Improving Power Quality of Full Wave Rectifier Using UPQC with Fuzzy Controller

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Abstract-To enhance power quality (PQ) of rectifier a technique using Voltage Source Inverter (VSI) based Unified Power Quality Conditioner (UPQC) with Fuzzy Logic Controller (FLC) is discussed in this paper. UPQC is moderately a new member of power device family that improves PQ of distribution system. UPQC made up of shunt and series active filters (APF). The primary center is on the control arrangement of UPQC that reduce the harmonic effects of voltage and current all the while. By controlling firing angle, harmonics distortions are decreased. The simulation of proposed system is done by utilizing MATLAB/ Simulink. Simulation results of proposed system show reduction in total harmonic distortions. For better performance, FLC is added in control algorithm of UPQC to decrease sag levels of output values.

Keywords-Active Power Filter (APF), Fuzzy Logic Controller (FLC), Voltage Source Inverter (VSI), Harmonics, Power Quality (PQ), Unified Power Quality Conditioner (UPQC).

I. INTRODUCTION

After enhancement of semiconductor devices since 1970, these devices have been used in electric utility applications. Increase in the electronics component used in residences and industry is a serious problem in electric systems. Manufactured equipment also distorts voltage in distribution system that has poor PQ [i, ii]. The power quality problems include voltage dips, voltage spikes, under voltages, voltage imbalance, flicker and harmonic distortion. The solution of these problems depends upon nature of disturbance. In the measurement of power quality, the important factors are active power, harmonics, variation of current, reactive power and voltage. Basically, power quality is a concept of power equipments that are suitable for the operation. Voltage, current and other harmonics are due to non-linear loads. Harmonic distortions (HD) are supposed as the most valid reason for PQ problems. HD are caused where current is not proportional to applied voltage because of nonlinear devices. In power system, if non linear load is used then current waveform will change.

One of the viable methodologies for the improvement of power quality is to utilize UPQC. UPQC is used for safety of responsive loads at common coupling. It is mixture of two three phase APFs having the same dc load [iii]. It is a powerful device that deals with all PQ problems like voltage (harmonics, unbalance, sags & swells, flicker) and current (reactive, harmonics, unbalance) [iv]. Among the other new techniques for the improvement of power quality, UPQC has found for compensation of voltage along with the current distortions in the meantime. The main focus is removal of sag and swells voltages. Number of sensitive loads like computer having AC/DC drive controller along with better requirement of voltages can work inappropriately and in some cases, data loose or gets damage because of these sag and swell conditions [v].

The classification of UPQC on bases of converter topology, here voltage source inverter(VSI) based UPQC is used . It decreases the average switching frequency of the switches and also switching losses in the inverter. The reduction in the DC link voltage requirement of the shunt active filter enables us to match the DC link voltage requirement of the series active filter and avoids the over rating of the series active filter in the UPQC compensation system. It has the ability to compensate the load at lower dc-link voltages. The advantages proposed VSI topology over CSI covers lighter in weight, blocking diodes are not required, having ability of multilevel capacities, cheaper and flexible over all control [vi]. For mitigating harmonics distortion of current and voltage to enhance reactive power and voltage regulation following work presents a UPQC technique. It also degrades voltage and current interference.

II. SYSTEM MODEL UPQC

A. UPQC

UPQC is a combination of shunt APF and series APF. UPQC joins the working of Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Restorer (DVR) [vii, viii]. In voltage control technique, bus voltage is converted to sinusoidal across any flicker or harmonics in source voltage and load current. In current control technique, it draws an adjusted sinusoidal current from utility bus regardless of harmonics in either source voltage or load current [ix]. The system for 3∅, three wire distribution system is appeared in Fig. 1. UPQC having two VSIs, one VSI act as shunt APF furthermore, alternate as series APF. Both APFs offer a typical dc join between them.

