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

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ABSTRACT: Most of the power quality problems created in power systems especially in power distribution systems are due to the nonlinear characteristics and rapid switching of power electronic equipment. Power quality problems are becoming stronger due to the widespread use of sensitive equipment that will constantly pollute. Among the many power quality issues, harmonics, voltage slack, bulge, and imbalance are considered. To avoid these issues, research work has been conducted to model Active Power Filters (APF) to suppress harmonics and PV (Photo Voltaic) based UPQC to mitigate power quality issues such as harmonics, voltage drops, swelling and imbalance. The proposed research work aims to enhance the use of PV approved UPQC in the distribution system, with multiple feeders to mitigate power quality issues and also to eliminate the need for an additional regulator to keep the load voltage constant.The effectiveness of PV based on UPQC is verified by implementing harmonic damping, voltage slack, and mitigation of swelling and imbalance. PV based on UPQC was used to reduce harmonics injected by nonlinear loads so that the sensitive load in a given feeder is protected from harmonic distortion. Relief of voltage sag, swelling and imbalance was performed by single conduction PV on the basis of UPQC so that the sensitive load is eliminated from voltage sag, swelling and unbalance and the load voltage is kept constant. The steady-state and dynamic performance of the system are evaluated by simulation in Matlab-Simulink under different loads.

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

I. INTRODUCTION

Ideally, power distribution systems should provide their customers with an uninterrupted flow of power with smooth sinusoidal voltages. However, in practice, power systems, especially distribution systems, have many nonlinear loads that greatly affect the quality of the power supply. As a result of nonlinear loads, the purity of the display waveform is lost. This ends up producing many power quality problems. Aside from non-linear loads, some system events, both usual (such as capacitor switching, motor starting) and unusual (such as malfunctions) may also cause power quality problems. The phenomenon of power quality or energy quality disturbance can be defined as the deviation of voltage and current from an ideal waveform [1].Malfunctions at the transmission or distribution level may cause voltage drop or amplification for the entire system or a significant portion of it. Also under heavy load conditions, a large voltage drop may occur in the system. Voltage sag, unbalance, and voltage swelling can cause sensitive equipment to malfunction and close and create significant current imbalance [2]. Electric utilities and end users of electrical energy are becoming increasingly concerned about meeting the growing energy demand. Growing concern about global warming and climate change has spurred the development of environmentally friendly power generation technologies [4].In the near future, the electric grid will involve a very large number of small-scale producers using renewable

