Power Quality Improvement and Harmonics Mitigation of APF based on Cascaded Multilevel Converters

N.Karthik
Electrical and Electronics Engineering,
Bapatla Engneering college,
Bapatla, India
karthik_21199@yahoo.co.in

Dr.M.Surya Kalavathi
Electrical and Electronics Engineering,
JNTU college of Engineering,
Kukatpally, Hyderabad, India
munagala12@yahoo.co.in

Dr.Shaik Abdul Gafoor
Electrical and Electronics Engineering,
IIT,Rajasthan
saadgafoor@gmail.com

***Abstract*—The worldwide increase of non-linear loads, significant amounts of harmonic currents are being injected into power systems. Active power filters (APF) have proved to be an interesting and effective solution to compensate current harmonics and reactive power to improve the power quality and mitigation harmonics. In this paper, operation of APF based on cascaded multilevel converter to compensate current harmonics and reactive power in distribution systems is discussed. A comparative study on the switching period is carried out with conventional system and with ANN, FLC and PI controller based system. The simulated results demonstrate the effectiveness of Fuzzy Logic controller and PI Controller in terms of harmonic mitigation and power quality. Power quality improvement and Harmonic Mitigation with proposed power electronic transformer based on cascaded multilevel converters has been verified by the simulation results with MATLAB/SIMULINK**

Keywords—Power Quality, Cascaded H Bridge, Active Filter, Fuzzy, ANN

I. INTRODUCTION

The worldwide increase of non-linear loads nowadays, significant amounts of harmonic currents are being injected into power systems. Harmonic currents flow through the power system impedance, causing voltage distortion at the harmonic currents' frequencies. The distorted voltage waveform causes harmonic currents to be drawn by other loads connected at the point of common coupling (PCC). The existence of current and voltage harmonics in power systems increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipments. The use of grid connected power electronic converters to improve power quality in power distribution systems represents the best solution, in terms of performance and stability, for the elimination of harmonic distortion, power factor correction, balancing of loads, and voltage regulation. The most common example of this type of equipment is the active power filter (APF) which has two main configurations: the shunt connected active power filter is placed in parallel with a non-linear load (NLL) and controlled to cancel the current harmonics created by it; its dual, the series active power filter, is employed for voltage correction and is connected in line with the NLL.

To mitigation of current harmonics in the system conventional method was involves passive LC filters, which are its simplicity and low cost. However, passive filters have several drawbacks such as large size, tuning and risk of resonance problems. To overcome this drawback rather than conventional approach the 4-leg APF proposed to mitigate current harmonics, reactive power, load current balancing and excessive neutral current simultaneously, and can be a much better solution. The three-phase four-wire system is now being widely used in different areas including industry, office and civil buildings and power supplies for cities and factories. This configuration results in problems with harmonics in addition to the potential unbalance of the three phases.

Active power filters may be used to effectively compensate the harmonic and reactive power on a three-phase four-wire grid. In the former the fourth leg is used to compensate the neutral wire current directly. One of the APF has been designed based on asymmetrical cascaded multilevel converter in recent years. This type presents an active power filter implemented with multiple single-phase cells connected in series. Each cell is composed by a dc capacitor and a full–bridge single–phase PWM voltage–source inverter. The cascaded topology requires a separate dc-link capacitor for each cell, requiring a complex control strategy to regulate the voltage across each capacitor. Recently cascaded transformer multilevel topology is proposed. Cascaded transformer multilevel has the advantage of having single storage capacitor for all its cells. Therefore, the dc voltage across each cell is equal. Hence the proposed method has much significance for higher rated converters used for high or medium voltage distribution system, as they require transformers to increase the inverter output voltage.

II. CONFIGURATION OF PROPOSED STRUCTURE

The configuration of system is as shown in Fig. 1. The APF is used to provide an effective current control. This APF generates the compensating currents to compensate the load currents, in order to guarantee sinusoidal, balanced, compensated currents drawn from the AC system. The circuit diagram of the three-phase four-wire active power filter with four-leg converter is presented in Fig. 1. The fourth leg is used to compensate the neutral wire current while legs 1, 2 and 3 generate the compensation currents for phases A, B and C, respectively.

