International Journal of Scientific & Engineering Research, Volume 8, Issue 2, February-2017
ISSN 2229-5518

Design of Fuzzy Logic Based Shunt Active Power Filter for Harmonic Current Compensation

Rakesh Kumar Pandey*, Nikhlesh Kumar Sharma**
*Research Scholar, Mewar University, Chittorgarh (RAJ.), ** Professor, GL Bajaj Institute of Technology and Management, Greater Noida (UP)

Abstract— *The shunt active power filter is a complete current source which provides a effective solution for elimination of current harmonics in power system. The main advantage of FLC based shunt active filters does not require any mathematical modeling. This system is based on linguistic description. This paper presents a comparative study between fuzzy logic controller and PI controller performance under constant load. The total harmonics distortion with respect to percentage of fundamental in source current, supply voltage has been analyzed and simulation results are presented. The THD of the source current after compensation is below 5% as per IEEE-519 standard.*

Index Terms— Minimum ***Shunt active power filter, PWM Inverter, PI controller, Fuzzy logic controller and Hysteresis current controller.***

1 INTRODUCTION

IN modern electrical system, there has been a sudden increase of power converter which behaves like non linear loads, such as power supplies, adjustable speed drives. These nonlinear loads draw non sinusoidal currents from source and causes distortion called harmonics[1]–[4]. In order to reduce this type of problem the shunt active power filter has been developed. The shunt active power filter is based on current controlled PWM inverter has been widely used[5]. Design of SAPF control scheme are based on sensing of the line current and used PWM inverter to inject current harmonics components in to point of common coupling(PCC) to cancel the load harmonics components .The shunt active power filter also compensate the reactive volt-ampere[6], [7].

The conventional PI controller will generate the reference current template but its require precise mathematical modeling which become a difficult task during parameter variation and load disturbance etc while a fuzzy logic controller do not require an accurate mathematical modeling[8]–[11].

A design criterion is explained for the selection of power circuit components and fuzzy logic based control scheme is developed.

2 BASIC COMPENSATION PRINCIPLE

Fig. 1 shows the basic circuit diagram of a shunt active filter which is connected in parallel to load. The power circuit of the SAPF consists of a three phase Voltage-Source PWM Inverter (*VSI*), using the MOSFET, coupled at the Point of Common Coupling (PCC) and for energy storage a dc capacitor is considered..

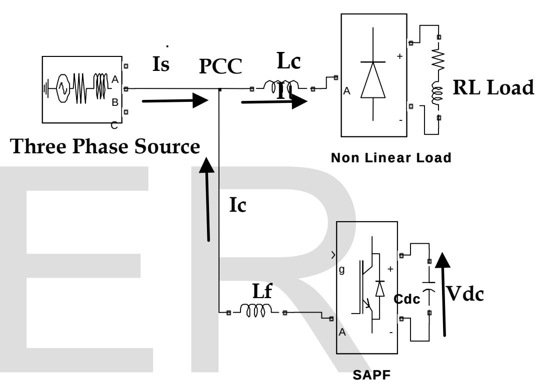
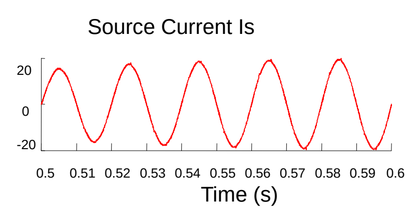
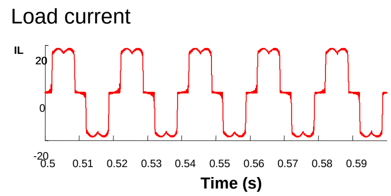


Fig.1. Basic Shunt Active Power





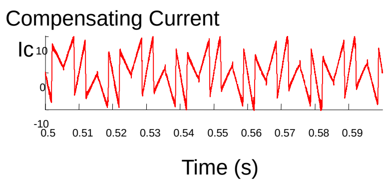


Fig.2. Shape of source, load and desired filter current waveforms

From Fig 2, the instantaneous currents can be written as Current supplied **by** source

$$is(t) = iL(t) - ic(t) \quad (1)$$

Source voltage is described by

$$Vs(t) = Vm \sin(wt) \quad (2)$$

When a nonlinear load is applied, then the load current will have a fundamental component and harmonic components, which can be represented as:

$$I_L(t) = \sum_{n=1}^{\infty} In\ Sin(nwt + \phi n)$$

$$I_L(t) = I_1 Sin(wt + \phi_1) + \sum_{n=2}^{\infty} In\ Sin(nwt + \phi n) \quad (3)$$

