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Power Quality Enhancement Using Shunt Active Filter with ANFIS Controller

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***Abstract* -Power Quality is a physical characteristics of electrical supply provided under normal operating conditions that do not disturb the process. Power quality problems occur if there is any deviation in the Voltage, Current or Frequency that results in a failure of equipment. Higher rated non-linear loads degrade the Quality of the supply. Due to this, component heating, malfunctioning of sensitive electronic loads, overheating of neutral conductors etc., is occurring. Thus the main objective is to improve the power quality by the shunt active power filters that compensate the current and voltage disturbances in power distribution system. The main function of shunt active power filter is to compensate current harmonics occurred on the load side . Thus the power quality improvement using shunt active filter using ANFIS controller is proposed. Software used for this simulation is MATLAB/SIMULINK.**

Keywords— Active power filter, Power quality improvement,Fuzzy logic controller, linear and non-linear load, reactive power, Hysteresis controller, harmonics.

1. Introduction

Power Quality is the concept of powering and grounding electronic equipment in a manner that is suitable for the operation of that equipment and compatible with the premise wiring system and other connected equipment. PQ Problem is any power problem that results in failure or misoperation of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment[Charles and Bhuvaneswari], [Chen and Jouanne]. When applied to the container crane industry, the power issues which degrade power quality includes: Power Factor, Harmonic Distortion, Voltage Transients, Voltage Sags or Dips,Voltage Swells. Power quality can be improved through: Power factor correction,Harmonic filtering, Special line notch filtering,Transient voltage surge suppression, Proper earthing systems[Dixon],[Hideaki Fujita]. Harmonics are integral multiples of some fundamental frequency that, when added together, result in a distorted waveform.They are of two types current Harmonics and voltage harmonics respectively . Series active filters are used to compensate the voltage harmonics in the load side.Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^{o}. This principle is applicable to any type of load considered a harmonic source [Hideaki Fujita],[Jefferson]. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor. In this way, the power distribution system sees the non linear load and the active power filter as an ideal resistor.

The desired switching signals for the filter inverter circuit are determined according to the error in the filter current using Fuzzy logic controller [KannanKarthik and Quaicoe],[Karuppanan and Mahapatra]. The parameters for the fuzzy logic current controller used in this paper are as follows. The design uses centrifugal defuzzification method [Kumar,Surendar and Selvan]. There are two inputs; error and its derivative and one output, which is the command signal to the PWM of the filer inverter. The two input use Gaussian membership functions while the output uses the triangle membership function.

This paper, therefore, presents a Shunt active power filter using ANFIS controller to control the harmonics under variable load conditions from balanced and load conditions.

2. Previous Work

Kumar et al, have been presented the performance comparison of Shunt Active Power Filter (SAPF) and Hybrid Active Power Filter (HAPF) with three different non-linear loads. MATLAB/ SIMULINK is used for the simulation of SAPF and HAPF.

Singh and Al-Haddad, presented a comprehensive review of active filter (AF) configurations, control strategies, selection of components, other related economic and technical considerations, and their selection for specific applications.

Dixon et al, tested SAF using computer simulations and experiments. From the experiments, it has been verified that the filter keeps the line current almost sinusoidal and in phase with the line voltage supply.

Moran, describes different power quality problems in distributed systems and their solutions to power electronics based equipment. Shunt, hybrid and series active power filters are described showing their compensation characteristics and principles of operation.

Mahesh Singh**,** identified the prominent concerns in the area and thereby to recommend measures that can enhance the quality of the power, keeping in mind their economic viability and technical repercussion

Charles, proposed a three of the three-phase shunt active filtering algorithms in timedomainhave been compared for a non-linear load. The non-linear load chosen here is a three-phase induction motor.

Litran, combined system of shunt passive and series active filter for a four wirethree-phase system has been designed and simulated with MATLAB/SIMULINK.

Salvador and Litran, described three different control strategies have been applied to a seriesactive filter. The first is based on that the filter voltage must be proportional to the harmonic of the source current.

