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POWER QUALITY IMPROVEMENT IN ELECTRICAL NETWORK BY USING UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT

Power quality (PQ) problems associated with non-linear loads have increased rapidly in electrical network. The non-linear loads are the main sourceof (PQ) problems. Harmonics, voltage sags, voltage swells are the most commonlyoccurring PQ problem in electrical networks. The unified power quality conditioner (UPQC) is one of the FACTS contrller used for mitigating the effect of current harmonic and voltage harmonics. The series compensator in the UPQC is used for compensating the voltage harmonics and the shunt compensator in the UPQC is used compensate the current harmonics. In the proposed UPQC, the conventional PI controller has replaced by a fuzzy logic controller (FLC). The control structure is developed with FLC and simulated using MATLAB/SIMULINK. The results presented in this paper clearly show that the proposed UPQC with FLC has capable to meet the IEEE-519 standard recommendations on harmonic levels

KEYWORDS: Power Quality (PQ), Unified Power Quality Conditioner (UPQC), Fuzzy Logic Controller (FLC)

INTRODUCTION

At present because of the growthof the nonlinear loads and powerelectronic (PE) equipment such as personal computers (PC), programmable logic controllers (PLC), energy efficient lighting and variable motion drives (VMD) into the powerdistribution networks (PDN) the power quality (PQ) has become the crucial concerned area. These types of loads are the prime source□f PQ issues. These loads usually disturb the voltage waveform. To identify the PQ issues any one of the following signs can be used Flicker, Blackoutsof frequency, Frequency drop outs in electronic equipment, Power line interference with communication, Equipment and overhead elements and sudden voltage to ground Any PE equipment has its own sensitivity with different type of PQ problems which depends on equipment's type and disturbance's type. The impact of PQ on PDN is because of use of PE equipment; depend on type of PE equipment used [1-2]. The UPQC is the most versatile power quality enhancement devices which offer advantages of both the shuntand series APFs, simultaneously [5]. The series APF is connected in series with the ac line and shunt APF is connected in shunt with the same ac line. These two are connected back to back with each other through a DC link. The seriese lement of the UPQ Cinserts voltage so as toreta in the voltage balanced at the load terminal of PD Nand free from distortion .Additionally, shunt component maintains the DC link voltage within reference value. Simultaneously, the shuntelement of the UPQ C injects current in the ac system such that the currents entering the bus towhich the UPQC is connecte dare balanced sinusoids. UPQC do the harmonice limination and simultaneous compensation of voltage and current which improves power quality offered by non-linear load [4-9]

POWER QUALITY PROBLEMS

When a non-linear load is connected to a PDN, It introduced harmonicsinto the network. As harmonics are integral multiples of fundamental frequency at which the supply system has designed tooperate for either of sinusoidal voltagesor currents. Due to the presence of harmonics in the PDN, the power quality related problems like current harmonics, voltage harmonics, voltage sag, voltage swell, voltage flicker etc. occurinto the system [9]

POWER QUALITY IMPROVEMENT

The FACTS devices in corporate PE based controllers to boost the control ability as well atoraise the power transfer capabilityof electrical network. FACTS devices also provide voltagere gulation and harmonicse limination. The voltage distortions caused due to current harmonic at the pointof common coupling (PCC). This results in mis-operation of equipments in the electrical network. To eliminate such problems, passive power filters have been used. Passive power filters introduce unwanted resonance and amplify harmonic currents. Toovercome this problemof passive power filters, active power filters (APF) has been utilized [3]. APF is the most promising solution tomitigatesome of the major power quality problems at the PDN level.They can be classified as parallel/shunt APFs, series APFs, hybrid APFs, and UPQC. Among these APFs, UPQC is the combination of series and parallel active power filters [4]. In addiction with harmonicelimination, UPQC has been used for compensation of reactive power (VAR), supply voltage sag, supply voltage unbalance, power factor correction; unbalance load current [6]. The proposed method introduces harmonic current elimination and compensation of unbalance in source current. The proposed UPQC has effective in compensating the voltage unbalance