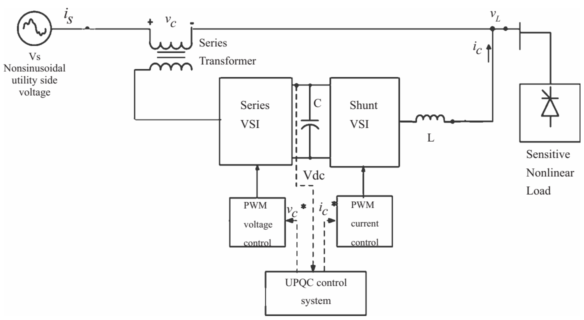


Fig. 1. Detailed configuration of UPQC

One of the VSI is associated in parallel and other is in series connected with the a.c system through a transformer named infusion transformer. Shunt compensation circuit is made with parallel inverter and its control circuit while series compensation circuit is made with series inverter and its control circuit. For effective UPQC operation, the dc capacitor should have value greater than 150% of line to line supply voltage. To direct the capacitor voltage steady a fuzzy controller can be utilized. Along these lines the control circuit of UPQC is isolated into shunt and series compensator [x].

B. Power Flow Analysis of UPQC

Powers are neglected as comparison with power at fundamental component, due to harmonic quantities. So, harmonic power is ignored and operation of steady state analysis is concluded only on base of fundamental frequency component. At load bus, UPQC is designed with sinusoidal voltage. So that, the injected voltage by series APF is voltage that is difference of supply and ideal load voltage. To control voltage source series APF is used. The purpose of shunt APF is kept up the dc joined voltage at steady level. The equal circuit of UPQC was appeared in the Fig. 2. [xi].

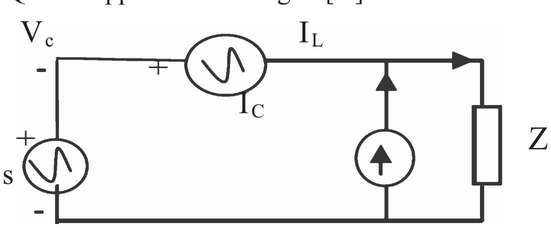


Fig. 2. UPQC: Equivalent circuit

Supply voltage, series compensation voltage and shunt compensation current is V_S, V_C and I_c respectively. Load voltages and currents are V_L and I_L. As well as harmonics components, voltage source also contain negative and zero value. The system having per phase voltage can be shown as in (1). V_{1pa} is positive sequence component of fundamental frequency. The V_{1na} is negative and V_{10a} is zero sequence components. The last term shows voltage harmonics. In order to maintain load voltage efficiently balanced and sinusoidal, the series filter producing voltage as shown in (2). Shunt AF provides the balancing of load current harmonics and keep DC link current constant [xii, xiii]. Shunt AF phase load current is expressed in (3)

$$V_a = V_{1Pa} + V_{1na} + V_{10a} + \sum_{K=2}^{\infty} V_{Ka} Sin(k\omega t + \theta_{Ka}) \quad (1)$$

$$V_{ah} = V_{1na} + V_{10a} + \sum_{K=2}^{\infty} V_{Ka} Sin(K\omega t + \theta_{Ka}) \quad (2)$$

$$i_{al} = I_{1Pm} Cos(\omega t - \theta_1) + I_{ah} + \sum_{K=2}^{\infty} i_{alk} \quad (3)$$

$$I_{ah} = I_{1Pm} Sin\,\omega t\, Sin\,\theta_1 + I_{a1n} + \sum_{K=2}^{\infty} i_{alk} \quad (4)$$

Equation (4) produces current that fulfill reactive power demand of shunt AF and also decreases current harmonics.

C. Control Phenomena

UPQC control circuit produce reference signal for both filters. The control strategy is able to remove effectively the most part of distortions. The series APF mitigates the supply voltage harmonics; though the shunt APF eases the supply current from the harmonics.

