International Journal of Ethics in Engineering & Management Education
Website: www.ijeee.in (ISSN: 2348-4748, Volume 1, Issue 4, April 2014)

Performance verification of SHAF with TYPE-2 Fuzzy Logic Controller

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***Abstract*—Due to a large impact of non-linear power electronic equipment's, impact and fluctuating loads(such as that of arc furnace, heavy merchant mill and electric locomotive, etc.), problems of power quality have become more and more serious with each passing day, as a result Active Power filter(APF) gains much more attention due to excellent harmonic compensation. But still the performance of the active filter seems to be in contradictions with the different controllers. This proposal presents the detailed analysis to compare and evaluate the performance of shunt active filter with two types of fuzzy logic controllers. In the present days most APF's are based on voltage source inverter (VSI) which is operated with PI controllers. Because of the simple arithmetic and high reliability in the steady state, PI controller gains extensive application in DC link voltage control system. But PI controller depends on the exact mathematical model of a system and has poor robustness in transient state; additionally it tends to cause dc voltage overshoot and inrush source currents which will further lead to damage of APF. However in recent past fuzzy controller gains their importance in power system applications. The advantage of fuzzy systems over conventional PI controller is they do not need any accurate mathematical model. They can work with the imprecise inputs and can handle the non-linearity and perfect robustness. The TYPE-2 fuzzy controller seems to be a dominating one when compared to conventional TYPE-1 and PI controllers. T1 FSs has limitations in the ability to model and minimize the effect of uncertainties In the present proposal we adopt a new adaptive control technique for three phase shunt active power filter (SHAF) using interval TYPE-2 fuzzy logic controller for By using T2FLC Gaussian M.F, the SHAF gains outstanding compensation abilities. Extensive simulation have been carried out using instantaneous real active and reactive power control strategy. The detailed simulation results using MATLAB/SIMULINK software are presented to support the feasibility of proposed control strategy.**

***Keywords* —Shunt active filter, P-Q control theory,TYPE-1 Fuzzy logic controller, TYPE-2 Fuzzy logic controller.**

I. INTRODUCTION

In advanced years, the usage of non-linear loads (such as that of arc furnace, heavy merchant mill and electric locomotive, etc.) is increased by the improvement of power electronic devices and semiconductor technology. The extensive use of non-linear loads deteriorates the power quality. The power quality generally expressed as quality of voltage or/and quality of current and defines as "the measure, analysis and improvement of the bus voltage with sinusoidal waveform at rated voltage and constant frequency" [2]. The NLL harmonic injection and reactive power burden in the power system. They result in poor power factor and lower efficiency of power system. The conventional passive power filters are used for elimination of harmonics and power factor correction, but they have the limitations of larger size, resonance and fixed compensation. So we use Active power filters for improved compensation. In the last two decades a number of publications have appeared on Active power filters [1-3].Most APF's are based on voltage source inverters due to its higher efficiency. According to PWM control laws, the DC link voltage of inverter must be kept constant in order that SHAF can compensate harmonics and reactive power effectively. However a lot of controls strategies have been developed although at rest the instantaneous real active and reactive power theory, the instantaneous active and reactive currents theory are always leading. The present paper principally concentrates on the instantaneous active and reactive power (P-Q) control strategy for SHAF using TYPE-1 and TYPE-2 fuzzy controllers.

The concept of fuzzy systems [1] was introduced by Lotfi Zadeh[8] in 1965. These concept had been extended to TYPE-2 fuzzy logic systems (T2FLSs) have the characteristics of membership of grades which are themselves fuzzy. The architecture of the T2FLSs is shown below. The main components are fuzzifier, rule base, fuzzy inference engine, and output processor which comprises type reducer and defuzzifier.

International Journal of Ethics in Engineering & Management Education
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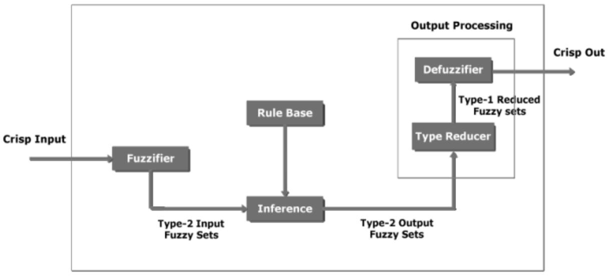

Fig: 1. Architecture of TYPE-2 Fuzzy Logic system

Similar to T1FLC, the fuzzifier in a T2FLC maps inputs into type-2 fuzzy sets. The output processor includes the type-reducer and the defuzzifier. The output of the type reducer is TlFLS and that of the defuzzifier is a crisp number (0 or1). T2FLCs can be used at the uncertain circumstances when the membership grades cannot be determined exactly. As a type-2 fuzzy set is characterized by a fuzzy membership function, i.e., the membership grade for each element also is a fuzzy set in [0,1], unlike a type-l fuzzy set, where the membership grade is a crisp number in [0,1].

