SIMULATION AND HARDWARE IMPLEMENTATION OF UPQC FOR POWER QUALITY IMPROVEMENT IN SECONDARY DISTRIBUTION SYSTEM

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Abstract— *Power quality is a prime issue in electrical distribution side. To alleviate the Power Quality problems, Unified Power Quality Conditioner (UPQC) is preferred. A UPQC that combines the feature of series and shunt active power filter, which are used at the Point of Common Coupling (PCC) for improving the power quality, is simulated using SRF control strategy. The synchronous reference frame (SRF) theory is used to obtain the reference signals for series and shunt active power filters (APFs). The UPQC is realized using two voltage source inverters (VSI) connected back to back, to a common dc link capacitor. For mitigation of voltage sag, voltage and current harmonics, a UPQC with robust control has been presented in this paper. The used technique is simulated using MATLAB/SIMULINK 7.8. The algorithm is validated by using a prototype of microcontroller (PIC18F877) based UPQC. Detailed experimental results are presented.*

Keywords: *Power Quality, Unified Power Quality Conditioner, Synchronous Reference Frame Theory.*

1. INTRODUCTION

Nowadays, Custom Power Devices (CPDs) which are applicable to distribution systems for enhancing reliability and quality of power are gaining popularity [1]. Custom power devices include static shunt compensator or distribution static compensator (D-STATCOM) [2] to compensate current based distortions and series static compensators or a dynamic voltage restorers (DVR) for the mitigation of voltage based distortions [3]. Their capabilities are limited to particular application they can solve only one or two power quality problems. Recent research efforts have been made toward utilizing a device called UPQC to solve most of the PQ problems [4].

The aim of unified power quality conditioner is to eliminate the disturbances that affect the performance of the critical load in power system. The UPQC, which has two inverters that share one dc link, can compensate the voltage sag and swell, the harmonic current and voltage. The shunt APF is usually connected across the loads to compensate for all current-related problems, such as the reactive power compensation, power factor improvement, current harmonic compensation, neutral current compensation, regulate the dc-link voltage and load unbalance compensation, whereas the series APF is connected in a series with a line through series transformer. It acts as a controlled voltage source and can compensate all voltage-related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc. [5], [6]. The control strategy is basically the way to generate reference signals for both shunt and series APFs of UPQC. Different UPQC controlling methods can be classified in the three following: time – domain controlling method, frequency domain controlling method and new techniques. Fourier method is one of the methods which can be categorized as frequency domain methods.

The methods such as PQ Theory[7] [8] , ZVS instantaneous reactive power[9] , algorithms based on the synchronous dq reference frame, instantaneous power balance method[10], synchronous detection algorithm, direct detection algorithm and notch filter based controlling method are some can be mentioned for time domain methods. Dead beat control, Space Vector Modulation (SVM) and wavelet conversion are some of the new techniques [11]. All methods end in similar results when the reference signal is calculated under balanced and sinusoidal conditions where each ends in to different results under unbalanced and non sinusoidal conditions. The reason is the fact that it needs sinusoidal and balanced voltage and is not sensitive to voltage distortions and is relatively simple [12]. In this paper Synchronous Reference Frame method has been proposed to generate the reference signal for the inverter which accordingly solves the problems like voltage sag, voltage and current harmonics.

2. System Description

The system under consideration is shown in Fig.1.The UPQC is connected before the load to make the load voltage free from any distortions. In order to create a voltage sag in source voltage, an inductive load is connected suddenly on the load side. The UPQC is realized by using two voltage source inverter, on which one acting as a shunt APF, while the other as series APF. Both the APFs share a common dc link in between them. Each inverter is realized by using six IGBT (Insulated Gate Bipolar Transistor) switches. The load under consideration is a combination of linear and non-linear loads. A three-phase R-L load is taken as a linear load, where as a three-phase diode bridge rectifier with a resistive load on dc side is considered as a non-linear load. Hysteresis controller is meant for the generation of pulses for the inverter switches.

