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# Performance Analysis of Solar PV Integrated UPQC with Multiple Feeders for Power Quality Enhancement

Vikash Tiwari<sup>1</sup>, Sandeep Kumar<sup>2</sup>

Research Scholar, Department of Electrical and Electronics Engineering LNCT Bhopal, India

Professor, Department of Electrical and Electronics Engineering LNCT Bhopal, India

**ABSTRACT:** Most of the power quality issues created in power systems especially in the power distribution systems are due to the non-linear characteristics and fast switching of power electronic equipment. Power quality issues are becoming stronger due to wide usage of sensitive equipment which will continuously polluting. Out of many power quality issues, harmonics, voltage sag, swell and unbalance are considered. In order to avoid these issues, a research work has been carried out to model Active Power Filters (APF) so as to suppress harmonics and PV (Photo Voltaic) based UPQC to mitigate power quality issues such as harmonics, voltage sag, swell and unbalance. The proposed research work aims at enhancing the use of PV based UPQC in the distribution system, having multiple feeders so as to mitigate power quality issues and also to eliminate the need for additional regulating device to maintain load voltage constant. The effectiveness of the PV based UPQC are verified by performing harmonic suppression, voltage sag, swell and unbalance mitigation. PV based UPQC have been used to reduce the harmonics injected by nonlinear loads such that sensitive load in a particular feeder is protected from harmonic distortion. Voltage sag, swell and unbalance mitigation have been performed by individually connecting PV based UPQC in such a way that the sensitive load is relieved from voltage sag, swell and unbalance and the load voltage is maintained constant. The steady state and dynamic performance of the system are evaluated by simulating in Matlab-Simulink under a different load.

**KEY WORDS:** shunt compensator, Power quality, PV module interconnection, Unified power quality controller, Harmonics, Switching Control.

## I. INTRODUCTION

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage. However in practice, power systems, especially the distribution systems, have numerous nonlinear loads which significantly affect the quality of power supplies. As a result of the nonlinear loads, the purity of the waveform of supply is lost. This ends up producing many power quality problems. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality problems. Power quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform [1]. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also under heavy load conditions, a significant voltage drop may occur in the system. Voltage sag, unbalance and voltage swell can cause sensitive equipment to fail, shutdown and create a large current unbalance [2]. Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. The growing concern regarding global heating and climate change has stimulated the development of environment friendly energy generation technologies [4]. In the near future, the electrical grid will include a very large number of small producers that use Renewable Energy Source (RES) like solar panels or wind generators, among other technologies. Hence it is necessary to utilize the renewable energy resources like solar, wind, biomass, hydro, co-generation, etc. so as to meet out tremendous energy demand. Out of this, a renewable energy resource like solar energy is mainly integrated into power system since it minimizes the environmental collisions like conventional plant. PV is budding as an important distributed resource and presents several benefits for use as a distributed energy resource. PV gives both the benefits of a distributed resource and a clean power source [3]. Power quality in electric networks is one of today's most distress areas of electric power system. The power quality has serious economic allegations for consumers, utilities, sensitive electrical equipment, and manufacturers. Modernization and automation of industrial application involves increased use of microprocessors, computers and power electronic system and also integration of renewable energy resources with utility grids often