The membership functions of type-2 fuzzy sets are three dimensional and include a footprint of uncertainty (FOU), which is the new third dimension of type-2 fuzzy sets and the footprint of uncertainty provides an additional degree of freedom to make it possible to directly model and handle uncertainties. Normally, Type2 Fuzzy logic controllers(T2FLCs) have characteristics of intensive computation due to heavy computational load at the step of type reducing process. To simplify the computation the secondary membership functions can be set to either zero or one and are called as interval type-2 FLSs.(IT2FLS)[12].

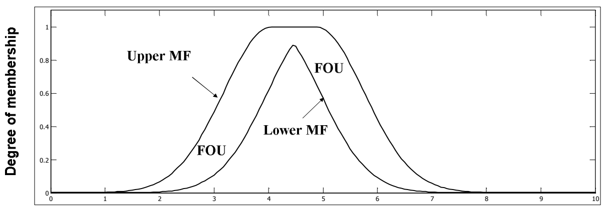

Fig: 2. FOU for Gaussian Membership Function.

This paper is organized as follows. In section II the shunt active filter was modeled and simulated and comparison was made between TYPE 1 AND TYPE2 fuzzy controllers. In section III an IT2FC was designed step by step in detail. In section IV the simulation results of IT2FC and type-1 fuzzy controllers was presented. The conclusions are drawn out based on wide-ranging simulations are carried out by means of fuzzy controllers for P-Q theory and satisfactory results were obtainable. Control strategy

A. Shunt Active filter Compensation principle

The compensation technique of shunt active power filter are based on injecting current of the same magnitude with reversed phase of the load harmonics (180 degrees phase opposition) and/or the reactive components at the point of common coupling (P.C.C) to cancel them. The compensation capabilities of shunt active power filter are Current harmonics

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

injection, Reactive power production, Resonance damping,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = C^{-1} \begin{bmatrix} V_{so} \\ V_{s\alpha} \\ V_{s\beta} \end{bmatrix} = \sqrt{2}/3 \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{so} \\ V_{s\alpha} \\ V_{s\beta} \end{bmatrix} \quad (2)$$

unbalanced load current compensation[12].

The analysis of active power filter and its operating principle were introduced by H.Sasaki and T.Machida in 1970.The current source converter type based active power filters were implemented using GTO thyristsor for first time in the world in 1982.then after MOSFETs and GTOs were utilized. Now a day the IGBTs are using for the real improvement in active power filter technology.

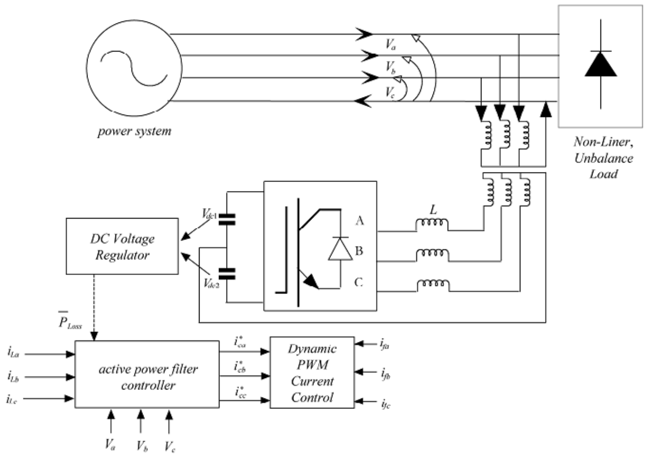

Fig: 3. the basic block diagram of three phase three wire shunt active power filter.