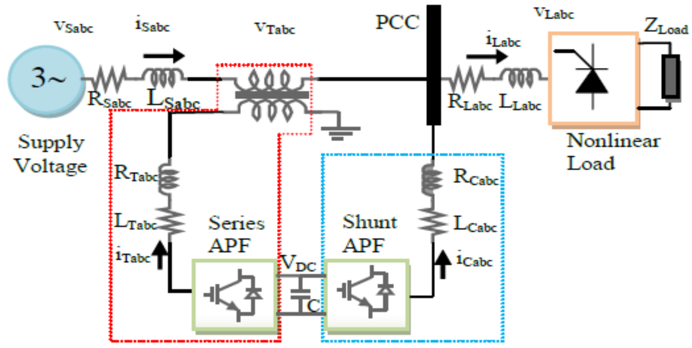

Fig .1.Basic system configuration UPQC

3. Synchronous Reference Frame Method

This method is also known as d-q method and is based on a-b-c to d-q transformation, proposed by Bhattacharya et al, 1995. This method can be used to extract the harmonics contained in the supply voltages or currents. For current harmonics compensation, the distorted currents are first transferred into two-phase stationary co-ordinates using α-β transformation. After that, the stationary frame quantities are transferred into synchronous rotating frame using cos and sin functions from the PLL. The sin and cos functions help to maintain the synchronization with supply system. Using a LPF, the harmonics and fundamental components are separated easily and transferred back to the a-b-c frame as reference signals for the APF. The Flowchart for SRF method is given in Fig.2

In d-q theory, to compute the instantaneous active and reactive powers, the knowledge of both the source voltage and the load current is essential. While the d-q theory deals with the current, independent of the supply voltage (or vice versa). Therefore, the d-q theory performs better under distorted supply voltage. The a-b-c to d-q transformation is called as Parks Transformation. The three phase quantities are transformed into two phase transformation using Transformation Matrix T. Transformation matrix is given by following equation 1.

$$T=\sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(\omega t) & \sin(\omega t-\frac{2\Pi}{3}) & \sin(\omega t+\frac{2\Pi}{3}) \\ \cos(\omega t) & \cos(\omega t-\frac{2\Pi}{3}) & \cos(\omega t+\frac{2\Pi}{3}) \end{bmatrix} \quad (1)$$

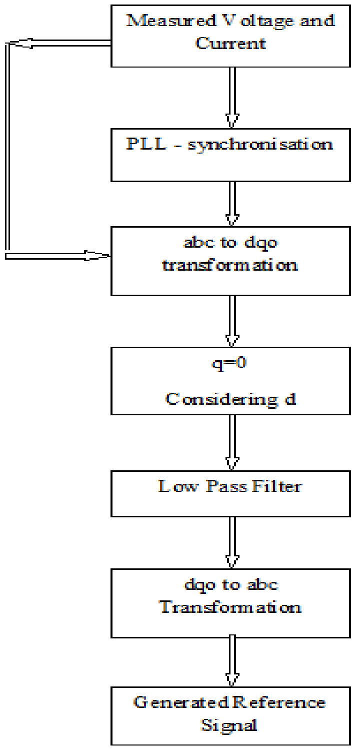

Fig .2 Flowchart for SRF method

The inverse Transformation matrix is given by equation 2

$$T^{-1}=\sqrt{\frac{2}{3}}\begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(\omega t) & \cos(\omega t) \\ \frac{1}{\sqrt{2}} & \sin(\omega t-\frac{2\Pi}{3}) & \cos(\omega t-\frac{2\Pi}{3}) \\ \frac{1}{\sqrt{2}} & \sin(\omega t+\frac{2\Pi}{3}) & \cos(\omega t+\frac{2\Pi}{3}) \end{bmatrix} \quad (2)$$

4. Design Procedure for Power Circuit of UPQC

The design procedure of the power circuit includes the following parameters

- *A.* DC capacitor voltage.
- *B.* Selection of DC side capacitor, C_{dc}
- *C.* Selection of filter inductor, L_f
- D. Selection of series injection transformer

4.1 *DC Capacitor voltage*

The value of the common link DC bus voltage of the UPQC depends on the instantaneous energy available to the UPQC. For a VSI, the DC link voltage is defined as

$$V_{dc}=\frac{2\sqrt{2}V_{LL}}{\sqrt{3}m} \quad (3)$$

Where, m is the modulation index and V_{LL} is the ac line voltage of UPQC.

