Power Quality Improvement using PV Integrated UPQC

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Abstract

There is an increasing demand of non-conventional energy systems with supplementary features predominantly in LV distribution systems. This is due to prenominal increase of power electronics based loads and non-conventional energy systems. These loads inject harmonic currents into the grid. Due to this, distortion takes place in weak grid system at Point of Common Coupling (PCC). Due to the usage of Non-Conventional energy sources like solar, wind etc., voltage fluctuations takes place at PCC. These voltage fluctuations lead to growing the maintenance cost. Hence Non-Conventional energy systems with PQ improvement systems such as DSTATCOM ,DVR, UPQC etc., affords an ultimate solution for clean energy with power quality enhancement. This paper proposes power quality (PQ) theory based control of a solar PV array integrated Unified Power Quality Conditioner (UPQC). This paper also proposes Synchronous Reference Frame (SRF) based controllers for compensation of harmonic voltages by series active filters. With the usage of SRF based UPQC control percentage of Total Harmonic Distortion (THD) is reduced and power factor of the system is improved.

Keywords: Power Quality, Solar PV, UPQC, Total Harmonic Distortion (THD), Synchronous Reference Frame (SRF)

1. Introduction

Some of the research scholars have done on power quality improvement in case of shunt VSC based system. Most of the researchers have proposed power improvement methods with the usage of FACTS devices. Power quality improvement was proposed for PV integrated shunt VSC with DSTATCOM functionalities (L. F. de Oliveira Costa 2016). Some has been proposed PV and DVR systems with a reduced number of switches (R. K. Agarwal 2017). Many researches have been done with the usage of DSTATCOM. But it has some drawbacks. Mainly it cannot protect load from harmonics in PCC voltage. So usage of UPQC is the better solution for justifying both the load-side and PCC-side power quality issues A single phase solar PV inverter along with active power filtering capability has been proposed in (A. Javadi 2016).

Some researchers proposed solar photovoltaic system integrated along with DSTATCOM and dynamic voltage restorer, SRF theory (B. Singh 2009). Some of the works has been done using time domain techniques. These are commonly used because of lower computational requirements in real-time implementation. The commonly used techniques include instantaneous reactive power theory (p-q theory), synchronous reference frame theory (d-q theory) and instantaneous symmetrical component theory (Sudeer Vinnakoti 2009). Some of the researchers proposed usage of moving average filter (MAF) to filter the d-axis current to obtain fundamental load active current. This gives optimal attenuation and without reducing the bandwidth of the controller. Recently, MAF has been applied in improving performance of DC-link controllers as well as for grid synchronization using phase locked loop (PLL) (M.Suneetha 2013).

This paper proposes power quality (PQ) theory based control of a solar PV array integrated Unified Power Quality Conditioner (UPQC). This paper also proposes Synchronous Reference Frame (SRF) based controllers for compensation of harmonic voltages by series active filters.

2. Proposed System Configuration

The proposed topology consists of a series and shunt active power filter. The active filter connected in series to a source acts as a voltage harmonic mitigation between the sources and loads whereas the shunt active filter is connected in parallel with a load and suppresses the harmonic current produced by the load as shown in Fig.1. The series active filter compensates the harmonic voltage by synchronous reference frame (SRF)-based controllers. The shunt active filter compensates the harmonic current by using synchronous reference frame (SRF) -based controllers.

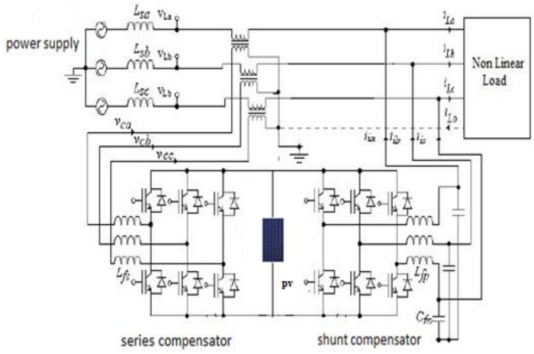

Fig .1 Series and Shunt compensators (UPQC)

The performance of an active power filter depends mainly on the technique selected to generate reference compensating current and voltage. The template to generate the reference current/voltage must include amplitude and phase information to produce the desired compensating current/voltage while keeping the voltage across the solar pv constant. The chosen technique must operate satisfactorily under both steady state and transient conditions. In the proposed model, the technique chosen for extracting reference currents/voltages with the synchronous reference frame (SRF) method.