Chen, suggested that an assessment and comparisonof hybrid active filters, including their topologies, ratings, and control algorithms. Simulations are presented, along with acomprehensive topology and performance comparison.

Karthik and Johns, proposed a control scheme based on synchronous d-q-0 transformation for a hybrid series voltage compensator. The effectiveness of the new controlscheme in compensating for voltage sags, distortion and voltage flickers is demonstrated usingsimulation results.

Ribeiro, have been presented a series active filter using a simple control technique.The series active filter is applied as a controlled voltage source contrary to its common usage as variable impedance.

Hideaki Fujita, presenteda combined system of a passive filter and a small-rated active filter, both connected in series with each other. The passive filter removes load producedharmonics just as a conventional one does.

Hideaki Fujita, have proposed the combined system of a shunt passive filter and asmall-rated series active filter. The purpose of the series active filter is to solve such a problem aseries and parallel resonance which is inherent in a shunt passive filter used alone.

3.System architecture

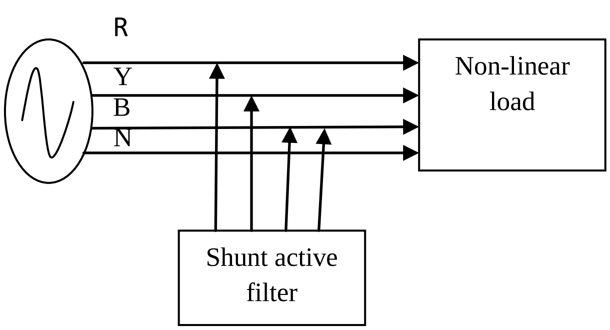

Fig 3.1 Architecture of Three Phase Four Wire Shunt Active Filter .

The three phase source is connected to the Non-linear load. V_a, V_b, V_c is the phase voltages taken from phase to neutral respectively. Due to non-linear load, current harmonics are generated at the load side [Kannan Karthik, Quaicoe]. To compensate the current harmonics shunt active filter is connected in parallel to the non-linear load. Through this parallel transformer this filter will inject equal and opposite current. It is built with IGBT and it acts as a switch .when the switch is open, it acts as a rectifier and when the switch is closed, it acts as a inverter.

4. Instantaneous Active and Reactive Current Method (I_d – I_q)

In this method reference currents are obtained through instantaneous active and reactive currents I_d and I_q of the non-linear load. Calculations follows Similar to the instantaneous power theory, however dq load currents can be obtained from **Equation (1).** Two stage transformations give away relation between the stationary and rotating reference frame with active and reactive current method [Litran, Salmeron ,Vazquez]. The transformation angle ‘θ’ is sensible to all voltage harmonics and unbalanced voltages; as a result dθ/dt may not be constant. Arithmetical relations are given in **Equ (1)to(6).**

$$\begin{bmatrix} V_0 \\ V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} V_a' \\ V_b' \\ V_c' \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_\alpha' \\ V_\beta' \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

where i_α, i_β are the instantaneous α-β axis current references

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{V_\alpha^2 + V_\beta^2}} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} \quad (6)$$

Where i_{cd}, i_{cq} are compensation currents for dq frame

$i_{c\alpha}$, $i_{c\beta}$ are compensation currents for α-β axis

V_0, V_α, V_β are voltages for α-β axis

i_0, i_α, i_β are currents for α-β axis

V_a, V_b, V_c are voltages for a-b-c axis

i_d, i_q are compensation currents for dq frame

One of the advantages of this method is that angle θ is calculated directly from main voltages and thus makes this method frequency independent by avoiding the PLL in the control circuit. Consequently synchronizing problems with unbalanced and distorted conditions of main voltages are also evaded. Thus $I_d - I_q$ achieves large frequency operating limit essentially by the cut-off frequency of voltage source inverter (VSI) [Moran].

