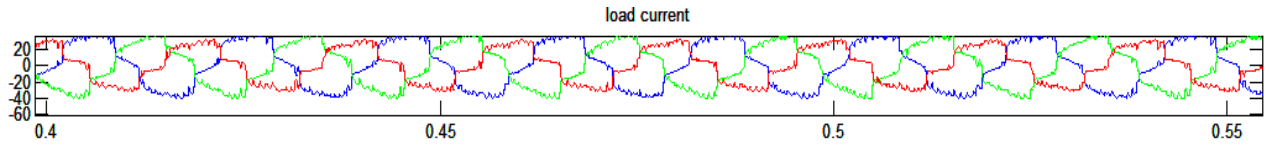
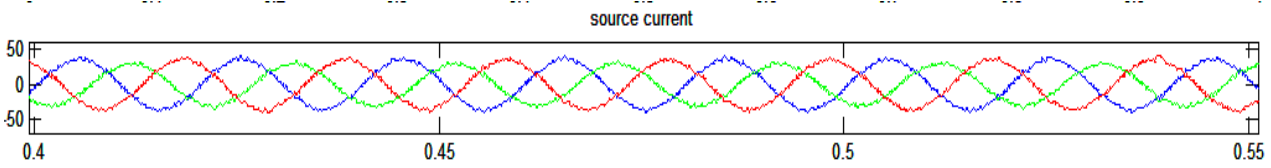Fig. 5(a): waveform of the load current

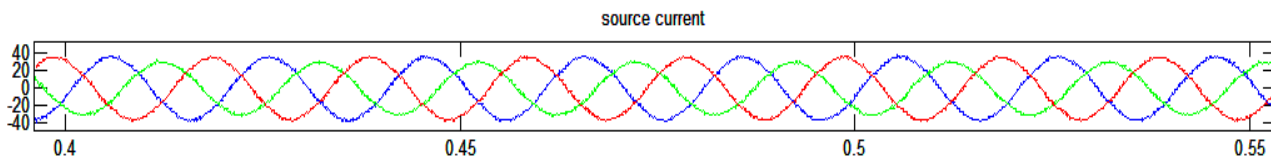Fig. 5(b): waveform of the source current using pure shunt active filter

Fig. 5(c): waveform of the source current using shunt hybrid active filter
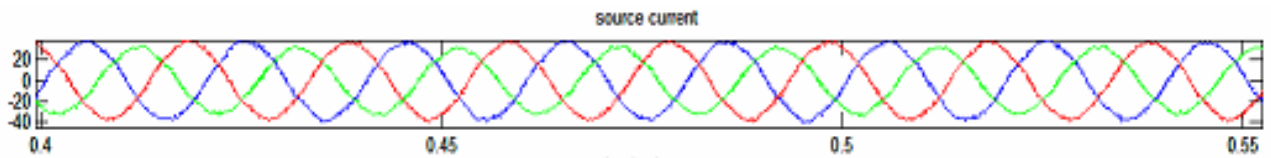