UNIFIED POWER QUALITY CONDITONER

The Unified Power Quality Conditioner (UPQC) consistsof two Voltage Source Converters (VSC), one is parallel connected to the electrical powernetwork and another is series connected to the load. The two converters are connected by a common DC bus as shown in Figure 1. [13]. During the voltage sag the series converter injects voltage to maintain the load terminal voltage and required energy at the DC bus is provided by the parallel connected VSC, which extracts the energy from the electrical powernetwork. The power comingfrom the sourceof power supply will be magnificently reduced during voltage sag. The shunt connected VSC must be designed tooperate accurately with reduced or unbalanced input voltage

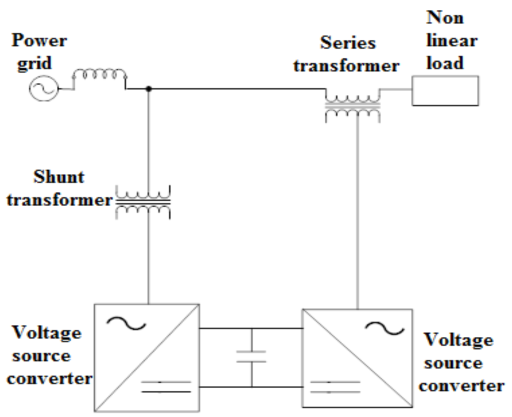

Figure 1: Unified Power Quality Conditioner

The block diagram of UPQC is shown in Figure 2. AC power sourceprovides the AC supply to the rectifier. The inverter is used to convert the DC voltage to AC voltage Transformer is used for step down or step up purpose. For isolation purpose it can be used. Rectifier converts AC supply to DC supply having ripples. The DC supply having some ripples which is filtered with the help of capacitor filter. Multilevel inverter generates AC output voltage. The control of output voltage is done with the help of pulse width modulation

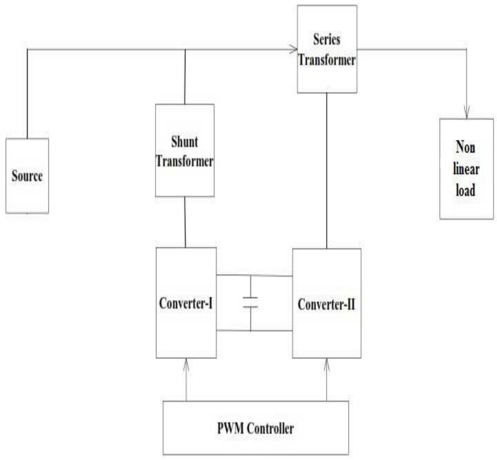

Figure 2: Block Diagram of UPQC

CONTROL STRATEGY

The control strategy of UPQC is shown in Figure 3. The perceived DC connection voltage (V_{dc}) is compared by a reference voltage (V_{dc}^{*}). The error signal acquired is treated in Fuzzy Logic Controller (FLC). The outputof the FLC $I_{sb}^{*}$is taken as the magnitude of Three-phase reference currents. The Three-phase unit current vectors$U_{sa}, U_{sb}\, and\, U_{sc}$are derived in phase with the Three-phase source voltages$V_{sa}, V_{sb}\, and\, V_{sc}$.The unit current vectorsfrom the Three-phase of supply currents. Multiply of magnitude $I_{sp}^{*}$with $U_{sa}, U_{sb}\, and\, U_{sc}$results in Three-phase reference supply currents $I_{sa}^{*}, I_{sb}^{*}\, and\, I_{sc}^{*}$Subtraction of load currents $I_{sha}, I_{shb}\, and\, I_{shc}$from the reference currents, results in Three-phase reference currents $I_{sha}^{*}, I_{shb}^{*}\, and\, I_{shc}^{*}$In case of shunt APF. The obtained reference currents are compared with the real shunt compensating currents$I_{sha}, I_{shb}\, and\, I_{shc}$and the error signal is transformedinto PWM gating signals, the shunt APF supplies harmonics currents and VAR demand of the load