requires power electronic interfaces. These power electronic systems in turn produce power quality problems such as generating harmonics in to source side and load side. Under the deregulated atmosphere in which electric utilities are looking forward to compete with each other, it is essential that the customer satisfaction becomes very important [1]. The impact of power quality problems are severely felt by customers, industrial, commercial and even residential. There are various techniques to mitigate harmonics, voltage sags, swells and unbalance in the power distribution systems. However, there are many methods to reduce the effect of harmonics alone in the system. One of those methods is to use active power filter which produces harmonic current of equal magnitude and opposite polarity to that of the harmonic current produced in the system such that it cancels the harmonic current in the system [3]-[8]. APF is used considering its advantages of high speed response and flexibility in operation as it contains the power electronic devices. Also the same device is used to integrate the power from the RES to the distribution system. So the need of additional equipment is avoided [20]. Thus the APF acts as the grid interfacing inverter for interfacing RES to the electrical grid without additional power conditioning equipment. These active power filters are mainly used to reduce only the THD in load side and source side of any system but not capable of mitigating major power quality issues such as voltage sag, voltage swell, unbalance etc. and the use of a custom power device is considered to be the most efficient method. At first for the improvement of power quality or reliability of the power system, FACTS (Flexible AC Transmission Systems) devices like Static VAR Compensator (SVC) Static Synchronous Compensator (STATCOM), Static Synchronous Series Compensator (SSSC), Interline Power Flow Controller (IPFC), Unified Power Flow Controller (UPFC) and Unified Power quality conditioner (UPQC) etc. were introduced. UPQC is a combination of series compensation and shunt compensation which provide solutions for both voltage quality as well as current quality issues [7]. Among different new technical options available to improve power quality, UPQC has found to be more promising for compensation of current as well as voltage harmonics simultaneously. It is a versatile device that can compensate almost all power quality problems such as harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, current unbalance, reactive current, etc. The UPQC is a combination of series active filter and shunt active filter linked through a common dc link capacitor. Recently more attention is being paid on mitigation of voltage sags and swells using UPQC. In other words, the UPQC has the ability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore one of the most powerful solutions to large capacity loads sensitive to voltage flicker/imbalance. A novel research is presented here on PV based UPQC with multiple feeders where all the custom power devices have been used individually to protect the sensitive load against various power quality issues such as voltage sag, swell, unbalance and harmonics such that the load voltage is maintained constant. It is known that the main power quality issues such as voltage sag, swell and unbalance in the power distribution systems may occur due to faults which in turn affect the PCC (Point of Common Coupling) point if a single source is used to supply number of loads through distribution feeders. Hence power quality disturbances at any feeder in which sensitive load to be connected can be mitigated by implementing UPQC.

## II. PROPOSED PV BASED UPQC SYSTEM CONFIGURATION AND DESIGN

A distribution system with multiple feeders is proposed in which PV based UPQC is connected individually for the purpose of protecting sensitive loads against power quality issues such as voltage sag, swell, unbalance and harmonics. The proposed system for UPQC is shown in the Figure 1.

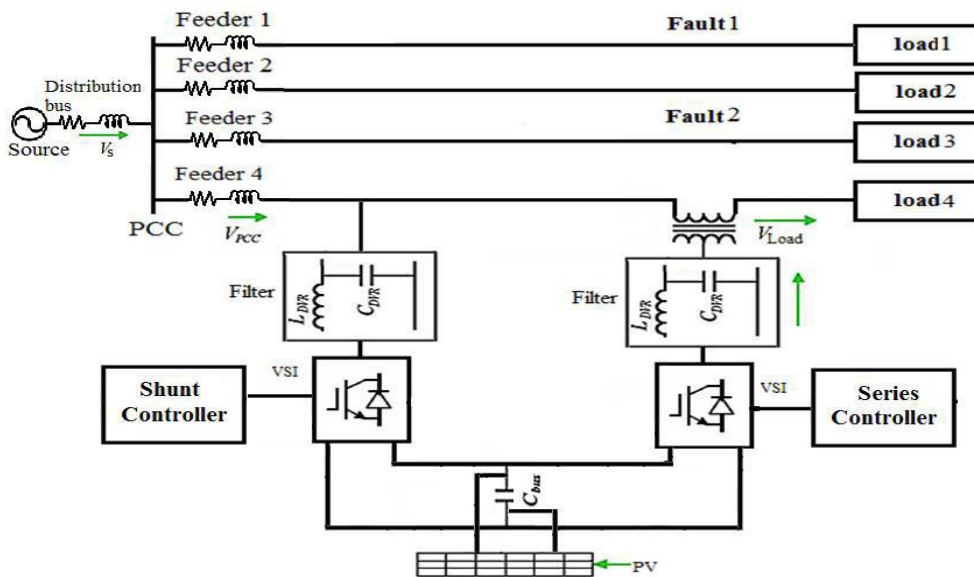


Figure1 Proposed System for PV based UPQC system

As seen from the Figure 4.9, the UPQC (composed of transformers, filters, inverters and DC source) power circuit is connected between PCC and load 4 in distribution feeder 4. Here load 4 is considered as sensitive load and is protected against power quality problems such as voltage sag, swell unbalance and harmonics.