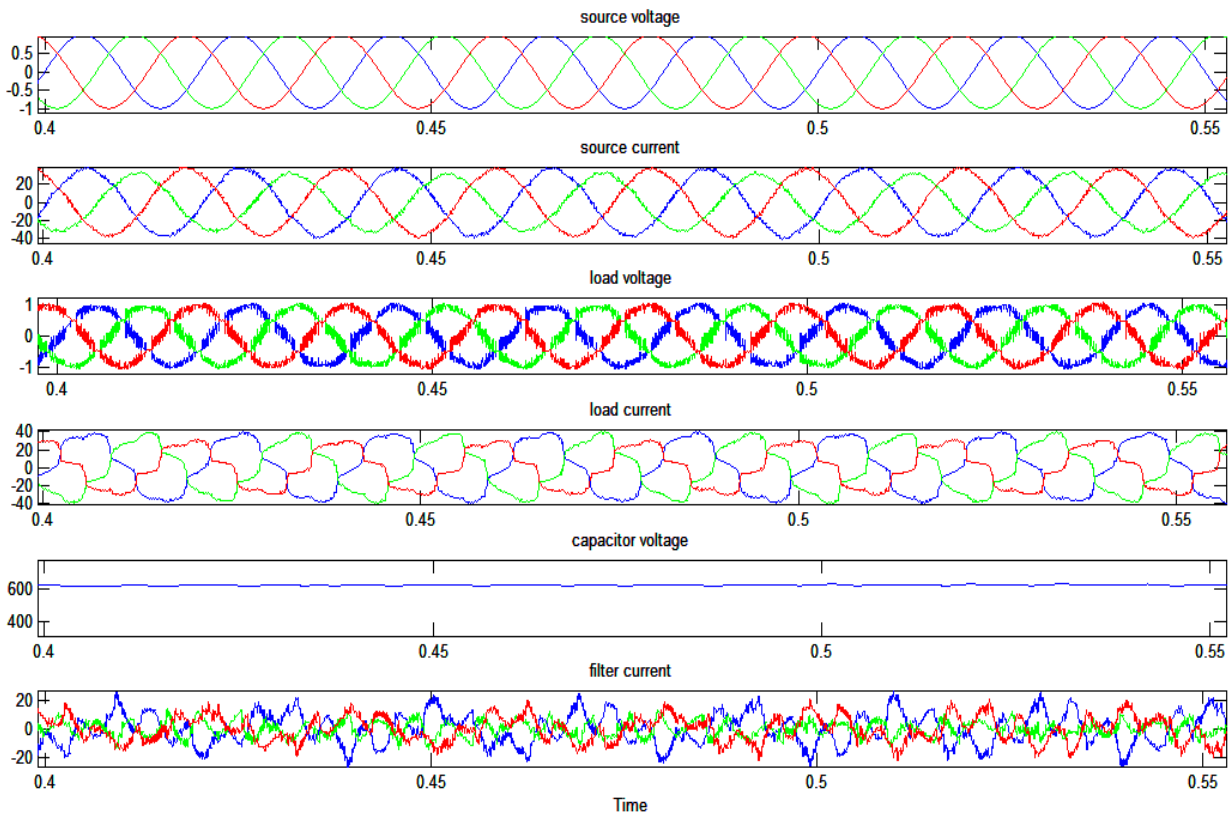Fig. 5(d): waveform of the source current using fuzzy based shunt hybrid active filter

Fig. 6: Source Voltage, Source Current Load Voltage, Load Current, Capacitor Voltage And Filter Current Using Fuzzy Based Shunt Hybrid Active Filter

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Fig.6 shows source voltage, source current load voltage, load current ,capacitor voltage and filter current using fuzzy based shunt hybrid active filter respectively. The values of harmonic content of load current and supply current from simulation in percent of fundamental current using different filter configurations have been given in the Table 3

Table 3: harmonic content of load current and supply current of simulation result in percent of fundamental current

	5th	7th	11th	13th	17th	19th
Load current Without Filter	12.76	5.42	3.92	2.23	1.55	0.97
Source current with Passive Filter	0.20	2.69	2.57	1.64	1.31	0.89
Source current with Pure Shunt Active Filter	1.83	0.54	0.60	0.65	0.83	0.05
Source current with Shunt Hybrid Active Filter	1.68	1.03	0.23	0.21	0.19	0.13
Source current with Fuzzy based Shunt Hybrid Active Filter	1.47	0.80	0.27	0.15	0.39	0.27