4.2 DC side capacitor

The value of dc capacitor (Cdc) of back to back connected VSIs of the UPQC depends on the change of DC voltage during increase and decrease of the load. Using the principle of energy conservation, the equation for C_{dc} is as follows

$$\frac{1}{2}C_{dc}\left[V_{dc}^2 - V_{dcm}^2\right] = 3V(\alpha I)t \qquad (4)$$

Where V_{dc} is the reference dc voltage and V_{dcm} is the minimum Voltage level of dc bus, α is the overloading factor, V is the phase voltage, I is the phase current, and t is the time by which the dc bus voltage is to be recovered.

4.3 *AC Inductor*

The selection of the ac inductance (Lf) of VSI depends on the current ripple $i_{cr(,p-p)}$, switching frequency f_s, dc bus voltage (V_{dc}), and L_f is given as

$$L_f = \frac{\sqrt{3}mV_{dc}}{12\ \alpha\ f_s i_{cr(p-p)}} \qquad (5)$$

4.4 Series Injection Transformer

The transformers reduce the voltage requirement of the inverters and provide isolation between the inverters. This can prevent DC storage capacitor from being shorted through switches in different inverters .The electrical parameters of series injection transformer should be selected correctly to ensure the maximum reliability and effectiveness. In normal bypass mode, full load currents pass through these semiconductor switches. The flowing current will increase during sags because of injected power for compensation so the switches and protection devices should handle the total current. Injection transformer rated at 1 kVA (5:1 turns ratio, primary/secondary) are used.

5. Simulation of UPQC

The analysis of SRF based UPQC three-phase system had been done in Simulink/MATLAB environment. Simulations have been performed to show the effectiveness of the UPQC regulation by means of SRF theory. The system parameters considered for the simulation studies are given in table 1. It consists of AC source, non-linear load, shunt APF, series APF reference current generation, and hysteresis current controller. The normal sinusoidal supply is 230 V_{rms}, 50 Hz. The overall Simulink diagram has been given in the Fig 3. A three phase supply is connected to two loads, one is a RL load and the other is a Rectifier load of 4KW at two different times. RL load is connected permanently in the system. A 3-phase fault is connected during the time period of 0.1ms to 0.2ms to create voltage sag in a system. Rectifier load is connected during the period of 0.3ms to 0.38ms to create the harmonics. Then UPQC is connected at duration of 0.15 to 0.38ms to overcome the voltage sag and harmonics.

Table.1: System parameters

Supply	V = 415 V L-L, f = 50 Hz
Transformer	1 KVA , 1:4
DC Capacitance	1300µF
Loads	Three phase rectifier load of 4KVA RL load of 4KW ,6 KVar
PI regulator	K_p = 0.5 Ki = 50

5.1. DC Link Voltage Control

A PI controller is used to track the error exists between the measured and desired values of capacitor voltage in order to control the D.C link voltage. This signal is applied to current control system in shunt voltage source inverter in a way that the D.C capacitor voltage is stabilized by receiving the required active power from the grid.