The amplitude of the source voltage is calculated from the Three-phase sensed values of voltages as

$$V_{sm} = \left[\frac{2}{3}(V_{sa}^{2} + V_{sb}^{2} + V_{sc}^{2})\right]^{\frac{1}{2}} \tag{1}$$

The Three-phase $U_{sa}, U_{sb}\, and\, U_{sc}$are calculated as

$$U_{sa} = \frac{V_{sa}}{V_{sm}}, U_{sv} = \frac{V_{sb}}{V_{sm}}, U_{sc} = \frac{V_{sc}}{V_{sm}} \tag{2}$$

Multiplication of Three-phase unit current vectors$U_{sa}, U_{sb}\, and\, U_{sc}$with the amplitude of the source current I_{sp} consequences in Three-phase reference supply currents as

$$a = I_{sa}^{*}, b = I_{sb}^{*}\ and\ c = I_{sc}^{*} \tag{3}$$

Where

$a = I_{sp}.U_{sa}$,$b = I_{sp}.U_{sb}$ And $c = I_{sp}.U_{sc}$

By subtracting Three-phase load currents are from Three-phase supply currents we can get reference currents as

$$I^*_{sha} = a_1, I^*_{shb} = b_1 \; and \; I^*_{shc} = c_1 \quad (4)$$

Where

$a_1 = I^*_{sa} - I_{la}$,$b_2 = I^*_{sb} - I_{lb}$ and $c_1 = I^*_{sc} - I_{lc}$

Control Strategy of Series APF

In Series APF working Principle and control Three-phase load voltages$V_{la}, V_{lb} \; and \; V_{lc}$ and are subtracted from Three-phase supply voltages$V_{sa}, V_{sb} and \; V_{sc}$ which gives Three-phase referencevoltages$V^*_{la}, V^*_{lc} \; and \; V^*_{lb}$ that is inserted in series with the load. By taking a suitable transformation, the three reference currents $I^*_{sea}, I^*_{seb} \; and \; I^*_{sec}$of the series APF are obtainedfrom the Three-phase reference voltages$V^*_{la}, V^*_{lc} and \; V^*_{lb}$. The reference currents are fed to a current controller along with their sensed counterparts$I_{sea}, I_{seb} \; and \; I_{sec}$. Supply voltage and load voltage are sensed and there from the desired injected voltage is computed as

$$V_{inj} = V_s - V_l \quad (5)$$

The Three-phase reference values of inserted voltage are stated as

$$V^*_{1a} = \sqrt{2}V_{inj}Sin\,(\omega t + \delta_{inj}) \quad (6)$$

$$V^*_{1b} = \sqrt{2}V_{inj}Sin\,(\omega t + \frac{2\pi}{3} + \delta_{inj}) \quad (7)$$

$$V^*_{1b} = \sqrt{2}V_{inj}Sin\,(\omega t - \frac{2\pi}{3} + \delta_{inj}) \quad (8)$$

Where $\delta_{inj}$is the phase with injected voltage

The Three-phase reference currents of the series APF are computed as follows

$$I_{sea} = \frac{V^*_{la}}{Z_{se}}, I_{seb} = \frac{V^*_{lb}}{Z_{se}} \text{ And } I_{sec} = \frac{V^*_{lc}}{Z_{se}} \quad (9)$$

Impedance Z_{se}includes inserted transformer impedance. The currents $I^*_{sea}, I^*_{seb} \; and \; I^*_{sec}$ are the ideal currents to be maintained through the secondary winding of the transformer in order to inject voltages$V_{la}, V_{lb} and \; V_{lc}$ there by accomplishing the desired task of voltage sag compensation the currents $I^*_{sea}, I^*_{seb} \; and \; I^*_{sec}$are the compared with series compensating currents $I_{sha}, I_{shb} and \; I_{shc}$in the PWM current controller for obtaining signals for the switches in inverter

