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Design and Simulation of Dual Unified Power Quality Conditioner with Fuzzy Logic Controller for Power Quality Improvement

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Abstract:- Power quality has turned into an imperative element today because of wide use of power electronics based equipment. Traditional equipment for upgrade of power quality is getting to be lacking. Unified power quality conditioner (UPQC) is one modern device which manages voltage and current defects all the while. This paper displays the Unified Power Quality Conditioner (UPQC) with completely fuzzy logic controller for enhancing the dynamic execution of UPQC. The UPQC is a custom power device which is integrated by series and shunt active power filters (APF) sharing a typical dc bus capacitor. Fuzzy control has developed as a standout amongst the most dynamic and productive regions for examination in the utilizations of fuzzy set hypothesis, particularly in the domain of industrial procedure, which don't lend of quantities data information in regards to the data yield relations. In this a simplified intelligent control system for a dual three-phase topology of a unified power quality conditioner i-UPQC is Different from an ordinary UPQC, the i-UPQC has the series filter controlled as a sinusoidal current source and the shunt filter controlled as a sinusoidal voltage source. In this way, the pulse width modulation (PWM) controls of the i-UPQC manage a surely understood frequency spectrum, since it is controlled utilizing voltage and current sinusoidal references, not the same as the conventional UPQC that is controlled utilizing non sinusoidal references. The dynamic examination of proposed plan is assessed by utilizing Matlab/Simulink platform and results are displayed.

Index Terms:- Active filters, control design, Fuzzy Controller, power line conditioning, unified power quality conditioner (UPQC).

I. INTRODUCTION

As of late, numerous specialists offer regard for tackling power quality issues. These issues are showed up because of use of reactive loads and non-linear loads. This load make reactive power burden and harmonic issue. This harmonic pollution degrades the quality of power at transmission side and distribution side . Typically the term power quality alludes to keeping up a sinusoidal waveform of bus voltages at evaluated voltage and frequency. Electric power quality (EPQ) issues basically incorporate unbalance voltage and current, flicker, harmonics, voltage sag, dip, swell, and power interruption [1], [2]. These power quality issues may bring about unusual operations of offices or even trip protection devices. Consequently, the maintenance and improvement of electric power quality has turned into an imperative situation today. Despite the fact that the power generation is genuinely solid, the quality of power is not generally so reliable. Fuzzy control depends on fuzzy logic; it is much closer in spirit to human deduction and regular dialect than conventional coherent frameworks application to numerous businesses and private utilizations. Henceforth supply of reactive power at the load ends gets to be fundamental [3-5]. Power Quality (PQ) predominantly manages issues like keeping up an fixed voltage at the Point of Common Coupling (PCC) for different distribution voltage levels regardless of voltage fluctuations, keeping up close unity power factor power drawn from the supply, obstructing of voltage and current unbalance from passing upwards from different conveyance levels, lessening of voltage and current sounds in the system [6-7].

By using a unified power quality conditioner (UPQC) [1] it is possible to ensure a regulated voltage for the loads, balanced and with low harmonic distortion and at the same time draining undistorted currents from the utility grid, even if the grid voltage and the load current have harmonic contents. The UPQC consists of two active filters, the series active filter (SAF) and the shunt or parallel active filter (PAF) [1], [2]. The PAF is usually controlled as a non sinusoidal current source, which is responsible for compensating the harmonic current of the load, while the SAF is controlled as a non sinusoidal voltage source, which is responsible for compensating the grid voltage. Both of them have a control reference with harmonic contents, and usually, these references might be obtained through complex methods [4], [5], [14], [17].Some works show a control technique to both shunt and SAFs which uses sinusoidal references without the need of harmonic extraction, in order to decrease the many-sided quality of the reference era of the UPQC. A fascinating option for power quality conditioners was proposed and was called line voltage controller conditioner. This conditioner comprises of two single-phase current source inverters where the SAF is controlled by a current loop and the PAF is controlled by a voltage loop. Along these lines, both grid current and load voltage are sinusoidal, and consequently, their references are additionally sinusoidal. A few creators have connected this idea, utilizing voltage source inverters as a part of uninterruptable power supplies and in UPQC [10]. In [10], this idea is called "dual topology of unified power quality conditioner" (iUPQC), and the control plans utilize the p−q hypothesis, requiring determination progressively of the positive sequence segments of the voltages and the currents. The aim of this project is to propose a disentangled control system for a dual three-phase topology of a unified power quality conditioner (iUPQC) to be utilized as a part of the utility grid association. The proposed control plan is produced in ABC reference outline and permits the utilization of traditional control hypothesis without the requirement for coordinate transformers and computerized control usage. The references to both SAF and PAFs are sinusoidal, apportioning the harmonic extraction of the grid current and load voltage

II. DUAL UPQC

The ordinary UPQC structure is made out of a SAF and a PAF, as appeared in Fig. 1. In this arrangement, the SAF fills in as a voltage source keeping in mind the end goal to repay the grid distortion, unbalances, and disturbances like sags, swells, and flicker. Consequently, the voltage remunerated by the SAF is made out of a fundamental content and the harmonics. The PAF work as a current source, and it is in charge of remunerating the unbalances, displacement, and harmonics of the load current, guaranteeing a sinusoidal grid current.

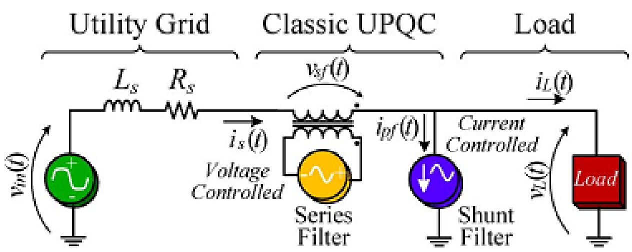


Fig. 1. Conventional UPQC.

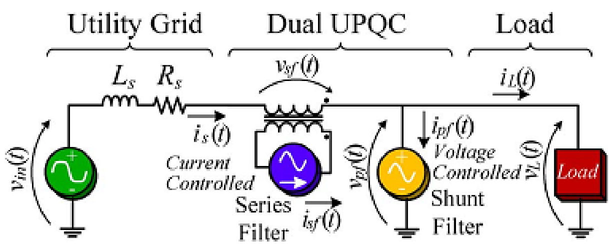


Fig. 2. Dual UPQC (iUPQC).

