Fuzzy Logic Controller Based Shunt Active Filter with Different MFs for Current Harmonics Elimination

Shreyash Sinai Kunde, Siddhang Tendulkar, Shiv Prakash Gupta, Gaurav Kumar, Suresh Mikkili

Abstract—One of the major power quality concerns in modern times is the problem of current harmonics. The current harmonics is caused due to the increase in non-linear loads which is largely dominated by power electronics devices. The Shunt active filtering is one of the best solutions for mitigating current harmonics. This paper describes a fuzzy logic controller based (FLC) based three Phase Shunt active Filter to achieve low current harmonic distortion (THD) and Reactive power compensation. The performance of fuzzy logic controller is analysed under both balanced sinusoidal and unbalanced sinusoidal source condition. The above controller serves the purpose of maintaining DC Capacitor Voltage constant. The proposed shunt active filter uses hysteresis current controller for current control of IGBT based PWM inverter. The simulation results of model in Simulink MATLAB reveals satisfying results.

Keywords—Shunt active filter, Current harmonics, Fuzzy logic controller, Hysteresis current controller.

I. INTRODUCTION

IN recent years, the harmonic distortion in electric power system has become a serious problem. This problem generally caused by non-linear loads which draw non-sinusoidal current. The problem associated with non-sinusoidal currents are Voltage swell, Voltage sag, Voltage flicker, Harmonics distortion etc [1]. When it comes to three phase system this above mentioned problem are more significant and causes poor Power Quality [2]. These distortions are mainly caused due to line impedance or the distribution transformer leakage inductance. The conventional methods of mitigating these power quality problems are by using passive filter but there are drawbacks such as resonance, large size, weight, tuning complexity etc. Basic architecture of Shunt active Filter is given in Fig. 1.

The conventional controllers such as PI controller require precise linear mathematical model of the system which is difficult to obtain under parameter variations, non-linearity and load disturbance. Also the proportional and integral gains are chosen heuristically. The research includes fuzzy logic controller (FLC) [3] which can give good results because of its performance under parameter variations and non-linear condition.

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This article is organized as follows. Section II deals with Shunt active filter; Section III deals with fuzzy logic controller; Section IV provides the details of hysteresis controller; Section V provides simulation results; and finally Section VI states all concluding remarks.
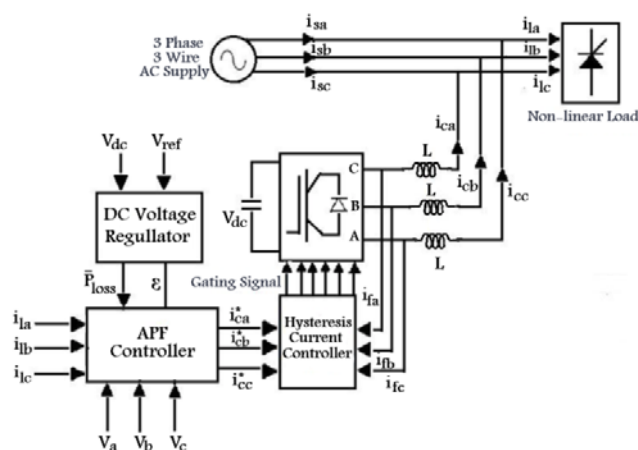

Fig. 1 Basic architecture Shunt active Filter

II. SHUNT ACTIVE FILTER

The shunt active power filter is a voltage source inverter (VSI) which is controlled as a current source by means of pulse width modulation signals [4]. As it is shown in Fig. 2, the filter is connected in parallel with the non-linear load. Harmonic current compensation can be achieved by injecting equal and opposite harmonic current components at the point of connection, to cancel the original distortion and improving the power quality. In a three-phase unbalanced source as well as in case of non-linear loads; it is also possible to redistribute power and to keep the system balance. The active power filter [5] is composed of the reference current calculating circuit, current tracking circuit, driving circuit and the main circuit. While, the generation circuit of compensating current is composed of the last three parts.

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A. Basic Principle of Working

As it shown in Fig. 2 that the source current is I_S, load current is I_L and compensating current is given by I_C. Now, because of non-linear load the source current will get distorted and to make it sinusoidal, compensating current (I_C) is given by active filter. Hence we are able to improve THD [6].

$$THD = \frac{\sqrt{(i_2^2 + i_3^2 + i_4^2 + \ldots\ldots + i_n^2)}}{i_1} \quad (1)$$

where, I_1 = Fundamental Current Value; I_n (n = 1, 2, 3 ....n) = Harmonic Current Values.

