PERFORMANCE ANALYSIS OF FUZZY BASED UNIFIED POWER QUALITY CONDITIONER FOR THREE PHASE FOUR WIRE DISTRIBUTION SYSTEM

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Abstract: **This paper introduced a new structure of 3P4W Distribution System (DS) using fuzzy based Unified Power Quality Conditioner (UPQC). The origin of 3P4W System is from 3P3WDS. In 3P4WDS the fourth wire is the neutral terminal of series transformer. The main aim is to control the unbalanced voltages and currents on source side and load side in order to provide uniform power to nonlinear loads. Neutral currents flowing from the load towards the transformer neutral, Harmonics mitigation etc. In this paper 3P4WDS system is implemented by using two controllers i.e., Proportional Integral Controller (PIC) and Fuzzy Logic Controller (FLC) and the results are validated through Matlab/Simulink.**

Index Terms **-Unified Power Quality Conditioner (UPQC), Three phase four wire (3P4W), Three phase three wire (3P3W), Distribution System (DS), Proportional Integral Controller (PIC), Fuzzy Logic Controller (FLC), Power Quality (PQ), Matrix Laboratory (MATLAB), Total Harmonic Distortion (THD), Active Power Filter (APF), Voltage Source Inverter (VSI).**

1. INTRODUCTION

The drastic development of semi-conductor technology the usage of sensitive equipment's is increased at each level of the power system. Sensitive equipment's needs quality of power to function properly. Hence the power engineers have been challenged to provide quality of power. In this aspect there are many power quality improvement techniques [13] designed by the researchers. One of such schemes is the usage of 3P4W-UPQC.

3P4W-DS [1]can be implemented by different ways such as running a neutral wire from the generation station, Running neutral from the star connected transformer at the distribution side etc.,. In this paper a new technique is introduced in which the system is fed by 3P3W but with the help of UPQC a series transformer connected in star passion is served as 4th wire results to the 3P4W-DS.In general 3P4Wsystem[4,7,9] faces a major problem of unbalanced loading. In this paper a new technique is introduced to mitigate the problem in which the active power of each phase is calculated individually and then distributed again to all the three phases equally.

2. APPROACH TOWARDS 3P4WDS

With the drastic industrialization the demand of power increased to a large extent. Meeting the load is one of the task with the quality of power to the consumer points from the service providers. There are some limits for the consumer regarding the THD of the current because due to the THD the power system will be polluted as a result the other consumers will be affected. Hence the usage of UPQC plays a major role in every part of power system for the enhancement of the power quality.

3P4W system can be obtained in different ways one is by running a neutral conductor from the power producing station, a neutral from the transformer connected in the star passion. To protect the sensitive loads if a system is already connected with the UPQC by 3P3W system must be upgraded to a 3P4W system to have a provision for the installation of some single phase loads. Hence there is a need for up-gradation from 3P3W system to 3P4W system.

In this paper the up-gradation of 3P4W system is clearly shown even though the supply is 3P3W the utilities are having another option to realize the 3P4W system.

Up-graded 3P4W system must consist of a series transformer for connecting one of the inverters for the controlling of source voltage. The utilization of the neutral from the star connected series transformer results to the realization to the 3P4W system from 3P3W system.

If the neutral current present in the system, it flows towards the neutral of the series transformer from the consumer side. This neutral current can be compensated by different techniques such as split capacitance technique [9, 7, 11] and four leg VSI technique. In this work four leg VSI technique [4,11] is used due to less complexity than split capacitance technique. Series part of the UPQC controlling scheme is based upon the vector pattern generation and the shunt part of the UPQC controlling scheme is based upon the αβ theory.