3. Moving Average

As the name implies, the moving average filter operates by averaging a number of points from the input signal to produce each point in the output signal (Pengfei Luo 2012).
In equation form, this is written

$$y[i] = \frac{1}{M}\sum_{j=0}^{M-1} x[i+j] \quad (1)$$

Where *x* [ ] is the input signal, *y* [ ] is the output signal, and *M* is the number of points in the average. For example, in a 5 point moving average filter, point 80 in the output signal is given by:

$$y[80] = \frac{x[80]+x[81]+x[82]+x[83]+x[84]}{5} \quad (2)$$

As an alternative, the group of points from the input signal can be chosen symmetrically around the output point: Symmetrical averaging requires that M be an odd number. Programming is slightly easier with the points on only one side; however, this produces a relative shift between the input and output signals. You should recognize that the moving average filter is a convolution using a very simple filter kernel. That is, the moving average filter is a convolution of the input signal with a rectangular pulse having an area of one.

4. Synchronous Reference Frame (SRF)

SRF-based controller was employed in a hybrid APF solution for improving passive filter performance in high power applications, whereas in the SRF-based controller was used to generate the sinusoidal compensating current references applied to a three-phase line-interactive UPS system. In this work, for this purpose, an algorithm based on SRF is also used. In the SRF-based algorithm the fundamental terms of voltage and/or current of the abc-phase stationary reference frame are transformed into continuous quantities into the dq synchronous axes, in which they rotate at a synchronous speed in relation to the spatial vectors of voltage and/or current. In the dq-axes, the harmonic contents of voltage and/or current can be represented by alternate quantities, which are superposed on the continuous components. Therefore the fundamental component can be easily obtained by means of MAFs. The estimation of the utility grid phase-angle (θ) can be performed by using PLL algorithms, allowing the generation of the unit vector coordinates (sin θ and cos θ) used in the SRF-based algorithm.

5. Proposed Method

In SRF theory the distorted three phase harmonic load current (I_{La}, I_{lb}, I_{lc})are achieved in a-b-c coordinates by the three phase measurement block and these quantities are transformed into d-q coordinates (Rotating reference frame) by using equation (3) and cosine and sine functions from phase locked loop. The extraction of harmonic component present in the load current is done with the use of SRF theory [13].

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \quad (3)$$

After transformation on d-q axes fundamental components become D.C quantities,5^{th},7^{th} , order harmonics and so on. For the required compensation high pass filtered d-axis and q-axis component will be considered reference current. The d-component of load current represents active component of the current and q-component of load current indicates capacitive current drawn by the PF and also reactive power demand by the load. The high pass filter can be realized by a moving average filter (MAF), whose output is subtracted by original signal (Sudeer Vinnakoti 2009). .

$$\begin{bmatrix} I_{La}^* \\ I_{Lb}^* \\ I_{Lc}^* \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \sin\theta & \cos\theta \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \quad (4)$$

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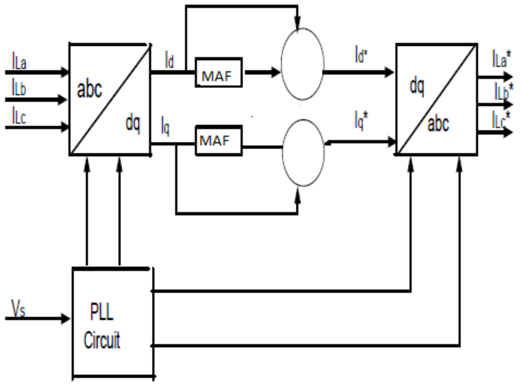

Fig.2 Block diagram of SRF current control technique with MAF

The output of MAF extract only dc quantities and attenuates the ac components corresponding to harmonic frequency. The output of MAF is Id*,Iq* is transformed into I_{CA},I_{CB} ,I_{CC} by using inverse SRF transformation and it is used as reference current of hysteresis controller.