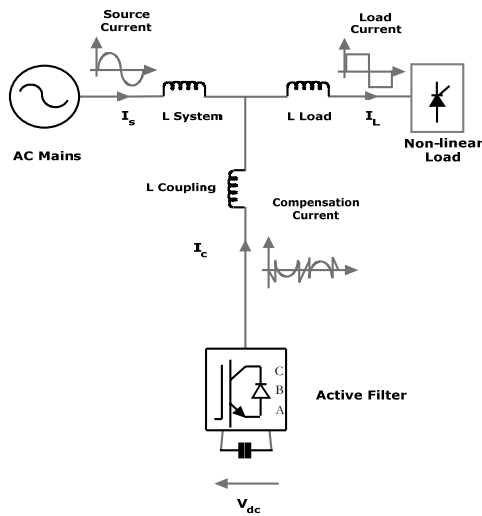In general compensating current is given by $I_c = I_s - I_L$

Fig. 2 Compensation Principle of a Shunt Active power filter

B. Converter Based Classification

APF can be classified on the topology based, converter based and supply based [2].

1. *Current-Fed Type APF*

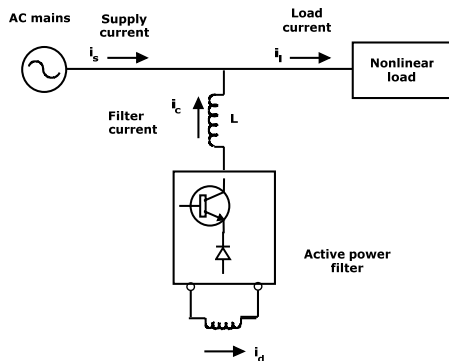It acts as a non-sinusoidal current source to meet the harmonic current requirement of the non-linear load.

Fig. 3 Current-fed-type APF

2. *Voltage-Fed Type APF*

It has a self-supporting dc voltage bus with a large dc capacitor. It is lighter, cheaper, and expandable to multilevel and multistep versions, so we can enhance performance with lower switching frequencies.
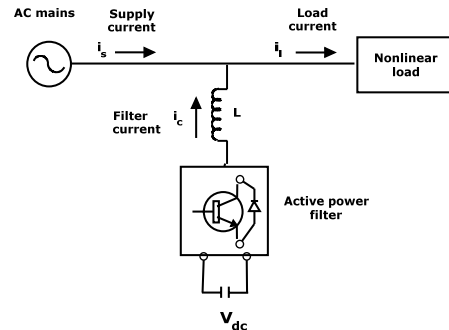

Fig. 4 Voltage-fed-type APF

C. Supply System Based Classification

Supply system based categorization generally depends on the supply or load of the system. It can be Single-phase Two-wire APF, Three-phase Three-wire APF and Three-phase four-wire APF [7]. There are many non-linear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase non-linear loads are without neutral, such as ASDs, fed from three-wire supply systems.
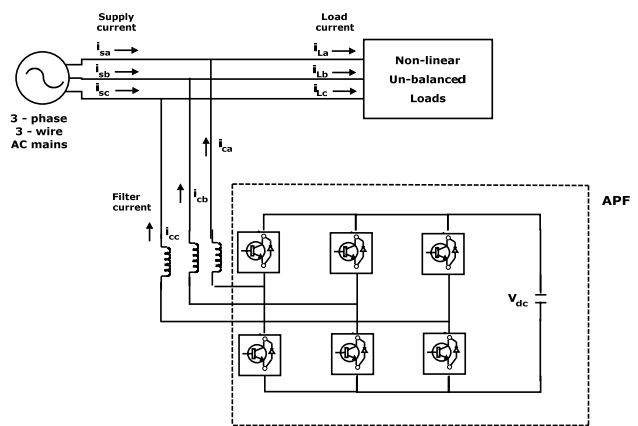

Fig. 5 Three-phase three-wire APF

As shown in 3-phase 3-wire Active power filter structure (Fig. 5) which is compensating harmonics in all three phase by injecting compensating currents (i_{ca}, i_{cb}, i_{cc}).where,

Supply current = i_{sa} ,i_{sb}, i_{sc}
Load current   = i_{La}, i_{Lb} ,i_{Lc}
Filter current   = i_{ca}, i_{cb}, i_{cc}

III. FUZZY LOGIC CONTROLLER

Fuzzy logic control is deduced from fuzzy set theory in 1965 [8]. In the recent years the Fuzzy Logic Controllers (FLCs) [9] have found greater application in the field of APFs. It has a better performance with respect to the Conventional controllers such as PI controller since in comparison to

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conventional controllers they do not require accurate mathematical model, can handle imprecise inputs and non-linearity and are robust.

Fig. 6 is schematic diagram of fuzzy control scheme. In order to implement the control algorithm the shunt active power filter in a closed loop, the dc capacitor voltage V_{dc} is sensed and then compared with the reference value V_{dcref}. In case of fuzzy logic control scheme the error e = V_{dcref} -V_{dc} and integration of error signal are used as input for fuzzy processing. The output of fuzzy controller after a limit is considered as the magnitude of peak reference current I_{max}. The switching signal of a PWM converter is obtained by comparing the actual source current (I_{sa},I_{sb},I_{sc}) with the reference current template (I^*_{sa}, I^*_{sb} ,I^*_{sc}) in the hysteresis current controller. The output pulses are then given to the switching device in a PWM converter.
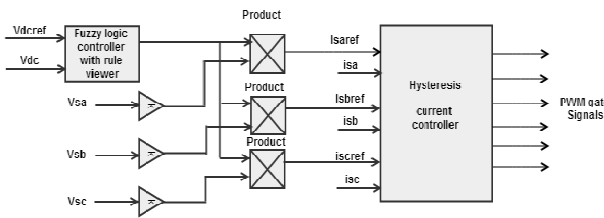