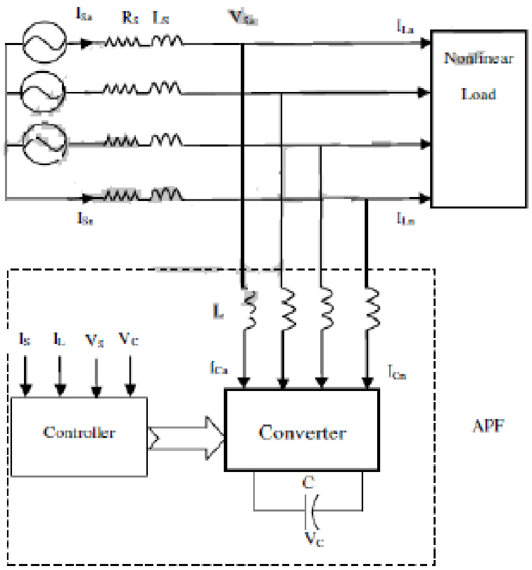


Fig. 1. Basic Configuration of system

The basic principle of a shunt active power filter is shown in Fig. 1 as:

$$I_C = I_S - I_L \qquad (1)$$

Where IC is the compensation input current, IS is the source current and IL is the load current, respectively. The main feature of the APF is that the supply current is forced to be sinusoidal and in phase with the supply voltage regardless of the characteristics of the load. Therefore, the shunt APF is mitigate the harmonics and reactive power compensation by injecting equal but opposite harmonic and reactive currents into the supply line by means of solid-state amplifier circuits. The APF shown in Fig. 1 may be described as a synchronous rectifier that is connected to a dc-link. In this paper asymmetric cascaded transformer multilevel converter with single dc-link has been used. This converter has four leg. Four H-bridge modules are connected to the same dc input source in parallel, and each secondary of the four transformers is connected in series. In this configuration, the output voltage becomes the sum of the terminal voltages of each H-bridge module. The amplitude of the output voltage is determined by the input voltage and turn ratio of the transformer. To provide a large number of output steps without increasing the number of DC voltage sources (or transformers), asymmetric multilevel converters (AMC) can be used. One leg of this converter is shown in Fig. 2.

It consists of asymmetric cascaded multilevel converter configuration, in multilevel converter with anti-parallel diodes connected to each switch to provide a mechanism for bi-directional flow of compensation current to be either absorbed from or injected into the Power supply. Here the purpose of the filter inductor, L is to regulate the max allowable magnitude ripple current flow into the APF, by means of closed-loop control. In order to get the stability (sinusoidal) of the supply current and mitigate the harmonics has to implement the required control strategy.

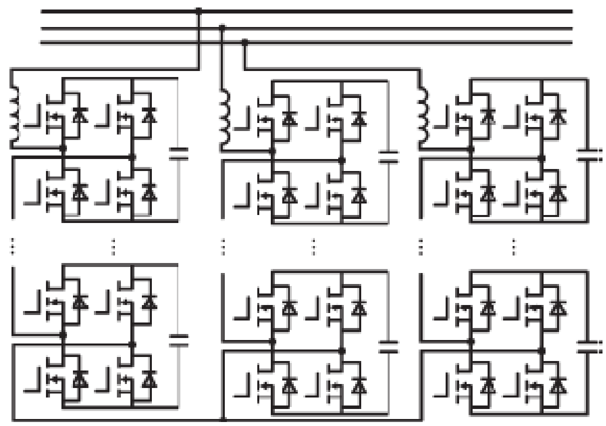


Fig. 2. Cascaded Multilevel converter

III. HARMONICS

A. Harmonic Mitigation

Current Harmonic Mitigation: Current harmonic Mitigation strategies are exceptionally important .Current harmonics are greatly reduced by the compensation of voltage harmonics at the consumer's point of common coupling. The reduction in current harmonics is not only important for reasons such as device heating and reduction in life of devices but also in design of power system equipment. One of the major design criteria covers the magnitude of the current and its waveform. This is to reduce cable and feeder losses. Since the root mean square (RMS) of the load current incorporates the sum of squares of individual harmonics, true current harmonic Mitigation will aid system designers for better approached power rating equipment.