Fig 3.2 shows the harmonic injection circuit. On owing load currents I_d and I_q are obtained from park transformation then they are allowed to pass through the high pass filter to eliminate DC components in the non-linear load currents. Filters used in the circuit are Butterworth type and to reduce the influence of high pass filter an alternative high pass filter (AHPF) can be used in the circuit. It can be obtained through the low pass filter (LPF) of same order and cut-off frequency simply difference between the input signal and the filtered one, which is clearly shown in Figure 4

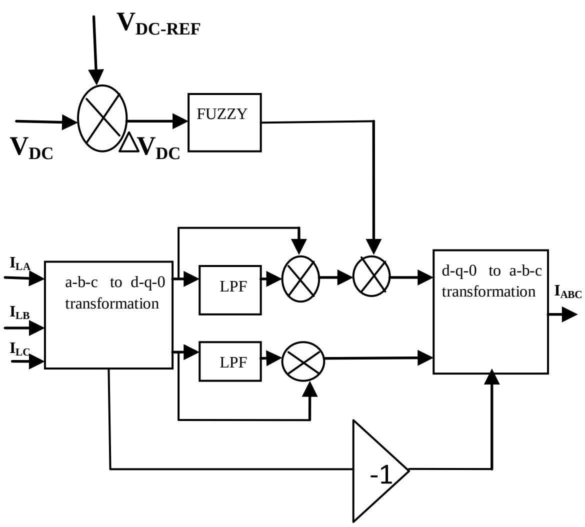

Fig.3.2 Harmonic Injection Circuit.

5. Design of Fuzzy Logic Controller

The concept of Fuzzy Logic (FL) was proposed by Professor Lotfi Zadeh in 1965, at first as a way of processing data by allowing partial set membership rather than crisp membership. Soon after, it was proven to be an excellent choice for many control system applications since it mimics human control logic. The block diagram of Fuzzy logic controller is shown in **Fig 5.1.** It consists of blocks: Fuzzification Interface, Knowledge base, Decision making logic, Defuzzification.

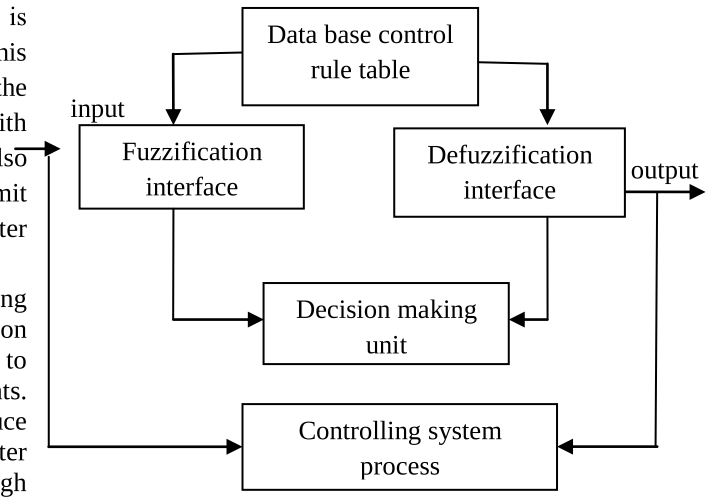

Fig. 5.1 Block Diagram of Fuzzy Logic Controller

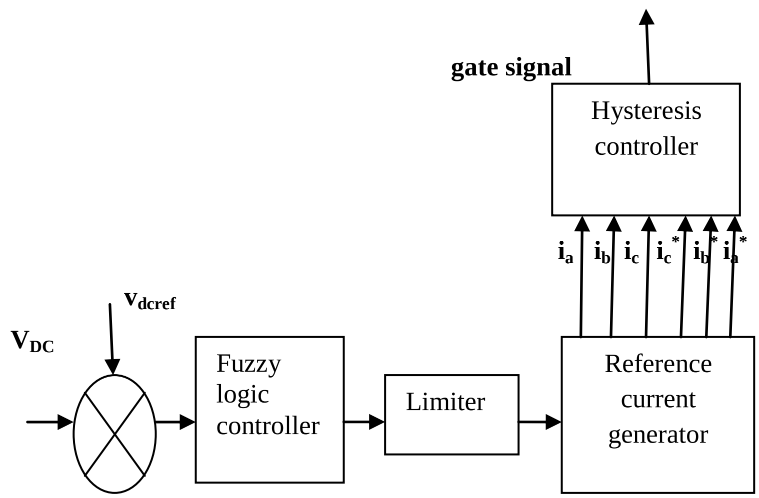

Fig.5.2 Internal Structure of the Control Circuit.