Fig. 6 Hysteresis current controller based PWM generation using SHAPF

This tool is very important for our research work as it helps us to form a crisp value out of discrete input values. The fuzzy logic Controller consists of Fuzzification, Fuzzy Inference system and Defuzzification. In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules and the process of converting a numerical value to a linguistic value is known as Fuzzification [10].
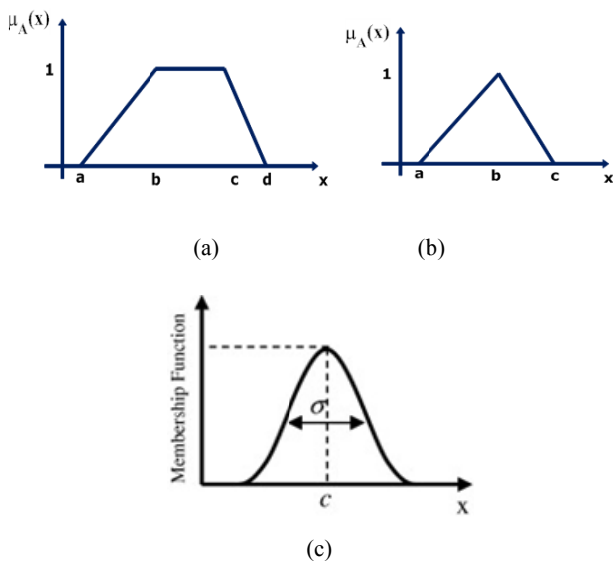

(a)   (b)

(c)

Fig. 7 (a) Trapezoidal M.F (b) Triangular M.F(c)Gaussian M.F.

The development of a rule requires a thorough understanding of the process to be controlled but it does not require a mathematical model of the system. The design of a fuzzy logic controller requires the choice of membership function. The membership function should be chosen in such a way that they cover the whole universe of discourse and they overlap each other. The various membership functions that are available are trapezoidal, triangular, and Gaussian is shown in Fig. 7. Generally to achieve the finer control the membership function near to zero regions should be made narrower while away from the zero it should be wider to achieve the faster response to the system. Fig. 8 shows the 7x7 triangular function when adjusted properly yields better performance.

TABLE I
RULE BASE TABLE

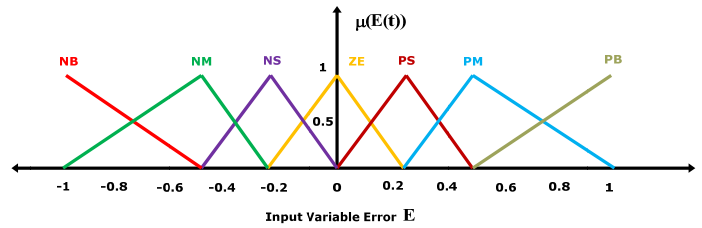| E	ΔE	NB	NM	NS	Z	PS	PM	PB
NB		NB	NB	NB	NB	NM	NS	Z
NM		NB	NB	NB	NM	NS	Z	PS
NS		NB	NB	NM	NS	Z	PS	PM
Z		NB	NM	NS	Z	PS	PM	PB
PS		NM	NS	Z	PS	PM	PB	PB
PM		NS	Z	PS	PM	PB	PB	PB
PB		Z	PS	PM	PB	PB	PB	PB

Fig. 8 Input Triangular M.F of size 7x7

The error and change of error are used numerical variable from the real system. To convert these numerical variable and linguistic variable, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), Z (Zero), PS (positive small), PS (positive small), PM (positive medium), PB (positive big) and presented in input and output normalized membership functions[3]. Block diagram of Fuzzy system is given in Fig. 9.
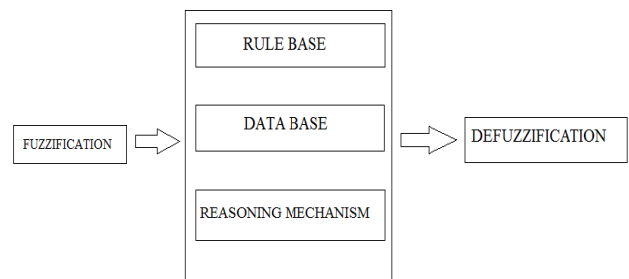

Fig. 9 Block diagram of Fuzzy system

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The bock diagram of Fuzzy logic controller is shown in Fig 9. It consists of blocks Fuzzification; Fuzzy Inference system; Knowledge base and Defuzzification.

Fuzzificationis the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification. In de-fuzzification, the rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements, linguistic variables have to be transformed to crisp output (Real number).The Database stores the definition of the membership Function required by fuzzifier and defuzzifier [11].The elements of rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in Table I.