B. Instantaneous Real and Reactive Power Method (p-q)

Earlier days the power flow calculations were derived from the average powers or rms values of voltages and currents. H.Akagi defined a new concept in 1982, called the instantaneous real active and reactive power theory in the journal transaction of IEEE Japan. The P-Q theory is founded on the instantaneous active and reactive powers in time domain analysis by using instantaneous voltages and current components on αβ0 coordinates. So the P-Q theory first uses the Clarke transformation. It is used to map three phase instantaneous voltages and line currents into αβ0 coordinates. The transformation matrices C and C^{-1} for Clarke transformation and inverse Clarke transformation are given respectively in equations.

The above equations are given for voltage vectors but they are also valid for current vectors. The “0” indicates for zero sequence components either in voltage or current. In three phase three wire system, no zero sequence components can flow. So the zero sequence components in above equations are eliminated and to show the αβ axes mapping of a three phase balanced linear system.

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ V_{s\beta} & -V_{s\alpha} \end{bmatrix} \begin{bmatrix} I_{l\alpha} \\ I_{l\beta} \end{bmatrix} \quad (3)$$

Rearranging equation(3)

$$\begin{bmatrix} I_{s\alpha} \\ I_{s\beta} \end{bmatrix} = \frac{1}{V_{s\alpha}^2 + V_{s\beta}^2} \begin{bmatrix} V_{s\alpha} & V_{s\beta} \\ V_{s\beta} & -V_{s\alpha} \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (4)$$

$$p = \ddot{p} + \hat{p} \quad (5)$$

$$q = \ddot{q} + \hat{q} \quad (6)$$

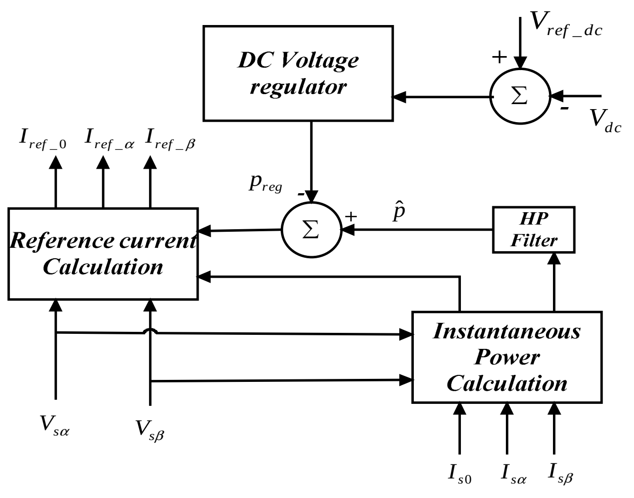

Fig: 4. Reference current Generation scheme.

From equations (5) and (6), p is the instantaneous real power and q is the instantaneous imaginary power. The real power and imaginary power are having only constant values. However if load is non linear load, the current vector will contain not only the fundamental frequency component but also the harmonic components depending on the order. Then the instantaneous real and imaginary powers will contains dc (average) element and oscillating element as decomposed in equations (5) and (6). The oscillating parts of real and imaginary powers should be selected as power references, if the shunt active power filter is constructed for compensation of current harmonic. From the active power filter controller block diagram , the high - pass filter (HPF) is used to take away the average (dc) element and extracting the oscillating elements in equations (5) and (6) and inverse Clarke transformation respectively yields the desired compensation current references ($i_{ca}^*, i_{cb}^*, i_{cc}^*$) in abc coordinates in Fig: 3.

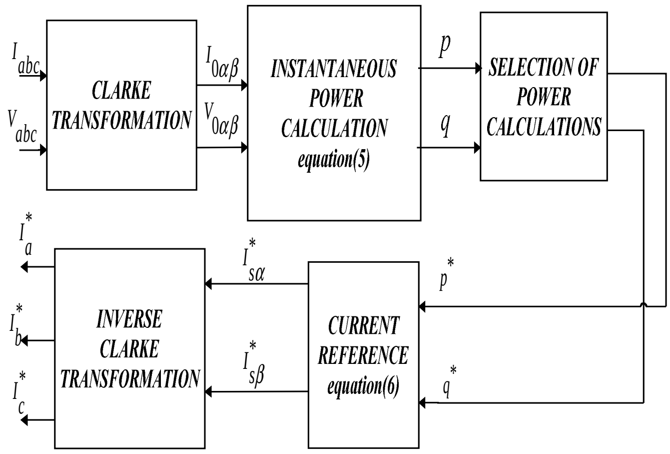

Fig: 5. Calculation of current reference based on P-Q theory

C. Significance of dc capacitor

The dc capacitor voltage possibly controlled through a dc voltage regulator. A high –pass filter is used, it insensible to the fundamental (50 Hz) frequency voltage fluctuations[10]. The filtered voltage variation develops regulation of voltage (ε) according to the subsequent equations