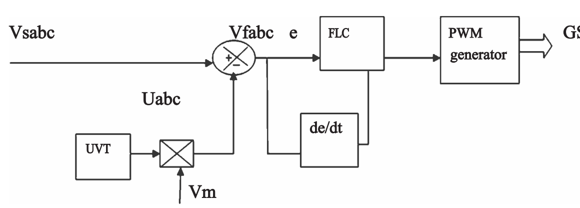


Fig. 3. Control techniques for Series APF

To make load voltages perfectly balanced, the series filter must create a voltage as shown in (5).

$$\begin{bmatrix} U_a \\ U_b \\ U_c \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} \sin\theta \\ \cos\theta \end{bmatrix}$$

To control the series filter, reference voltages remove the distortions and imbalance in source voltages, that makes voltage at load side perfect balance and sinusoidal at required amplitude. Similarly, subtraction of these reference and supply voltage makes required voltage at load terminals. Fig. 4. portrays the most important side of three phase shunt APF for balancing harmonic current. The control figure shows that instantaneous power deals with phase voltages of PCC as inputs and then line current of non-linear load should be adjusted. This implies that shunt AF has a particular mananging characteristics. If there are other non-direct loads associated with PCC, a particular non linear load can also be set for compensation [xiv]. There is no traditional controller in UPQC.

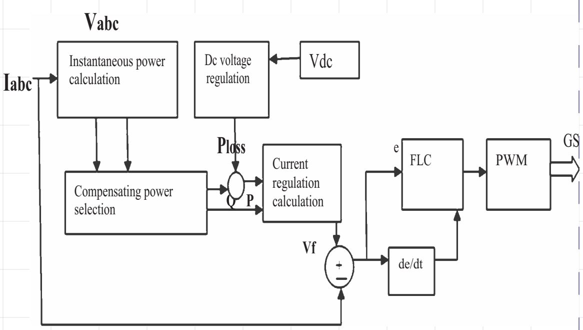


Fig. 4. Block diagram of shunt APF

In pq theory, there is existence of active and reactive powers with no neutral and zero sequence power [xv]. Power is compensated which determine performance of shunt filter. Shunt AF having power injector consists on a three-phase VSI that is consist of IGBT or power MOSFETs with anti parallel diodes [xvi].

D. Fuzzy Logic Implementation in UPQC Controller

Keeping in mind the end point of execution of self managed dc link, shunt control circuit helps to detect capacitor voltage. The link voltage (Vdc) is detected consistent point and is linked to its reference value. The error signal and its change is used in fuzzy controller. Fuzzy process based on three main steps named fuzzification (input variables), membership function (MF) graph (output variable) and finally defuzzification (linguistic output variable). This arrangement is clearly shown in Fig. 5.

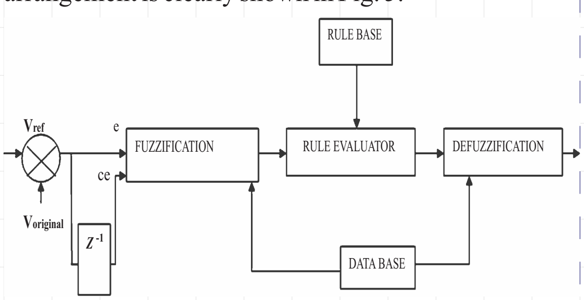


Fig. 5. FLC block diagram

The fuzzy sets are triangular or trapezoidal shapes etc [xvii, xviii, xix]. Fuzzy MF between 6 inputs and outputs for voltage and current are arranged in control scheme of series and shunt AF. One of the fuzzy membership functions having two inputs and one output shown in Fig. 6. Rules of FLC are made for a particular quantity between error and its change that based on given voltage or current as its output as 49 rules are outlined in Table 1 [xx]. Optimum solution is obtained by tuning of fuzzy MF. Seven inputs are more capable to explain all values than the five inputs. These values fully cooperate all zero, negative, positive values either its big or small. The linguistic rule table is standard table which have seven inputs.