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energy sources (RES) such as solar panels or wind generators, among other technologies. Hence it is necessary to utilize renewable energy resources like solar energy, wind energy, biomass, hydro power, cogeneration etc. to meet the huge energy demand. To get out of this, a renewable energy resource like solar energy is mainly integrated into the power system as it reduces environmental collisions like the conventional plant. PV is in its infancy as a significant distributor resource and offers many benefits for using it as a distributed energy resource. PV gives both the advantages of a distributed resource and a clean energy source [3]. Energy quality in electrical grids is one of the most distressing areas of today's electric power system. Energy quality has serious economic claims to consumers, utilities, sensitive electrical equipment, and manufacturers. The modernization and automation of industrial applications includes the increased use of microprocessors, computers, and the electronic energy system and also the integration of renewable energy resources with utility networks often requires electronic energy interfaces. These electronic power systems in turn produce energy quality problems such as generation harmonics on the source side . In an unorganized environment in which electrical utilities are looking to compete with each other, it is imperative that customer satisfaction becomes very important [1]. Whether industrial, commercial, or even residential, energy quality issues are deeply affected by customers. There are various techniques for mitigating harmonics, voltage drops, amplification and imbalance in power distribution systems. However, there are many ways to reduce the influence of harmonics alone in a system. One of these methods is to use an active power filter that produces a harmonic current of equal size and opposite polarity to the harmonic current produced in the system so that it cancels the harmonic current in the system [3] - [8].APF is used with high-speed response in mind and flexibility in operation as it houses powerful electronic devices. The same device is also used to integrate power from RES into the distribution system. Therefore, the need for additional equipment is avoided [20]. Thus APF acts as a network interface inverter to connect RES to the electrical grid without additional power conditioning equipment. These active power filters are mainly used to reduce THD only at the load side and the source side of any system but they are not able to alleviate major power quality issues such as voltage drop, voltage swell, imbalance etc., and using dedicated power the device is the most efficient method.Initially to improve power quality or power system reliability, FACTS devices (AC flexible transmission systems) like VAR static compensator (SVC), static synchronous compensator (STATCOM), static synchronous compensator (SSSC), Interline Power was introduced Flow Controller (IPFC), Unified Power Flow Controller (UPFC) and Unified Energy Quality Conditioner (UPQC) etc. UPQC is a combination of sequence compensation and shunt compensation that provides solutions to both voltage quality as well as current quality issues [7]. Among the various new technology options available to improve power quality, UPQC has found it most promising to offset current as well as voltage simultaneously.It is a versatile device that can compensate for almost all power quality problems such as harmonics, voltage imbalance, voltage flickers, voltage slack and amplification, current harmonics, current imbalance, reactive current, etc. UPQC is a set of series active filter and active switching filter linked through a common link capacitor. Recently, more attention is being given to mitigating voltage slack and amplification with UPQC. In other words, UPQC has the potential to improve power quality at the point of installation over power distribution systems or industrial power systems. Thus, UPQC is one of the most powerful solutions for large capacity loads sensitive to flash / voltage imbalance.A New research is presented here PV based on UPQC with multiple feeders where all individually dedicated power devices have been used to protect the sensitive load against various power quality issues such as voltage drop, amplification, imbalance and harmonics such that the load voltage remains constant. It is known that major power quality problems such as voltage slack, inflation and imbalance in power distribution systems may occur due to faults that in turn affect point PCC (common connection point) if one source is used to supply the number of loads through distribution feeders. Hence power quality disturbances in any feeder in which the sensitive load to be connected can be mitigated by implementing UPQC.

II. PROPOSED PV BASED UPQCSYSTEM CONFIGURATION AND DESIGN

A A distribution system with multiple feeders in which PV based on UPQC is individually connected in order to protect sensitive loads against power quality issues such as voltage drops, swelling, unbalance, and harmonics. The proposed system for UPQC is shown in Figure 1.

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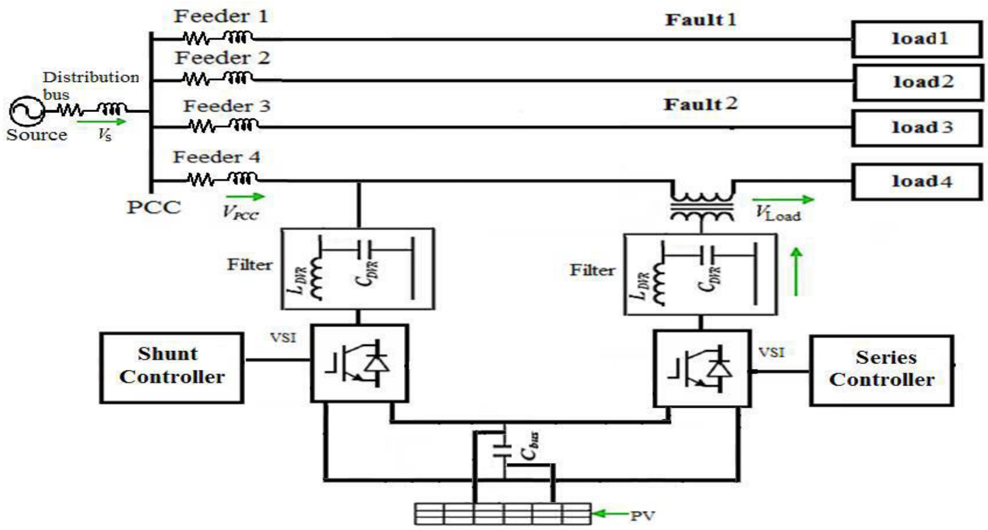