B. Harmonic detection and extraction:

A shunt active filter acts as a controllable harmonic current source. In principle, harmonic compensation is achieved when the current source is commanded to inject harmonic currents of the same magnitude but opposite phase to the load harmonic currents. Before the inverter can subtly inject opposing harmonic currents into the power system, appropriate harmonic detection strategies must be implemented to efficiently sense and determine the harmonic current from the nonlinear load.

C. Types of harmonic detection strategies

There are 3 different types of harmonic detection strategies used to determine the current reference for the active filter.

These are:

- Measuring the load harmonic current to be compensated and using this as a reference command.

- Measuring source harmonic current and controlling the filter to minimize it.
- Measuring harmonic voltage at the active filter point of common coupling (PCC) and controlling the filter to minimize the voltage distortion.

So out of these harmonic detection strategies here we are using first method i.e., measuring the load current.

IV. Implementation

A. Proposed Control System

The quality and performance of the APF depend mainly on the method implemented to generate the compensating reference currents. In this paper proposed a method to get the reference currents, in order to the control of the APF.

The basic operation of this proposed control method is shown in Fig. 1 and equation 1. The three-phase compensating reference current of APF are estimated using reference supply currents and sensed load currents. The compensating currents of APF are calculated by sensing the load currents, dc-link voltage, peak voltage of AC source (Vsm) and zero crossing point of source voltage. The last two parameters are used for calculation of instantaneous voltages of AC source as below:

$$V_{Sa} = V_{Sm}\sin(\omega t)$$
$$V_{Sb} = V_{Sm}\sin(\omega t - 2\pi/3)$$
$$V_{Sc} = V_{Sm}\sin(\omega t + 2\pi/3) \qquad (2)$$

The basic function of the proposed shunt APF is to eliminate harmonics and compensation of current unbalance and reactive power of load. After compensating the AC source feeds fundamental active power component of load current and loses of inverter for regulating the DC capacitor voltage. Therefore the peak of source reference current (Ism*) has two components. The first component is corresponding to the average load active power (Ismp*). In order to compensating the current harmonics and reactive power of load the average active power of AC source must be equal with average power of load. With considering the unity power factor for AC source side currents the average active power of AC source can be calculated as bellow:

$$P_S = \frac{3}{2} V_{s\,m} I^*_{smp} = P_{Lav} \qquad (3)$$

From this equation, the first component of AC side current can be obtained and named Ismp*. Fig. 3 shows system that calculates Ismp*. The second component of AC source current (Ismd*) is obtained from DC capacitor voltage regulator as Fig. 4, with fuzzy controller replace the PI controller with Fuzzy Block from Simulink. The AC source currents must be sinusoidal and in phase with source voltages. Therefore the desired currents of AC source can be calculated with multiplying peak source current to a unity sinusoidal signal. The desired source side currents can be obtained from system that is shown in Fig. 5. The desired value for natural line current is zero.

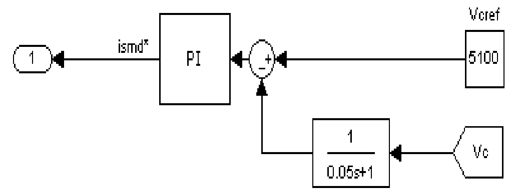


Fig. 3. DC link voltage regulator

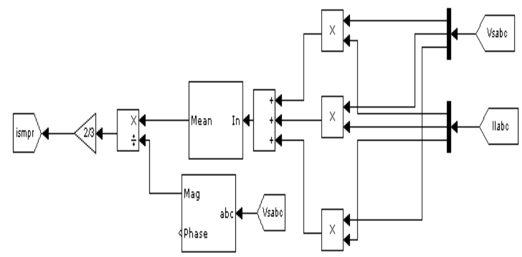


Fig. 4. Calculation of Ismp*

The AC source currents must be sinusoidal and in phase with source voltages. Therefore the desired currents of AC source can be calculated with multiplying peak source current to a unity sinusoidal signal. The desired source side currents can be obtained from system that is shown in Fig. 5. The desired value for natural line current is zero.