$$Vs(t) = \sum_{n=1}^{\infty} (Vn\ Cos\ nwt + \phi n) \quad (4)$$

The instantaneous load power can be given as

$$P_1(t) = Vs(t) * I_l(t)$$

$$= Vm\, I_1 \sin^2 \omega t * \cos \emptyset 1 + Vm\, I_1 sinwt * coswt * sin\emptyset_1 + Vm\ sinwt * \sum_{n=2}^{\infty} In\ sin(nwt + \emptyset) \quad (5)$$

$$P1(t) = Pf(t) + \Pr(t) + Ph(t) \quad (6)$$

From (5), the real power drawn by the load is

$$Pf(t) = VmI_1 \sin^2 wt * cos\Phi_1 = Vs(t) * Is(t) \quad (7)$$

From equation (7), the source current supplied by the source, after compensation is

$$Is(t) = {Pf(t)}/{Vs(t)} = I^1 cos\emptyset^1 * sin\omega t$$

$$= Ism \sin \omega t \quad (8)$$

Where $Ism = I_1 \cos \emptyset_1$

There are some switching losses in the PWM converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load. The total peak current supplied by the source is [8], [10]

$$Isp = Ism + Isl \quad (9)$$

The compensation current is describe as

$$ic(t) = i_l(t) - is(t) \quad (10)$$

The desired source currents, after compensation, can be given

$$isa^* = Isp\ sin\omega t \quad (11)$$

$$isb^* = Isp \sin(\omega t - 120) \quad (12)$$

$$isc^* = Isp \sin(\omega t + 120) \quad (13)$$

3 PARAMETERS DESIGN PROCEDURES

The design of SAPF requires three main parameters:

A. Reference Capacitor voltage estimation Vdc

In[12], it is assume that PWM converter operates in the linear modulation mode (*i.e.* $0 \le ma \le 1$) then,

$$ma = 2\sqrt{2}\frac{Vf1}{Vdc}, \text{ for } ma = 1 \quad (14)$$

$$Vdc = 2\sqrt{2}.Vf1 \quad (15)$$

$$Vdc = 2\sqrt{2}.Vs \quad (16)$$

B. Output filter inductor estimation Lf

In [12], the designing of inductor filter the peak current is considered at no load condition.

So the required inductance is given as:

$$Lf = \frac{Vs}{2\sqrt{6}\ fs\ \Delta I_{f(p-p)max}} \quad (17)$$

Where, $\Delta I_{f(p-p)max}$=15% of peak compensation current.

C. Design of the DC side Capacitor Cdc

In [12], The dc side capacitor is designed according to the principle of instantaneous power flow on dc and ac side of converter.

The dc side capacitor is calculated as:

$$C_{dc} = \frac{\pi * I_{f1_{rated}}}{\sqrt{3}.\,\omega.\,V_{dc.p-p(max)}} \qquad (18)$$

where, *Vdc,p-p(max)* is the peak-to-peak voltage ripple.

4 PROPOSED CONTROL STRATEGIES

A. PI Controller

The block diagram of proposed PI control scheme of shunt active power filter is shown in fig.3 .the dc side capacitor voltage is compared with reference voltage.

Error *e* =*Vdc, ref - Vdc*

The error signal passed with BW filter to suppress the higher order of harmonics and allow only fundamental component. The peak ref current Imax to be estimated by PI controller. The steady state error in Vdc is minimize by PI controller[10], [12], [13].

The Transfer function of PI controller is represented as

$$H(s) = Kp + \frac{Ki}{s} \qquad (19)$$

Where, [*Kp* =0.5] describe the dynamic response of Vdc control, where [*Ki* =10] describe the settling time.

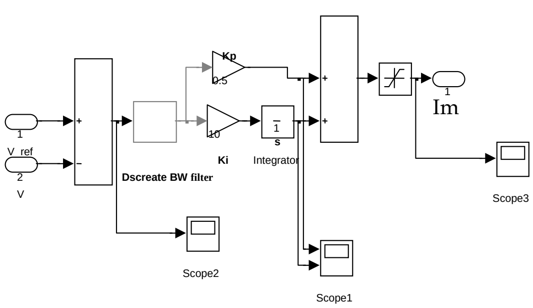


Fig.3. Simulink Model of PI Controller

B. Proposed Fuzzy Control Scheme

Fig.4 shows block diagram the active power filter compensation system and Fig. 5 shows the schematic block diagram of the fuzzy control scheme. The Vdc is sensed and compared with reference value of dc side capacitor voltage. In case of a fuzzy logic control scheme, the error $e = Vdc_{ref} - V_{dc}$ and integration of error signal $\int e$ and change of error signal *ce(n)* = *e(n)-e(n-* 1) at nth sampling instant are used as input variable for fuzzy processing. The output of FLC is the amplitude of peak reference current *Imax. By* comparing the source current $(i_{sa}, i_{sb}\, and\ i_{sc})$ with reference current templates $(i*_{sa}, i*_{sb}\ and\ i*_{sc})$ in HCC, switching signal for PWM converter is obtained.