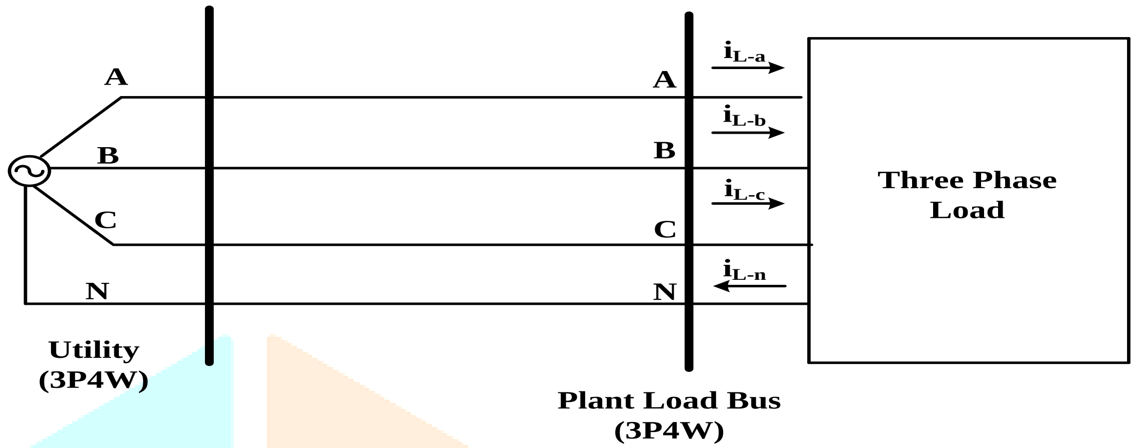

Fig.1 Running Neutral from Generating Station

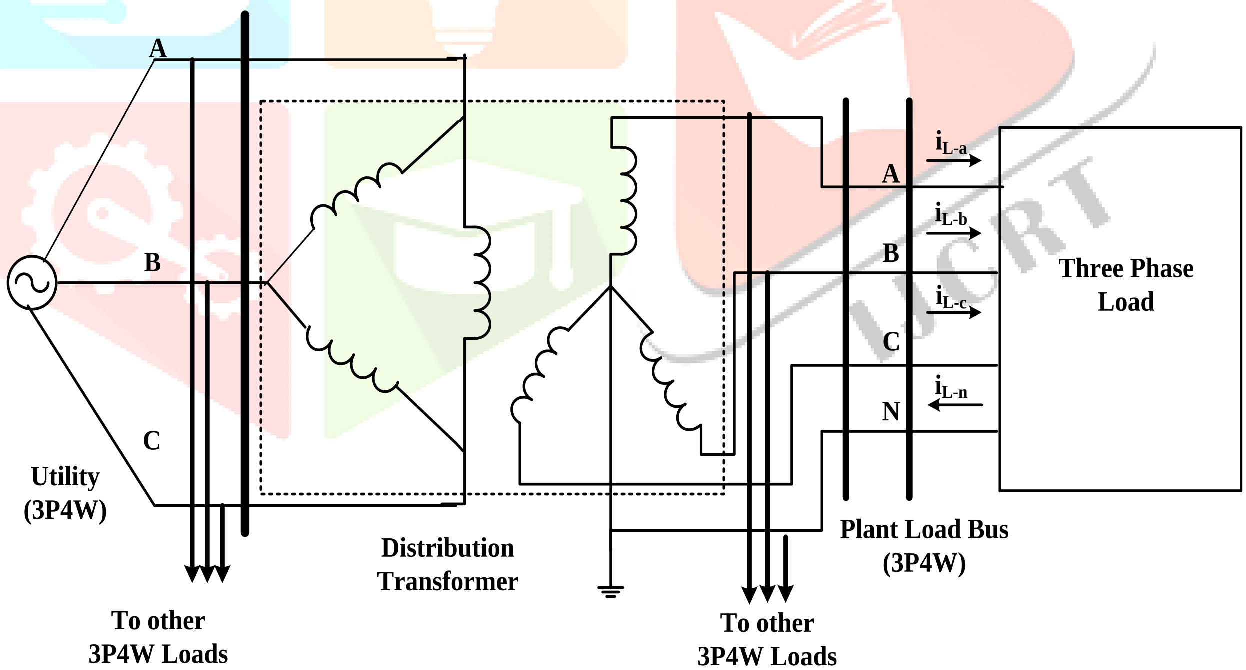

Fig. 2 Running Neutral from the transformer.