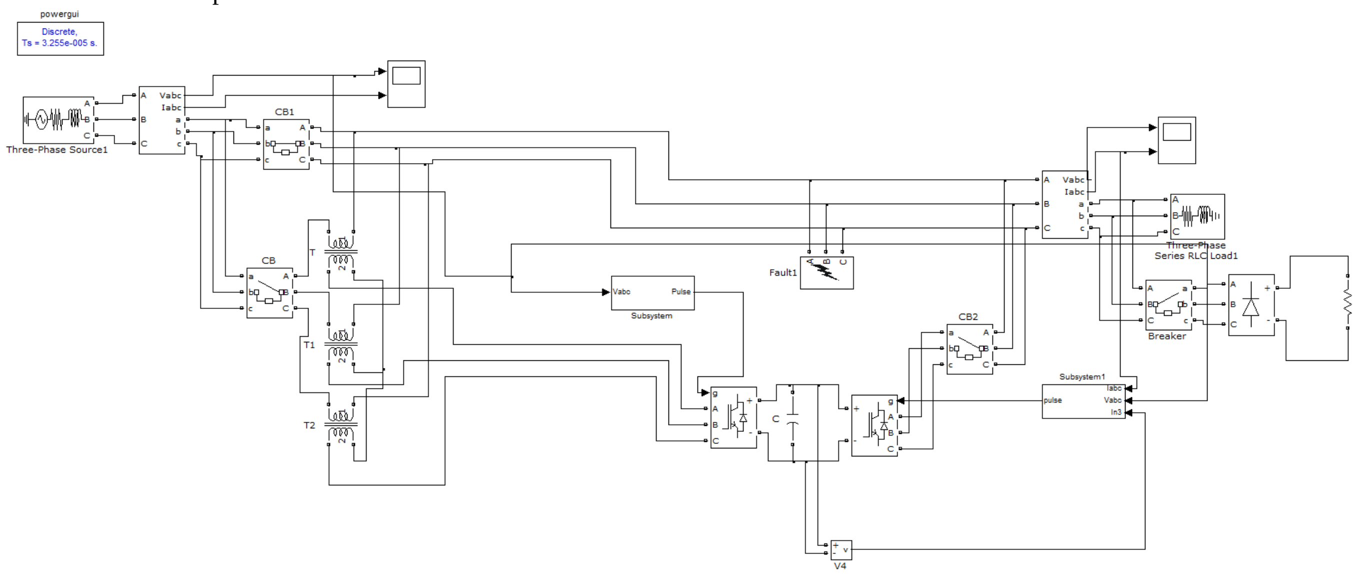

Fig.3 Overall circuit diagram

Correct regulation of proportional controller's parameters plays an important role in D.C voltage control system's response. Too much increase in proportional gain leads to instability in control system and too much reduction decreases the responding speed of control system. Integral gain of controller corrects the steady state error of the voltage control system.

5.2. Shunt Active Power Filter Control Diagram

The load current is taken and given to the abc to dq0 transformation block. The other input to the block is from PLL which generates required sine and cosine function. After converting the three phases to two phase quantity, q and 0 components are terminated and the d-component alone is send to the low pass filter to extract the ac component present in it. PI regulator is used in order to maintain the DC link voltage stable. The desired and the measured voltage is compared and sent to the PI block in order to track the error. The output of PI added to the d–component and again two phase quantity is transformed to three phase quantity to generate the reference signal for the hysteresis current controller. The shunt inverter control diagram is given in fig.4.

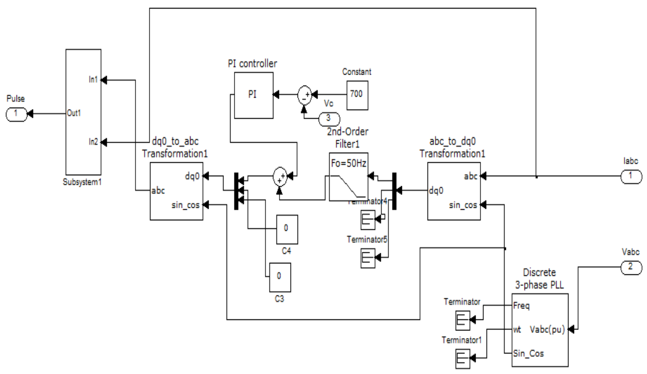

Fig.4 Shunt Inverter Control Diagram

5.3. Series Active Power Filter Control Diagram

The operation of series active filter is same as that of shunt active filter, but instead of measured current the measured voltage is taken to generate the reference voltage for the hysteresis voltage controller. The shunt inverter control diagram is given in fig.4.

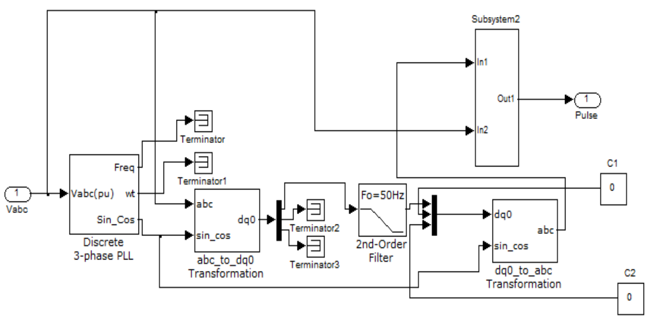

Fig.5 Series Inverter Control Diagram

6. Simulation Results and Discussions

The simulation results are clearly discussed without and with UPQC under balanced conditions. The waveform of phase voltage, source current and %THD of the source current is obtained for the system without UPQC is shown clearly in figures 6,7 and 8, that the THD is relatively high (19.62%). When the UPQC is connected o the three-phase system, the reference compensation currents and voltages are generated by SRF theory. The simulation results with the proposed control strategies under balanced conditions. When the UPQC is applied, the injected compensation current (*if*) forces the source current (*is*) to become a near sinusoidal waveform and in phase with the source voltage waveform shown in figure 8, resulting in improved power factor and also injected compensation voltage mitigate voltage sag.