Fig. 10 shows fuzzy inference system with triangular M.F. It consists of

- Fuzzy Inference System (FIS) Editor
- Membership Function Editor
- Rule Editor
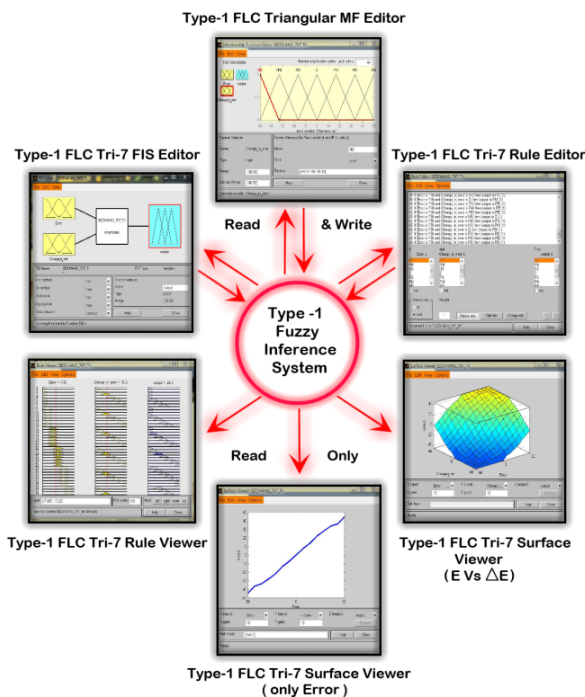- Rule Viewer
- Surface Viewer

Fig. 10 Fuzzy Inference System with Trapezoidal M.F

The FIS Editor handles the high-level issues for the system: How much input and output variables? What are their names? The Present model consists of two inputs and one output, named as Error, change in Error and output respectively. The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. The rule editor is used for editing the list of rules that defines the behavior of the system. In the present model 49 rules are developed. The Rule Viewer and the Surface Viewer are used for looking at, as opposed to editing, the FIS. They are strictly read-only tools. Used as a diagnostic, it can show which rules are active, or how individual membership function shapes are influencing the results. The Surface Viewer is used to display the dependency of one of the outputs on any one or two of the inputs i.e., it generates and plots an output surface map for the system.

The implication steps helps to evaluate the consequence part of a rule. There are a number of implication methods in the theory out of which Mamdani is frequently used. In this method, the output is truncated at the value based on degree of membership given by fuzzy output. The result of the implication aggregation steps in a fuzzy output which is the union of all the outputs which is validated. Conversion of the fuzzy output to a crisp output is called defuzzification.

There are different types of methods [12] associated with defuzzification are Centroid of Area (COA), Bisector of Area (BOA), Smallest of Maximum (SOM), Largest of Maximum (LOM), Mean of Maximum (MOM). The above mentioned methods can be represented or obtained as shown in Fig. 11. Centroid of Area (COA) is the best defuzzification method and is being used in this research work. Mathematically centroid of Area is obtained as,

$$COA = \frac{\int_a^b \mu_A(x) \; x \; dx}{\int_a^b \mu_A(x) \; dx} \tag{2}$$

With a discretized universe of discourse, the expression is

$$COA = \frac{\sum\limits_{i=1}^{n} \mu_A(x_i) \; x_i}{\sum\limits_{i=1}^{n} \mu_A(x_i)} \tag{3}$$

Bisector of Area (BOA) The bisector is the vertical line that will divide the region into two sub-regions of equal area. It is sometimes, but not always coincident with the centroid line. Mathematically bisector of area (BOA) can be expressed as:

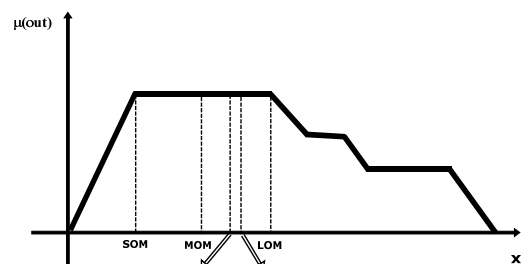$$\int\limits_{\alpha}^{X_{BOA}} \mu_A(x)dx = \int\limits_{X_{BOA}}^{\beta} \mu_A(x)dx \tag{4}$$

Fig.11 Defuzzification strategies

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IV. HYSTERESIS BAND CURRENT CONTROL

The hysteresis band control is used because of its simplicity of implementation. Also this method does not require any knowledge of load parameters. However the current control with a fixed hysteresis band has some disadvantages like the PWM frequency varies within a band because peak to peak current ripple is required to be controlled [13].