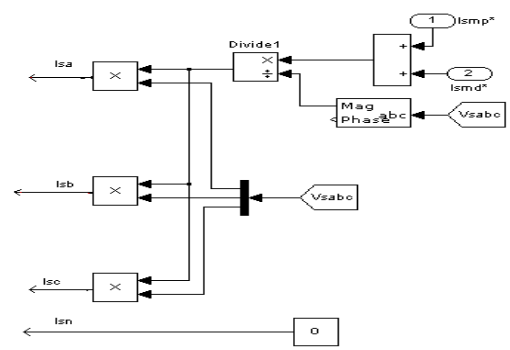


Fig. 5. Desired source side currents

The reference currents of APF can be obtained as equation 4.

$$i^*_{ca} = i^*_{sa} - i_{La}$$
$$i^*_{cb} = i^*_{sb} - i_{Lb}$$
$$i^*_{cc} = i^*_{sc} - i_{Lc} \qquad (4)$$

The reference signals (REFA, REFB, REFC and REFN) for converter switching are obtained from comparison between reference currents of APF and currents of APF. Calculation of signals for multilevel converter switching is shown in Fig. 6.

The control of the multilevel converters is to choose a series of switching angles to synthesize a desired sinusoidal voltage waveform. Several modulation strategies have been proposed for multilevel converters. Among these methods, the most common used is the multi-carrier sub-harmonic pulse width modulation (PWM). The principle of the multi-carrier PWM is based on a comparison of a sinusoidal reference waveform, with vertically shifted carrier (triangular or direct line) waveforms. In this paper we use a closed loop multi-carrier PWM technique for tracking the computed currents by APF.

B. Implementation of Fuzzy Logic Controller

The disadvantage of PI controller is its inability to react to abrupt changes in the error signal, ε, because it is only capable of determining the instantaneous value of the error signal without considering the change of the rise and fall of the error, which in mathematical terms is the derivative of the error denoted as Δε.

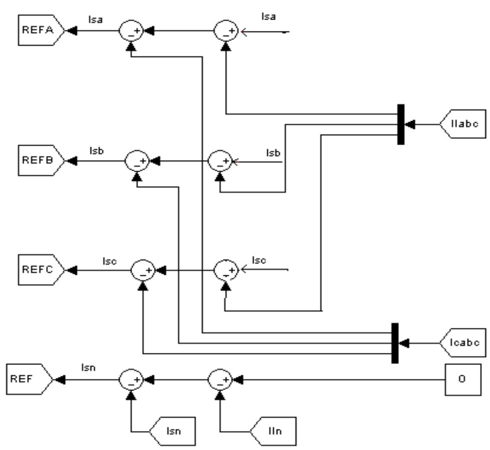


Fig. 6. Calculation of signals for multi level converter switching

To solve this problem Fuzzy logic control as it is shown in Fig 4 is proposed.

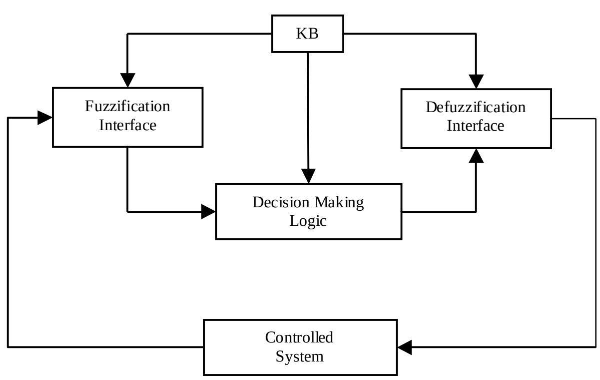


Fig. 7. Basic representation of FLC

The determination of the output control signal, is done in an inference engine with a rule base having if-then rules in the form of "IF ε is .... AND Δε is ...., THEN output is ...."With the rule base, the value of the output is changed according to the value of the error signal ε, and the rate-of-error Δε. The structure and determination of the rule base is done using trial-and-error methods and is also done through experimentation.