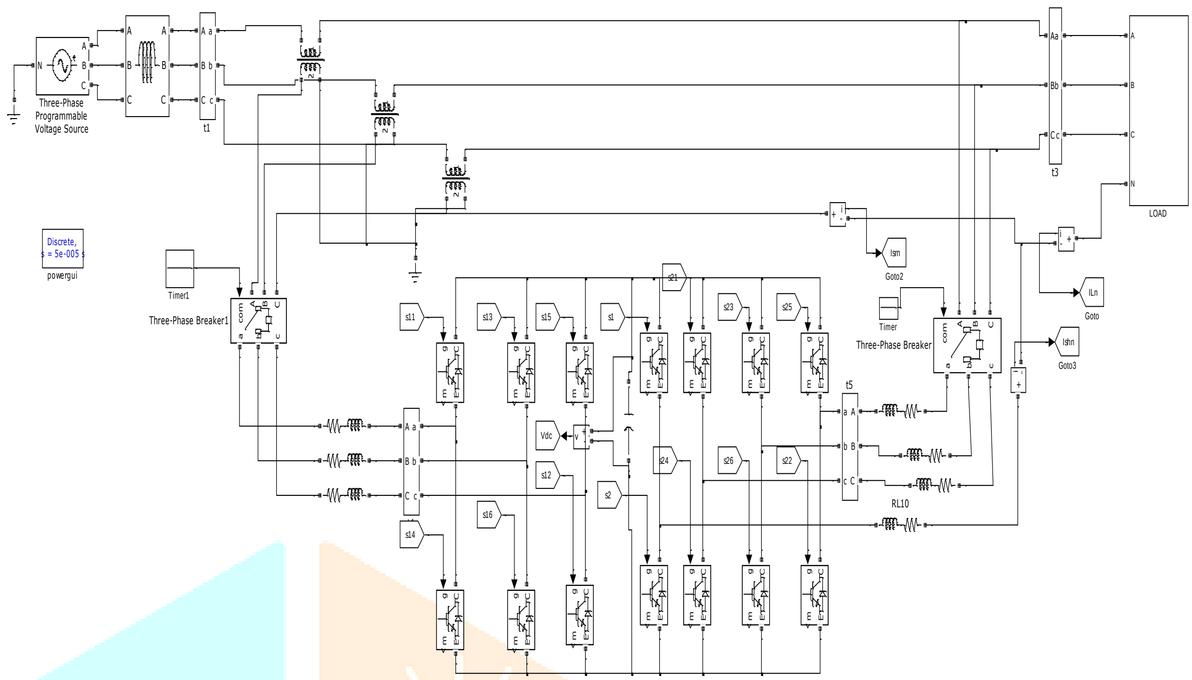

Fig. 3 Simulink model of 3P4W system

3. CONTROL SCHEMES OF THE PROPOSED SYSTEM

Control schemes of the system mainly divides in to two parts.

1. Controlling the series part of the UPQC.
2. Controlling the shunt part of the UPQC.

a) Vector Pattern Generation scheme:

In this scheme [2] the source voltage is fed to the PLL and the output produced is the angle which is fed to a trigonometric expression of sine function with three phases of phase shift of 120 for each phase and multiplied by the load peak voltage. The produced voltage from the vector pattern and the voltage of the point of coupling is subtracted and this is fed to the relay and the output of the relay is fed to the gate terminals of the series part of the switches [3].

The main aim of this controlling scheme is to inject the required compensating voltages during abnormal conditions through the series transformer which results in providing constant voltage.

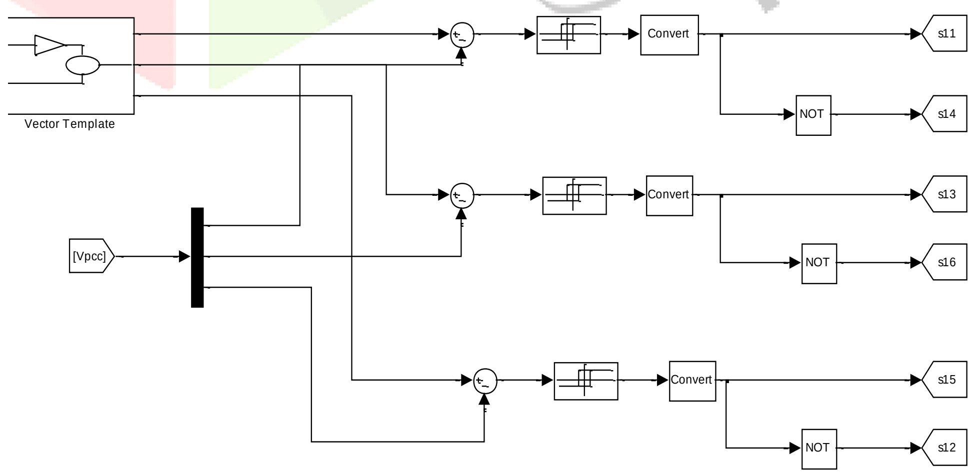

Fig. 4 Simulink model of Series controlling scheme

b) α β controlling scheme:

In this scheme the load voltages and currents of the three phase system [12] is divided into two phase system for every phase with 90° lead or 90° lag. In this paper 90° lead technique is used for achieving two phase system which is the improvised technique of P-Q theory [5,6]. Existing quantities of V and I are taken as α-axis quantities.90° lead of V and I are taken as β- axis quantities.

The equations for load voltage and current inα andβ axis for all phases are as follows:

$$\begin{bmatrix} V_{La-\alpha} \\ V_{La-\beta} \end{bmatrix} = \begin{bmatrix} V'_{La}(\omega t) \\ V'_{La}(\omega t) \end{bmatrix} = \begin{bmatrix} V_{Lm}\sin(\omega t) \\ V_{Lm}\cos(\omega t) \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} V_{Lb-\alpha} \\ V_{Lb-\beta} \end{bmatrix} = \begin{bmatrix} V'_{Lb}(\omega t) \\ V'_{Lb}(\omega t + \frac{\pi}{2}) \end{bmatrix} = \begin{bmatrix} V_{Lm}\sin(\omega t - \frac{2\pi}{3}) \\ V_{Lm}\cos(\omega t - \frac{2\pi}{3}) \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} V_{Lc-\alpha} \\ V_{Lc-\beta} \end{bmatrix} = \begin{bmatrix} V'_{Lc}(\omega t) \\ V'_{Lc}(\omega t + \frac{\pi}{2}) \end{bmatrix} = \begin{bmatrix} V_{Lm}\sin(\omega t + \frac{2\pi}{3}) \\ V_{Lm}\cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} I_{La-\alpha} \\ I_{La-\beta} \end{bmatrix} = \begin{bmatrix} I_{La}(\omega t + \psi l) \\ I_{La}(\omega t + \psi l + \frac{\pi}{2}) \end{bmatrix} \quad (4)$$

$$\begin{bmatrix} I_{Lb-\alpha} \\ I_{Lb-\beta} \end{bmatrix} = \begin{bmatrix} I_{Lb}(\omega t + \psi l) \\ I_{Lb}(\omega t + \psi l + \frac{\pi}{2}) \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} I_{Lc-\alpha} \\ I_{Lc-\beta} \end{bmatrix} = \begin{bmatrix} I_{Lc}(\omega t + \psi l) \\ I_{Lc}(\omega t + \psi l + \frac{\pi}{2}) \end{bmatrix} \quad (6)$$