### III. UNIFIED POWER QUALITY CONDITIONER (UPQC)

Unified Power Quality Conditioner is a multifunctional power conditioner used to compensate various voltage disturbance of the power supply, and also to prevent harmonic load current from entering the power system. The main purpose of a UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current and harmonics [94]. It is actually a custom power device basically designed to mitigate the disturbances that affect the performance of sensitive and/or critical loads. The best protection of sensitive loads from sources with poor power quality is to install shunt-series connection of custom power device called UPQC. Recent researches made unified power quality conditioner for solving most of the power quality problems such as voltage sag, swell, voltage outage and power factor correction and mitigating harmonics in the current and voltage. The basic configuration of UPQC is shown in Figure 2.

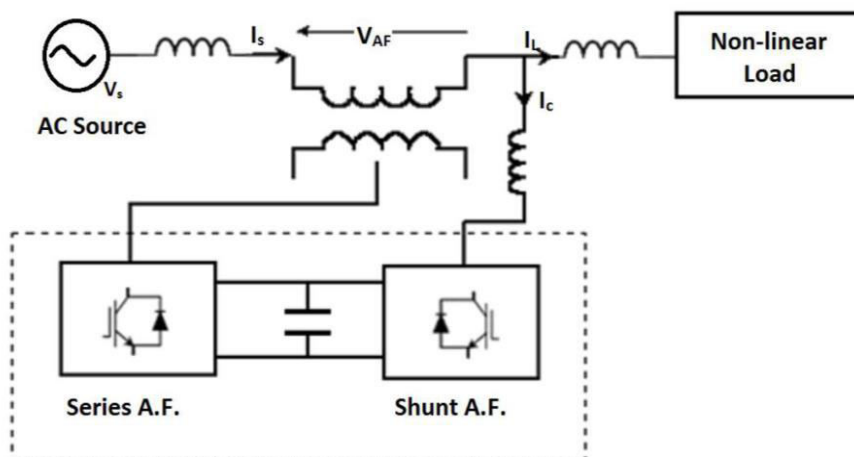


Figure 2. Basic Configuration of UPQC



The UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC is expected to be the most powerful solutions for protecting large capacity sensitive loads against power quality issues. Advantages of operating Unified Power Quality Conditioner for nonlinear and a sensitive load are as follows [111]

- It eliminates the harmonics in the supply current and voltage, thus improves utility current and voltage quality for nonlinear loads.
- UPQC provides the VAR requirement of the load in such a way that the supply voltage and current are always in phase with each other and therefore, no additional power factor correction equipment is required.
- UPQC maintains load end voltage at the rated value.
- The voltage injected by UPQC to maintain the load end voltage at the rated value is taken from the same dc link itself, thus no additional dc link voltage support is required for the series compensator.

#### IV. BASIC ARRANGEMENTS OF UPQC

The main components of a UPQC are series and shunt power converters, DC capacitors, low-pass and high-pass passive filters, and series and shunt transformers.

##### a) Series converter

It is a voltage-source converter connected in series with the ac line which acts as a controlled voltage source to mitigate voltage distortions such as eliminating supply voltage flickers or imbalance in the load terminal voltage and forces the shunt branch to absorb current harmonics generated by the nonlinear load. Control of the series converter output voltage is usually performed using sinusoidal pulsewidth modulation (SPWM). The gate pulses required for operating the voltage source converter are generated by the comparing fundamental voltage reference signal with a high-frequency triangular waveform.

##### b) Shunt converter

It is also a voltage-source converter connected in shunt with the same ac line and acts as a controlled current source to mitigate current distortions such as compensating reactive current of the load and to improve the power factor. It also regulates dc link voltage there by resulting in a significant reduction of the dc capacitor rating. The output current of the shunt converter is adjusted using a dynamic hysteresis band by controlling the switching status of the semiconductor switches such that output current follows the reference signal and remains in a predetermined hysteresis band.

##### c) DC link capacitor

The two VSIs are connected back to back with each other through this dc link capacitor. The voltage across this capacitor provides the self-supporting dc voltage for proper operation of both shunt and series inverters. With proper control, the dc link voltage acts as a source of active and reactive power and thus eliminates the need of external dc source like battery.