The series filter association with the utility network is made through a transformer, while the shunt filter is generally joined specifically to the load, for the most part in low-voltage grid applications. The traditional UPQC has the accompanying downsides: complex harmonic extraction of the grid voltage and the load including complex counts, voltage and current references with harmonic substance requiring a high bandwidth control, and the leakage inductance of the series connection transformer influencing the voltage pay created by the series filter. So as to minimize these downsides, the iUPQC is explored in this task, and its plan is appeared in Fig. 2. The plan of the iUPQC is fundamentally the same to the conventional UPQC, utilizing a relationship of the SAF and PAF, wandering just from the way the series and shunt filters are controlled. In the iUPQC, the SAF functions as a current source, which forces a sinusoidal input current synchronized with the grid voltage. The PAF functions as a voltage source forcing sinusoidal load voltage synchronized with the grid voltage. Thusly, the iUPQC control utilizes sinusoidal references for both active filters. This is a noteworthy point to watch identified with the excellent topology since the main solicitation of sinusoidal reference era is that it must be synchronized with the grid voltage. The SAF goes about as high impedance for the current harmonics and in a roundabout way compensates the harmonics, unbalances, and disturbances of the grid voltage since the association transformer voltages are equivalent to the contrast between the grid voltage and the load voltage. In the same way, the PAF by implication repays the unbalances, displacement, and harmonics of the grid current, giving a low-impedance way to the harmonic load current.

III. OUTPUT PASSIVE FILTER DESIGN

The iUPQC circuit can be analyzed by a single-phase wiring outline, as appeared in Fig. 4. The utility grid impedance is represented by $Z_s = j\omega L_s + R_s$, while the coupling transformer leakage impedance is represented by $Z_s = j\omega L_{\lg} + R_{\lg}$ and the voltage sources and represent the equivalent structures of the series and shunt filters, which create a waveform composed of the fundamental component and harmonics that began from the commutation of the switches. These high frequencies must be filtered by the output passive filters of the iUPQC, guaranteeing sinusoidal grid currents and load voltages. Fig.5 demonstrates the equal circuit utilized for the SAF output impedance examination, and Fig.6 demonstrates the equal circuit utilized for the PAF output impedance investigation. With a specific end goal to improve the investigation of the PAF, the voltage source and the inductance, which are series connected, were considered as a current source.

Watching the identical circuits, we can guarantee that the PAF output impedance influences the frequency response of the SAF, while the SAF output impedance does not influence the frequency response of the PAF. In this manner, the output passive filter configuration of the iUPQC ought to be begun with the PAF outline took after by the SAF design. The high-frequency filter transfer function of the PAF is determined by investigating the circuit of Fig.6 and is appeared in

$$\frac{v_L(s)}{v_{pc}(s)} = \frac{1}{L_{pf}C_{pf}} \cdot \frac{1}{s^2 + s.\frac{1}{C_{pf}R_L} + \frac{1}{L_{pf}C_{pf}}} \tag{1}$$

The inductor was characterized by the design, so the capacitor will be characterized by fancied cutoff frequency of the filter. In this outline, a 2.9-kHz cutoff frequency was utilized, bringing about an estimation of 10μf for the C_{pf} filter capacitor. Fig.7 demonstrates the PAF frequency reaction for the ostensible load and no load. The high-frequency filter transfer function of the SAF is inferred by breaking down the circuit of Fig.5 and is appeared as

$$\frac{i_s(s)}{v_{sc}(s)} = \frac{n}{\{sL_{sf} + n^2[sL_{lg} + R_{lg} + \alpha + \beta].\gamma\}} \tag{2}$$

Where

$$\alpha = \frac{sL_{pf}R_L}{s^2L_{pf}C_{pf}R_L + sL_{sf} + R_L} \tag{3}$$

$$\beta = \frac{sL_{rd} + R_{rd}}{s^2L_sC_{sf} + sC_{sf}R_s + 1} \tag{4}$$

$$\gamma = s^2C_{sf}L_s + sC_{sf}R_{lg} + 1 \tag{5}$$

As the inductor was characterized by the power design, the capacitor will be characterized by wanted cutoff frequency of the filter. In this outline, a 45-Hz cutoff frequency was utilized, bringing about an estimation of 1μFfor the load and no load

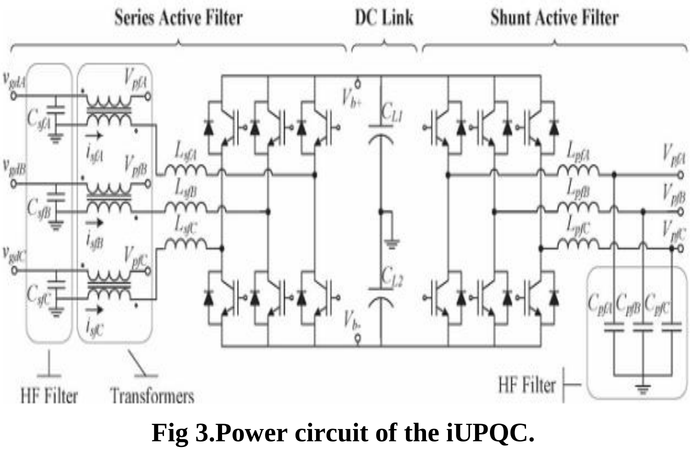


Fig 3.Power circuit of the iUPQC.

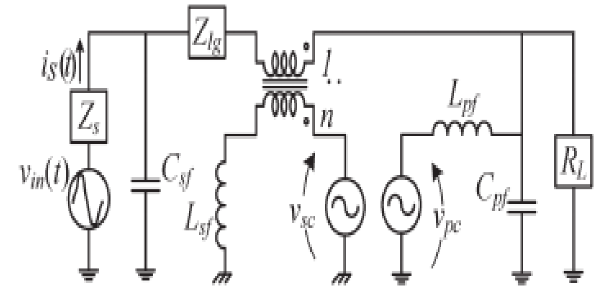


Fig 4. Single-phase wiring diagram of the dual UPQC

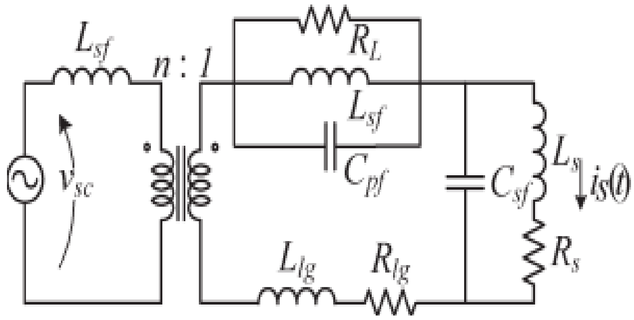


Fig 5. Equivalent circuit as viewed by SAF.

It can be noticed that the filter reaction has a low cutoff frequency that can diminish the bandwidth of the SAF, diminishing its adequacy under operation with harmonic contents on the grid voltage. This normal for low-frequency constriction is undesirable and natural for the structure because of the leakage impedance of the coupling transformers. An imperative commitment of this task and not quite the same as what it was expressed in some past articles, which manage the same iUPQC control technique, is that, notwithstanding the SAF works with sinusoidal reference, the control of this filter needs to manage high frequency since the current imposed

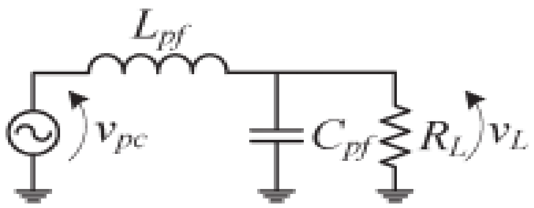


Fig 6. Equivalent circuit as viewed by PAF.