Fig 7 shows comparison of harmonic content of load current by shunt hybrid active filter using PI controller and fuzzy based shunt hybrid active filter.It can be clearly analysed that using decision making power of fuzzy controller 5th harmonic contents are considerably reduced from12.76%(without any filter) to 1.47% by using fuzzy based hybrid filter.
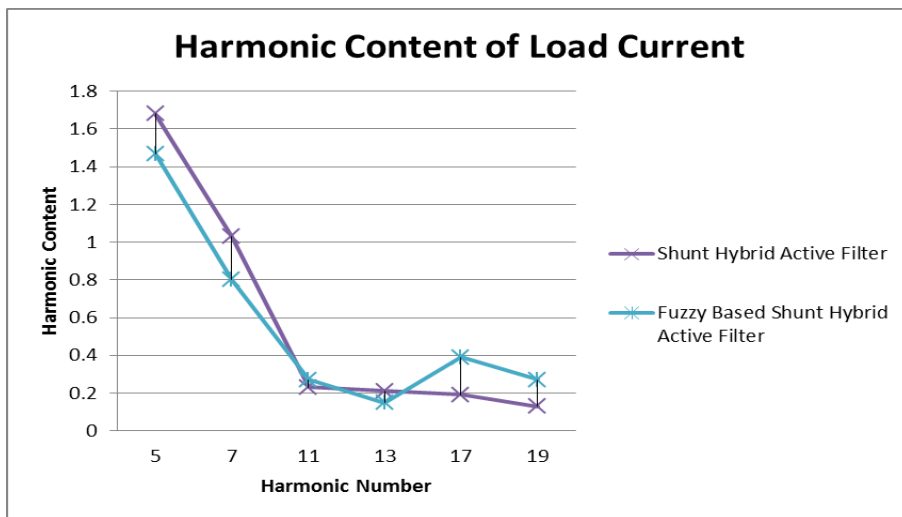

Fig. 7: Comparison graph for PI based and Fuzzy based shunt hybrid active filter
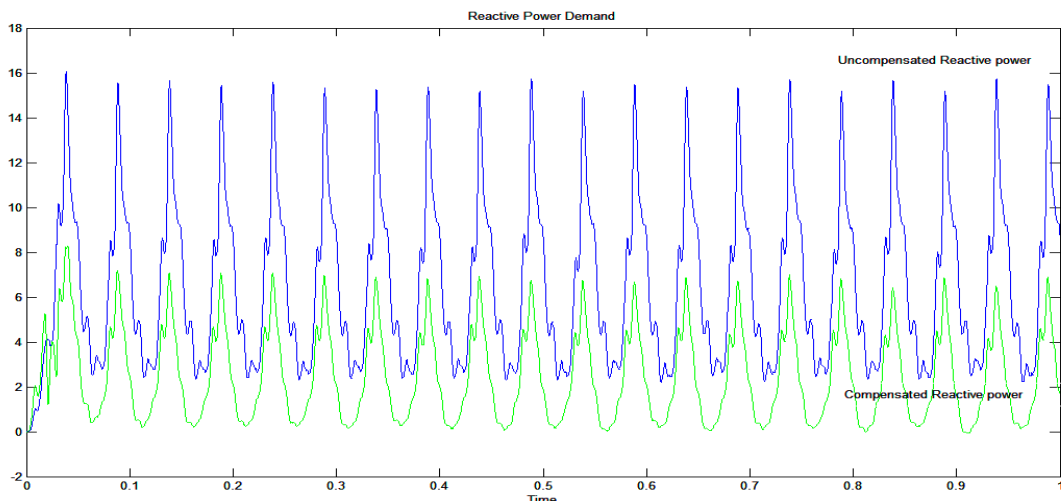

Fig. 8: Reactive Power for uncompensated and compensated system

Fig 8 shows uncompensated and compensated reactive power compensations and it can be analysed that passive filter parameters are calculated at 50% reactive power demand at fundamental frequency.

VI. Conclusion

The simulated fuzzy logic based shunt active hybrid active filter proves remarkable filtering results. The proposed control strategy has demonstrated the capability of intelligent controller for hybrid power filter to minimize the overall THD and the selective harmonic content of the source current. A complete evaluation between a conventional PI based hybrid active power filter and, fuzzy based the hybrid power filter is presented. Thus FLC seems more suitable and flexible for the active filter since it does not need a complex mathematic model to tune the PI controller gains and it is more robust compared to PID.

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