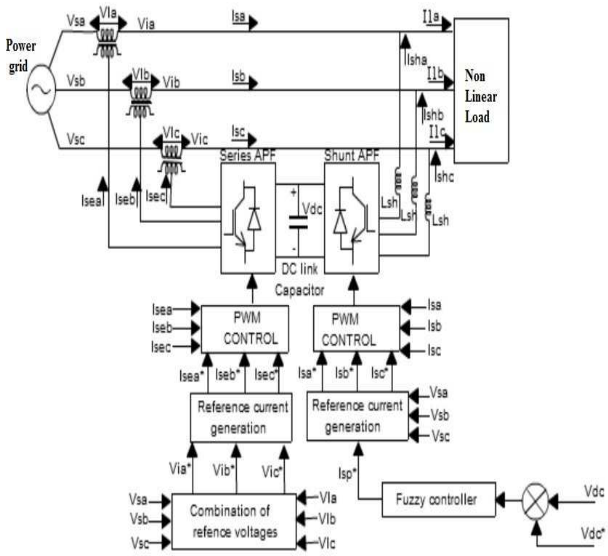

Figure 3: Control Strategy of UPQC

FUZZY LOGIC CONTROLLER (FLC)

FLC works on machine learning which is able to identify human action. Personal computersonly predict yes (true) or no (false) values however humans can aim the at the degree of truthnessor falseness. FLC models deduce the human actions so they calledexpert systems (ES). Processof changing areal scalar set of values into a fuzzy set of values is known as Fuzzification. To get different Fuzzification we need dissimilar types of fuzzifiers. FLC or expert system is a rule basedsystem. Expert system has their database tostore these rules. A scalarvalue input is given to the FLC which is fuzzified. As FLC workson a set of linguistic rules which is taking control action. FLC defined their rules accordingly. As the scalarvalue input is given to the FLC which is fuzzifiedinto linguistic variables. FLC does not need a mathematical modeling. The FLC has three major sections fuzzification, inference engine and defuzzification. Structure of FLC is shown in Figure 4 In this FLC is described as follows

- Seven fuzzy sets for each single input and single output has been considered
- Triangular membership functions has used for easiness
- Fuzzification using constant universe of discourse is used
- Implication using Mamdani’s “min” operator
- Defuzzification using the “height’’ scheme

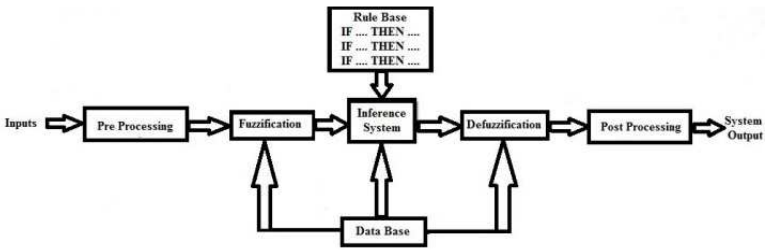

Figure 4: FLC Structure

Fuzzification

It is the transformation of a numerical value in a linguist value. Values of membership function have given to the linguistic variables, by using 7 fuzzy subsets as follows: Negative Big (NB), Negative Medium (NM), Negative Small (NS),Zero (ZE), Positive Small (PS), Positive Medium (PM) and Positive Big (PB)

Inference System

In the review of literature [11] - [14] some composition approaches such as Max (maximum) –Min (minimum) and Max-Dot have been presented. In this FLC has used Max–Min method. The output membership function of each rule is given by the Min operator and Max operator. FLC rules are written between error and change in error for one individual quantity based on that given current or voltage as its output; like that 49 rules are framed and shown in table 1

Defuzzification

It is the transformation of linguistic value in to a numerical value or defuzzification is the reverse of fuzzification. Height method has been used to calculate the output of FLC and that output of FLC transforms the control output