By the SAF is gotten through the voltage inconvenience on this filter output inductor. The voltage forced on these inductors is corresponding to the utility grid voltage harmonics with the goal that it promises a sinusoidal current through the filter. Different from the conventional UPQC whose narrow-band frequency control may distort the load voltage, in the iUPQC, the narrowband frequency control may distort the current drained from the utility grid. The usage of high-power coupling transformers, with low leakage inductance, and the design of higher voltage dc link, allowing the imposition of higher current rate of change on the filter output inductor, is solutions to change the characteristics of the filter attenuation in low frequencies.

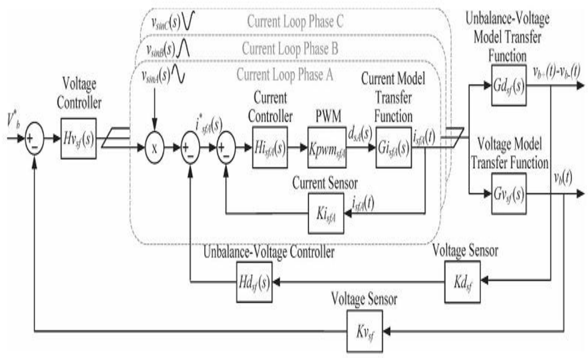


Fig. 7. Control block diagram of the SAF controller.

IV. PROPOSED CONTROL SCHEME

The proposed iUPQC control structure is an ABC reference frame based control, where the SAF and PAF are controlled in an autonomous way. In the proposed control scheme, the power calculation and harmonic extraction are not required subsequent to the harmonics, unbalances, disturbances, and displacement ought to be adjusted. The SAF has a current loop keeping in mind the end goal to guarantee a sinusoidal grid current synchronized with the grid voltage. The PAF has a voltage loop keeping in mind the end goal to guarantee a balanced regulated load voltage with low harmonic distortion. These control loops are independent from one another since they act freely in every avtive filter. The dc link voltage control is made in the SAF, where the voltage loop decides the amplitude reference for the current loop, in the same method of the power factor converter control plans. The sinusoidal references for both SAF and PAF controls are generated by a digital signal processor (DSP), which guarantee the grid voltage synchronism utilizing a phase locked loop.

A. SAF Control

Fig. 7 demonstrates the control block diagram for the SAF. The SAF control plan comprises of three indistinguishable grid current loops and two voltage loops. The current loops are in charge of tracking the reference to every grid input phase keeping in mind the end goal to control the grid currents freely. One voltage loop is in charge of controlling the total dc link voltage, and the other is in charge of maintaining a strategic distance from the unbalances between the dc link capacitors. The aggregate dc voltage control loop has a low-frequency response and decides the reference amplitude for the current loops. Subsequently, when the load increments, beating the input grid current, the dc link supplies quickly the active power utilization, bringing about a reduction of its voltage. This voltage controller acts to build the grid current reference, expecting to restore the dc link voltage. In the same way, when the load diminishes, the voltage controller declines the grid current reference to regulate the dc link voltage. Considering the three phase input current, sinusoidal and balanced, the voltage loop transfer function is obtained through the method of power balance analysis.

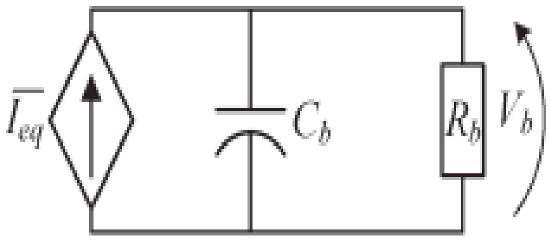


Fig. 8. Equivalent circuit of the SAF voltage loop.

The three-phase four wire converter with neutral point can be spoken to by the circuit appeared in Fig. 8, made out of a present source which is in parallel with the dc link impedance and whose current source speaks to the average charge current of the dc link. The resistor R_b is truant in the genuine circuit (R_b→∞); it just speaks to quick active power utilization of the dc link. The term momentary is identified with the time of the switching period, since active power utilization of the dc link is invalid for the utility grid voltage frequency. The normal charge current of the dc link is give

$$\bar{I}_{eq} = \frac{3}{2}.\frac{n.V_{gdpk}.I_{sfpk}}{V_b} \quad (6)$$

The SAF peak current is viewed as the same for the three phases because of balanced current. Through (6), the voltage loop transfer function is acquired and is represented by

$$Gv_{sf}(s) = \frac{V_b(s)}{I_{sf}(s)} = \frac{3}{2}.n.\frac{V_{gdpk}}{V_b}.\frac{1}{\frac{1}{R_b}+sC_b} \quad (7)$$

Where

V_{gdpk} Peak of the grid voltage;
V_b Dc link voltage;
R_b Load equivalent resistance;
C_b Total dc link equivalent capacitance;
n Transformer ratio.

The open-loop transfer function (OLTFv) is given by

$$OLTFv(s) = Gv_{sf}(s).\frac{Kv_{sf}}{Ki_{sf}}.Km_{sf} \quad (8)$$

Where
Km_{sf} = multiplier gain;
Kv_{sf} = voltage sensor gain;
Ki_{sf} = current sensor gain.
The gain is acquired by considering the gain of the multiplier integrated circuit and the peak of the synchronized sinusoidal signal created by the DSP.

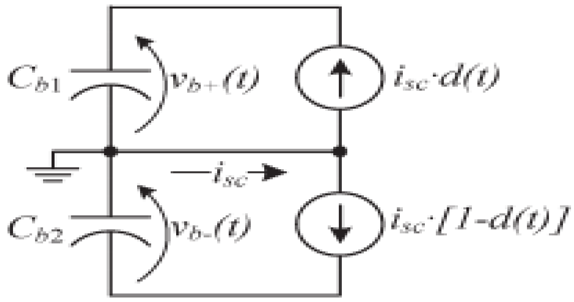


Fig. 9. Equivalent circuit of the SAF unbalanced-voltage loop.

The unbalanced voltage control loop likewise has a low frequency loop and follows up on the dc level of the grid current reference with a specific end goal to keep the voltage eqilibrium in dc link capacitors. At the point when a voltage unbalance happens, this loop adds a dc level to the references of the grid currents, planning to adjust both and voltages. The unbalanced voltage loop transfer function is gotten through the examination of the simplified circuit appeared in Fig. 9. The four-wire converter permits the single-phase investigation, where two current sources speak to the current on the inverter switches. In Fig. 10, the current i(t) to the current through the impartial point, and d(t)represents the duty cycle. Through the mesh analysis and by applying Laplace, the unbalanced voltage loop transfer function is given by

$$Gd_{sf}(s) = \frac{V_{b+}(s) - V_{b-}(s)}{I_{sc}(s)} = \frac{3}{2.s.C_b} \quad (9)$$

The open-loop transfer function (OLTF_d) is given by

$$OLTF_d(s) = Gd_{sf}(s).\frac{Kd_{sf}}{Ki_{sf}} \quad (10)$$

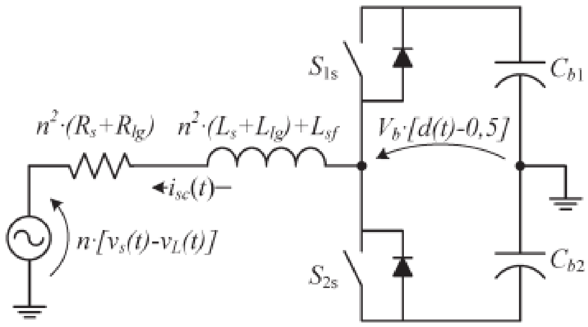


Fig. 10.Single-phase equivalent circuit of SAF.