All the variables' fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). The membership function of inputs is illustrated in fig.5&6. The fuzzy control rule is illustrated in the table I.

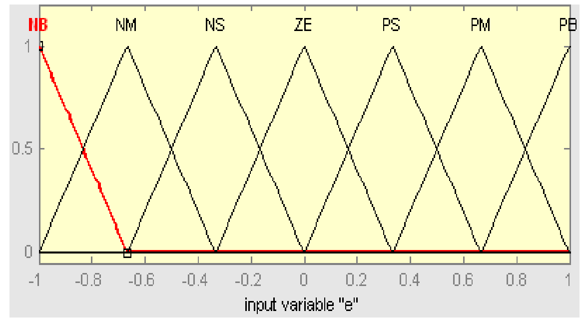


Fig. 8. Membership functions of input and output of Fuzzy controller

TABLE I. FLC RULE BASE

Δε \ε	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PM	NS	ZE	PS	PM	PM	PB	PB

All the variables fuzzy subsets for the inputs ε and Δε are defined as (NB, NM, NS, Z, PS, PM, PB). The membership function of inputs is illustrated in fig.5&6. The fuzzy control rule is illustrated in the table I.

C. Implementation of ANN controller

Artificial neural networks are inspired by sensory processing by the brain. An artificial neural network can be created by simulating a network of model neurons in a computer. By applying algorithms that mimic the process of real neurons, we can make the network 'learn' to solve many types of problems. In NN we need to set the weights and the threshold, such that the threshold correctly solves the problem. This can be done by an iterative manner called as learning or training.

Back propagation algorithm can be employed in feed forward networks with continuous output. Initially all the weights can be set with small random numbers, which generates random output. Squared difference between this output and desired output decides the correctness of chosen weights. The total error of the network is sum of all these squared differences. By minimizing this total error one can obtain better network.

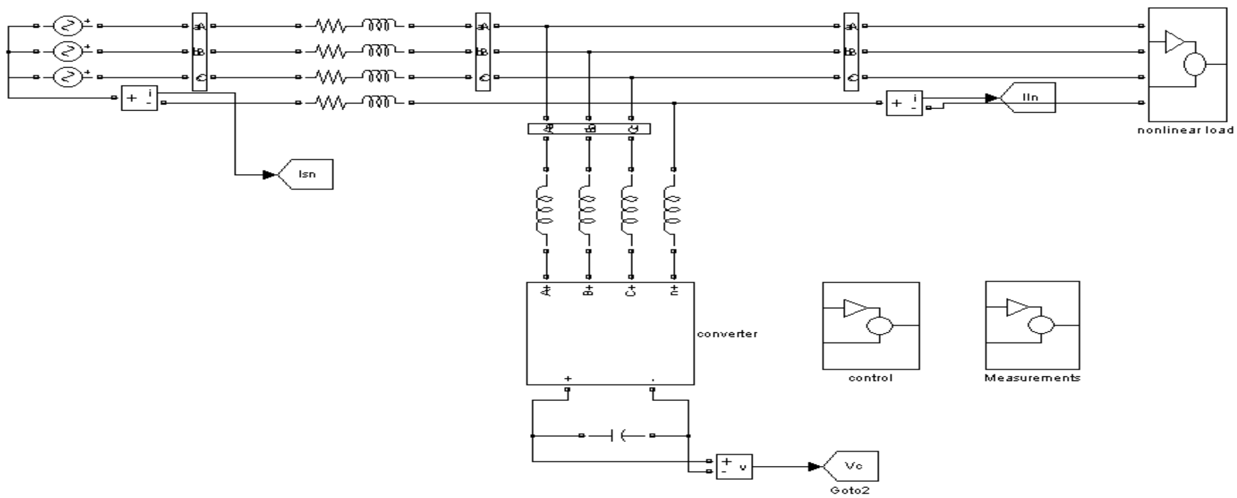


Fig. 9. Proposed System

In this paper input of the neural network is DC error voltage. And training was done by back propagation algorithm using neural network toolbox of MATLAB.