Table 1: Fuzzy Rules Base

Change	Error					
In Error	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	ZE
NM	PB	PB	PM	PM	PS	ZE	ZE
NS	PB	PM	PS	PS	ZE	NM	NB
ZE	PB	PM	PS	ZE	NS	NM	NB
PS	PM	PS	ZE	NS	NM	NB	NB
PM	PS	ZE	NS	NM	NM	NB	NB
PB	ZE	NS	NM	NM	NB	NB	NB

SIMULATION RESULTS

Simulations of the proposed method have been carried out by using the simulation tool MATLAB/SIMULINK. The simulation of UPQ without and using FLC has developed. The output wave forms without using FLC and with using FLC are compared. Addition of FLC in replacement of conventional controller has better results

- **Without FLC**

The circuit diagram of UPQC without FLC is shown in Figure 5

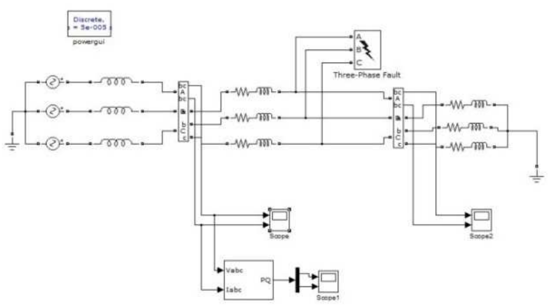

Figure 5: Simulink Circuit Diagram without FLC

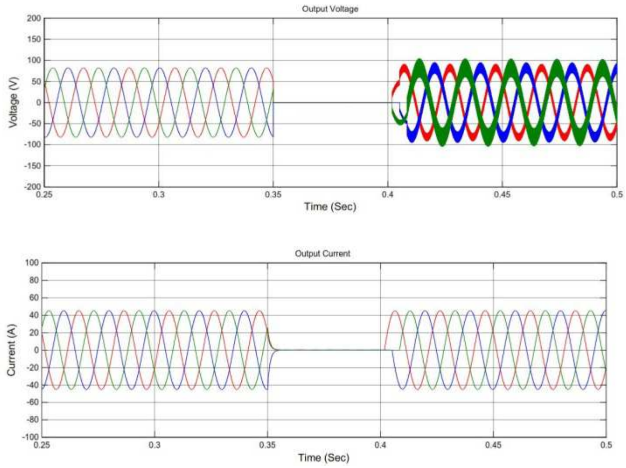

Figure 6: Load Side Voltage and Load Side Current with Interruption

The load side voltage and load side current with interruption is shown in Figure 6. Here the interruption occurs for a period of 0.05 sec. After that, due to the PQ disturbances, the outputwaveforms have been distorted.

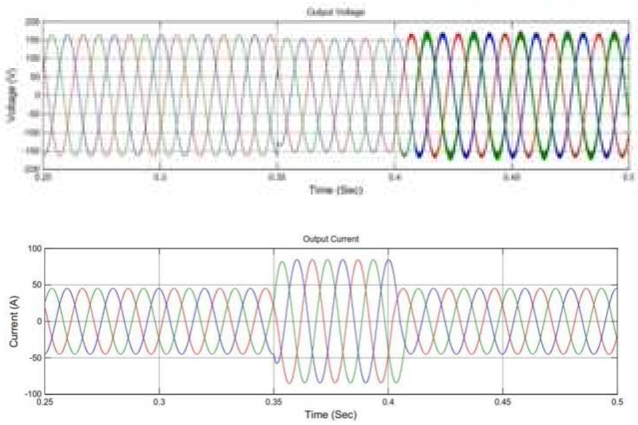

Figure 7: Supply Side Voltage and Supply Side Current with PQ Disturbances

The occurrence of PQ disturbances was shown in Figure 7, which exists for duration of 0.05 sec before the introduction of UPQC