The basic implementation of hysteresis current control (Fig. 12) is based on deriving the switching signals from the comparison of the current error with a fixed tolerance band. Power devices used in the inverter circuitry is IGBT/Diode. The compensatory circuit comprising of inverter with DC link capacitance which is maintained constant for which FLC is used. This control is based on the comparison of the actual phase current with the tolerance band around the reference current with that phase.
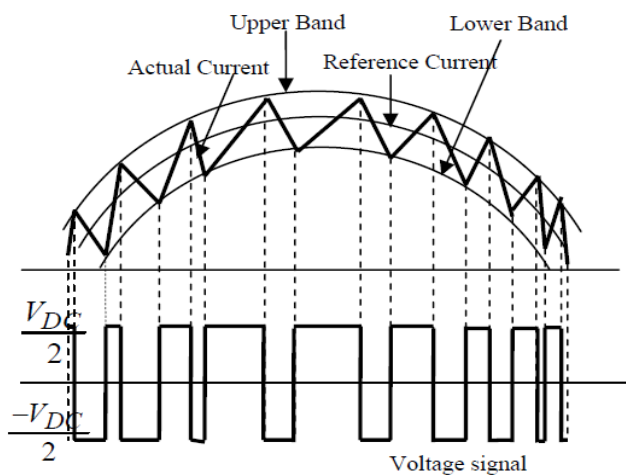

Fig.12 Hysteresis Current Control

V. SIMULATION RESULTS

The Simulation Results of the proposed Fuzzy Controller based shunt Active Filter is presented in the following section. The results are obtained using MATLAB SIMULINK software. The simulation results of the system with-out and with compensation for balanced and unbalanced source condition are given in Figs.13, 14, and 15 respectively.

The Results of the system without compensation is provided in the Fig. 13, 14 and 15 wherein (a) shows the three phase source voltage, (b)shows the distorted load current, (c) shows the compensation current supplied to system, (d) shows the single phase source current,(e) shows the V_{dc} and (f) shows the % THD content.

A. Balanced Sinusoidal Source Condition

Table II shows the parameters of APF and Non linear load for balanced source condition. For balanced sinusoidal condition, source voltage is taken to be 122.4 V_{rms} at 50 Hz. The load applied to the circuit is 10 Ω; 20mH up to 0.2 secs and 6.67 Ω; 20mH for period from 0.2 secs to 0.5 secs. The period under study for this work is up to 0.2 secs. The reference voltage (V_{dc}) in this case is taken to be

220V.Throughout the simulation this value has to remain constant.

B. Unbalanced Sinusoidal Source Condition

Table III shows the parameters of APF and Non linear load for unbalanced Sinusoidal source condition. For Unbalanced sinusoidal condition, magnitude of one of the phase is taken to be 220 V_{rms} whereas magnitude of other phases is 200 V_{rms} .Hence one of the phases has deviation of 10% from other two phases. The load variation for this case is similar to balanced source condition whereas the reference voltage (V_{dc}) in this case is taken to be 460V. Other parameters are same as the balanced source condition case. The results are obtained for same conditions as in case of balanced source condition.
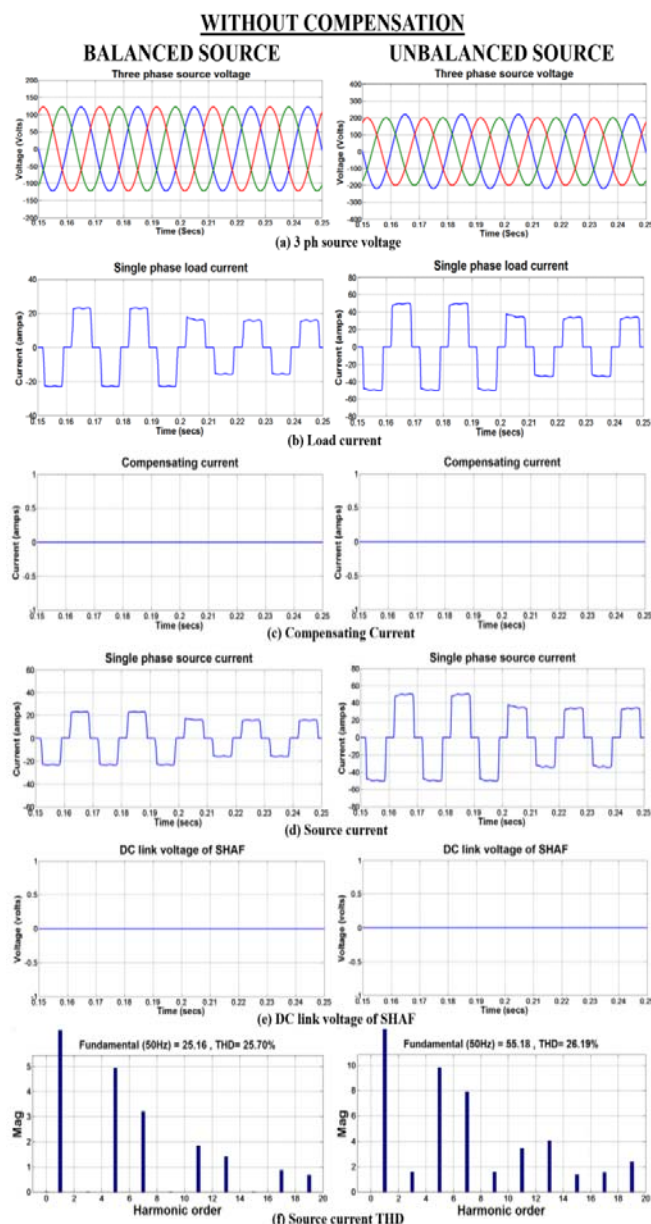