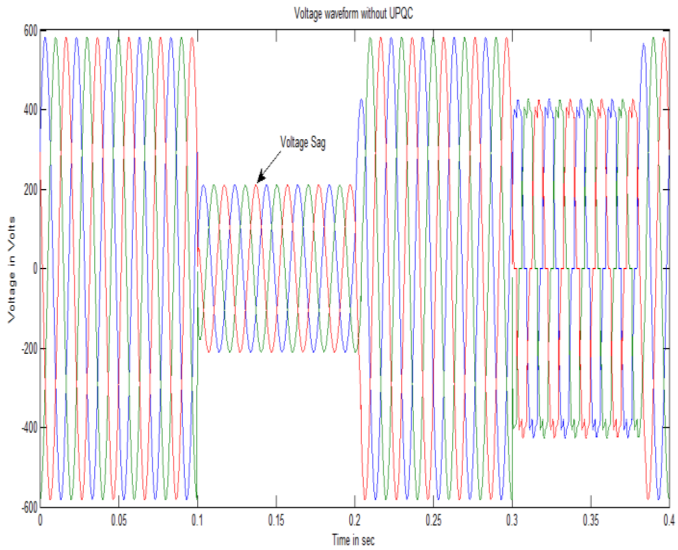

Fig.6 (a)

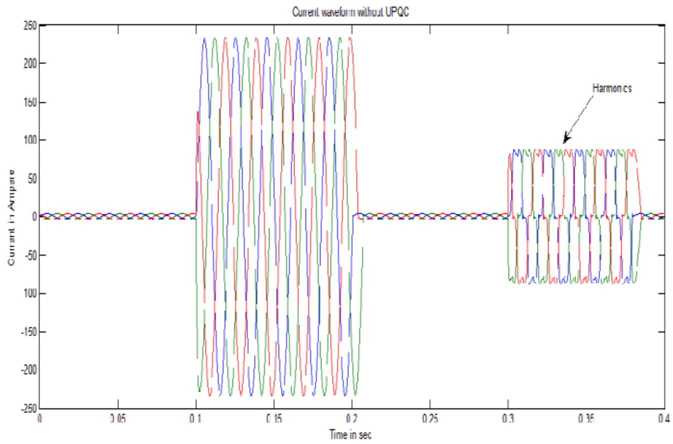

Fig.6 (b)

Fig.6 (a) & (b) Voltage and Current waveform without UPQC

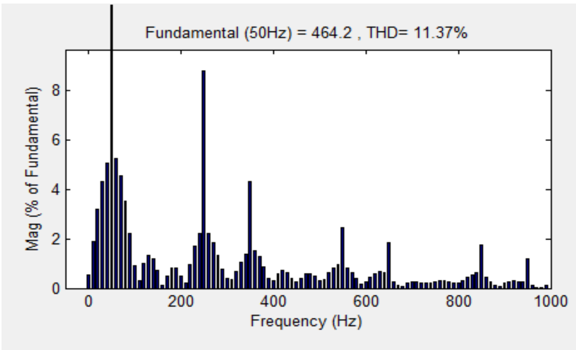

Fig.7(a) %THD source voltage without *UPQC*.

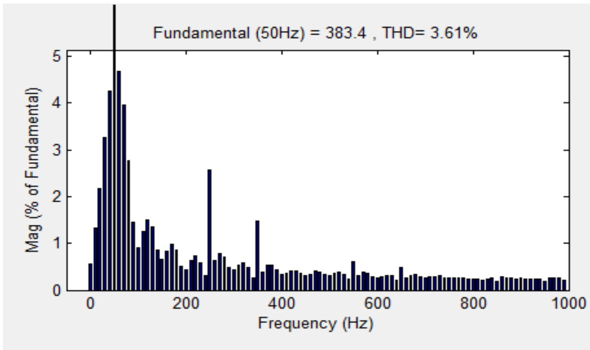

Fig.9(a) %THD source voltage with *UPQC*.