##### d) Low-pass filter

It is used to attenuate high frequency components at the output of the series converter that are generated by high-frequency switching.

##### e) High-pass filter

It is installed at the output of shunt converter to absorb current switching ripples.

##### f) Series and shunt transformers

These are implemented to inject the compensation voltages and currents, and also serve the purpose of providing electrical isolation of UPQC converters. The necessary voltage generated by the series inverter to maintain a pure sinusoidal load voltage at the desired value is injected in to the line through these series transformers. A suitable turns ratio should be considered to reduce the current flowing through the series inverter. Similarly shunt transformers inject compensation currents in to the line to mitigate current harmonics.

V. OPERATION OF UPQC

The UPQC consists of two three phase inverters connected in cascade in such a manner that Inverter I is connected in series with the supply voltage through series transformer and inverter II is connected in parallel with the load through shunt transformer. The main task of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the current and voltage harmonics and also to regulate the common dc link voltage. The series compensator injects voltage in quadrature advance to the supply voltage (current) such that the load voltage is always maintained at the rated value. The two inverters operate in a controlled and coordinated manner. The detailed configuration of UPQC in a distribution system is shown in Figure 3.

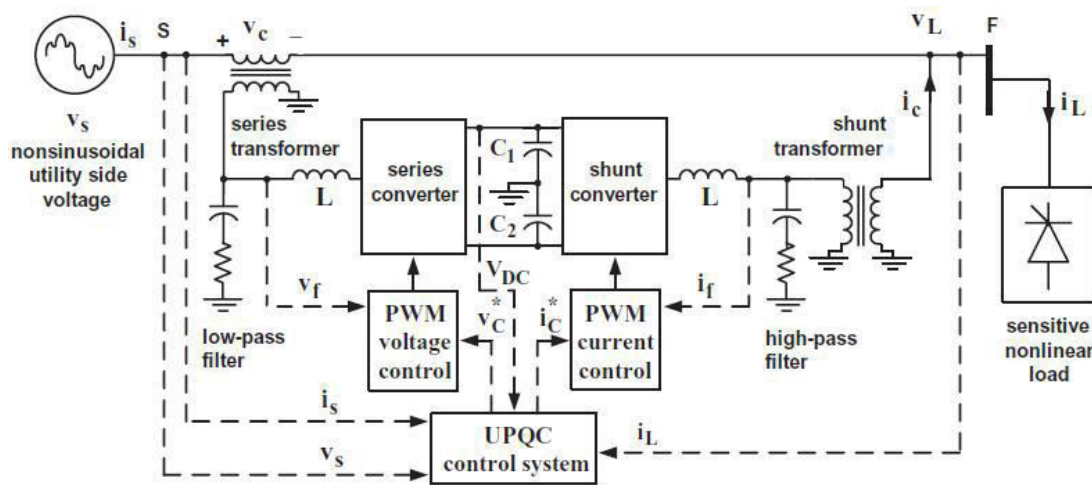


Figure 3. Detailed Configuration of UPQC in a Distribution System

$V_s, V_c, i_c, V_L$  are the supply voltage, series compensation voltage, shunt compensation current and load voltage respectively. The source voltage may contain harmonics. The system voltage at point S can be expressed as:

$$V_s = V_{1p}(t) + V_{1n}(t) + \sum_{k=2}^{\infty} V_k(t)$$

Equation (4.1) can also be written as:

$$V_s = V_{1p} \sin(\omega t + \theta_{1p}) + V_{1n} \sin(\omega t + \theta_{1n}) + \sum_{k=2}^{\infty} V_k(k\omega t) + \theta_k$$

Where

$V_{1p}$  is the fundamental frequency positive sequence components

$V_{1n}$  is the fundamental frequency negative sequence components respectively

$\theta_{1p}, \theta_{1n}, \theta_k$  are the corresponding voltage phase angles.