Fig. 13 With-out compensation for balanced and unbalanced source condition

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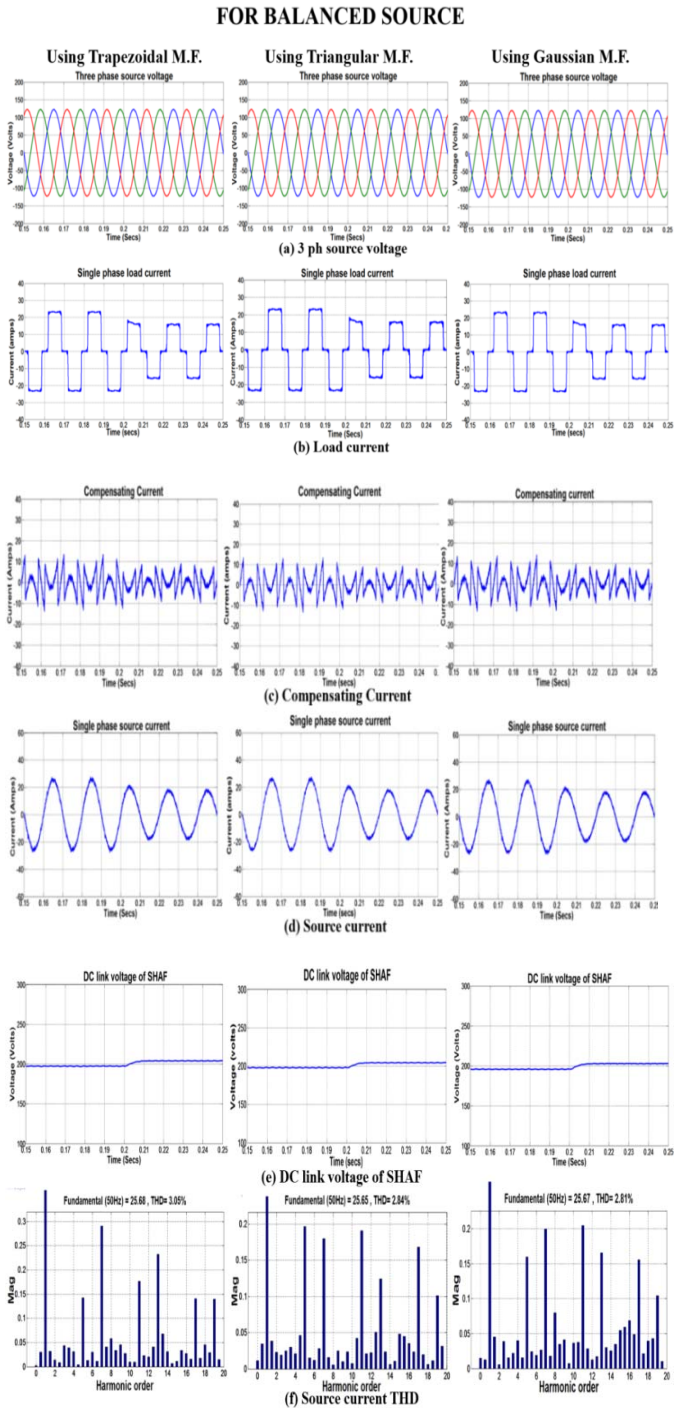Vol:8, No:3, 2014