TABLE I
.LINGUISTIC RULE TABLE

e /ce	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NM	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PM	PM	PL
PL	Z	PS	PM	PL	PL	PL	PL

III. Results and Discussion

In Matlab Simulink, a Power System Blockset is used to verify UPQC performance. UPQC analysis is done in discrete domain and compensators are applied by discrete blocks.

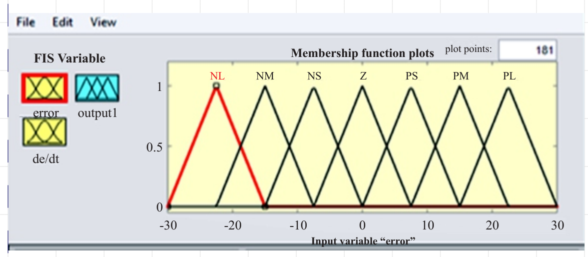


Fig. 6. Triangular Membership Function

At first, working of shunt AF for voltage correction is examined by switching on shunt filter and then series AF is turned on. Collected data for reference load voltage, reference compensation current and source current by conventional method is calculated with sample rate of 1µsec and saved in Matlab workspace. This extensive data is used in FLC. UPQC is designed with FLC and is presented for non-linear load and then it is derived by uncontrolled diode bridge.

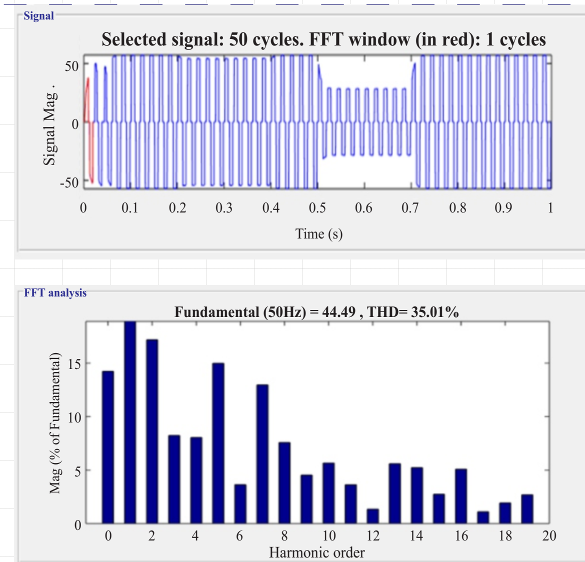


Fig. 7. Harmonic analysis source current without UPQC

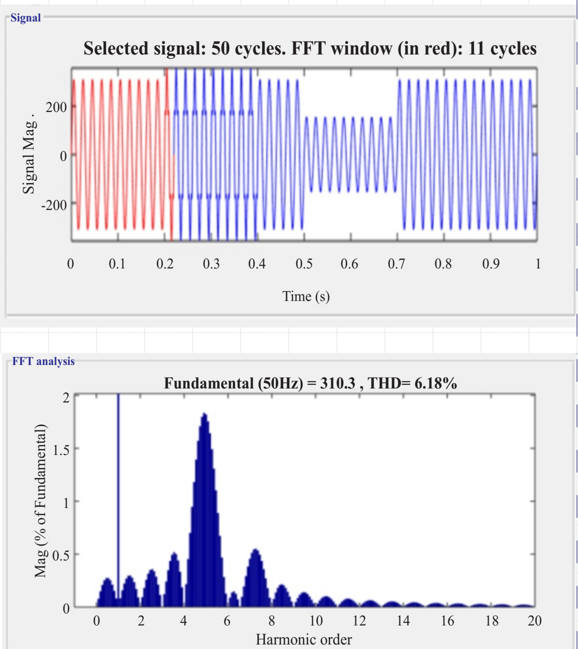
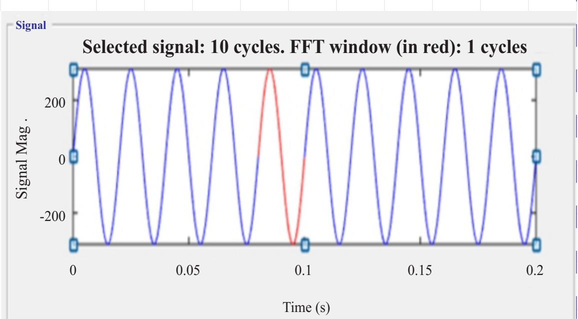