The instantaneous load powers of all phases are as follows:

$$\begin{bmatrix} P_{La} \\ q_{La} \end{bmatrix} = \begin{bmatrix} \bar{P}_{La} + \tilde{P}_{La} \\ \bar{q}_{La} + \tilde{q}_{La} \end{bmatrix} = \begin{bmatrix} V_{La\_\alpha} & V_{La\_\beta} \\ -V_{La\_\beta} & V_{La\_\alpha} \end{bmatrix} \begin{bmatrix} I_{La\_\alpha} \\ I_{La\_\beta} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} P_{Lb} \\ q_{Lb} \end{bmatrix} = \begin{bmatrix} \bar{P}_{Lb} + \tilde{P}_{Lb} \\ \bar{q}_{Lb} + \tilde{q}_{Lb} \end{bmatrix} = \begin{bmatrix} V_{Lb\_\alpha} & V_{Lb\_\beta} \\ -V_{Lb\_\beta} & V_{Lb\_\alpha} \end{bmatrix} \begin{bmatrix} I_{Lb\_\alpha} \\ I_{Lb\_\beta} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} P_{Lc} \\ q_{Lc} \end{bmatrix} = \begin{bmatrix} \bar{P}_{Lc} + \tilde{P}_{Lc} \\ \bar{q}_{Lc} + \tilde{q}_{Lc} \end{bmatrix} = \begin{bmatrix} V_{Lc\_\alpha} & V_{Lc\_\beta} \\ -V_{Lc\_\beta} & V_{Lc\_\alpha} \end{bmatrix} \begin{bmatrix} I_{Lc\_\alpha} \\ I_{Lc\_\beta} \end{bmatrix} \quad (9)$$

Where

$\bar{P}_{La}, \bar{P}_{Lb}, \bar{P}_{Lc}$ are the fundamental quantities of the active power of DC component.

$\bar{q}_{La}, \bar{q}_{Lb}, \bar{q}_{Lc}$ are the fundamental quantities of the reactive power of DC component.

$\tilde{P}_{La}, \tilde{P}_{Lb}, \tilde{P}_{Lc}$ are the active harmonic power of AC component.

$\tilde{q}_{La}, \tilde{q}_{Lb}, \tilde{q}_{Lc}$ are the reactive harmonic power of AC component.

In this paper unbalanced loading condition is present. The variation of reactive power component in the load side is mitigated by shunt APF [8]. While coming to the active power the unbalanced [10] active power is redistributed equally by dividing the total component by 3.

$$P^{*}_{s/ph} = 0.33(P_{La,1} + P_{Lb,1} + P_{Lc,1}) \quad (10)$$

Where,

$P_{La,1}, P_{Lb,1}, P_{Lc,1}$ are the instantaneous fundamental load active powers for all phases

By the above equation it is clear that with the variation in the load current also the active power demand will be in a balanced condition.[1]

Currents of a perfectly balanced system is obtained from equation (7)

$$\begin{bmatrix} I^{*}{}_{Sa-\alpha} \\ I^{*}{}_{Sa-\beta} \end{bmatrix} = \begin{bmatrix} V_{La\_\alpha} & V_{La\_\beta} \\ -V_{La\_\beta} & V_{La\_\alpha} \end{bmatrix}^{-1} * \begin{bmatrix} P^{*}{}_{S/\mathrm{ph}} + P_{\mathrm{dc/ph}} \\ 0 \end{bmatrix} \qquad (11)$$

Where $P_{\mathrm{dc/ph}}$ is the active power per phase.