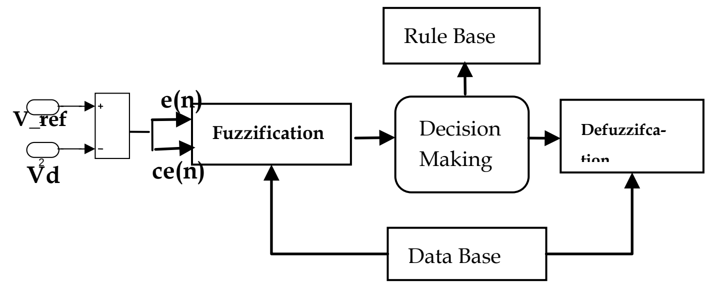


Fig.5. Fuzzy Logic controller

1) Basic fuzzy Algorithm

The fuzzy controller is set of simple linguistic rule which requires a proper understanding of the process to be controlled. The internal structure of the fuzzy controller is shown in Fig. 5.

The error e and change of c_e are two input numerical variable are converted in to linguistic variable by choosing seven fuzzy sets as NB (negative big), NM (negative medium), NS (negative small), ZE(zero), PS (positive small), PM (positive medium), and PB (positive big)[8], [11], [13].The fuzzy control scheme is characterized as

a) Seven fuzzy sets for each input and output.
b) Traingular MF
c) Fuzzification using continuous universe of discourse.
d) Implication using Manidani's 'min' operator.
e) Defuzzification using centroid method

2) Fuzzification

Fuzzy logic uses linguistic variables instead of numerical variables. In a control system, error between reference and output can be labeled as zero(ZE), positive small(PS), negative small(NS), positive medium(PM), negative medium(NM), positive big(PB), negative big(NB). The process of converting a numerical variable to a linguistic variable is called fuzzification[13].