TABLE II. PARAMETERS OF CASE STUDY

Parameter	Values
Input line voltage	4160 V
Rs, Ls	0.5Ω, 3 mH
Power frequency	50 Hz
Transformer	50 Hz, 250 KVA
L, C	2 mH, 1000μF

V. SIMULATION RESULTS

Simulation results with different operating conditions of Active Power Filter (APF) are presented here with PI and Fuzzy controllers to show effectiveness of the system. The basic construction of APF as shown in Fig. 1, the APF is connected in parallel with nonlinear load. Then, the three-phase controlled rectifier with RL load has to be compensated by the APF. Table 1 shows the case study parameters.

The Proposed Simulation circuit and nonlinear load configuration is described in Fig. 7. Since the compensation of the APF depends upon the firing angle (α) of the rectifier, two operative conditions have been considered. The rectifier is the first case when α =0, while the second one is the controlled rectifier with firing angle α =90^o.

A. Simulation with Firing Angle α =0

The simulation results in steady state operation are presented. Fig. 11 shows the performance of the APF system using PI controller.

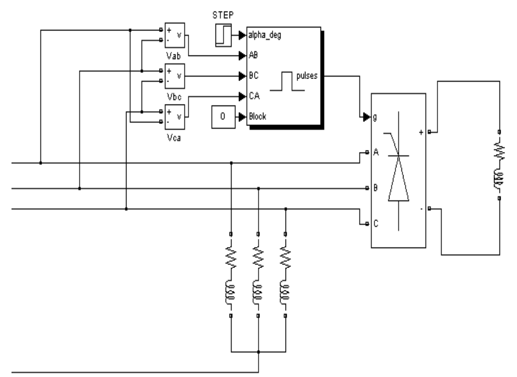
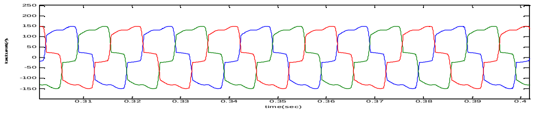


Fig. 10. nonlinear load configuration of nonlinear load

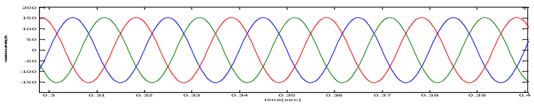
Current of the non linear load is shown in Fig. 11(a). Fig. 11(c) shows the APF current. APF current consists of harmonic compensation current. Supply current is shown in Fig. 11(b) that is sinusoidal and balance current. Fig. 11(f) shows the supply and non linear load current superimposed to the supply voltage or power factor correction is shown in figure.

Fig. 12(b) reveals the harmonic spectrum of load current. Fig. 10(c) describes the harmonic spectrum of supply current. It can be observed from the harmonic spectrum of currents that, presented structure is effective to obtain desired harmonic level.

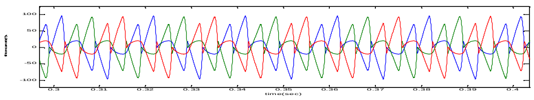
By replacing PI controller with fuzzy for DC voltage regulation in addition with constant voltage regulation further reduction in source current harmonics can be achieved.



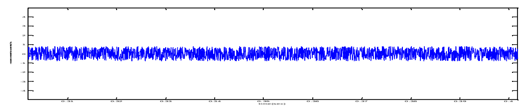
(a)



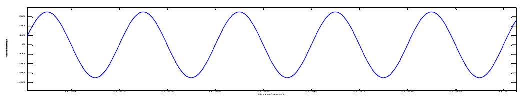
(b)



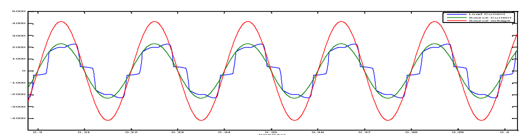
(c)



(d)



(e)



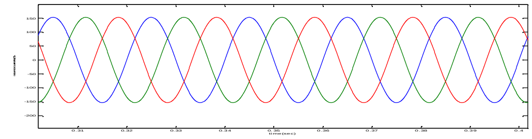
(f)