Figure1 Proposed System for PV based UPQC system

As can be seen from Figure 1, the power circuit UPQC (consisting of transformers, filters, transformers and DC sources) is connected between PCC and load 4 in the distribution feeder 4. Here the load 4 is a sensitive load and is protected against power quality problems such as Sagging voltage, imbalance and harmonics.

III.UNIFIED POWER QUALITY CONDITIONER (UPQC)

Unified Power Quality Conditioner is a multifunctional power conditioner used to compensate for various voltage disturbances of the power source, as well as to prevent harmonic load current from entering the power system. The main purpose of UPQC is to compensate for flashing / unbalance supply voltage, reactive power, negative series current and harmonics [94]. It is, in fact, a dedicated power device primarily designed to mitigate disturbances that affect the performance of sensitive and / or critical loads. The best protection for sensitive loads from sources with poor power quality is to install a switching chain connection for a dedicated power device called UPQC. Recent research has done a power quality standardized air conditioner to solve most power quality problems such as voltage sag, swelling, power outage, power factor correction, and mitigation of harmonics in current and voltage. The basic configuration of UPQC is shown in figure 2.

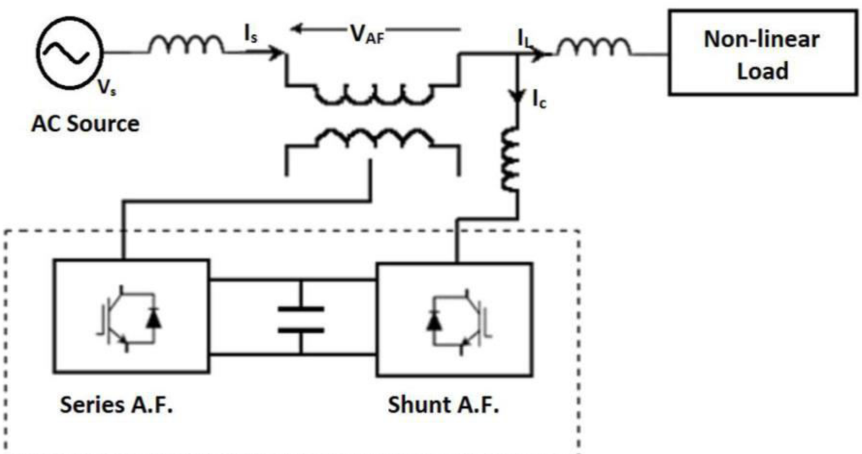

Figure 2. Basic Configuration of UPQC

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UPQC has the potential to improve power quality at the point of installation on power distribution systems or industrial power systems. UPQC is expected to be the strongest solution to protect sensitive loads with large capacity from power quality issues. The advantages of operating a uniform power quality conditioner for a nonlinear and sensitive load are as follows [111]

∟ Eliminates harmonics in supply current and voltage, thereby improving utility current and voltage quality for nonlinear loads.

∟ UPQC VAR provides the load requirement such that the supply voltage and current are always in phase with each other, thus, no additional equipment is required to correct the power factor.

∟ UPQC maintains the load end voltage at rated value.

∟ The voltage injected by UPQC to keep the load end voltage at the rated value is taken from the same DC jumper itself, and thus no additional DC junction voltage support for the series compensator is required.

IV. BASIC ARRANGEMENTS OF UPQC

The major components of UPQC are series and shunt transducers, DC capacitors, low and high passive filters, series and shunt converter.