Fig 5.2 shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller [Mahalekshmi], limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal.

A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database [Mahalekshmi]. Input voltage V_{dc} and the input reference voltage V_{dcref} have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presentedby the control Current $I_{max.}$

To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in **Table 1.**

Rule Base: The elements of this 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 [Al-Haddad]. Based on this the elements of the rule table are obtained as shown in **Table 1**, with "V_{dc}" and "$V_{dc\text{-}ref}$" as inputs.

Table 1 Rule Base Design

	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

6. Neural Network

Recently fuzzy logic plays an important role in designing real time control applications. To determine the performance in the system, it is important to obtain membership function type, number of rules and selection of parameters. it is made by means of trial and error method.

Adaptive Neuro-Fuzzy Inference system is the integration of artificial neural networks and fuzzy inference systems. It consists of three elements namely auxiliary, compatible and integrative. The main aim of ANFIS is to automatically realize the fuzzy system by using the neural networks .it permits the combination of numerical and linguistic data.it has the ability to obtain fuzzy number from real number.

In this model, two learning algorithms are required. They are structural learning algorithm used to find suitable fuzzy logic rules and parameter learning algorithm used to find adjust the membership functions and other parameters according to desired performance from the system

To express the ANFIS structure, two fuzzy if-then rules under Takagi-Sugeno (TS) model are given as follows:

Rule 1: If (x is A1) and (y is B1) then f1 = p1x+q1y+r1
Rule 2: If (x is A2) and (y is B2) then f2 = p2x+q2y+r2

Here, *ri*, *pi* and *qi* are the design parameters determined during the period of training phase. Fig 6.1 shows the diagram of ANFIS controller. The ANFIS controller system realizes TS rules in 5 layers by using multi-iteration learning procedure and hybrid learning algorithm [Al-Haddad]. In the block structure of ANFIS ,there are two adaptive layers (Layers 1 and 4). Layer 1 has three adjustable parameters related to input membership functions (a_i , b_i and ci). These parameters are pioneer parameters. Layer 4 has three adjustable parameters (*ri*, *pi ve qi*) related to first degree polynomial. These parameters are called result parameters [Al-Haddad].

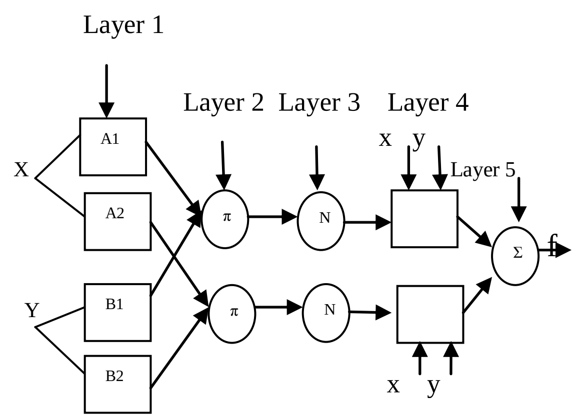

Fig 6.1 Internal Structure of the ANFIS .

7. Simulation Results

A Simulink model is developed to simulate the ANFIS controller based shunt active power filter in MATLAB/SIMULINK. The complete active power filter system is composed mainly of three-phase source, a non-linear load, a voltage source PWM converter, and a ANFIS controller. All these components are modeled separately, integrated and then solved to simulate the system.

Fig 7.1(a) to Fig 7.1(b) shows the simulink model of the proposed shunt active power filter controlled by Fuzzy logic and ANFIS controller with MATLAB simulink. The three phase source voltages are assumed to be balanced, unbalanced and sinusoidal.