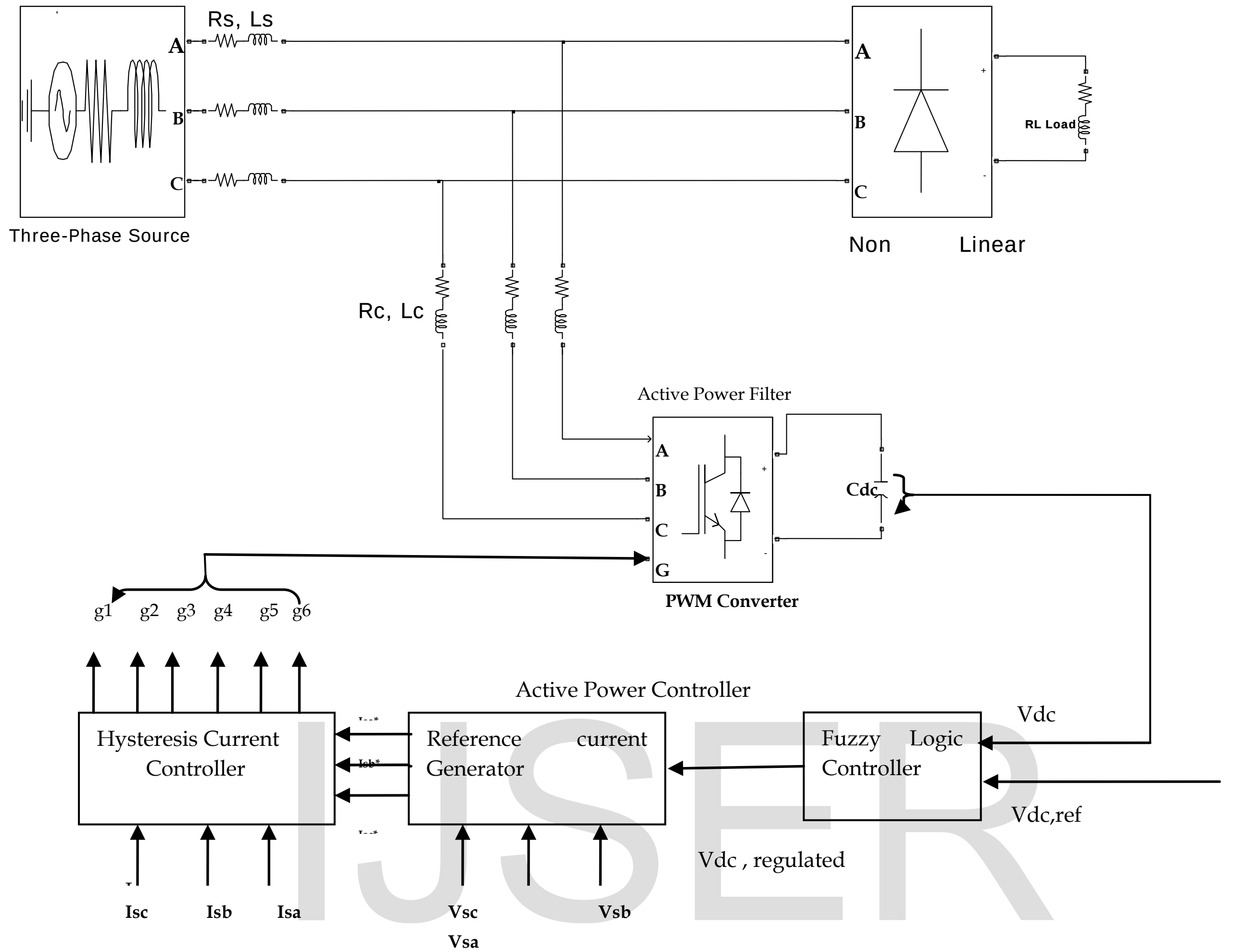


Fig.4. Proposed Fuzzy logic controlled based Shunt Active power filter

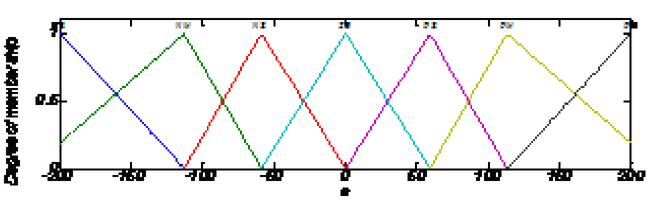


Fig 6 .MF of Error input e(n)

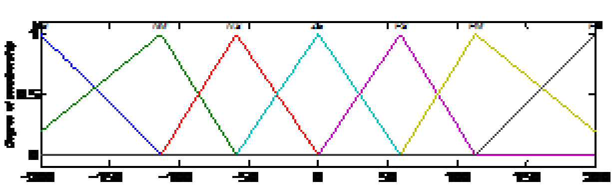


Fig 7 . MF of Change in error input ce(n)

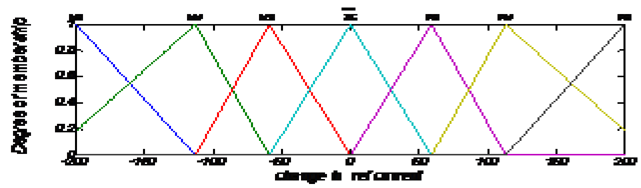


Fig8. MF for Change of reference output (δImax (n))

3) Rule Elevator

FLC uses linguistic variable in place of numerical variable like PI controller. FLC use the following fuzzy set rules to control the system.

$$\text{AND -Intersection: } \mu_{A\cap B} = \min[\mu_A(X), \mu_B(X)]$$

$$\text{OR -Union:} \mu_{A\cup B} = \max[\mu_A(X), \mu_B(X)]$$

$$\text{NOT -Complement: } \mu_{\bar{A}} = 1 - \mu_A(X)$$

4) Defuzzification

The reversal of fuzzification [15] is called defuzzification .The linguistic variable to be converted in to crisp output.

5) Database

The Database stores the definition of the triangular membership function required by fuzzifier and defuzzifier.

6) Rule Base

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

TABLE I. RULE BASE TABLE

e(n) / ce(n)	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

C Hysteresis current controller (HCC)

Hysteresis current controller is easiest control method to gerenrates the switching signal for three phase volatage source inverter,when the error signal exxeed the upper limit of Hysteresis band the upper switch of inverter arm is turn OFF and lower arm is turn ON and vice versa.

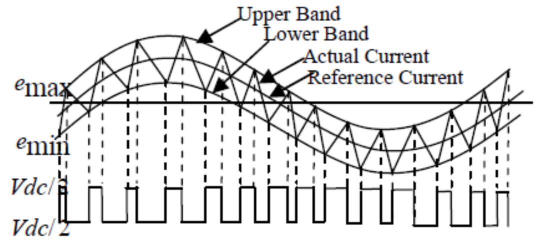


Fig 9. Diagram of hysteresis current control

As a result, the current start to decay that is shown in Fig 9. The switching performance as follows.

$$S = \begin{cases} 0 & if\, i_{actual}(t) > i_{ref}(t) + h \\ 1 & if\, i_{actual}(t) < i_{ref}(t) - h \end{cases}$$

5 SIMULATION RESULT AND ANALYSIS

The performance of the proposed PI and fuzzy logic control is evaluated through simulation using MATLAB Simulink power tools. The power device used is MOSFET with diodes.