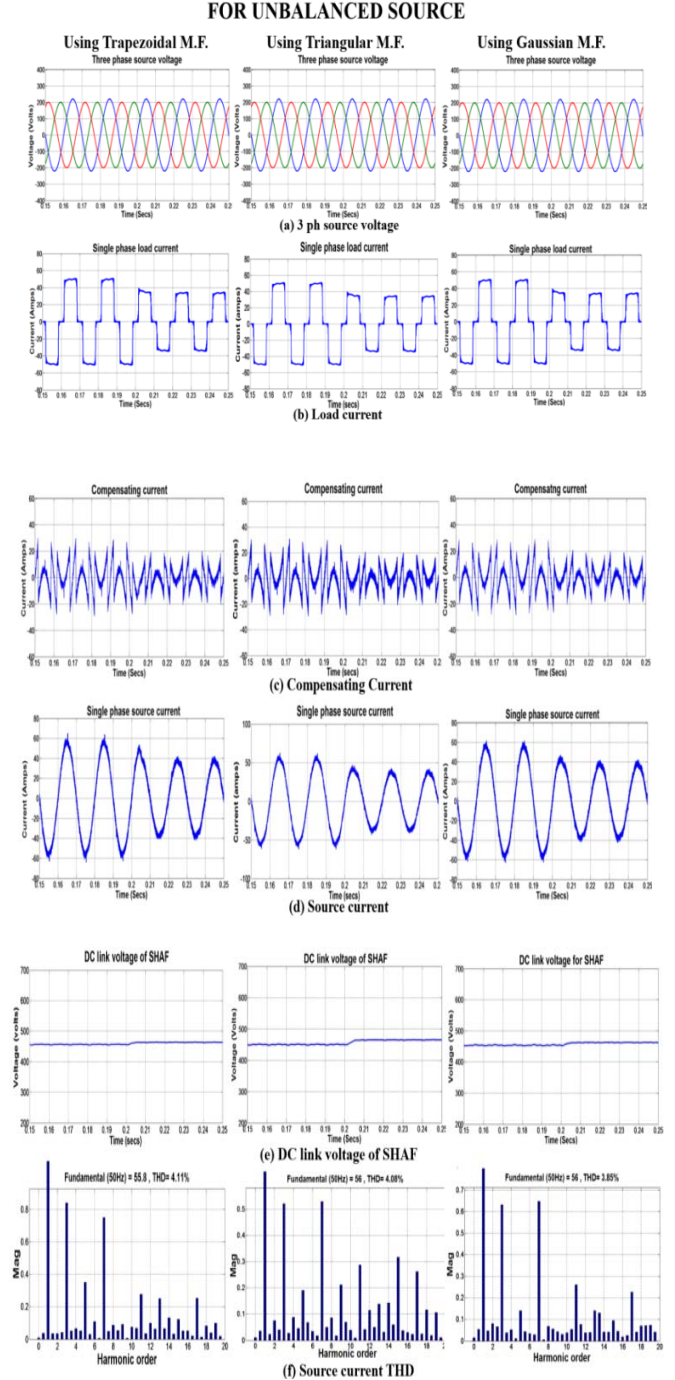Fig. 14 Balanced source condition with compensation

Fig. 15 Un-balanced source condition with compensation

In case of balanced source condition without compensation, THD was observed to be 25.70% as shown in Fig.16 which quite high. The source THD is high due to the non-linear load and hence the source current gets altered to non-linear nature leading to current harmonics in the system.

For FLC based SHAF compensation with trapezoidal MF, the source THD is drastically reduced as seen from Fig. 17 to 3.05% and hence current harmonics are reduced and source current is observed to be close to sinusoidal waveform.

But with the use of triangular and Gaussian MF, source THD are observed to be 2.84% and 2.81% .hence further reducing the THD and thereby reducing current harmonics more. So the circuit is able to achieve reduction in THD from 25.7% to 2.81%. During analysis, Gaussian MF was observed to be the best MF for the balanced source condition.

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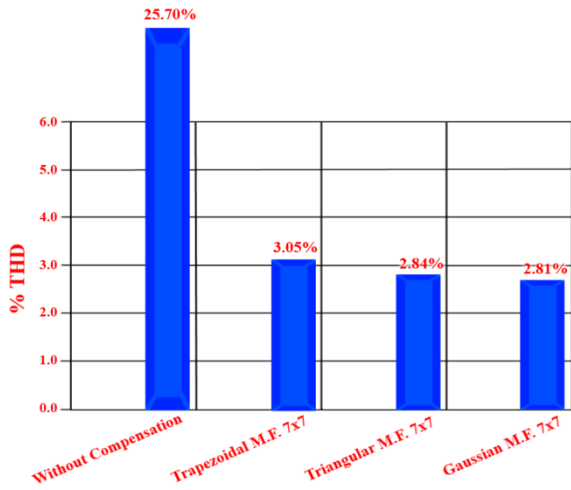Vol:8, No:3, 2014

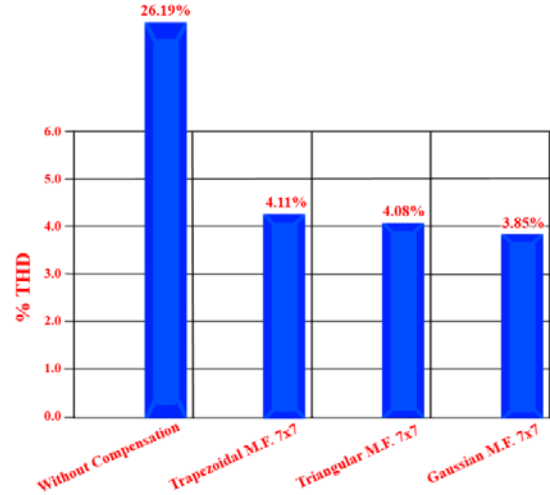Fig. 16 Graphical representation of THD values for balanced case