A) series Converter

It is a voltage source converter connected in series to an alternating current line which acts as a controlled voltage source to mitigate voltage distortions such as eliminating flicker of supply voltage or imbalance in load terminal voltage and forcing the transformer branch to absorb current harmonics caused by non-linear load. The output voltage of a serial transformer is usually controlled using sine pulse width modulation (SPWM). The gate pulses required to operate the voltage source transformer are generated by comparing the base voltage reference signal with the high frequency triangular waveform.

b)Shunt converter

It is also a voltage source converter connected in shunt to the same AC line and acts as a controlled current source to mitigate current distortions such as load reactive current compensation and power factor improvement. It also regulates the DC junction voltage there by reducing the DC rating of the capacitor. The output current of the shunt transformer is adjusted using a dynamic hysteresis range by controlling the switching state of the semiconductor switches so that the output current follows the reference signal and remains in a predetermined hysteresis range.

c)DC link capacitor

The two VSIs are connected from back to back with each other through a DC junction capacitor. The voltage across this capacitor provides a self-supporting DC voltage for proper operation of both shunt and series transformers. With proper control, the DC junction voltage acts as a source of active and reactive power thus eliminating the need for an external DC source such as a battery.

d)Low-pass filter

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

e)High-pass filter

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

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f)Series and shunt transformers

It is implemented to inject compensating voltages and currents, and also serves the purpose of providing electrical insulation for UPQC transformers. The necessary voltage generated by the serial inverter to maintain a pure sinusoidal load voltage at the desired value is injected into the line through these series transformers. A An appropriate winding ratio must be considered to reduce the current flowing through the chain inverter. Shunt transformers likewise inject compensating currents into the line to attenuate current harmonics.

V. OPERATION OF UPQC

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

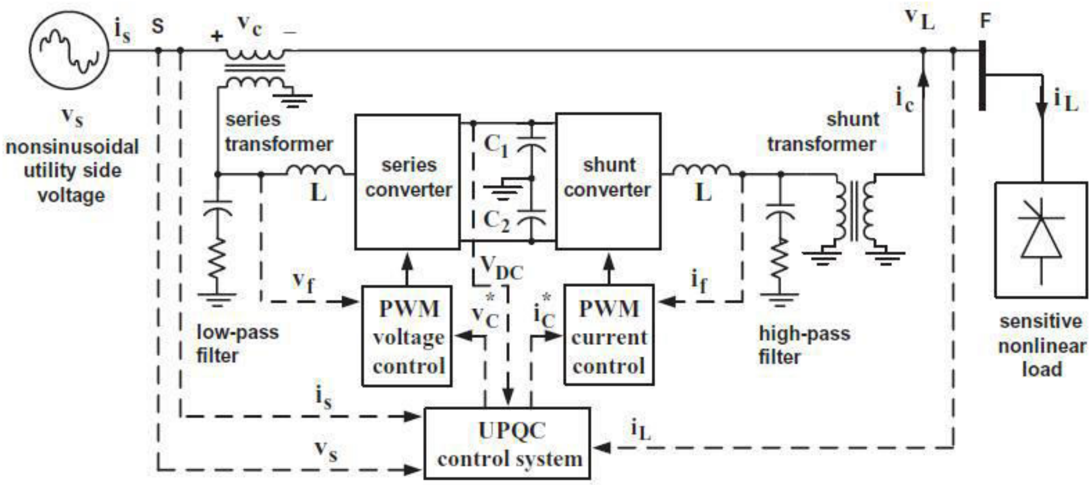

Figure 3. Detailed Configuration of UPQC in a Distribution System

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:

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

Equation (4.1) can also be written as:

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

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Where

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

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

θ_{1p} , θ_{1n}, $\theta_k$are the correspondingvoltage phase angles.

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

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

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

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

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

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

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

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

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

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

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

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

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

$$i_s = i_l + i_c = I_{1p}\sin(wt + \theta_{1p})cos\emptyset_L$$

There are also some switching losses in the converter, and hence theutility must supply a small overhead for the capacitor leakage and converterswitching losses in addition to the real power of the load. The total current suppliedby 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 andharmonic power it is essential to estimate the harmonic component of the loadcurrent as the reference current of shunt APF.