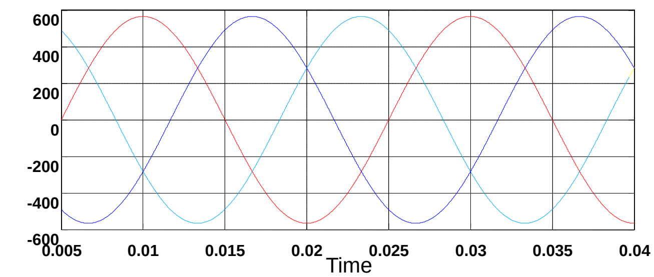
1) TABLE II : SYSTEM PARAMETERS FOR SIMULATION STUDY

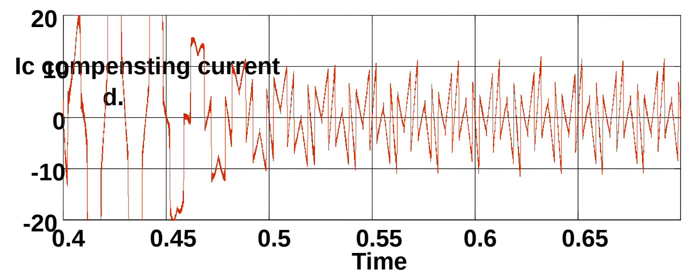
1) System Parameters	1) Value
1) Source Voltage(Vs)	2) 400V
1) System Frequency(f)	3) 50 Hz
1) Source impedance(Rs;Ls)	4) 0.2Ω ;5mH
1) Filter impedance(Rf;Lf)	5) 0.2Ω ; 5mH
1) Load impedance(RL;LL)	6) 20Ω; 30mH
1) Ref DC link voltage(Vdc,ref)	7) 700V

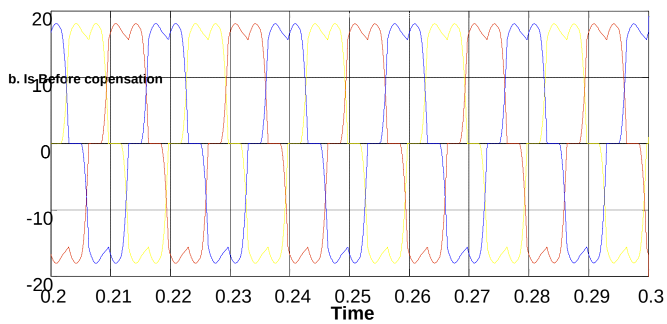
Case 1: Simulation result of PI controller

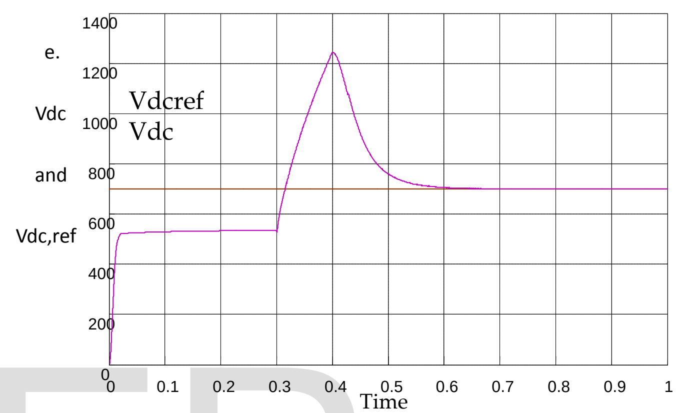
The six-pulse diode rectifier load current is shown in Fig 10 (b)The source current after compensation is presented in Fig 10 (c) that indicates that the current becomes sinusoidal. The shunt active filter supplies the compensating current that is shown in Fig 10(d).