$I^{*}{}_{Sa-\alpha}$ is the compensating source current at a instant

$I^{*}{}_{Sa-\beta}$ +is the $\frac{\pi}{2}$ lead compensating current

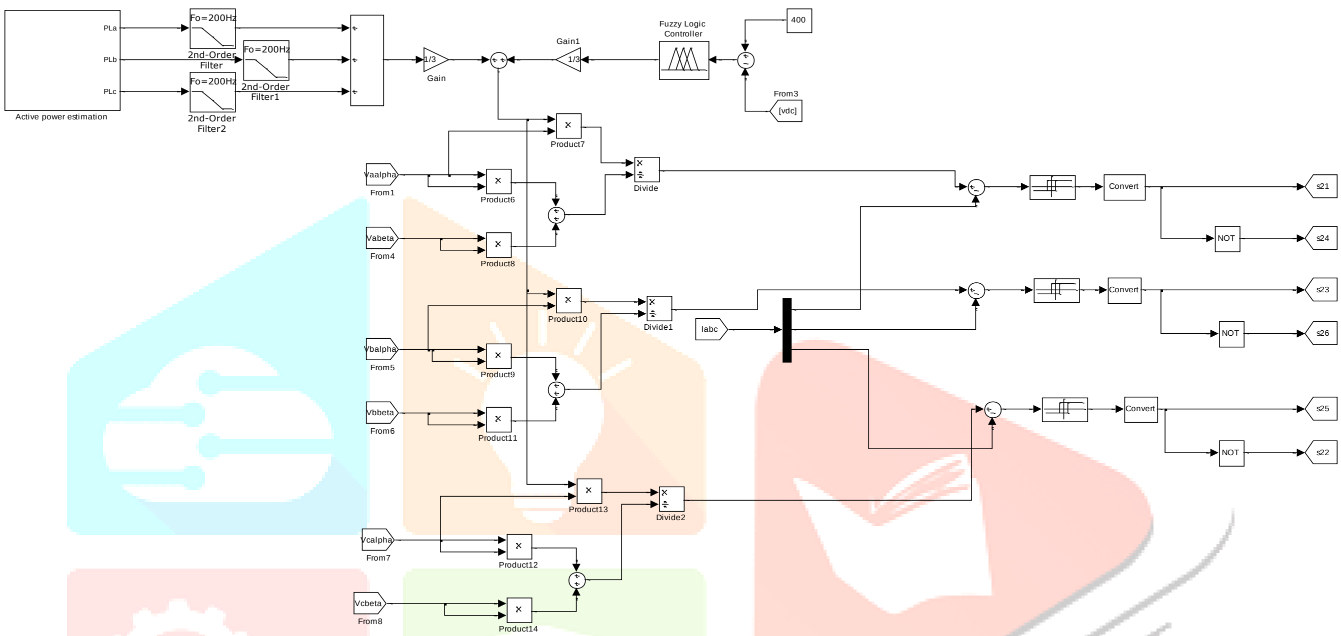

Fig. 5 Simulink model of Shunt controlling scheme

In the shunt controller any one of the two types of controllers are used one is the PI controller and the other is FL controller. With the usage of PI controller the THD of the load voltages is high. To improve the performance PI controller is replaced with the Fuzzy Logic controller. The reactive power component q_{La} in equation (11) is zero since in the source the load reactive power demand is zero.

The reference source currents for all the phases are as follows:

$$I^{*}{}_{Sa}(t) = \frac{V_{La\_\alpha}(t)}{V^2_{La\_\alpha}(t) + V^2_{La\_\beta}(t)} (P^{*}{}_{S/\mathrm{ph}} + P_{\mathrm{dc/ph}}) \qquad (12)$$

$$I^{*}{}_{Sb}(t) = \frac{V_{Lb\_\alpha}(t)}{V^2_{Lb\_\alpha}(t) + V^2_{Lb\_\beta}(t)} (P^{*}{}_{S/\mathrm{ph}} + P_{\mathrm{dc/ph}}) \qquad (13)$$

$$I^{*}{}_{Sc}(t) = \frac{V_{Lc\_\alpha}(t)}{V^2_{Lc\_\alpha}(t) + V^2_{Lc\_\beta}(t)} (P^{*}{}_{S/\mathrm{ph}} + P_{\mathrm{dc/ph}}) \qquad (14)$$

The reference neutral current is obtained by summing all the load currents of all phases.

$$I_{L-n}(t) = I_{La}(t) + I_{Lb}(t) + I_{Lc}(t) \qquad (15)$$

$$I^{*}{}_{Sh-n}(t) = -I_{L-n}(t) \qquad (16)$$

The rule table of 7×7 fuzzy logic controller is as follows

Error / Diff. error	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Table-1: Rule Table

4. RESULTS OF THE PROPOSED SYSTEM

The simulation results with THD's for PI controller and Fuzzy Logic Controller are as follows

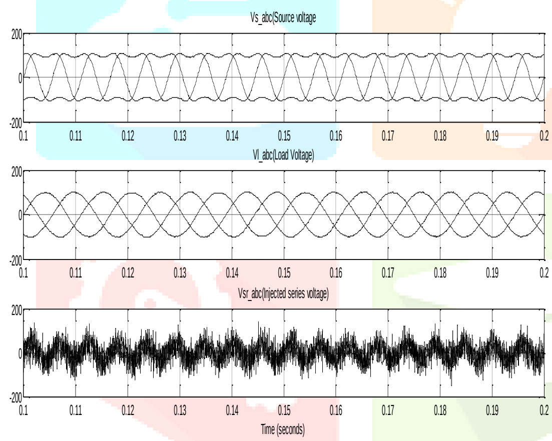

Fig. 6 Simulation results of source voltage, Load Voltage and injected voltage with PIC