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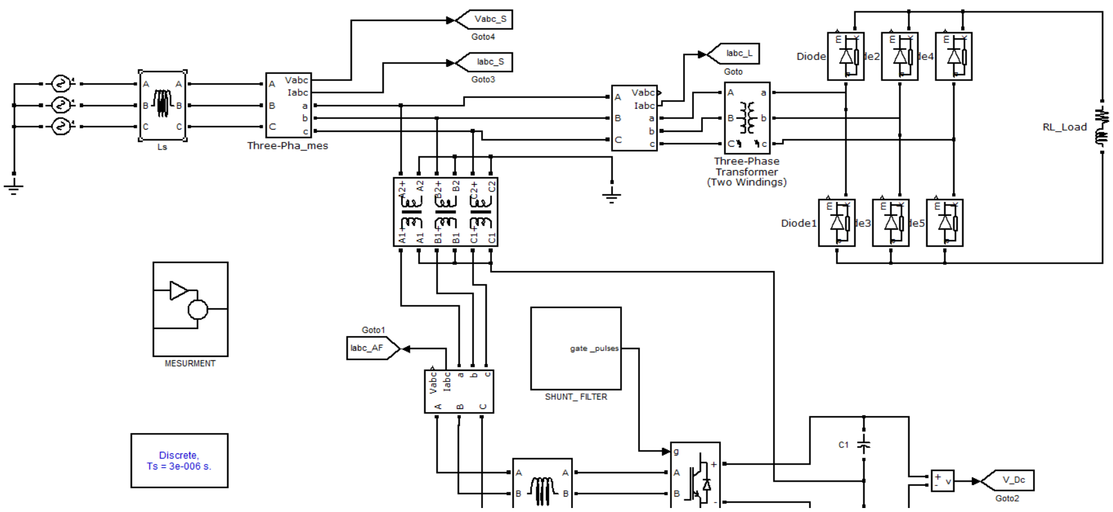

Fig.7.1(a) Simulink Model of Three Phase Four Wire Shunt Active Filter of Fuzzy logic controller