ISSN 2229-5518









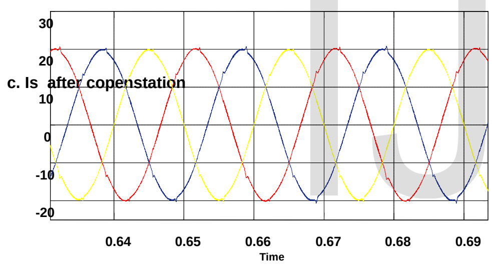
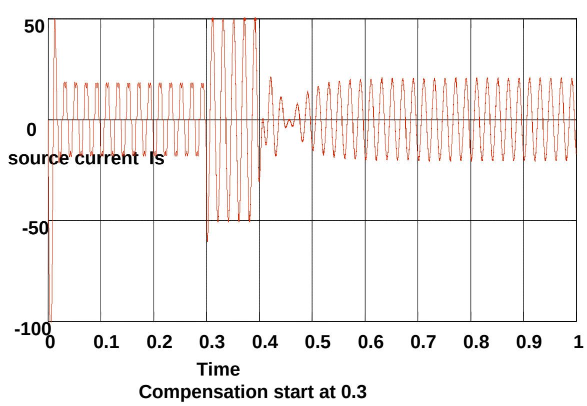
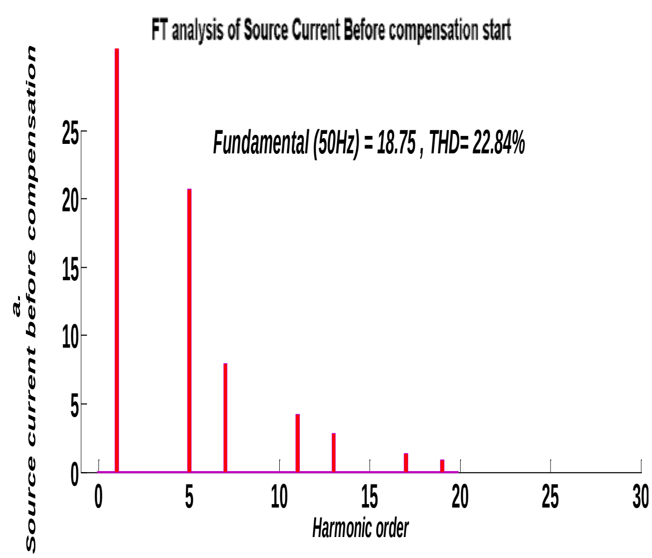


Fig 10. Simulation results for PI-controller based 3-phase SAPF under Nonlinear load condition (a)3 ph source voltage Vs (b) source currents before compensation Is (c)Is source currents after compensation (d) Compensating current Ic and (e) DC side capacitor voltage Vdc and Vdc,ref.



The FFT analysis used to measure the harmonics in source current



ISSN 2229-5518

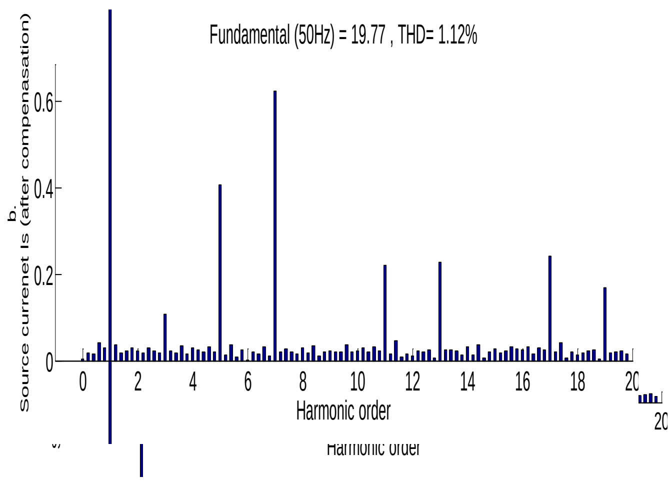
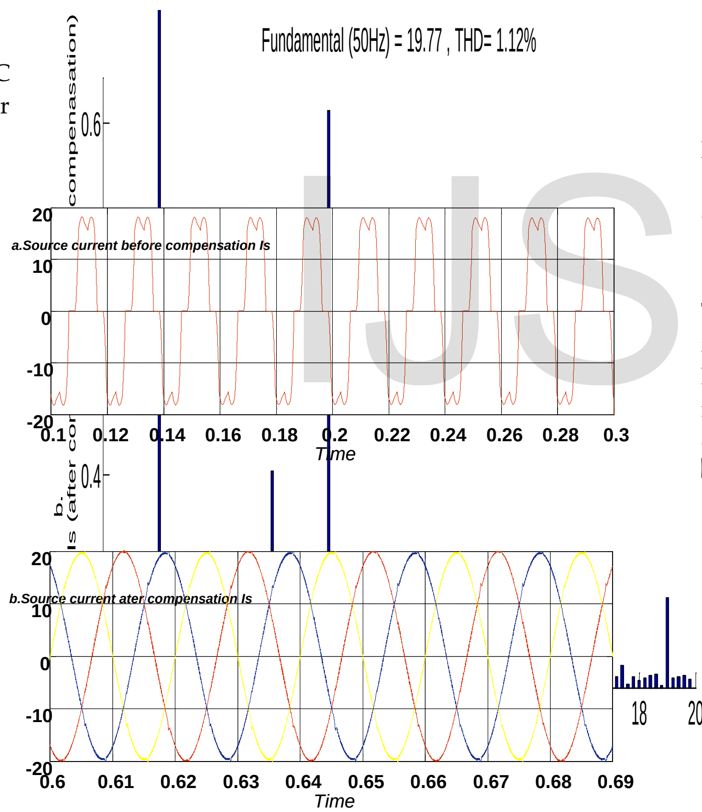
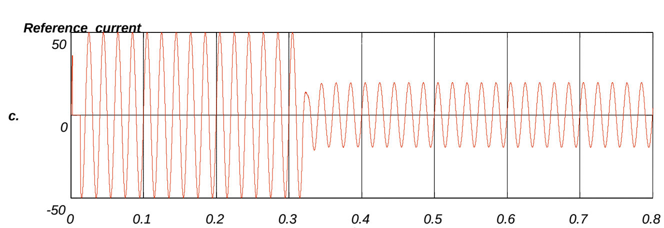
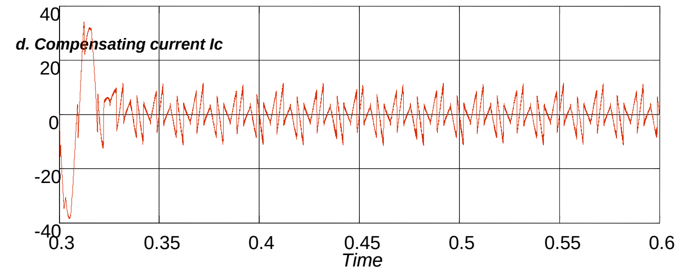