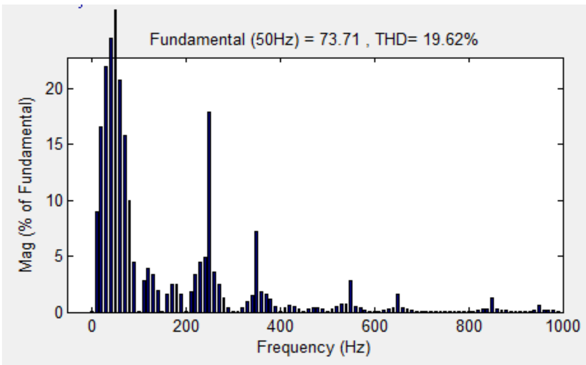

Fig.7(b) %THD source current without *UPQC*.

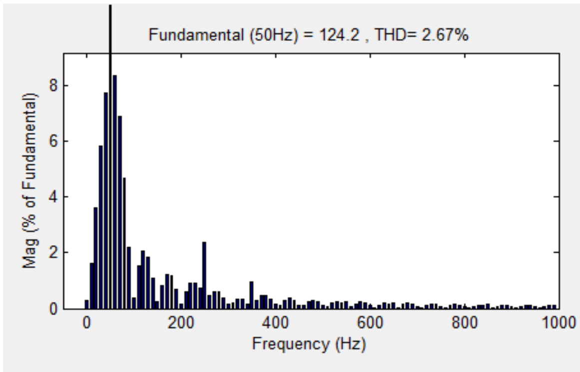

Fig.9(b) %THD source current with*UPQC*.

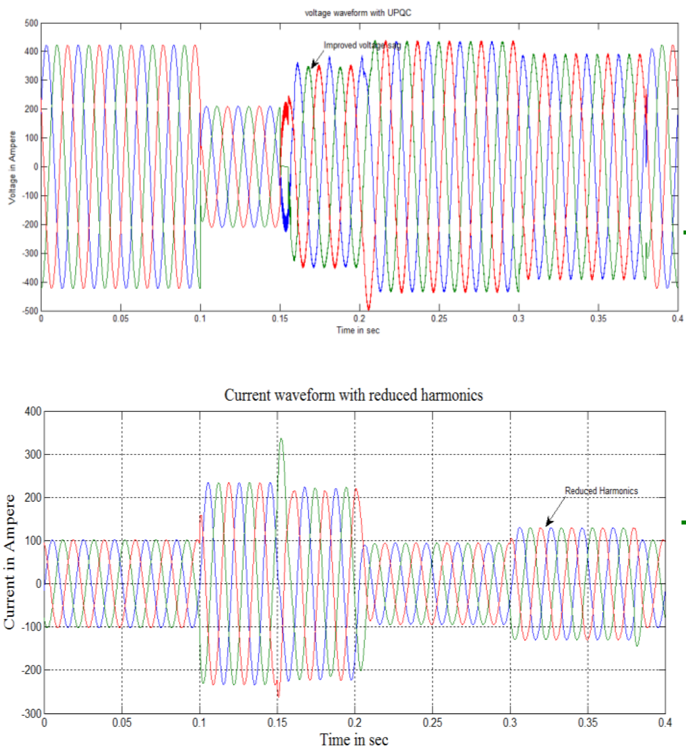

Fig.8 Voltage and Current waveform with UPQC

Figure 9(a)&(b)shows the THD in the source voltage and current with UPQC. The THD value comes down to about 2.67% with UPQC from the without UPQC value of 19.62%. Table 2 gives the clear view of comparison of voltage sag and THD For without and with UPQC.