- **With FLC**

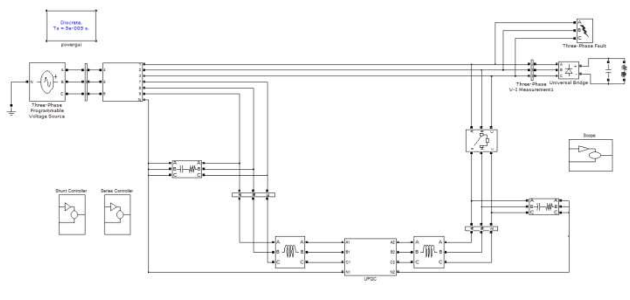

Figure 8: Circuit Diagram with FLC

The FLC/Subsystem of proposed UPQC is shown in Figure 9 and Figure 10

Subsystem diagram for Series APF

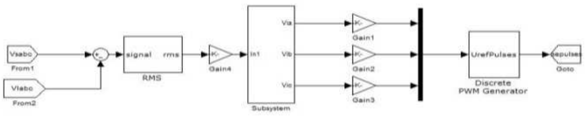

Figure 9: Subsystem Diagram for Series APF with FLC

Subsystem diagram for Shunt APF

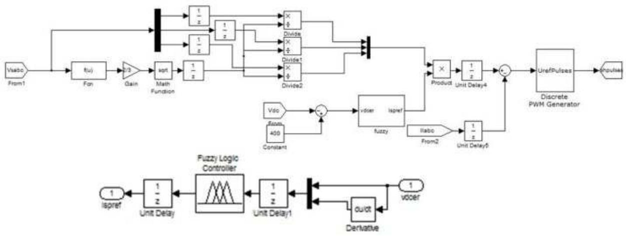

Figure 10: Subsystem Diagram for Shunt APF with FLC

Current Harmonic Compensation

Figure 11 shows the the simulation results for UPQC working as current harmonics compensator. Shunt APF helps in compensating the current harmonics generated by the non linear load. The load current is shown in Figure 11 (a). The shunt injects a current (Figure 11 (c)) in such a manner that the source current becomes sinusoidal. At the same time, the shunt APF compensates for current profile is shown in Figure 11 (b)

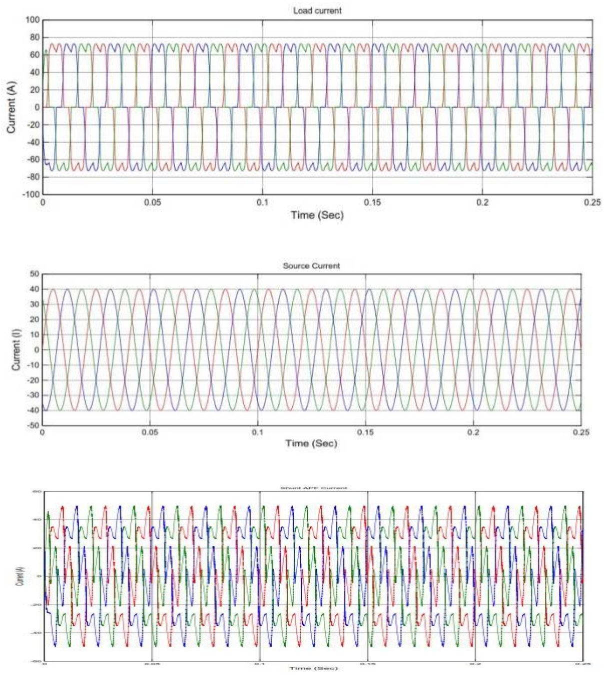

Figure 11: Simulated Results of UPQC (a) Load Current (b) Source Current (c) Shunt APF Current

Figure 12 (a-b) shows the harmonic spectrum of load current and source current for phase a after shunt APF is put in the operation. THD of load current is 22.99%. With shunt APF in operation there is a significant reduction in the THD at source side current, from 22.99% to0.13%. Shunt inverter is able to reduce the current harmonics entering into the source side