The present control scheme comprises of three identical current loops, with the exception of the 1200 phase displacements from the references of one another. The current loops have a quick reaction to track the sinusoidal references, permitting the decoupling examination in connection to the voltage loop. The current loop transfer function is gotten through the examination of the single-phase equivalent circuit appeared in Fig. 10. The voltage source speaks to the voltage on the coupling transformer. The dynamic model is acquired through the circuit investigation utilizing average values identified with the switching period. Under these conditions, the voltages v_s(t) and v_L(t) are constants. Through small signal analysis and by using Laplace, the current loop transfer function is given by

$$Gi_{fs}(s) = \frac{I_{sc}(s)}{D(s)} = \frac{V_b}{sA_1 + n^2.(R_s + R_{lg})} \quad (11)$$

Where

$$A_1 = n^2.\left(L_s + L_{lg}\right) + L_{sf} \quad (12)$$

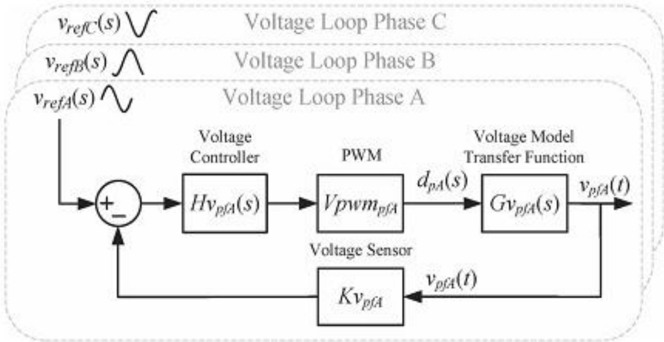


Fig. 11. Control block diagram of the PAF voltage loop.

and

L_S Series grid inductance;

R_S Series grid resistance;

L_{lg} Leakage inductance of the coupling transformer;

R_{lg} Series resistance of the coupling transformer.

The open-loop transfer function (OLTF_I) is given by

$$OLTF_i(s) = Gi_{sf}(s).Kpwm_{sf}.Ki_{sf} \tag{13}$$

Where series filter pusle width modulation (PWM) modulator gain.Gain is equivalent to the inverse peak value of the triangular carrier. Expecting to track the current reference, a PI+pole controller was outlined, which ensures a cross over frequency of 5 kHz and a phase margin of of 700. The frequency response of the current loop is appeared in Fig. 5.12, including the open-loop transfer function (OLT+), controller transfer function (OLT+), and compensated loop transfer function (OLT+).

B. PAF Control

Fig. 12 demonstrates the control block diagram of the shunt active filter controller. The PAF control plan is shaped by three indistinguishable load voltage feedback loops, with the exception of the 1200 phase displacements from the references of one another. The voltage loops are in charge of following the sinusoidal voltage reference for every load output phase keeping in mind the end goal to control the load voltages freely.

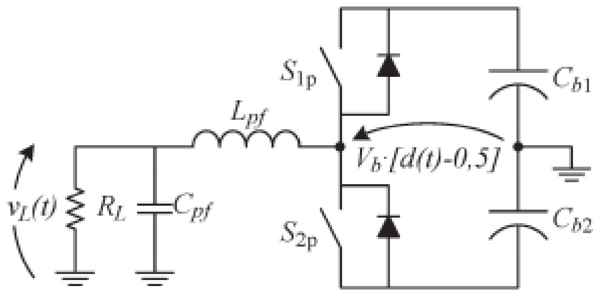


Fig. 12. Single-phase equivalent circuit of PAF

The voltage loop transfer function is gotten through the examination of the single-phase equivalent circuit appeared in Fig. 12. The dynamic model is gotten through the circuit examination utilizing normal qualities identified with the switching period. Through little signal examination and by utilizing Laplace, the voltage loop transfer function is given

$$Gv_{pf}(s) = \frac{V_b}{L_{pf}C_{pf}}.\frac{1}{s^2+\left(\frac{1}{C_{pf}R_L}\right)+\frac{1}{L_{pf}C_{pf}}} \tag{14}$$

Where

$$Gv_{pf}(s) = V_L(s)/D(s).$$

The open-loop transfer function (OLTF) is given by

$$OLTF_v(s) = Gv_{pf}(s).Kpwm_{pf}.Kv_{pf} \tag{15}$$

Where
Kpw shunt filter PWM modulator gain. Aiming to track the voltage reference, a proportional integral derivative (PID)+ additional pole controller was designed, which ensures a crossover frequency of 4 kHz and a phase margin of 35^0.

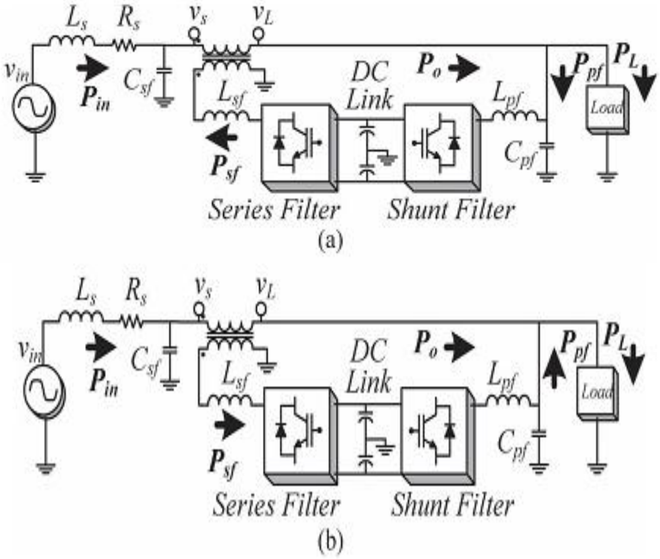


Fig. 13. Power flow of iUPQC. (a) Vs< V_L, (b) Vs >$V_L v_L$

Controller transfer function (Hv_{PF}), and compensated loop transfer function ($OLTFv_{pf} + Hv_{pf}$).