Table.2: Comparison of voltage sag and THD For without and with UPQC

Performance Metrices	% of Voltage Sag	THD	
		For Voltage	For current
With UPQC	49.87%	11.37%	19.62%
Without UPQC	15.66%	3.61%	2.67%

7. Experimental Results

A prototype of UPQC was implemented with a PIC18F877 microcontroller. A 230 Volt is step down to 110V and it is connected to the load. Three types of loading are considered, both of linear and nonlinear type namely 50 Watts linear load and 0.5kW of non linear load (rectifier load). The actual voltage from the source side and current are from the load sensed through the respective sensing circuit and sent to the microcontroller. In the microcontroller, the input signals are compared with the corresponding reference level. The output of the comparator logic will be either a low or high level. This is anded with a high frequency carrier signal 5 KHz and switching sequence is obtained. The switching sequences are applied to the UPQC through a driver unit. The driver will turn on the corresponding switches by supplying necessary voltage, so that needed voltage or current will be injected to the series or shunt side respectively. When the inductive load is connected to the system, it will create the voltage sag and affects the source as well as the other loads in point of common coupling and waveform is shown in Fig11. Similarly if the non linear load is connected to the system it creates the harmonics and affects the source and other loads on the PCC and distorted current waveform shown in Fig12.Fig 13 and fig14 shows the dynamic response of the UPQC.