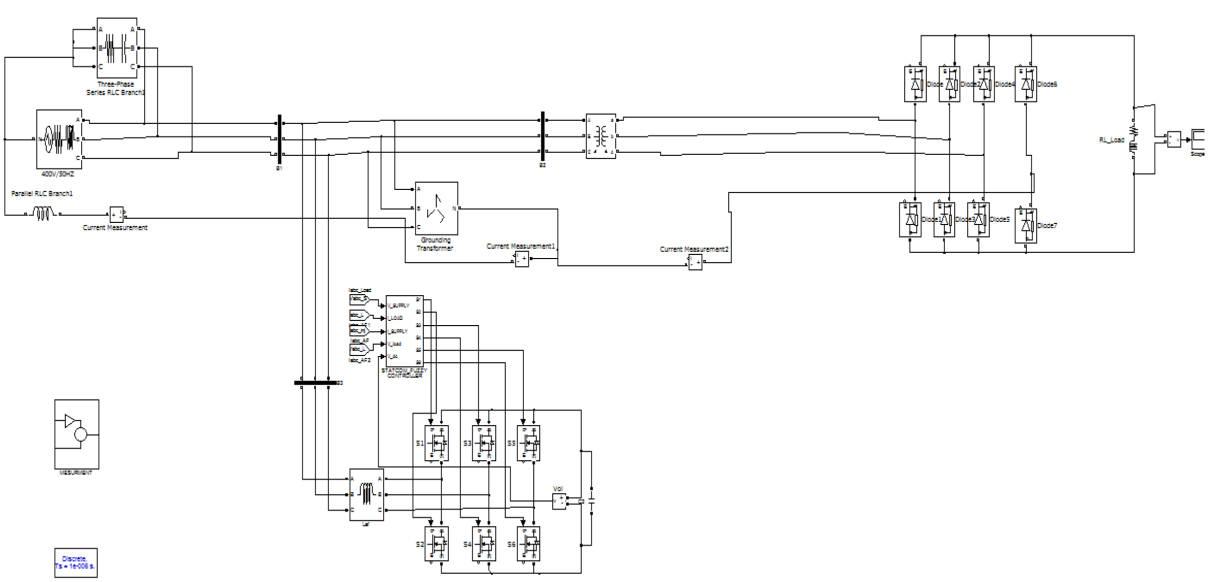

Fig. 7.1(b) Simulink Model of ANFIS controller

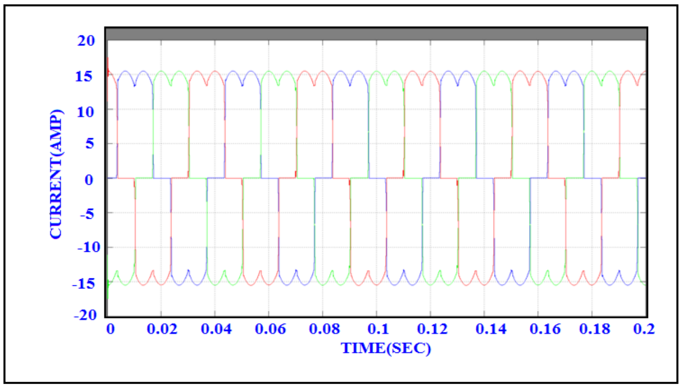

Fig. 7.1(c) Three phase Balanced Load current (fuzzy)

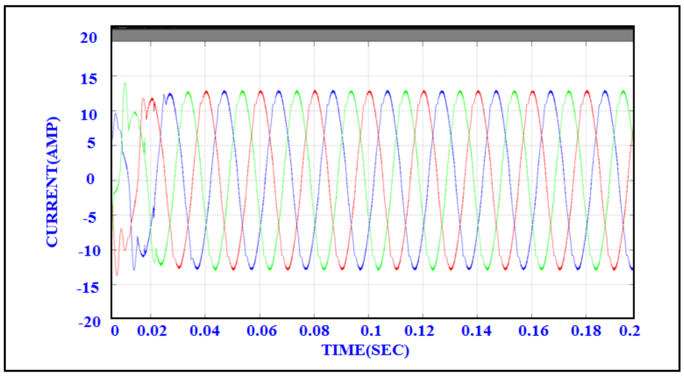

Fig. 7.1(d) Three phase Balanced source current (fuzzy)

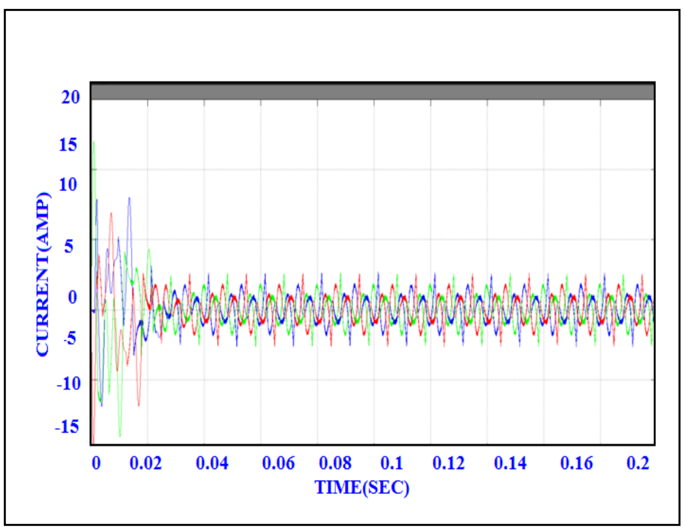

Fig. 7.1(e) Filter Current(fuzzy)

Fig 7.1(c) to Fig 7.1(e) shows the result of the proposed shunt active power filter controlled by Fuzzy logic with MATLAB Simulink.It shows the performance of Shunt active power filter under balanced sinusoidal voltage condition. Fuzzy controller is the finest controller in all the controllers but it has some drawbacks like redundancy and iteration problems. So one has to choose the membership function on the basis of system complexity .THD for i_d-i_q method with Fuzzy Controller is 1.21%.

Fig 7.2(a) to Fig 7.2(c) shows the result of the proposed shunt active power filter controlled by ANFIS controller with MATLAB Simulink.It shows the performance of Shunt active power filter under balanced sinusoidal voltage condition. ANFIS controller is accurate when compared to other controllers. So it is used for non-linear applications. THD for Neuro fuzzy method under balanced condition is 0.92%. THD for Neuro fuzzy method under unbalanced condition is 0.62%.