V. FUZZY LOGIC CONTROL

L. A. Zadeh exhibited the first paper on fuzzy set hypothesis in 1965. From that point forward, another dialect was produced to portray the fuzzy properties of reality, which are extremely troublesome and at some point even difficult to be depicted utilizing conventional methods. Fuzzy set hypothesis has been broadly utilized as a part of the control range with some application to power system [5]. A simple fuzzy logic control is developed by a gathering of tenets in light of the human information of framework conduct. Matlab/Simulink simulation model is assembled to ponder the dynamic behaviour of converter. Moreover, design of fuzzy logic controller can give alluring both small signal and large signal dynamic execution at same time, which is impractical with linear control procedure. In this way, fuzzy logic controller has been potential capacity to enhance the heartiness of compensator.

The fundamental plan of a fuzzy logic controller is appeared in Fig 14 and comprises of four vital parts, for example, a fuzzy fication interface, which changes over info information into suitable etymological qualities; a learning base, which comprises of an information base with the vital phonetic definitions and the control guideline set; a choice making logic which, recreating a human choice procedure, construe the fuzzy control activity from the learning of the control rules and semantic variable definitions; a de-fuzzification interface which yields non fuzzy control activity from a derived fuzzy control activity [10].

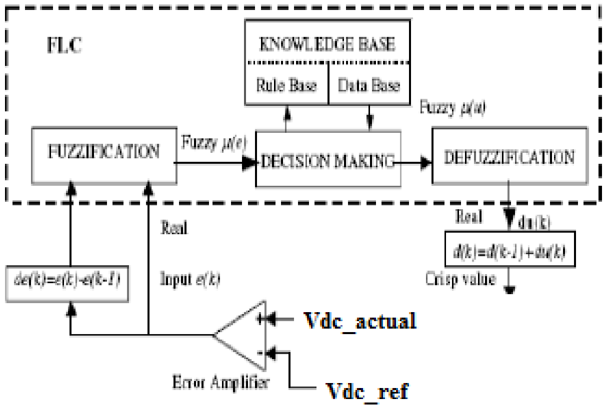


Fig.14 Block diagram of the Fuzzy Logic Controller (FLC) for proposed converter

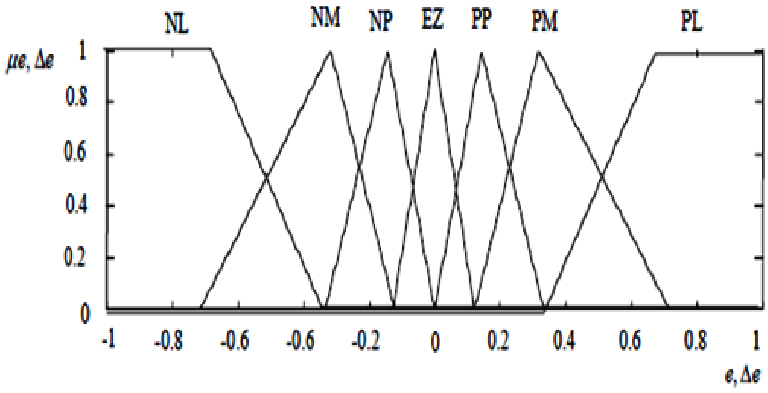


Fig.15 Membership functions for Input, Change in input, Output.

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 in- put/yield variables; in the enduring state, little blunders need fine control, which requires fine inpup/output variables. In view of this the components of the principle table are acquired as appeared in Table 1, with "Vdc" and 'Vdc-ref' as inputs.

Δe \ e	NL	NM	NS	EZ	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PS	NM	NS	EZ	PS	PM	PL	PL
PM	NS	EZ	PS	PM	PL	PL	PL
PL	NL	NM	NS	EZ	PS	PM	PL

VI. MATLAB RESULTS

Here reproduction is completed in a few cases, proposed UPQC model is assessed as voltage sag conditions as for sudden load changes and same proposed idea is connected to intelligence based fuzzy systems to approve the ideal results and may expand the heartiness of the system.

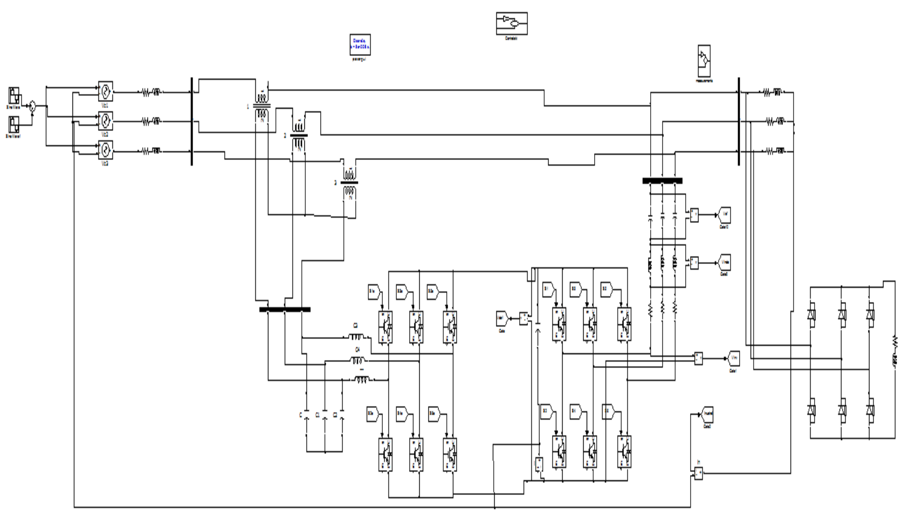


Fig.16 shows the Matlab/Simulink model of proposed UPQC model with simplified Control scheme using Matlab/Simulink platform.