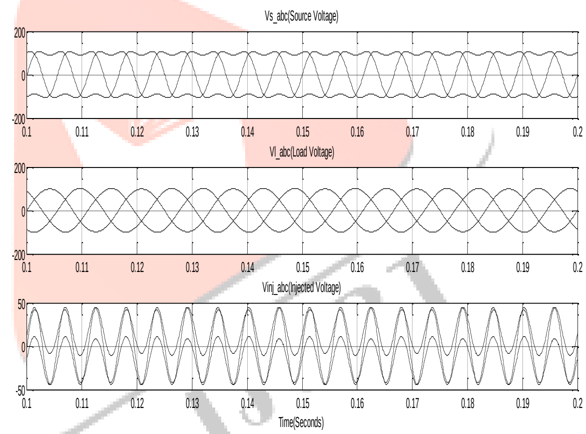

Fig. 8 Simulation results of source voltage, Load Voltage and injected voltage with FLC

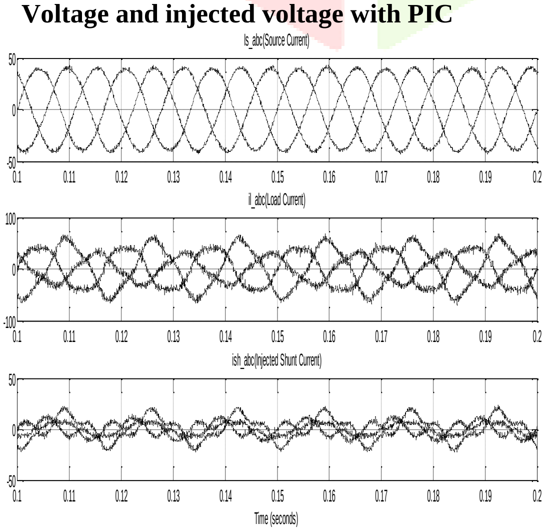

Fig. 7 Simulation results of source current, Load current and injected shunt current with PIC

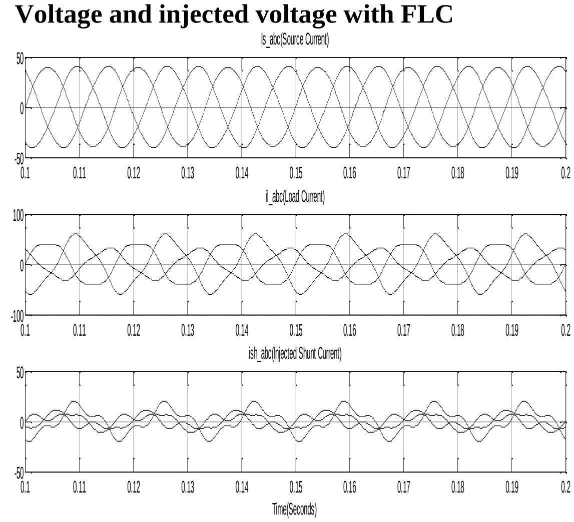

Fig. 9 Simulation results of source current, Load current and injected shunt current with FLC

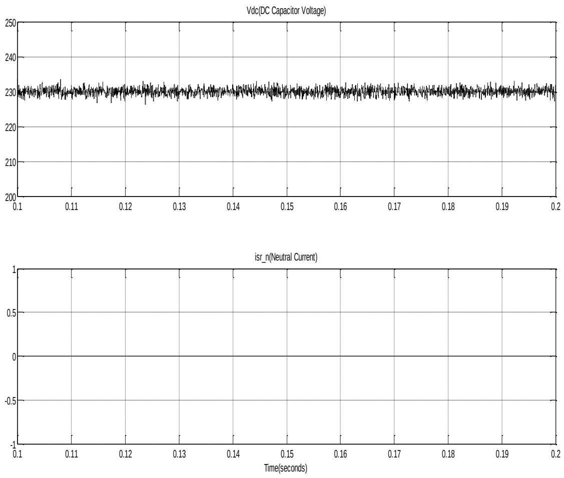

Fig. 10 Simulation results of DC Capacitor Voltage and Load neutral current with PIC

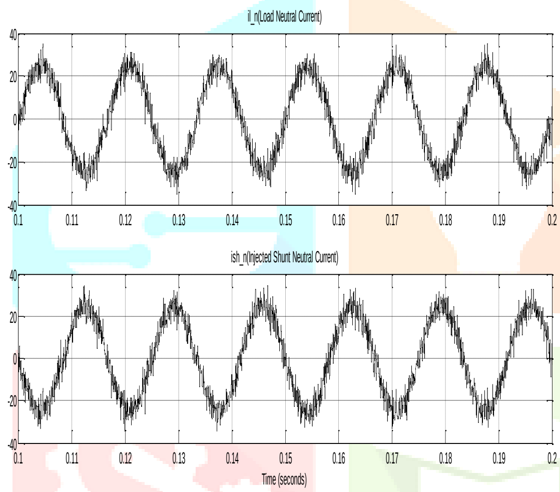

Fig. 11 Simulation results of load neutral current and shunt neutral current with PIC