Fig 7.3(a) to Fig 7.3(c) shows the result of the proposed shunt active power filter controlled by ANFIS controller with MATLAB Simulink.It shows the performance of Shunt active power filter under unbalanced sinusoidal voltage condition. THD for Neuro fuzzy method under unbalanced condition is 0.62%.

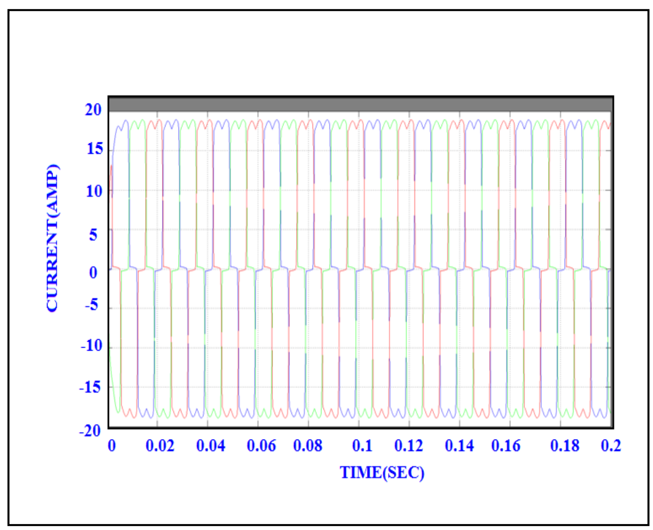

Fig 7.2(a) Three phase Balanced Load Currents(anfis)

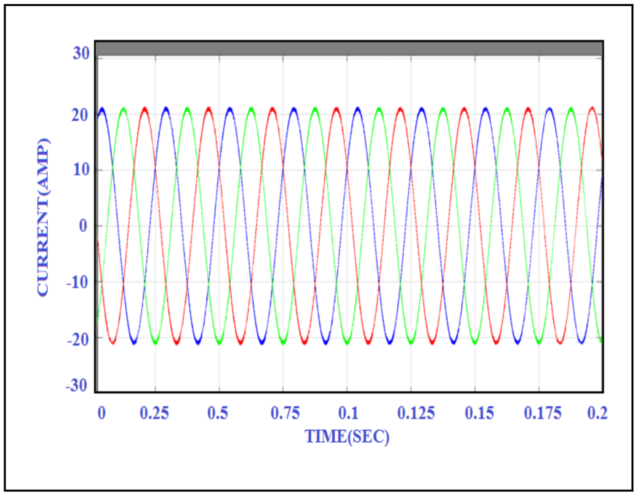

Fig 7.2(b) Three phase Balanced Source Currents(anfis)

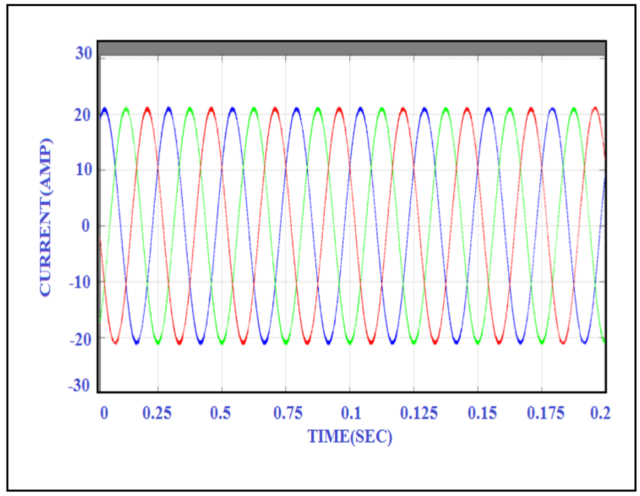

Fig 7.3(b) Three phase unbalanced Source Currents(anfis)