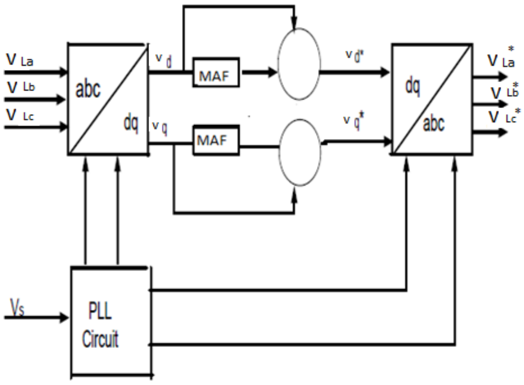

Fig.3 Block diagram of SRF voltage control technique with MAF

6. Hysteresis Current Control Method

Hysteresis current control method of generating the switching signal for the inverter switches in order to control the inverter output current. It is adopted in shunt active filter due to easy implementation and quick current controllability (M.Suneetha 2013).

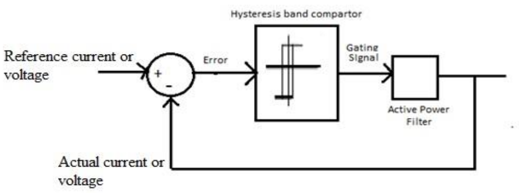

Fig 4 Block diagram of hysteresis current controller

It is a fed back current control method shown in fig 4, where the actual current continuously tracks the reference current in the hysteresis band .The reference and actual current is compared with respect to hysteresis band which decides switching pulse of voltage source inverter. As the current crosses a set hysteresis band, the upper switch in the half-bridge is turned off and the lower switch is turned on. As the current exceeds the lower band limit, the upper switch is turned on and the lower switch is turned off. The switching frequency depends on how fast the current changes from upper limit to lower limit and vice versa. This, in turn depends on voltage v_d and load inductance. When the error reaches an upper limit, the IGBT are switched to force the current down. When the error reaches a lower limit the current is forced to increase. The range of the error signal directly controls the amount of ripple in the output current from the inverter and this is called the Hysteresis Band. The Hysteresis limits relate directly to an offset from the reference signal and are referred to as the Lower Hysteresis Limit and the Upper Hysteresis Limit.

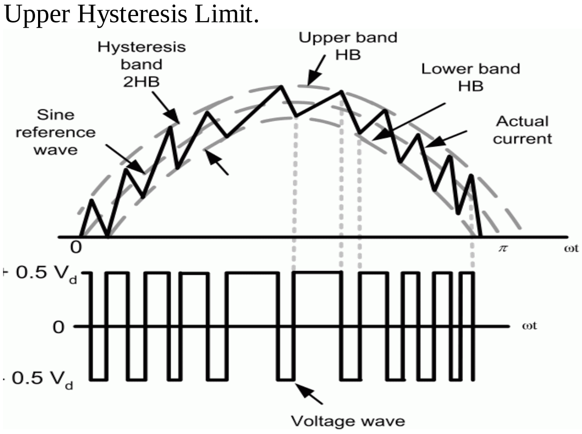

Fig 5 Hysteresis tolerance band

The current is forced to stay within these limits even while the reference current is changing.

7. Pulse Width Modulation Method

It is a technique which is used to change the output parameters by changing the width of the pulses. It is adopted in series active filter due to easy implementation.

In sinusoidal PWM technique as shown in fig 6, the sine wave is taken as reference wave and triangular is taken as carrier wave or high frequency wave. In order to generate the pulses, the sine wave magnitude is compared with the triangular wave magnitude. If the sine wave magnitude is greater than the magnitude of triangular wave, it gives one positive pulse otherwise it gives zero. By changing the magnitude of sine wave we change the width of the pulses.