Usually, the load voltage at point of common coupling is expected to be sinusoidal with fixed amplitude

$$V_L = V_L \sin(\omega t + \theta_{1p})$$

The series inverter needs to compensate for the following components of voltage

$$V_c = (V_L - V_{1p}) \sin(\omega t + \theta_{1p}) - V_{1n}(t) - \sum_{k=2}^{\infty} V_k(t)$$



To provide load reactive power demand and for compensation of load harmonic and negative sequence currents, the SAPF acts as a controlled current source and its output component should include harmonic and negative sequence components in order to compensate these quantities in the load current [2,18]. The distorted non-linear load current can be expressed as:

$$i_l = I_{1p} \sin(\omega t + \delta_{1p}) \cos \phi_L + i_{1n}(t) + \sum_{k=2}^{\infty} i_k$$

It is usually desired to have a certain phase angle (Displacement power factor angle) between the positive sequence voltage and current at the load terminal [98].

$$\phi_L = \delta_{1p} - \theta_{1p} \text{ or } \delta_{1p} = \theta_{1p} + \phi_L$$

Substituting Equation (4.6) into Equation (4.5) and simplification yields

$$i_l = I_{1p} \sin(\omega t + \theta_{1p}) \cos \phi_L + I_{1p} \cos(\omega t + \theta_{1p}) \sin \phi_L + i_{1n}(t) + \sum_{k=2}^{\infty} i_k$$

In order to compensate harmonic current and reactive power demand, the shunt active filter should produce the following current:

$$i_c = I_{1p} \cos(\omega t + \theta_{1p}) \sin \phi_L + i_{1n}(t) + \sum_{k=2}^{\infty} i_k$$

Then the harmonic, reactive and negative sequence current will not flow into power source. Hence, the current from the source terminal will be:

$$i_s = i_l + i_c = I_{1p} \sin(\omega t + \theta_{1p}) \cos \phi_L$$

There are also some switching losses in the converter, and hence the utility must supply a small overhead for the capacitor leakage and converter switching losses in addition to the real power of the load. The total current supplied by the source is therefore

$$i_s = i_s + i_{sl}$$

where

$i_{sl}$  is the current drawn due to switching loss.

Hence, for accurate and instantaneous compensation of reactive and harmonic power it is essential to estimate the harmonic component of the load current as the reference current of shunt APF.

## VI. SIMULATION RESULTS AND DISCUSSIONS

The proposed system has been analyzed under various situations such as voltage sag and unbalance. Series RL load in feeder 3 is connected in such a way that it leads to unbalance in all adjacent feeders. Load in feeder 4 is a rectifier fed RL load which is to be considered as sensitive load so that the load in feeder 4 is protected from sag, unbalance and harmonics by connecting UPQC between PCC and load. Here source current is protected from harmonics due to nonlinear load in feeder 4 by injecting equal and opposite harmonics to make PCC current almost sinusoidal.