Fig. 8. Harmonic analysis source voltage without UPQC



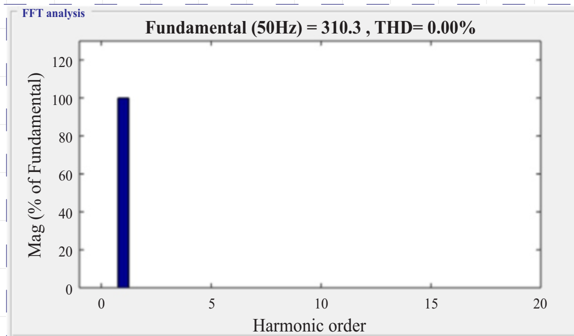


Fig. 9. Harmonic analysis source voltage with UPQC and FLC (zero angle)

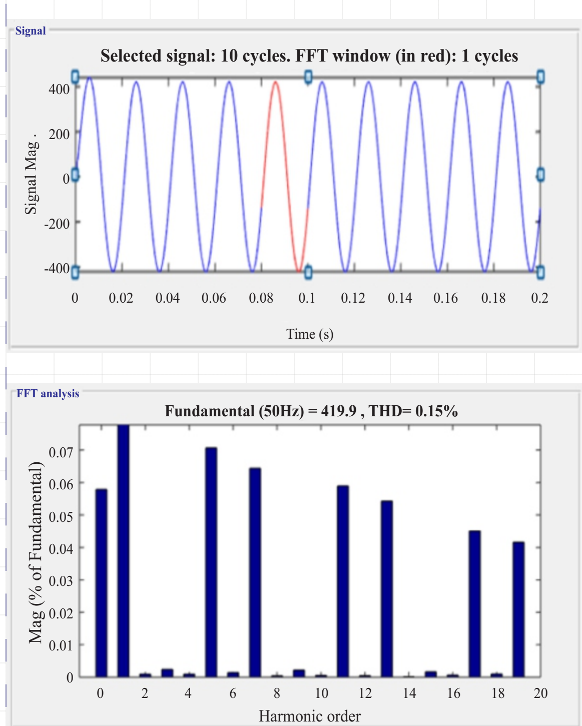
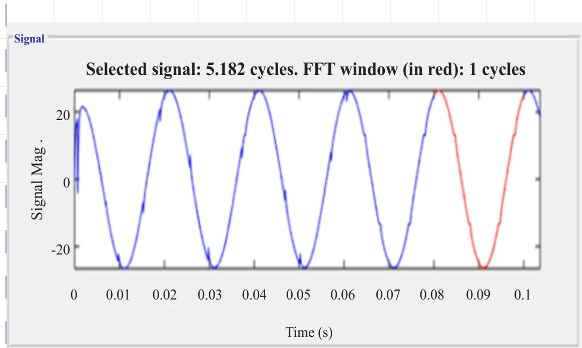


Fig. 10. Harmonic analysis source current with UPQC and FLC(zero angle)