$$\varepsilon = -1; \qquad V_{dc} < -0.05V_{ref\_dc}$$

$$\varepsilon = \frac{V_{dc}}{-0.05V_{ref\_dc}}; \qquad -0.05V_{ref\_dc} \le V_{dc} \le 0.05V_{ref\_dc}$$

$$\varepsilon = 1; \qquad V_{dc} > 0.05V_{ref\_dc}$$

If Vdc < Vref_dc; the pwm inverter should be take up the energy from ac main to the dc capacitor. If Vdc>Vref_dc; the pwm inverter should be transport the energy from dc capacitor to ac main.

II. MODELLING OF SHAF USING FUZZY LOGIC CONTROLLER

The internal structure of the fuzzy controller is shown in fig. 6. For a T1FLC,the output processing block only contains a defuzzifier, but for a T2FLC, the output processing block includes a type-reducer . Fuzzy logic theory is based on the computation with fuzzy sets. While type-1 fuzzy sets allow for a fuzzy representation of a term to be made, the fact that the membership function of a type-1 set is crisp means that

International Journal of Ethics in Engineering & Management Education
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the degrees of membership set are completely crisp ie [0,1] – not fuzzy. The fuzzy controller is characterized by five sets of Input as a Gaussian membership function and Output with Triangular membership functions.

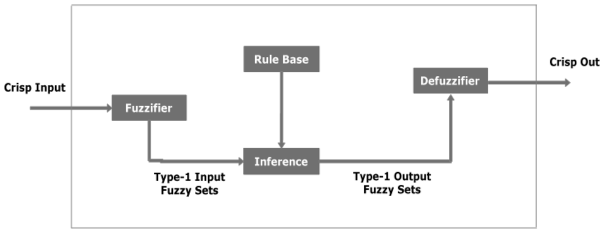

Fig 6: Architecture of TYPE-1.FLSs

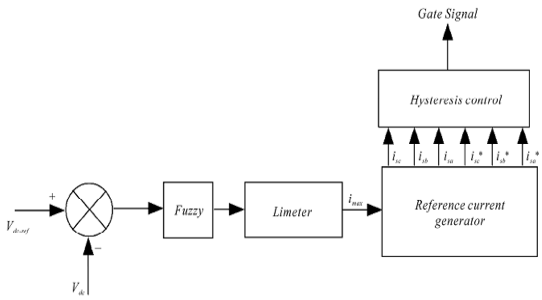

Fig: 7. Control Scheme of shunt active filter

The above fig: 7 control scheme of shunt active power filter contains Fuzzy controller, limiter, reference current generator and hysteresis controller. The crest values of current references are obtained as a result of regulating the dc link voltage. The error signal is getting by comparing the actual dc link voltage with voltage reference.[6-8] For this work five unequal spaced Gaussian membership functions have been chosen for representing each linguistic variable NB, NM, ,Z, PM, PB. The number of linguistic variables is directly related to the accuracy of approximating functions and plays an important role for approximating the nonlinear input output mapping. As the number of linguistic variables increases the output of the fuzzy controller becomes a linear function of the input.

To tradeoff between accuracy and complexity, through rigorous simulation studies it has been found that seven membership functions are sufficient to produce desired results in required band. Reducing the number of MFs will produce improper results at some band, while increasing the number of MFs will produce a delay due to more computational steps required.

III.DESIGN OF IT2 FUZZY LOGIC CONTROLLER

The architecture of interval type-2 (IT2) fuzzy logical system (FLS) as shown in fig. 1:

There are five stages to any FIS: Fuzzification, antecedent computation ,implication, aggregation and defuzzification.

A. Fuzzifier

In this paper we adopt two input one output FLC to introduce the design procedure of IT2 FLC that is we consider error and change in error s to the same range as the inputs of the proposed FLC. The membership functions for error and the change error are shown in fig. The fuzzy labels are negative big (NB), negative medium (NM), zero (Z), positive medium (PM), positive big (PB).