Fig 11. Order of harmonics (a) the source current without active filter (THD=22.72%), (b) with active power filter (THD=1.12%)

FLC
curr







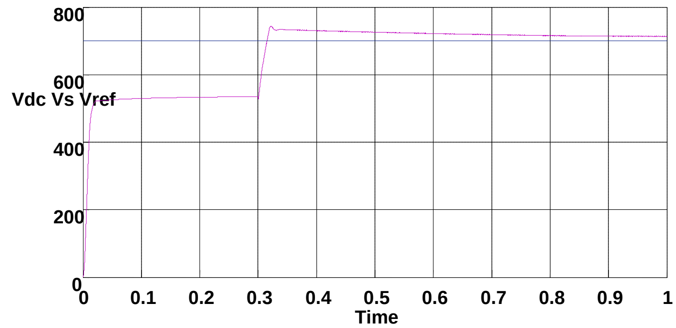


Fig 12.FLC based APF Simulation results under non-linear load (a) Source current before compensation (b) Source current after compensation (c) Reference currents (d) Compensation current (e) DC side capacitor voltage and settling time

The harmonic components evaluated using Fast Fourier Transform (FFT. Fig 12.FLC based APF Simulation results under non-linear load (a) Source current before compensation (b) Source current after compensation (c) Reference currents (d) Compensation current (e) DC side capacitor voltage and settling time.

TABLE III : HARMONICS CONTENT OF LOAD AND SOURCE CURRENT

Harmonics order	Is(Amp) without AF	Is(Amp) with Fuzzy controller	Is(Amp) with PI controller
1	18.70	19.72	19.62
5	3.85	0.06	0.08
7	1.51	0.03	0.12
11	0.81	0.04	0.05
13	0.52	0.02	0.05
17	0.25	0.04	0.05
19	0.17	0.02	0.04
THD%	22.73	0.77	1.15

The harmonic components evaluated using Fast Fourier Transform (FFT.