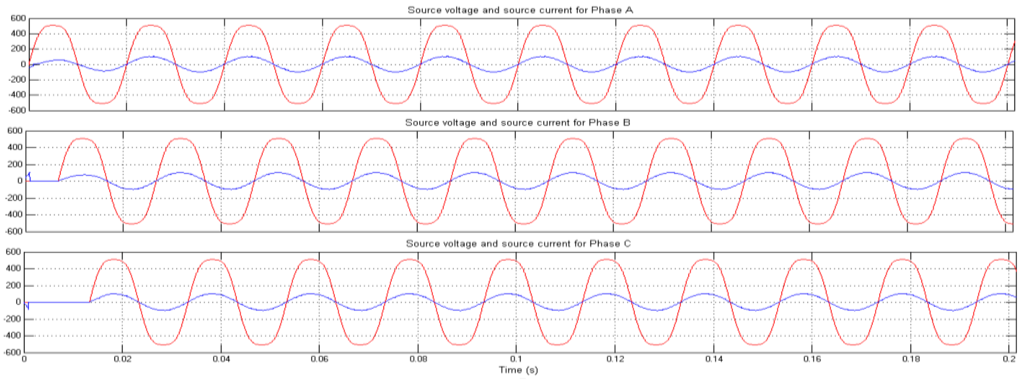


Fig.17 Source Voltage & Source Current

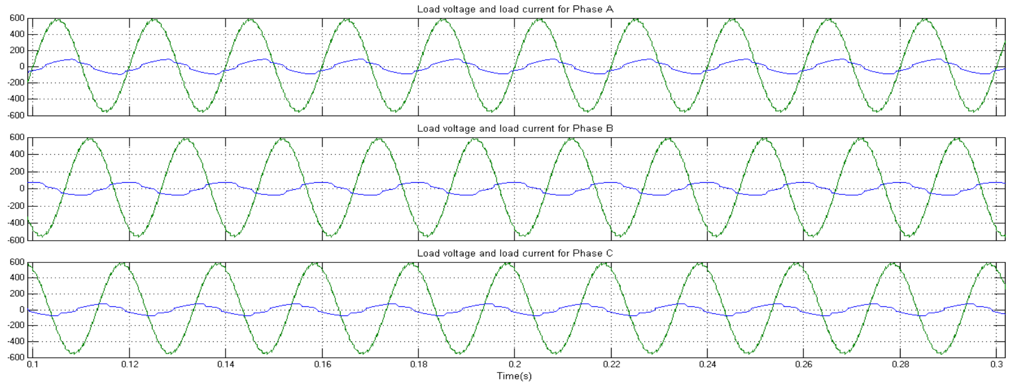


Fig.18 Load Voltage & Load Current

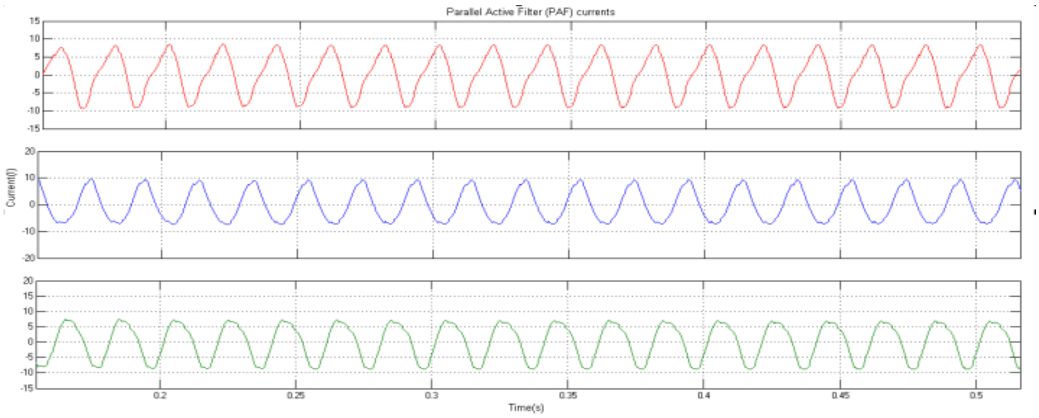


Fig.19 PAF Currents

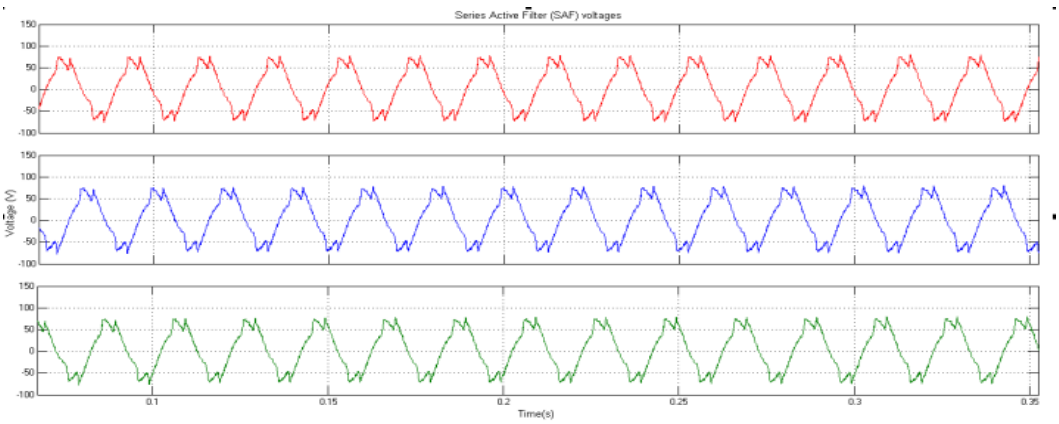
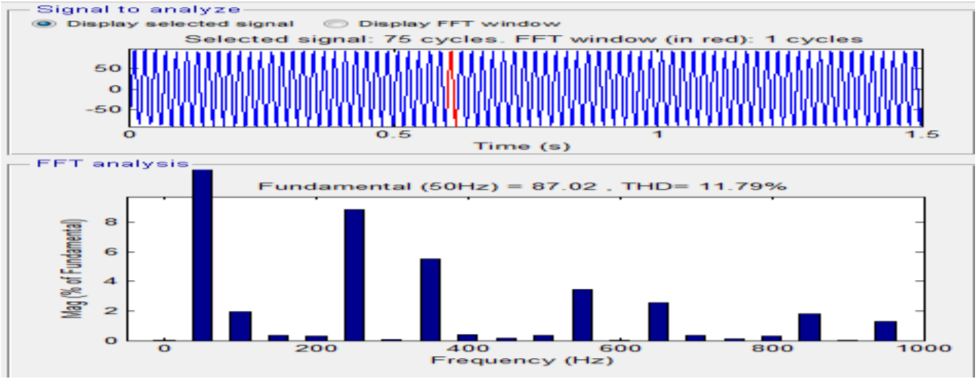
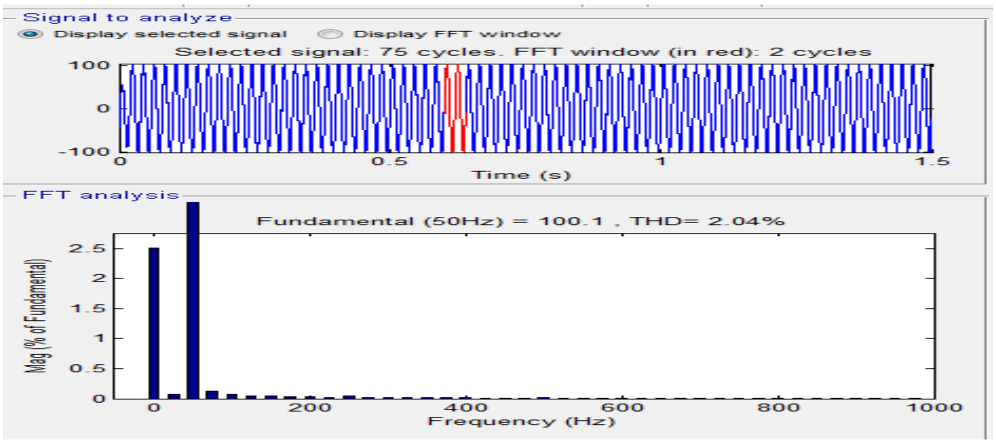