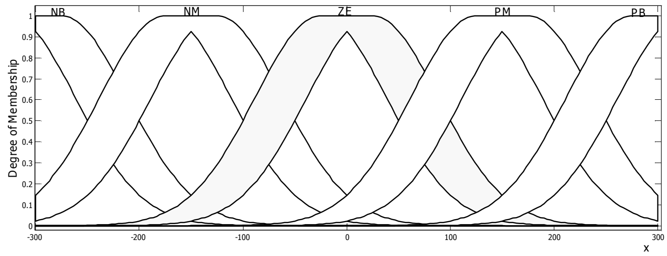

Fig 8(a): membership function for error and change_in_error

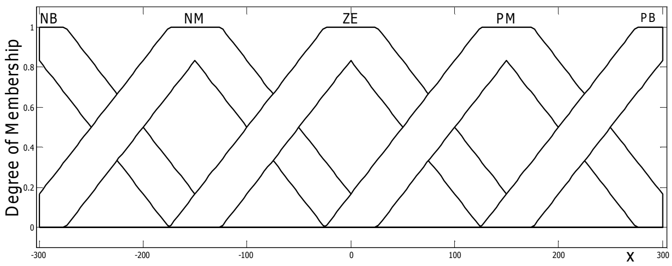

Fig 8(b): membership function output

B. Rule base

The rules for IT2 FLS are still remained the same as that of T1 FLS. But their antecedents and consequents will be represented by IT2 fuzzy sets. The diagonal rule table is summarized in table I which is constructed for the scenario in which error and change of error approach zero with a fast rise time and without overshoot.

Δerror / error	**NB**	**NM**	**ZE**	**PM**	**PB**
NB	NB	NB	NB	NM	ZE
NM	NB	NB	NM	ZE	PM
ZE	NB	NB	ZE	PM	PM
PM	NM	ZE	PM	PB	PB
PB	ZE	PM	PB	PB	PB

TABLE 1 :CONTROL RULE TABLE

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C. Fuzzy inference engine

The inference engine combines all fired rules and gives a nonlinear mapping from input IT2 FS to output IT2 FS. In the inference engine multiple antecedents are combined using the meet operation.

D. Type reduction and Defuzzification

The type-2 defuzzification consists of two parts type reduction and defuzzification. Type reduction os property by which a type-2 fuzzy set is converted into a type-1 fuzzy set and this set is the defuzzified to give a crisp number.

The Nie-Tan method is formulated to calculated the centroid of the LMF and UMF of fuzzy set □ at each x_i ,namely

each centroid m_i is a spike that is located at $x=x_i$. Then, one computes the COG of the N spikes , m_{NT} (also called as the NT defuzzified output),as:

$$m_i = \frac{1}{2}\left(\underline{\mu}_{\tilde{A}}(x_i) + \overline{\mu}_{\tilde{A}}(x_i)\right), \ldots. i = 1,..,N$$

the above equation shows that the NT formulation for the crisp output of IT2FLS depends only on the Upper and the Lower limits of its FOU(□). As the iterations are no longer needed to calculate the defuzzified value of the type-2 fuzzy logic system, the computation cost of defuzzification will be greatly

$$m_{NT} = \frac{\sum_{i=1}^{N} x_i c_i}{\sum_{i=1}^{N} c_i} = \frac{\sum_{i=1}^{N} x_i\left(\underline{\mu}_{\tilde{A}}(x_i) + \overline{\mu}_{\tilde{A}}(x_i)\right)}{\sum_{i=1}^{N}\left(\underline{\mu}_{\tilde{A}}(x_i) + \overline{\mu}_{\tilde{A}}(x_i)\right)}$$

reduced. It has been shown from the membership function for the interval type2 has only five variables. So there are only 25(5x5) rules required whereas in a type-1 fuzzy logic controller we need to take seven variables so a total of 49 rules are required. So as the number of AND /OR operation increases the number of iterations and the complexity increases. So it can be seen that type-2 FLC's can outperform the counter parts. .Another advantage is for the NT in closed-form nature of above equation enables theoretical analysis of IT2FLSs.