V. SIMULATION RESULTS AND DISCUSSIONS

The proposed system was analyzed under various conditions such as voltage slack and imbalance. The chain load RL in feeder 3 is connected in such a way as to cause unbalance in all adjacent feeders. The load in feeder 4 is a rectifier load RL fed which is a sensitive load so that the load in feeder 4 is protected from sagging, imbalance and harmonics through the UPQC connection between PCC and the load. Here the source current is protected from harmonics due to nonlinear load in feeder 4 by injecting equal and reverse harmonics to make PCC current quasi-sinusoidal.

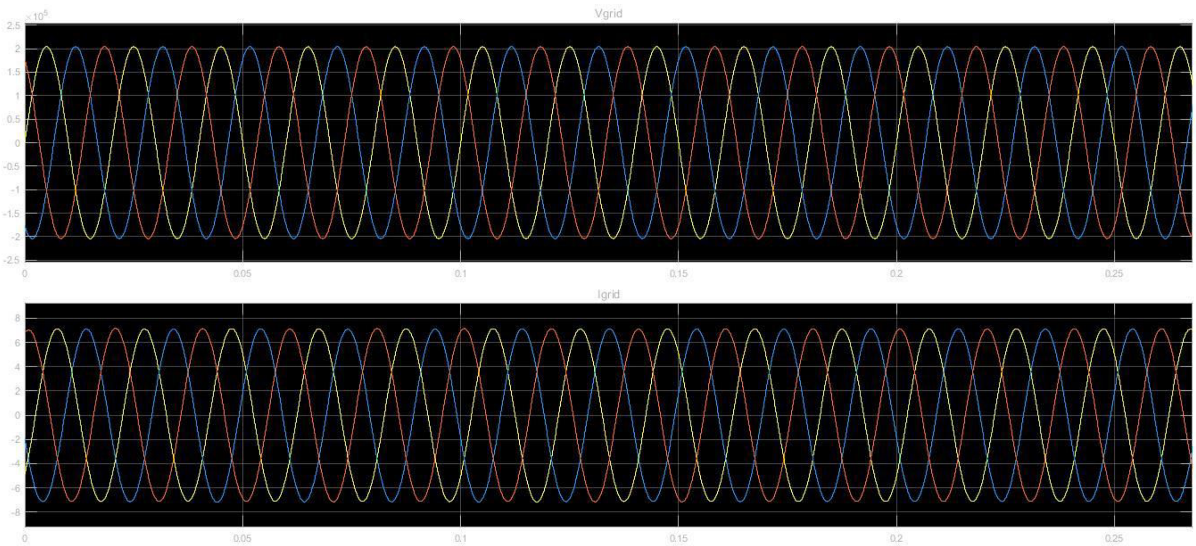

Figure 4. Voltage and current at grid point source side

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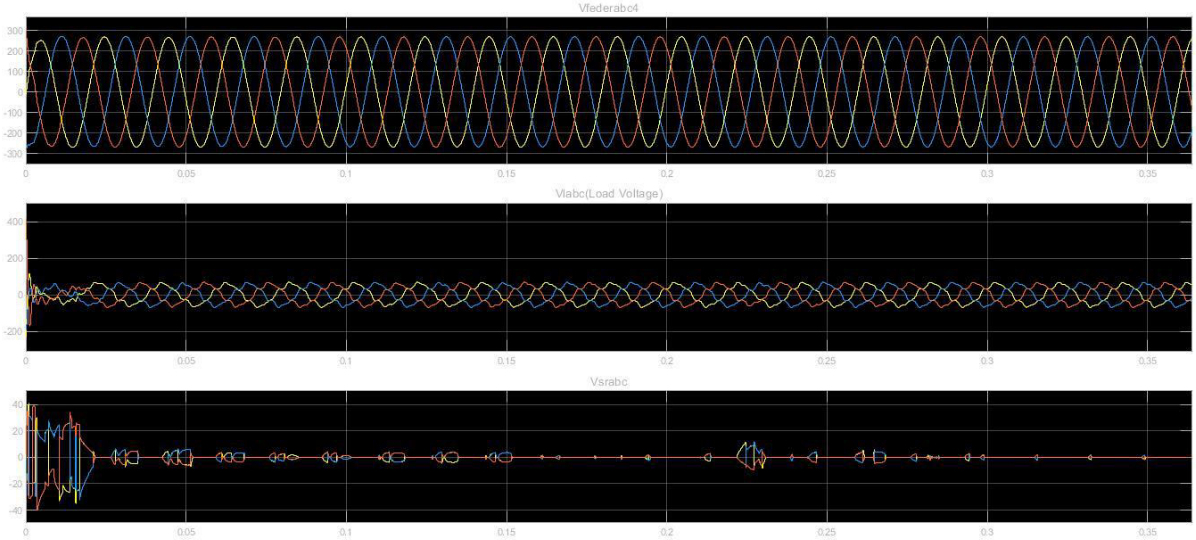