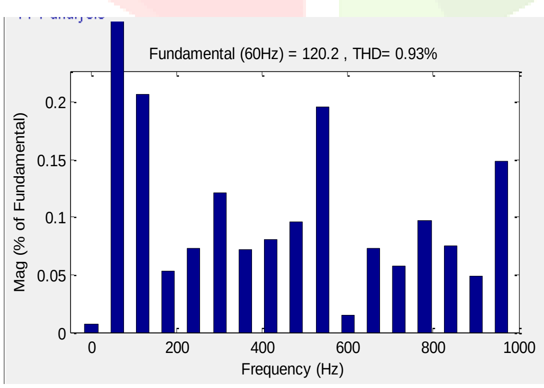

Fig. 12 THD of 0.93% for Source voltage with PIC

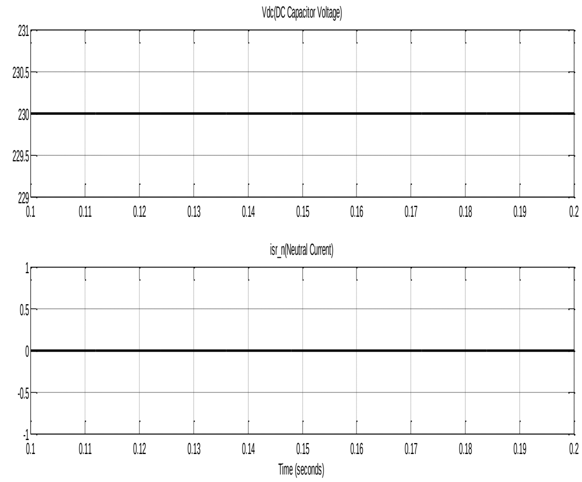

Fig. 13 Simulation results of DC Capacitor Voltage and Load neutral current with FLC

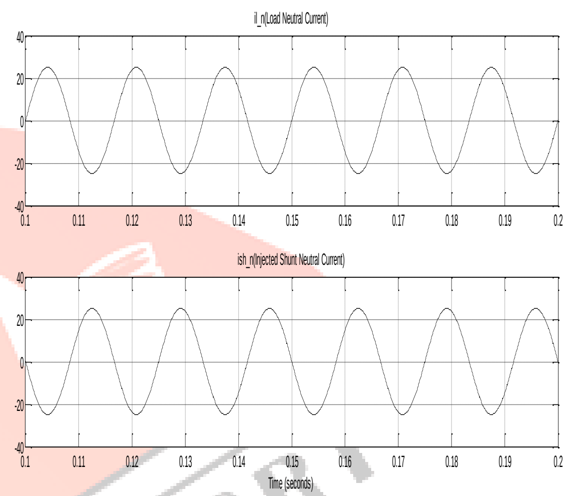

Fig. 14 Simulation results of load neutral current and shunt neutral current with FLC