Fig. 11. (a) load current (b) source current (c) active filter current (d) source neutral current (e) load neutral current (f) source voltage, load current*15 and source current*15 $\alpha = 0^0$ with PI

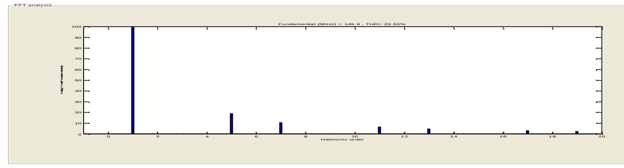
B. Simulation with firing angle $\alpha = 90^0$

The simulation results in case of steady state operation with static load when $\alpha = 90^o$ are presented. Fig. 13 shows the simulation waveforms of the non linear current, the APF current and the supply current. The non linear current is unbalanced. APF injects current to balance supply current. These results show that supply currents always remain sinusoidal and balanced.

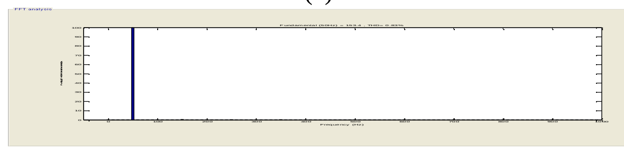
Supply and non linear load current superimposed to the supply voltage (power factor correction) are shown in Fig. 13(d). From this figure it can be seen that the voltage and current are in phase. Therefore, this figure describes the proper power factor compensation by proposed system. Matlab\Simulation results show that the effectiveness of proposed active power filter for mitigation of harmonic currents and power quality improvement in power distribution systems.



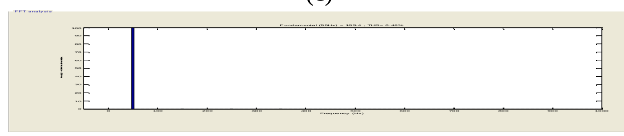
(a)



(b)

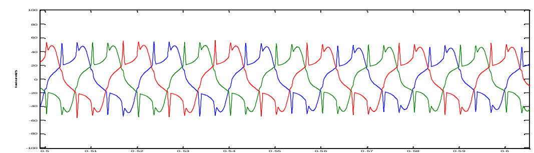


(c)

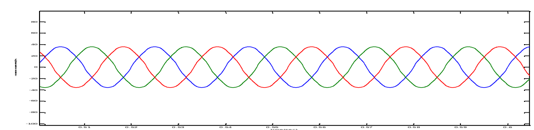


(d)

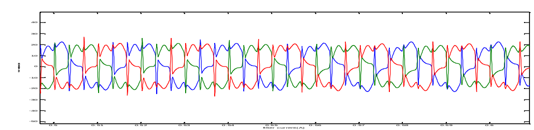
Fig. 12. (a) source current with fuzzy controller (b) load current THD (c) source current THD with PI (d) source current with fuzzy $\alpha = 0^0$



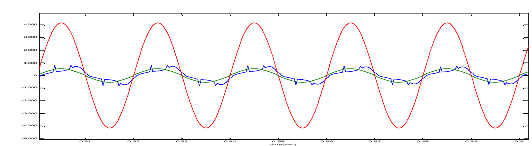
(a)



(b)



(c)

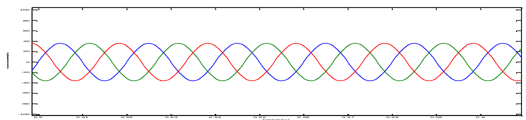


(d)

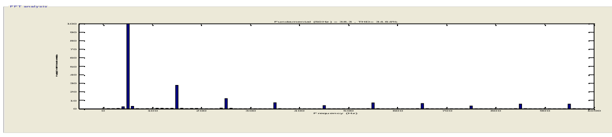
Fig. 13. (a) load current (b) source current (c) filter current (d) source voltage, load current*15 and source current*15 at $\alpha = 90^0$ with PI