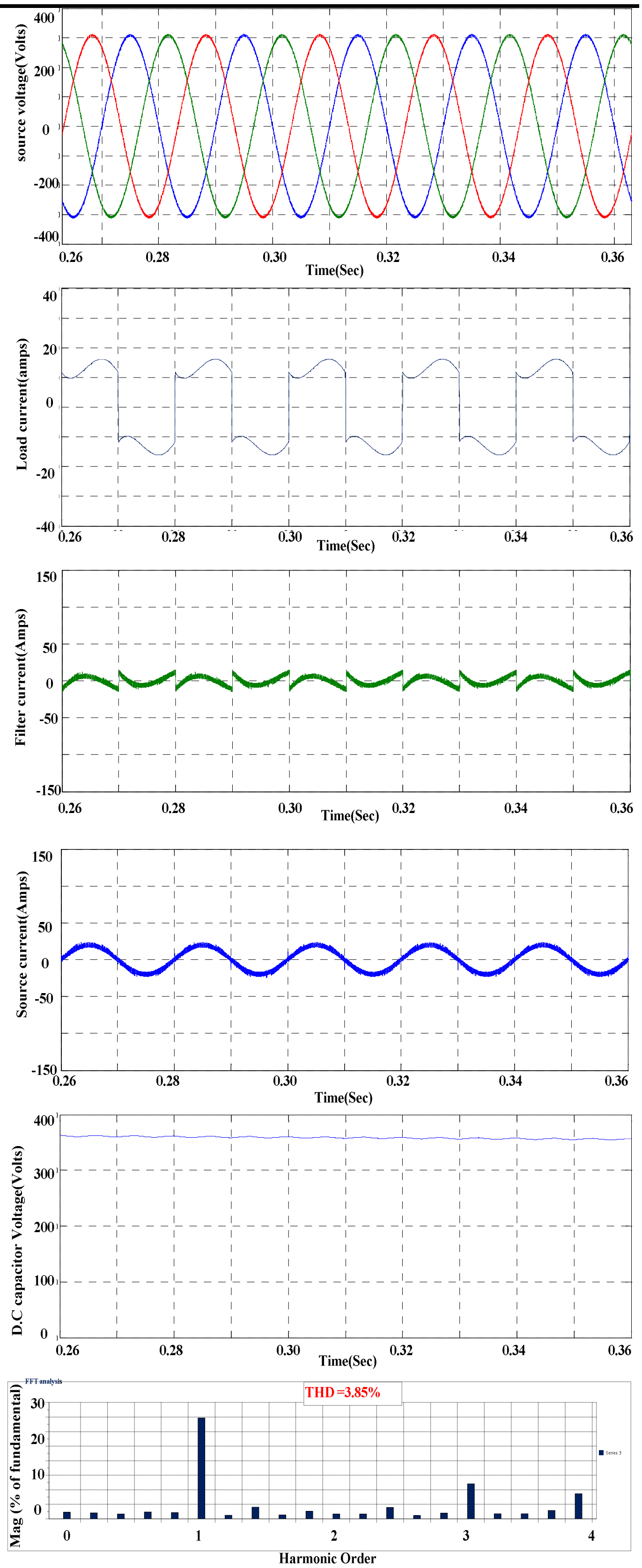

Fig: 9. Simulation results of 3-□ four wire balanced voltage for steady conditions with TYPE-2 FLC for shunt active power filter.