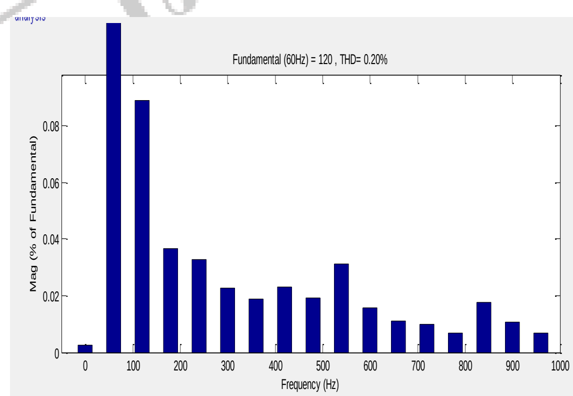

Fig. 15 THD of 0.20% for Source voltage with FLC

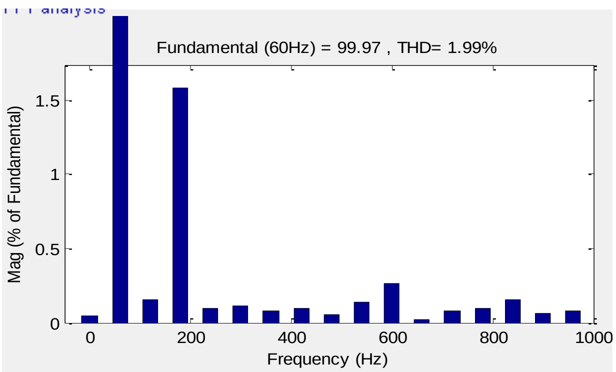

Fig. 16 THD of 1.99% for Load Voltage with PIC

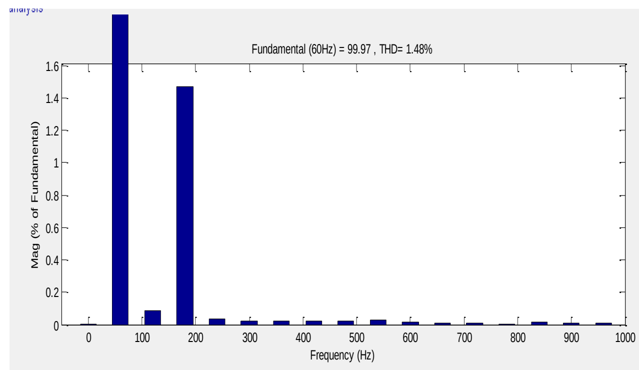

Fig. 19 THD of 1.48% for Load Voltage with FLC

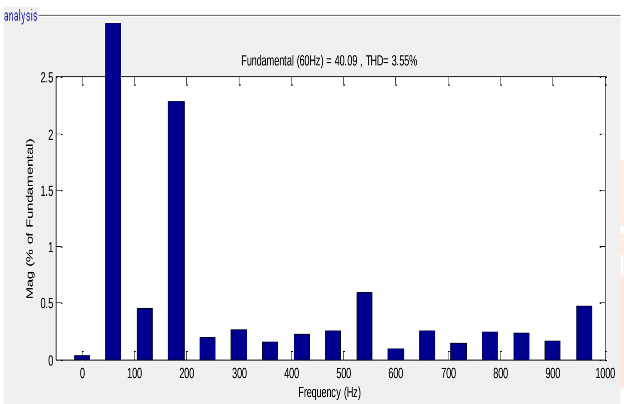

Fig. 17 THD of 3.55% for Source Current with PIC

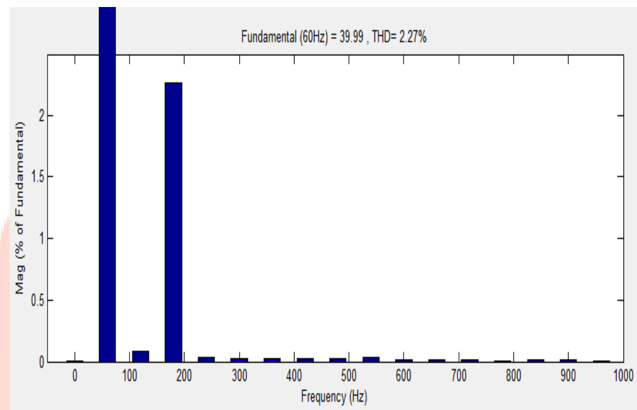

Fig. 20 THD of 2.27% for Source Current with FLC

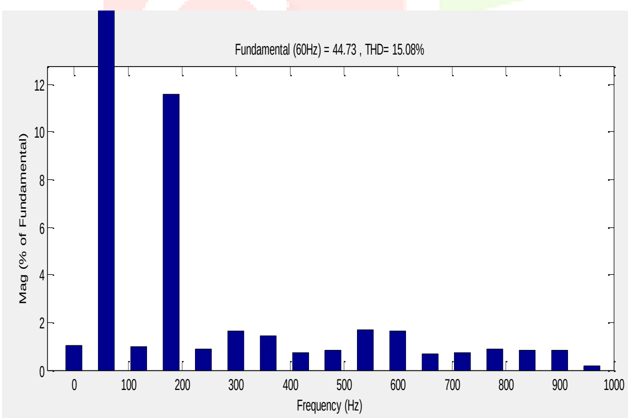

Fig. 18 THD of 15.08% for Load Current with PIC

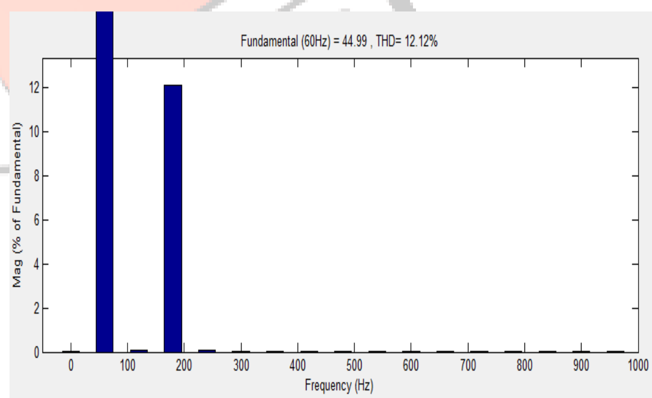

Fig. 21 THD of 12.12% for Load Current with FLC

The Simulink results of proposed 3P4W system with PIC and FLC are compared in this section .In the source voltage the 3rd and 5th order harmonics are introduced and in the load side unbalanced single phase loads along with nonlinear load is introduced. The UPQC which is in between source and load must clear these problems. The shunt part of UPQC will turn on at t = 0.1 sec which is helpful for attaining constant DC link Voltage 220volts and to attain source current as constant under unbalanced load condition also. The series part of UPQC will turn on at t=0.2sec and injects the required voltage through the transformer and as a result load voltage will be constant.

5. CONCLUSION

Hence in this paper UPQC performance with Fuzzy based controller is analyzed in MATLAB/SIMULINK and it is used for controlling source side and load side parameters in order to provide uniform power distribution to load. The performance of Fuzzy based UPQC is compared with PI based UPQC and the simulation results confirms that Fuzzy based UPQC is reliable for the operation of distribution system.

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