TABLE III. THD COMPARISON FOR THREE CONTROLLERS

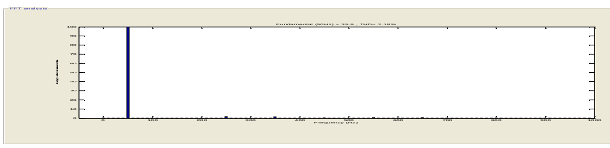
	Without SAF	PI	FUZZY	ANN
THD at α =0	23.83	0.83	0.41	0.26
THD at α =45	23.9	1.26	0.65	0.36
THD at α =90	24.94	2.18	1.08	0.6
Power factor	0.75	0.95	0.99	0.995



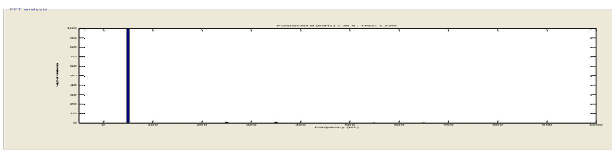
(a)



(b)



(c)



(d)

Fig. 14. (a) source current with fuzzy controller (b) load current THD (c) source current THD with PI (d) source current with fuzzy α =90^0

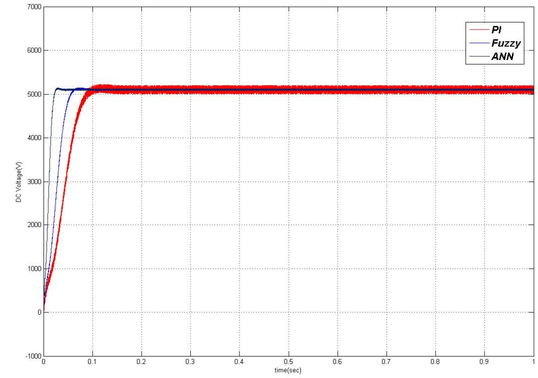


Fig. 15. DC voltage with PI and Fuzzy

VI. CONCLUSIONS

In this paper an active power filter based on multilevel cascaded transformer voltage source inverter has been presented. The advantage of the proposed scheme is the straight forward application in medium and high voltage power distribution systems. The proposed method has simple construction, and low cost due to it has one dc-link and control is easy. A Novel and simple controller has been proposed and analyzed for mitigating current harmonics, reactive power and current unbalance of nonlinear loads by operation of active power. Matlab\Simulation results shows that the effectiveness of proposed active power filter with ANN, Fuzzy and PI controllers for mitigation of harmonic currents and power quality improvement.

REFERENCES

[1] A. Ajami and S. H. Hosseini, "Implementation of a Novel Control Strategy for Shunt Active Filter," ECTI TRANSACTIONS ON ELECTRICAL ENG., ELECTRONICS, AND COMMUNICATIONS. Vol.4, No.1, pp. 40-46, February 2006.

[2] M. Ghandchi, A. Ajami and M. Moeini, "A Simple and Low Cost Control Strategy for Multilevel Shunt Active Filters," in Proceeding of International Conference on Control, Automation and Systems 2008 in COEX, Seoul, Korea. pp. 14-17, October 2008.

[3] P. Zanchetta, M. Sumner, M. Marinelli and F. Cupertino, "Experimental modeling and control design of shunt active power filters," Control Engineering Practice, Vol.17, pp. 1126 – 1135, May 2009.

[4] M.George, K. P. Basu, "Three-Phase Shunt Active Power Filter," American Journal of Applied Sciences, Vol. 5, No. 8,pp. 909-916, 2008.

[5] M.C. Benhabib, S. Saadate, " New control approach for four-wire active power filter based on the use of synchronous reference frame", Electric Power System Research, Vol.73 , pp. 353–362, 2005.

[6] C. Yanbo, Z. Fudan, K.W. E. Cheng, "Shunt Active Power Filter – SIMULINK Simulation and DSP-based Hardware Realization," in Proceeding of 2006 2nd International Conference on Power Electronics Systems and Applications, pp. 120-125, 2006.

[7] G. Zhoua, B. Wub, D. Xuc, "Direct power control of a multilevel inverter based active power filter", Electric Power System Research, Vol.77 , pp. 284–294, 2007.