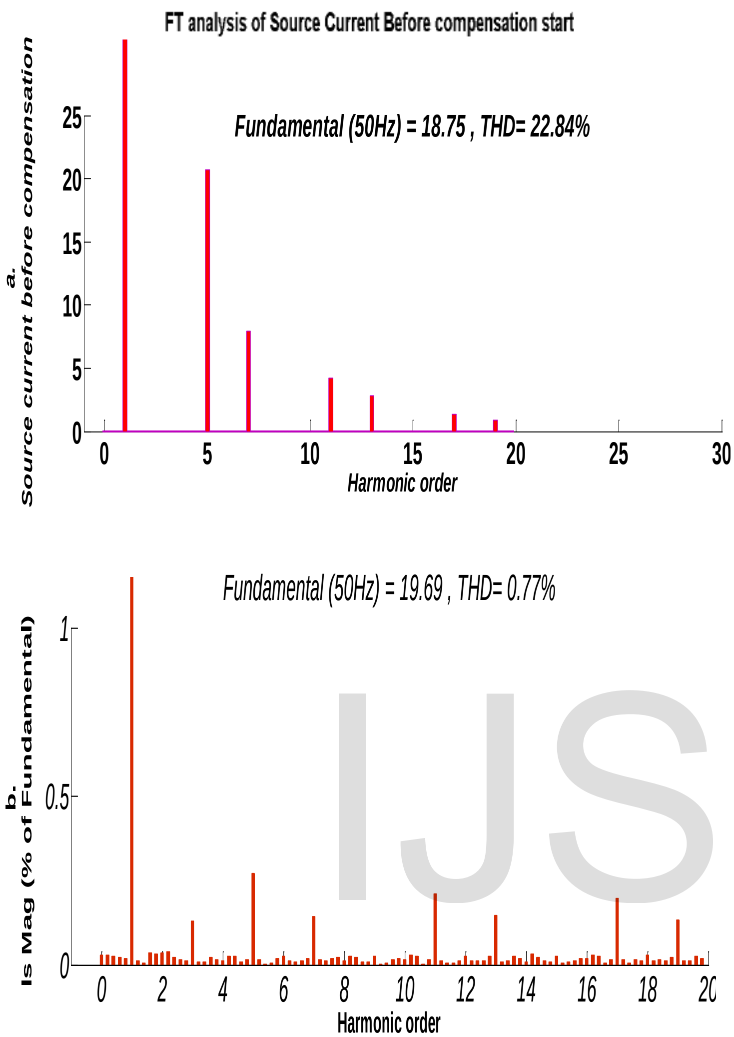


Fig 11. FLC based APF; Order of harmonics (a) the source current without active filter (THD=22.84%), (b) with active power filter (THD=0.77%)

6 CONCLUSIONS

This paper has described and illustrated that when the shunt active filter is connected with the system of non-linear load, current and voltage can be prevented effectively from harmonic distortion. Therefore Simulink model of the shunt active filter is very useful for getting the newer controlled strategy or advanced techniques for the filtering of non-linear load.

In addition to this POWERGUI FFT analysis provides effective percentage values of total harmonic distortion for different firing angles provided with the system of non linear load which provides prediction of harmonic distortion in current according to the specifications of the system. This approach brings down the THD of the source current that is in compliance with IEEE-519 and IEC 61000-3 required harmonic standards.

7 REFERENCES

[1] H. Akagi, "Trends in Active Power Line Conditioners," *IEEE Trans. Power Electron.*, vol. 9, no. 3, pp. 263–268, 1994.

[2] B. Singh, "A New Control Approach to Three-phase Activt: Filter for Harmonics and Reactive Power Compensation," *IEEE Trans. Power Syst.*, vol. 13, no. 1, pp. 133–138, 1998.

[3] B. Singh, K. Al-Haddad, and A. Chandra, "Review of active filters for power quality improvement," *IEEE Trans. Ind. Electron.*, vol. 46, no. 5, pp. 960–971, 1999.

[4] V. Mahajan, P. Agarwal, and H. O. Gupta, "Simulation of shunt active power filter using instantaneous power theory," *2012 IEEE Fifth Power India Conf.*, no. 3, pp. 1–5, 2012.

[5] F. Z. Peng, H. Akagi, and A. Nabae, "A Study of Active Power Filters Using Quad-Series Voltage-Source PWM Converters for Harmonic Compensation," *IEEE Trans. Power Electron.*, vol. 5, no. 1, pp. 9–15, 1990.

[6] K. Chatterjee, B. G. Fernandes, and G. K. Dubey, "An instantaneous reactive volt-ampere compensator and harmonic suppressor system," *IEEE Trans. Power Electron.*, vol. 14, no. 2, pp. 381–392, 1999.

[7] S. K. Jain, P. Agarwal, and H. O. Gupta, "A Control Algorithm for Compensation of Customer-Generated Harmonics and Reactive Power," *IEEE Trans. Power Deliv.*, vol. 19, no. 1, pp. 357–366, 2004.

[8] S. K. Jain, P. Agrawal, and H. O. Gupta, "Fuzzy logic controlled shunt active power filter for power quality improvement," *IEE Proc. - Electr. Power Appl.*, vol. 149, no. 5, p. 317, 2002.

[9] C. N. Bhende, S. Mishra, and S. K. Jain, "TS-fuzzy-controlled active power filter for load compensation," *IEEE Trans. Power Deliv.*, vol. 21, no. 3, pp. 1459–1465, 2006.

[10] P. Karuppanan and K. Mahapatra, "PLL with PI, PID and fuzzy logic controllers based shunt active power line conditioners," *2010 Jt. Int. Conf. Power Electron. Drives Energy Syst. PEDES 2010 2010 Power India*, 2010.

[11] C. C. C. Lee, "Fuzzy logic in control systems: fuzzy logic controller - Part 2," *IEEE Trans. Syst. Man. Cybern.*, vol. 20, no. 2, pp. 404–418, 1990.

[12] A. Chaoui, J.-P. Gaubert, F. Krim, and L. Rambault, "On the design of shunt active filter for improving power quality," *2008 IEEE Int. Symp. Ind. Electron.*, pp. 31–37, 2008.

[13] V. S. C. Raviraj and P. C. Sen, "Comparative study of proportional-integral, sliding mode, and fuzzy logic controllers for power converters," *IEEE Trans. Ind. Appl.*, vol. 33, no. 2, pp. 518–524, 1997.