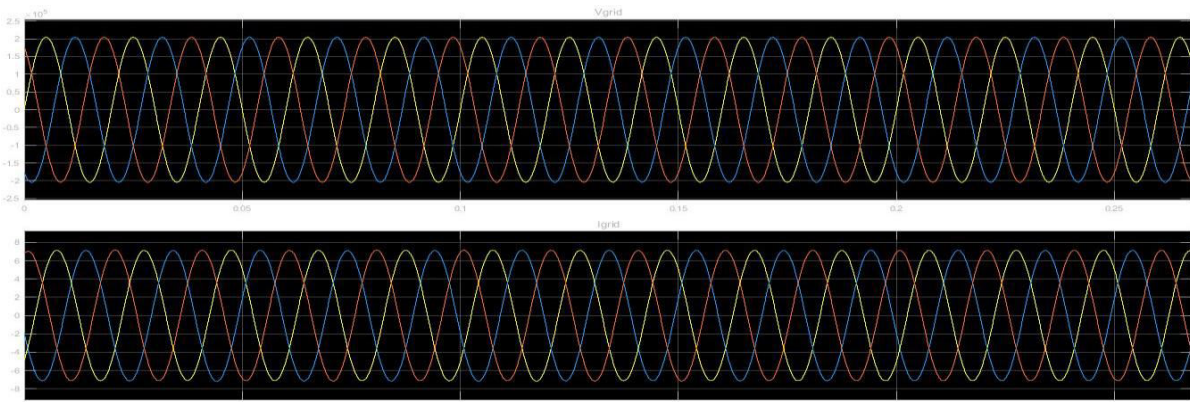


Figure 4. Voltage and current at grid point source side

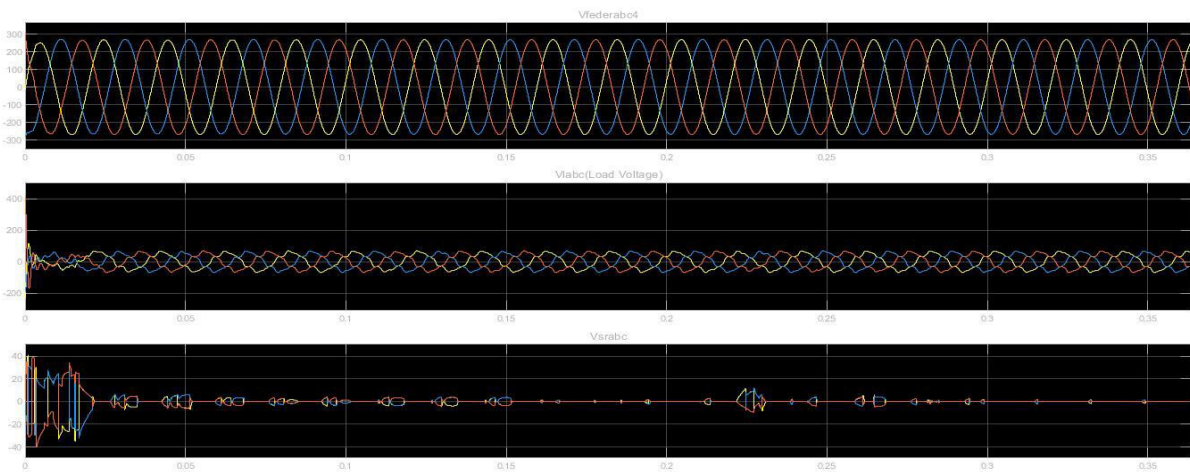


Figure 5. Injected Voltage and Injected Current of Series Controller

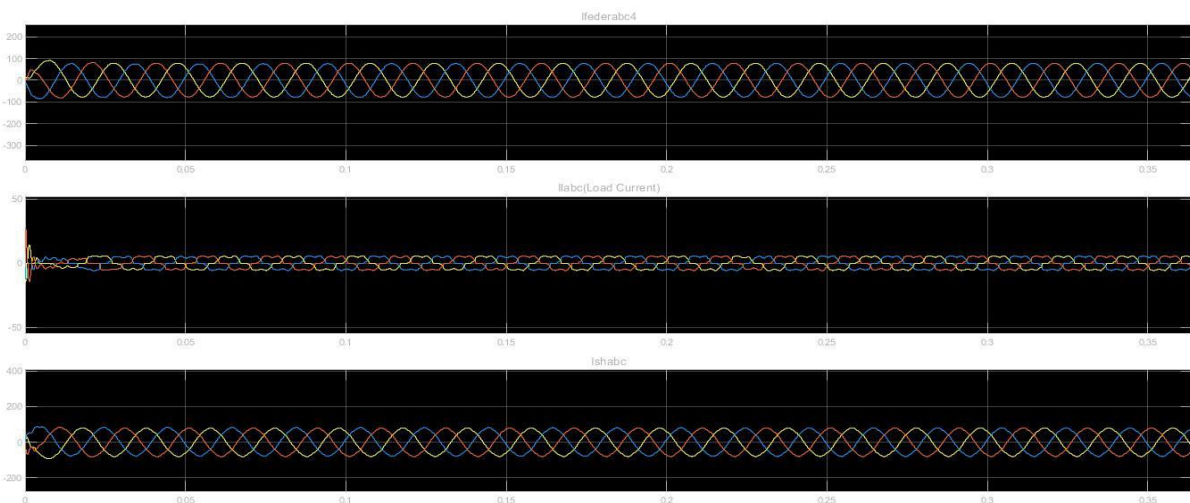


Figure 6. Injected Voltage and Injected Current of Shunt Controller





## VI. CONCLUSION

Most of the proposed or practiced control strategies for power quality conditioners have been reviewed with regard to performance and implementation. This work reveals that there has been a significant increase in interest of UPQC and associated control methods. This could be attributed to the availability of suitable power - switching devices at affordable price as well as generation of fast computing devices (microcontroller and DSP) at low cost. Each technique has its advantages and disadvantages.

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