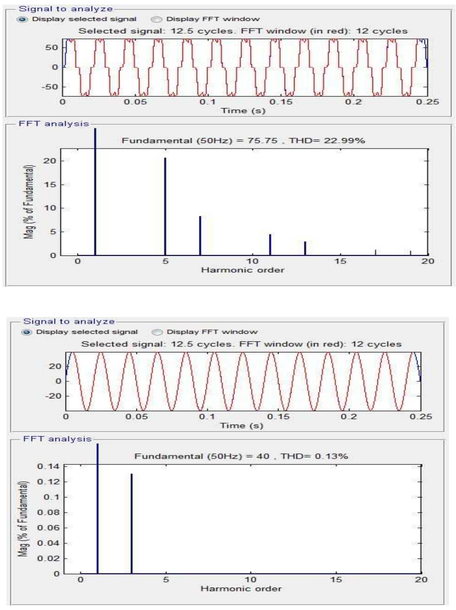

Figure 12: (a) THD Distorted Source Current (b) Compensated Source Current

Voltage Harmonic Compensation

Figure 13 shows the the simulation results for UPQC working as voltage harmonics compensator. Series APF helps in compensating the voltage harmonics generated by the non linear load. The load voltage is shown in Figure 13 (a). The series APF injects a voltage in such a manner that the source voltage becomes sinusoidal. At the same time, the series APF compensates for voltage profile is shown in Figure 13(b)

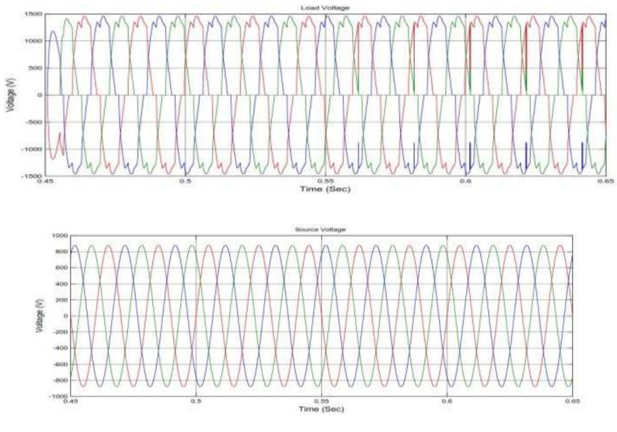

Figure 13: Simulated Results of UPQC (a) Load Voltage (b) Source Voltage

Figure14 (a-b) shows the harmonic spectrum of load voltage and source voltage for phase a after series APF is put in the operation. THD of load voltage is 11.86%. With series APF in operation there is a significant reduction in the THD at source side voltage, from 11.86% to0.39%. Series inverter is able to reduce the voltage harmonics entering into the source side

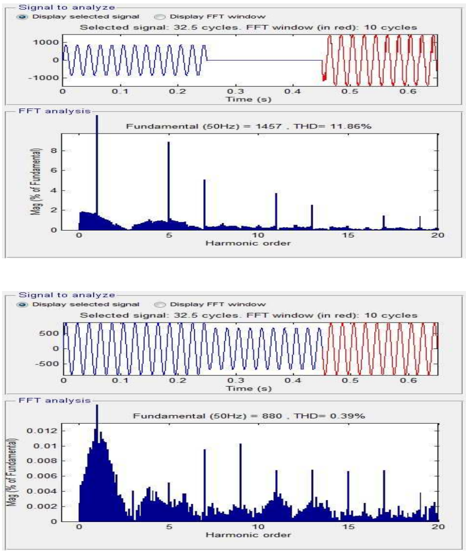

Figure 14: (a) THD Distorted Source Voltage (b) Compensated Source Voltage

CONCLUSIONS

UPQC using FLC has been investigated for compensating reactive power and harmonics. It is clear from the simulation results that the UPQC using FLC is simple, effective and is based on sensing the line currents. The THD of the source current and source voltage using the proposed FLC is well below 5%, the THD harmonic limit imposed by IEEE-519- 1992 standard

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