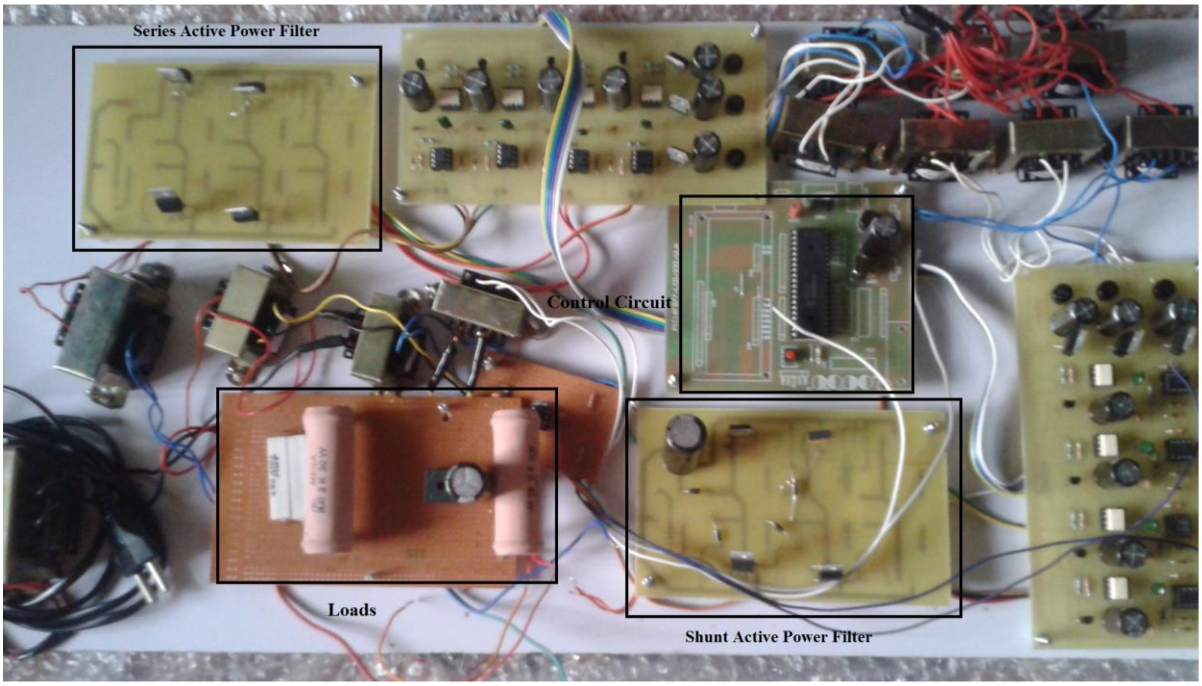

Fig10.Small scale model

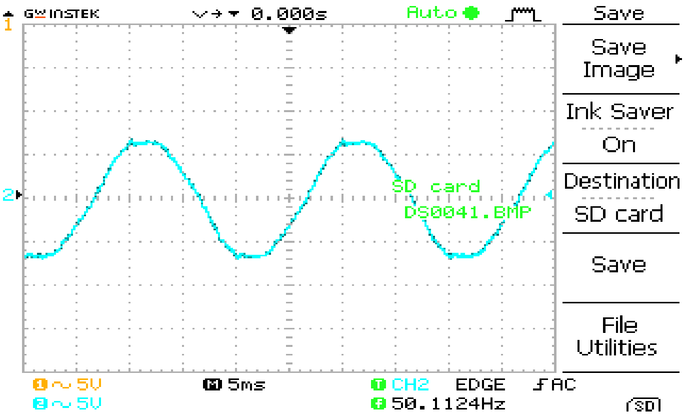

Fig11. Voltage waveform without UPQC

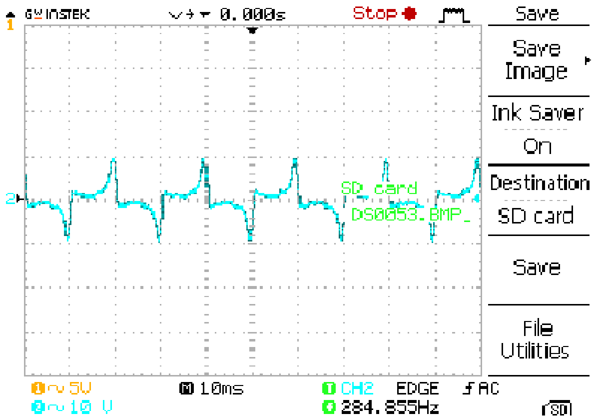

Fig12. Source Current waveform without UPQC

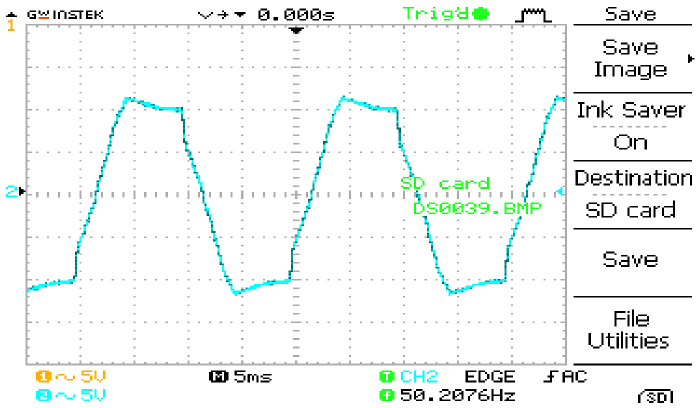

Fig 13.Voltage waveform with UPQC

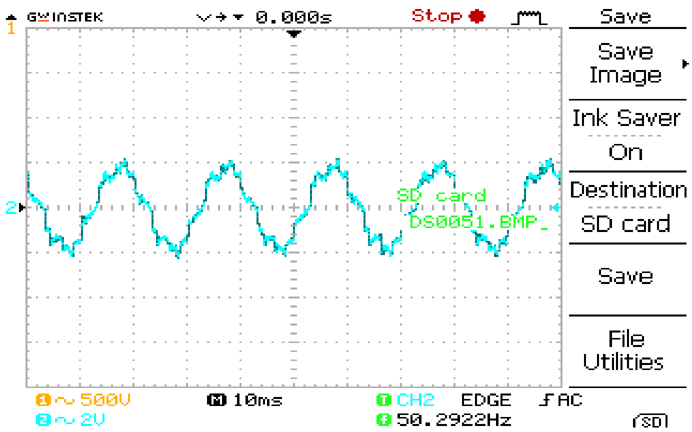

Fig14.Current waveform with UPQC

8. Conclusion

This paper presented the power quality problems like voltage sag, voltage and current harmonics and its mitigation technique using custom power based electronic device. In this paper a devices called Unified Power Quality Conditioner (UPQC) which can mitigate both the voltage sag, voltage and current harmonics is used. A simple control algorithm, Synchronous Reference Frame method has been proposed for the generation of the reference signal for both current and the voltage. The voltage sag and the THD for voltage and current have been reduced after adding the UPQC (Voltage sag to 15.66%, THD for voltage (3.61%) and for current (2.67%)). The system was simulated using MATLAB (Simulink) Version 7.8.0 (R2009a). From the simulation study it has been found that the UPQC system is an ideal candidate for compensating the sag and eliminating all harmonics in the supply side and providing a sinusoidal shape to the three-phase supply current in phase with the supply voltage. The above results were verified with an eexperimental and it was carried out on a reduced-scale prototype of UPQC based on microcontroller (PIC18F877). From the results, it is clear that the SRF control algorithm renders the best possible compromise between the voltage sag and the harmonic distortion.

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