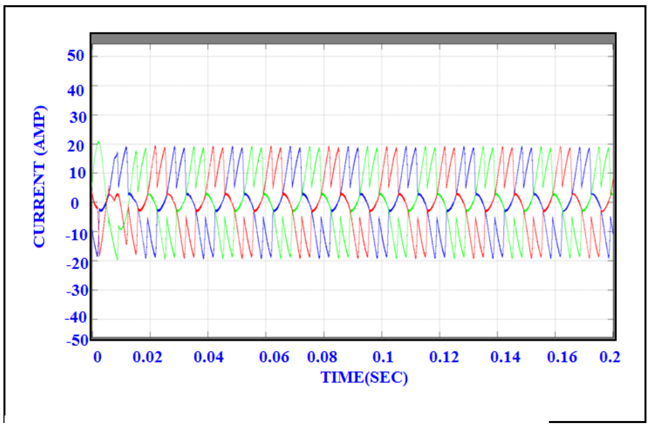

Fig 7.2(c) Filter Current(anfis)

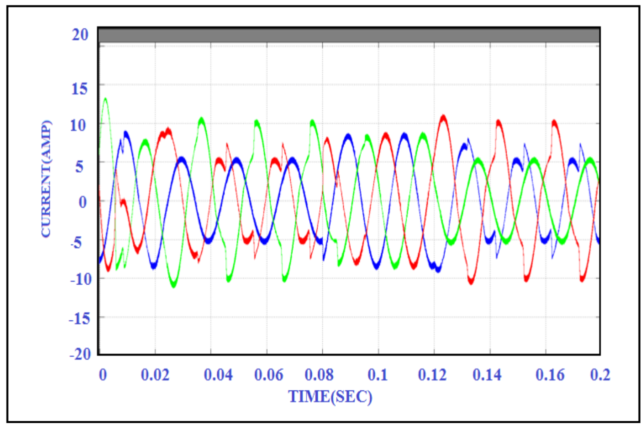

Fig 7.3(c) Filter Currents(anfis)

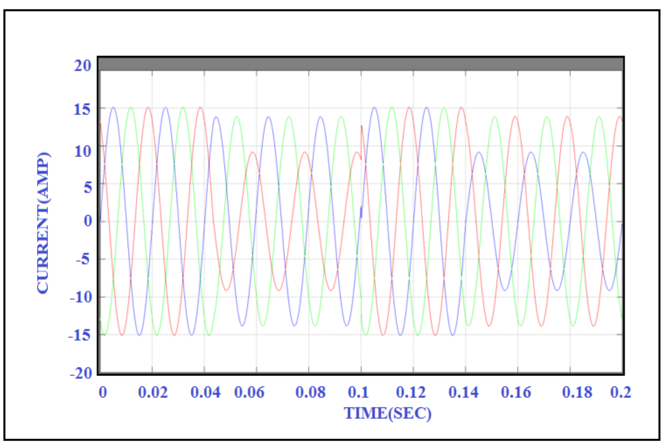

Fig 7.3(a) Three phase unbalanced Load Currents(anfis)

COMPARISON OF FLC WITH ANFIS CONTROLLER

CONTROLLER	LOAD CONDITION	THD
Fuzzy	Balanced	1.67
ANFIS	Balanced	0.92
ANFIS	Unbalanced	0.62

8. CONCLUSION

This paper presents a three phase four wire shunt active power filter using ANFIS controller is proposed.it is a cost effective solution to power quality problems. The filter presents good dynamic and steady-state response and it can be a much better solution for power factor and current harmonics compensation than the conventional approach (capacitors to correct the power factor and passive filters to compensate for current harmonics). Besides, the shunt active filter can also compensate for load current unbalances, eliminating the neutral wire current in the power lines.

Some of the advantages of the proposed controller are: It is independent of the source voltage distortion and unbalance; fast and accurate tracing of fundamental component under balanced and unbalanced nonlinear condition;simple architecture and easy for implementation; and active filter controller compensates the whole neutral current of the load. The proposed Shunt Active Filter (SAF) can compensate for balanced, non-linear load currents. Proposed SAF adapt itself to compensate for variation in non-linear currents.Simulation results shown that system limits THDpercentage of source current under limits of IEEE-519 standard (5%).

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