Fig.20 SAF Currents

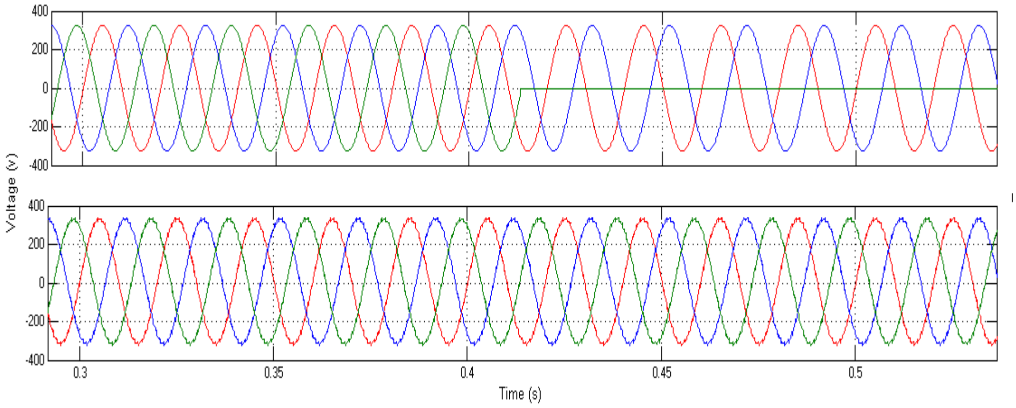


(a) THD Analysis of load current

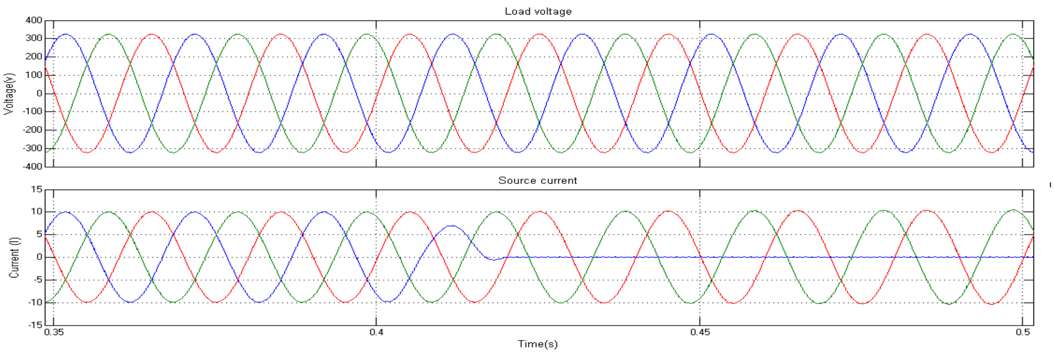


(b) THD Analysis of source current

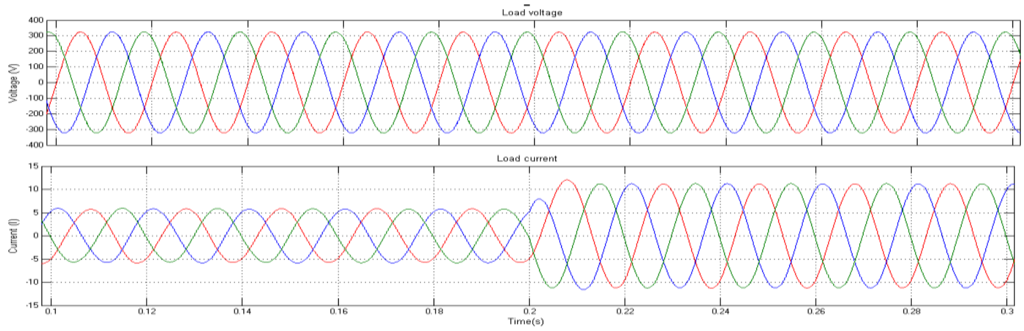
Fig.21 THD Analysis of load current and source current , without compensation source current is equal to load current then THD value is 11.79%, when compensation is performed getting 2.04%, with in IEEE-519 standards.



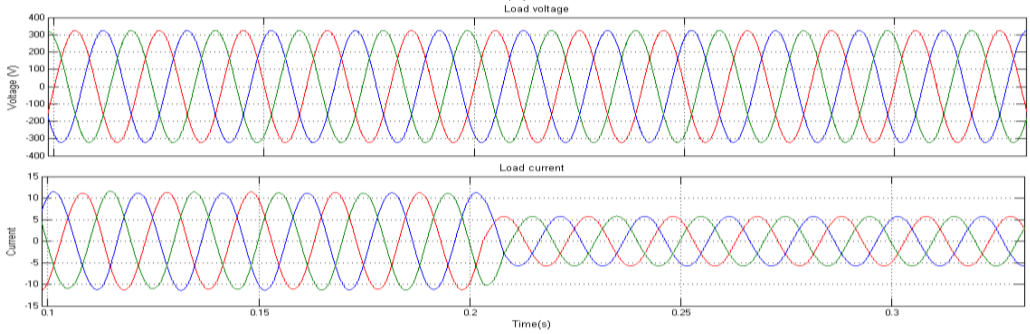
(a)



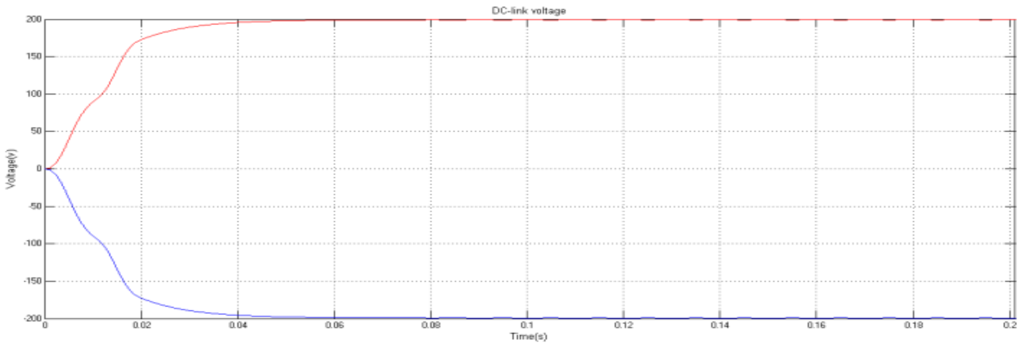
(b)



(c)



(d)



(e)

Fig.22. **(a)** Source voltages and load during a voltage dip in phase A. **(b)** Load voltages and source currents **(c)** Load voltages and load currents during a load step from 50% to 100%. **(d)** Load voltages and load currents during a load step from 100% to 50%. **(e)** DC link voltages during a load step from 100% to 50%.