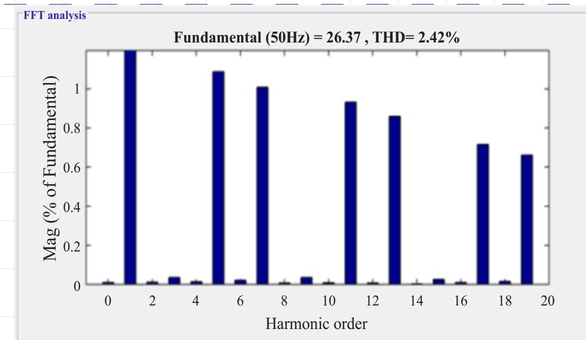
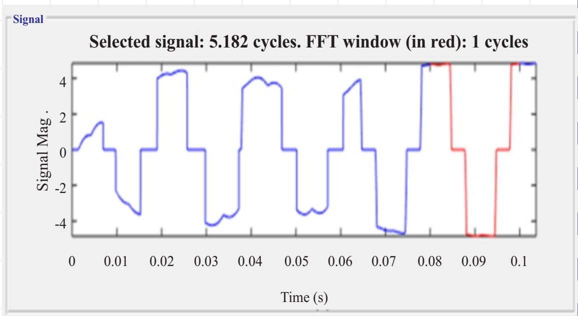


Fig. 11. Harmonic analysis load voltage with UPQC and FLC (zero angle)



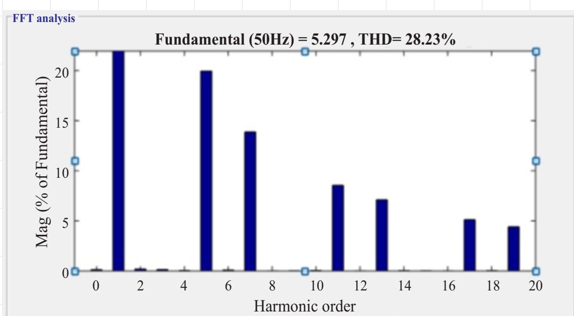
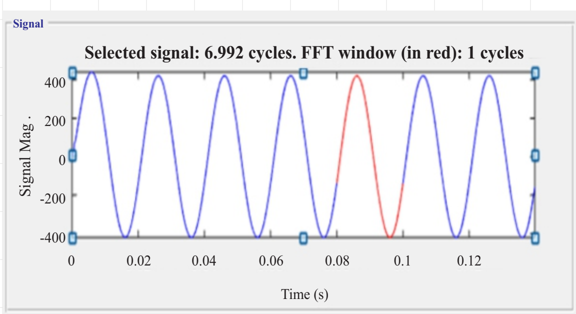


Fig. 12. Harmonic analysis load current with UPQC and FLC (zero angle)



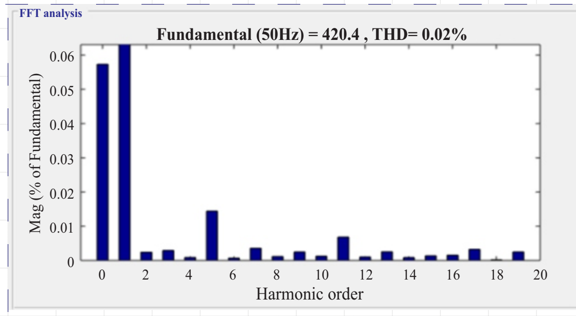


Fig. 13. Harmonic analysis Source current with UPQC and FLC (90 angle)

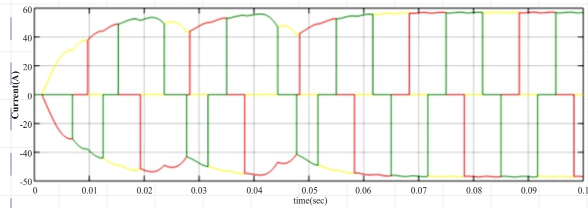


Fig. 14. Source current without UPQC (at zero angle)

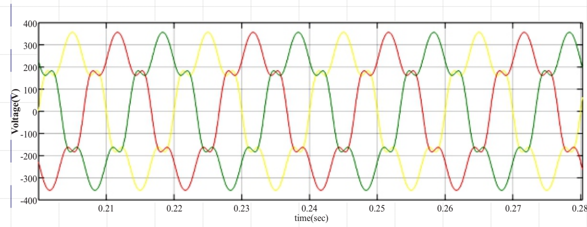


Fig. 15. Source voltage without UPQC (at zero angle)