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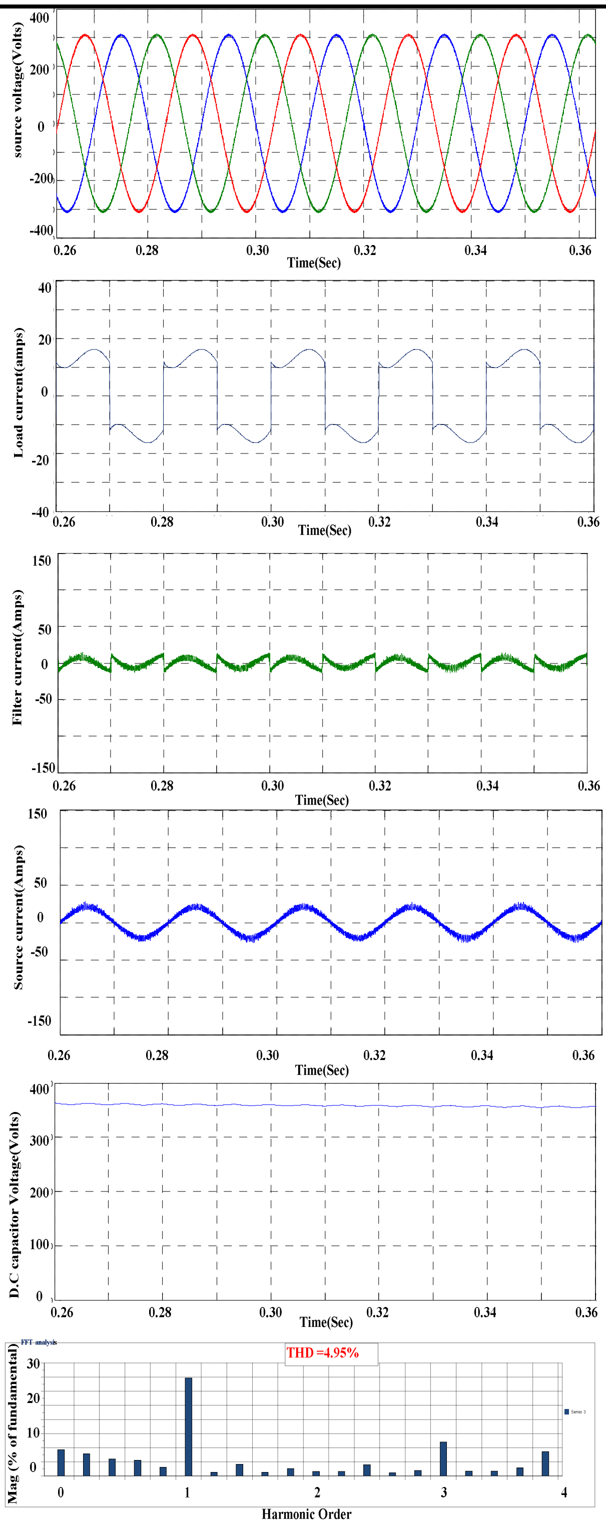

Fig: 10 Simulation results of 3-□ four wire shunt active filter with balanced voltage under steady using l TYPE-1 FLC for Shunt active power filter.

IV. Performance of system

The analysis of 3-□ three wire shunt active power filter given in Fig: 3 has been done in SIMULINK/MATLAB software. The act of the three phase four wire shunt active filter is observed under steady and transient for both balanced and unbalanced conditions and the simulations are acquired for type-1 and type-2 fuzzy logic controller with instantaneous real and reactive power (P-Q) theory.

The below Fig:9 gives the simulation results of 3-□ three wire balanced voltage under steady with shunt active filter. The system has three phase 220*sqrt (2) volts ac voltage source at 50 Hz frequency feeding a bridge rectifier with RL – load (R=33 ohms and L=69 henrys)..

For Fig:3, the simulations are carried out for 3-□ voltage source, phase A source current (Ia), load current (Il) and filter current (If). Finally the THD of source current (Ia) is reduced to 3.85% of fundamental source current using a type-2 fuzzy logic controller also there are no low frequency components due to the absence of notches in source current. The THD value is strictly within the limits of the standards.

The Fig:10 gives the simulation results of 3-□ four wire balanced voltage under steady conditions for TYPE-1 FLC with shunt active filter. The system has three phase 220*sqrt (2) volts ac voltage source at 50 Hz frequency feeding a bridge rectifier with RL – load (R=33 ohms and L=69 henrys). For Fig: 3, the simulations are carried out for 3-□ voltage source, phase A source current (Ia), load current (Il) and filter current (If). Finally the THD of source current (Ia) is reduced to 4.95% of fundamental source current and due to the presence of notches in the source current the low frequency components exists.

CONCLUSION

In this paper the three phase three wire shunt active filter based on the instantaneous real and reactive power control strategy with Type-1 and Type-2 Fuzzy logic controllers is have been analyzed and studied for steady conditions of different voltage conditions of balanced and unbalanced conditions in SIMULINK / MATLAB environment in synchronous reference frame. The simulation results assured that the performance for the Type-2 Fuzzy controller is better compared to the Type-1 Fuzzy controller. The THD of source current before compensation is 36.9% and after compensation is well below 5%, the harmonics limit imposed by the IEEE-519 standards. A new adaptive control technique using IT2 Fuzzy controller is proposed. Simulation results show that IT2FLC is better than the T1 fuzzy controller and is robust against parameter variation and rule uncertainty. Also there is a advantage oof the rule redundancyThe voltage source shunt active filter has been investigated for the compensation of harmonics, reactive power, power factor improvement and input current balancing for three phase three wire system.

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