Figure 5. Injected Voltage and Injected Current of Series Controller

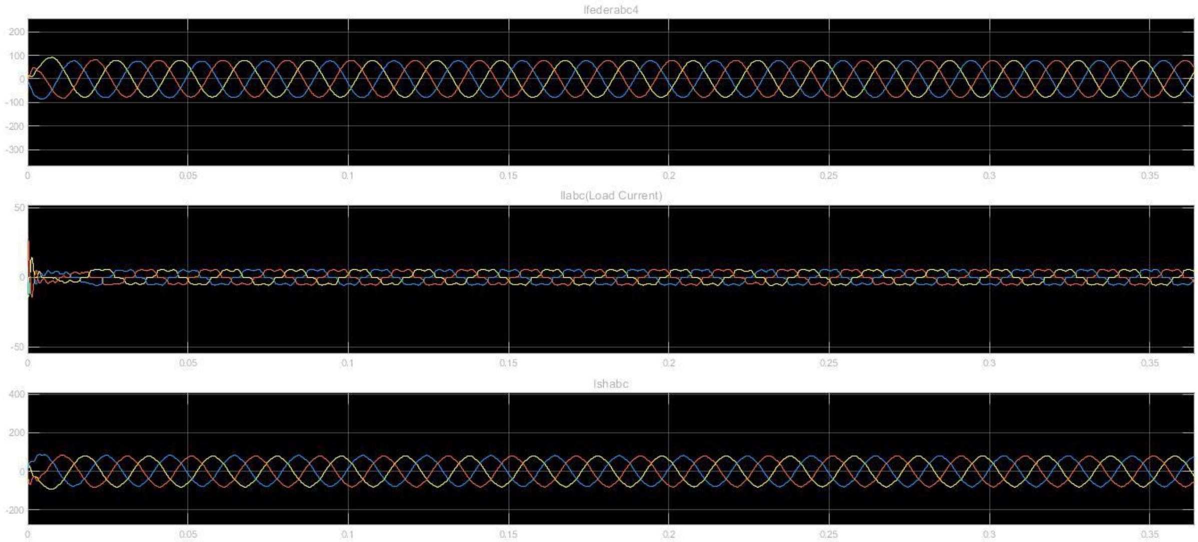

Figure6. Injected Voltage and Injected Current of Shunt Controller

VI. CONCLUSION

Most of the control strategies proposed or practiced for energy quality conditioners have been revised with respect to performance and implementation. This work reveals a marked increase in interest in UPQC and the associated control methods. This can be attributed to the availability of suitable power switching devices at an affordable price, as well as the low cost generation of fast computing devices (microcontroller and DSP). Each technique has its own advantages and disadvantages.

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