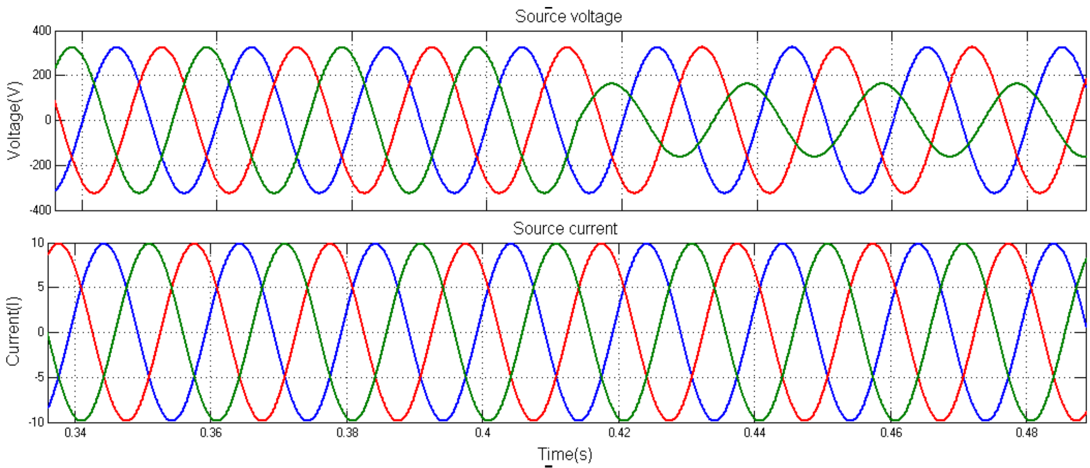


Fig.23 source voltage and Source Current with Fuzzy based UPQC compensation scheme

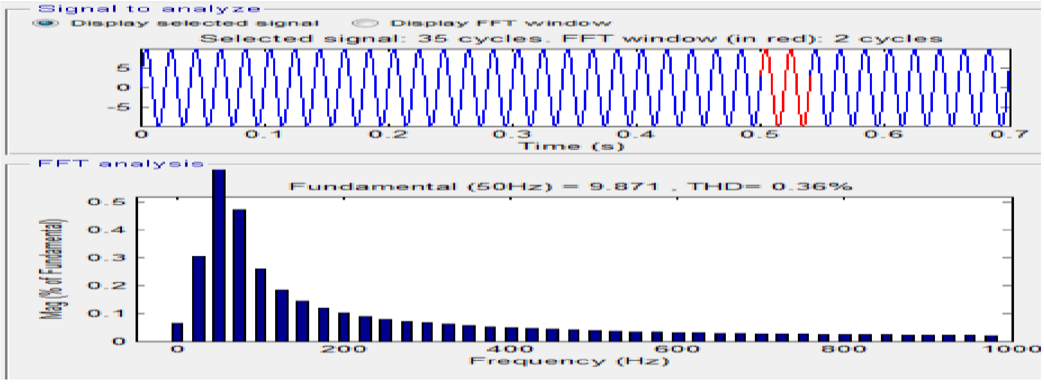


Fig.24 THD Analysis of source current and source voltage with Fuzzy compensation then THD value is 0.36%, with in IEEE-519 standards.

VII. CONCLUSION

The control of unified power quality conditioner (UPQC) is finished by Fuzzy Logic Controller (FLC). The outcomes acquired with the proposed fuzzy based iUPQC affirms that the proposed ABC reference edge control works exceptionally well and that it had the the nonlinear load currents furthermore guarantee the sinusoidal voltage for the load in each of the three phases. Before compensate load current equivalent to source current then THD has 11.79%, after compensation of iUPQC with PI controller source current got to be 2.04% and with intelligent controller source current has 0.36% according to IEEE standards then resultant waveform keeps up sinusoidal. Along these lines, power quality enhances better.

REFERENCES

[1]. M. Aredes, K. Heumann, and E. Watanabe, “An universal active power line conditioner,” IEEE Trans. Power Del., vol. 13, no. 2, pp. 545–551, Apr. 1998.

[2]. H. Fujita and H. Akagi, “The unified power quality conditioner: The integration of series and shunt-active filters,”IEEE Trans. Power Electron., vol. 13, no. 2, pp. 315–322, Mar. 1998.

[3]. B. Han, B. Bae, S. Baek, and G. Jang, “New configuration of UPQC for medium-voltage application,”IEEE Trans. Power Del., vol. 21, no. 3, pp. 1438–1444, Jul. 2006.

[4]. S. Chakraborty, M. Weiss, and M. Simoes, “Distributed intelligent energy management system for a single-phase high-frequency ac microgrid,” IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 97–109, Feb. 2007.

[5]. M. Forghani and S. Afsharnia, “Online wavelet transform-based control strategy for UPQC control system,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 481–491, Jan. 2007.

[6]. A. Jindal, A. Ghosh, and A. Joshi, “Interline unified power quality conditioner,” IEEE Trans. Power Del., vol. 22, no. 1, pp. 364–372, Jan. 2007

[7]. Y. Kolhatkar and S. Das, “Experimental investigation of a single-phase UPQC with minimum VA loading,”IEEE Trans. Power Del., vol. 22, no. 1, pp. 373–380, Jan. 2007.

[8]. M. Basu, S. Das, and G. Dubey, “Investigation on the performance of UPQC-Q for voltage sag mitigation and power quality improvement at a critical load point,”IET Gen. Transmiss. Distrib., vol. 2, no. 3, pp. 414– 423, May 2008.

[9]. V. Khadkikar and A. Chandra, “A new control philosophy for a unified power quality conditioner (UPQC) to coordinate load-reactive power demand between shunt and series inverters, ”IEEE Trans. Power Del., vol. 23, no. 4, pp. 2522–2534, Oct. 2008.

[10]. M. Aredes and R. Fernandes, “A dual topology of unified power quality conditioner: The iUPQC,” in Proc. 13th Eur. Conf. Power Electron. Appl., Sep. 2009, pp. 1–10.

[11]. M. Brenna, R. Faranda, and E. Tironi, “A new proposal for power quality and custom power improvement: OPEN UPQC,”IEEE Trans. Power Del., vol. 24, no. 4, pp. 2107–2116, Oct. 2009.

[12]. S. Chakraborty and M. Simoes, “Experimental evaluation of active filtering in a single-phase high-frequency ac microgrid,” IEEE Trans. Energy Convters., vol. 24, no. 3, pp. 673–682, Sep. 2009.

[13]. V. Khadkikar and A. Chandra, “A novel structure for three-phase four-wire distribution system utilizing unified power quality conditioner (UPQC),” IEEE Trans. Ind. Appl., vol. 45, no. 5, pp. 1897–1902, Sep./Oct. 2009.

[14]. K. H. Kwan, Y. C. Chu, and P. L. So, “Model-based H ∞control of a unified power quality conditioner,”IEEE Trans. Ind. Electron., vol. 56, no. 7, pp. 2493–2504, Jul. 2009.

[15]. J. Munoz, J. Espinoza, L. Moran, and C. Baier, “Design of a modular UPQC configuration integrating a components economical analysis,” IEEE Trans. Power Del., vol. 24, no. 4, pp. 1763–1772, Oct. 2009.

[16]. I. Axente, J. Ganesh, M. Basu, M. Conlon, and K. Gaughan, "A 12-Kva DSP-controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current,"IEEE Trans. Power Electron., vol. 25, no. 6, pp. 1471–1479, Jun. 2010.
[17]. I. Axente, M. Basu, M. Conlon, and K. Gaughan, "Protection of unified power quality conditioner against the load side short circuits,"IET Power Electron., vol. 3, no. 4, pp. 542–551, Jul. 2010.