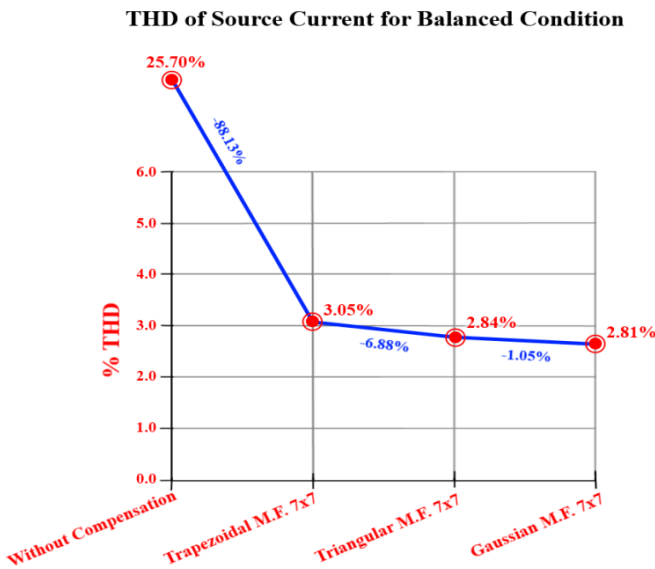Fig. 18 Graphical representation of THD values for unbalanced case

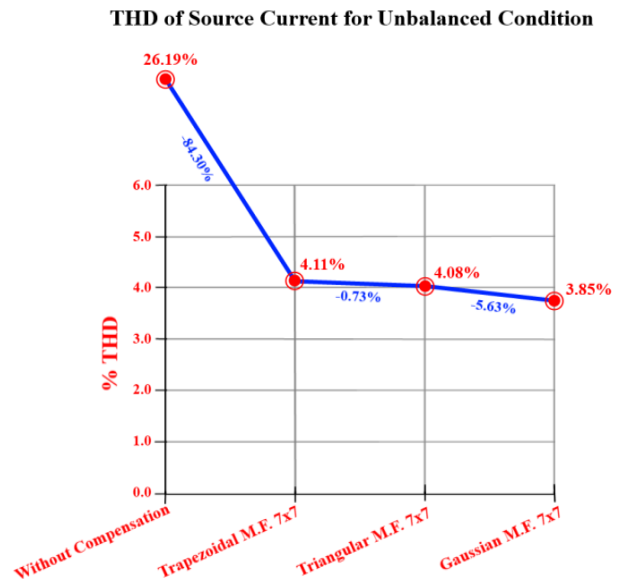Fig. 17 % change in source THD for balanced condition

Fig. 19 % change in source THD for balanced condition

In case of unbalanced source condition without compensation where in the magnitude of one of the phase deviates from the other two phases by 10%, source THD observed is 26.19% as seen from Fig, 18 which is high. Due to the high THD, source current can get distorted leading to current harmonics and variety of other power quality issues.

With the introduction of compensation system consisting of FLC based shunt active filter and by use of Trapezoidal MF, % source THD is drastically reduced as seen from Figs, 18, 19 to 4.11% .With applications of Triangular and Gaussian MF, source THD was observed to be 4.08% and 3.85% respectively thus ensuring cancellation of current harmonics. The source THD is reduced from 26.19% to 3.85% which follows IEEE 519 standard. During analysis Gaussian MF performed best in reducing harmonics.

TABLE II
BALANCED SOURCE APF PARAMETERS

System Parameters	Values
Source Voltage (V_s)	122.4V_{rms}
System Frequency (f)	50 Hz
Source Impedence (R_s,L_s)	0.1 Ω ; 0.15mH
Filter Impedance (R_c,L_c)	0.1 Ω ; 0.66mH
Load Impedence (R_L,L_L)	Upto 0.2 secs : 10 Ω ; 20mH 0.2-0.5 secs : 6.67 Ω ; 20mH
DC link Capacitance (C_{dc})	2000 µF
Reference Voltage (V_{dc})	220 V
Power Devices	IGBT/Diode

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TABLE III
UN-BALANCED SOURCE APF PARAMETERS

System Parameters	Values
Source Voltage (V$_s$)	A phase-220V$_{rms}$ B phase-200 V$_{rms}$ C phase-200 V$_{rms}$
System Frequency (f)	50 Hz
Source Impedance (R$_s$,L$_s$)	0.1 Ω ; 0.15mH
Filter Impedance (R$_c$,L$_c$)	0.1 Ω ; 0.66mH
Load Impedance (R$_L$,L$_L$)	Upto 0.2 secs : 10 Ω ; 20mH 0.2-0.5 secs : 6.67 Ω ; 20mH
DC link Capacitance (C$_{dc}$)	2000 µF
Reference Voltage (V$_{dc}$)	460 V
Power Devices	IGBT/Diode

VI. CONCLUSION

The paper analyses the performance of the FLC based shunt active filter for mitigating current harmonics problem. The results are obtained using three different membership functions i.e. Trapezoidal, Triangular and Gaussian for both balanced and unbalanced sinusoidal condition.

The results show excellent performance of the circuit as it is found to be following IEEE 519 standard. This facilitates to improve the power quality parameters such as reactive power and Current harmonics due to nonlinear load. The best observed result for balanced and unbalanced condition was obtained using Gaussian Membership function which was observed to be 2.81% and 3.85% respectively. From the results obtained, the observation was made that the fuzzy logic controller enhances the performance of the Shunt active filter and thus help to suppress current harmonics in the system.

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