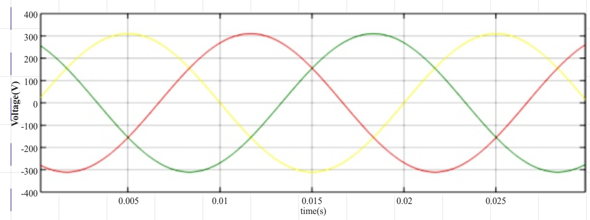


Fig. 16. Source voltage with UPQC (at zero angle)

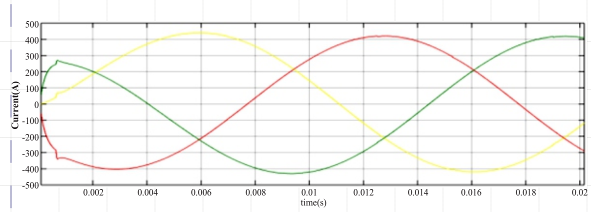


Fig. 17. Source current with UPQC (at zero angle)

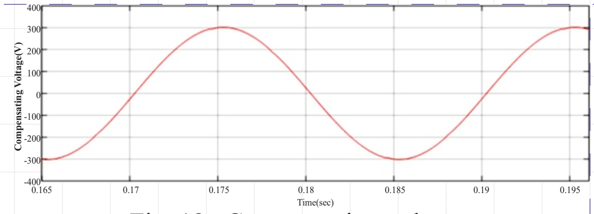


Fig. 18. Compensating voltages

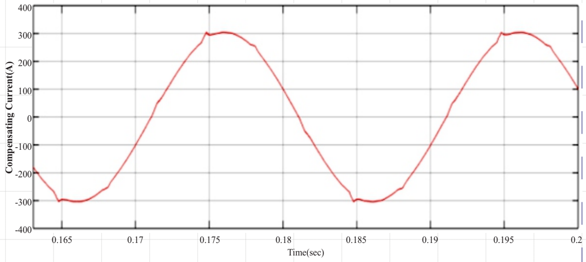


Fig. 19. Compensating current

Without UPQC, THD values of source current are 35.0%. In the case of source voltages, distortion is removed with UPQC from 6.18 % to zero. These distortions are mitigated by using UPQC based on voltage source inverter topology (VSI). After designing the series and shunt APF, the total harmonic distortions are removed. At the end, THD value of source current is 0.15% at zero firing angle. But when the angle is further increased THD values of source current are decreased at 90 angle THD value is 0.02% as in Table II.

IV. CONCLUSIONS

UPQC system is effectively composed and demonstrated by utilizing the circuit components/ elements of simulink. The simulation results exhibit that nonlinear load current and distorted voltage conditions are decreased by use of proposed technique. It eliminates the effect of unbalance and distortions of load and source current with voltage on the power cable. The robustness of UPQC and its controller is practically verified under modified different conditions, which is shown in table two. Basically, the working of UPQC relies on the correctness of reference signals. By utilizing conventional compensator information, FLC is adjusted with extensive number of data points. Simulation is done by utilizing Matlab for RL load having a rectifier which is uncontrolled. THD values are removed by UPQC. UPQC with FLC is managed in this paper for enhancing power quality and in addition enhancing power component. The simulation results give conclusion that UPQC performance is increased with FLC and mitigate both voltage and current harmonics efficiently.

TABLE II
CALCULATED RESULT OF PROPOSED MODEL

No.	Firing Angle	Total Harmonic Distortion %			
		Source Voltage	Source Current	Line Voltage	Line Current
1	0	0	0.15	2.42	28.23
2	30	0	0.19	3.02	31.05
3	45	0	0.15	2.39	30.78
4	60	0	0.12	1.84	30.50
5	90	0	0.02	0.33	37.84

To determine compensation signals, the response time decreased with the improving accuracy. Proposed UPQC topology offers high efficiency and low cost for high power applications.

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