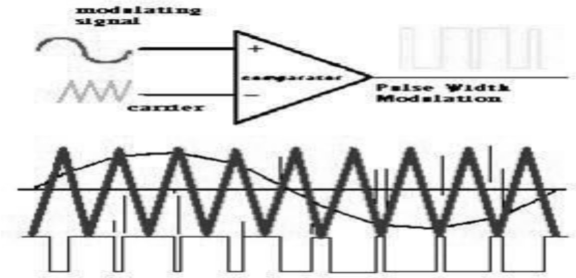

Fig 6 Pulse width Modulation

8. Simulation and Results

A. Pv Module with Boost Converter

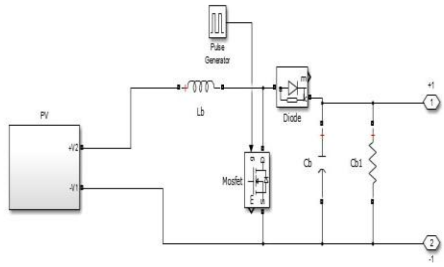

Fig 7 PV Module with Boost Converter

B. Model for Control of Harmonics

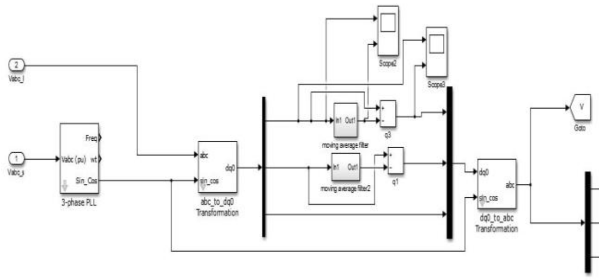

Fig 8 SRF Control for Series Converter

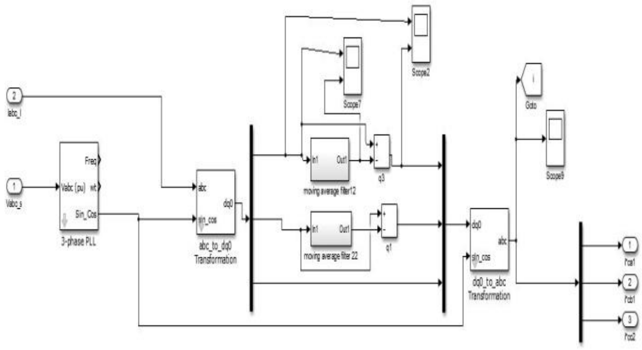

Fig 9 SRF Control for Shunt Converter

C. Shunt and Series Converters Integrated with Pv

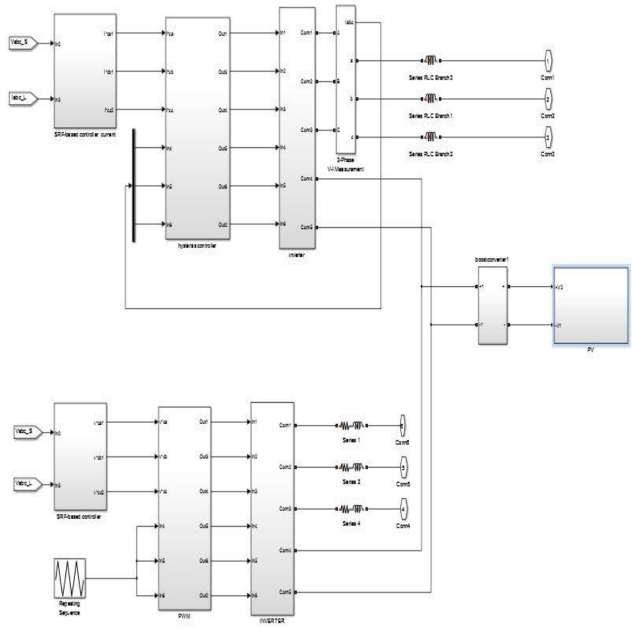

Fig 10 Unified Power Quality Condition

D. Model for PV-UPQC

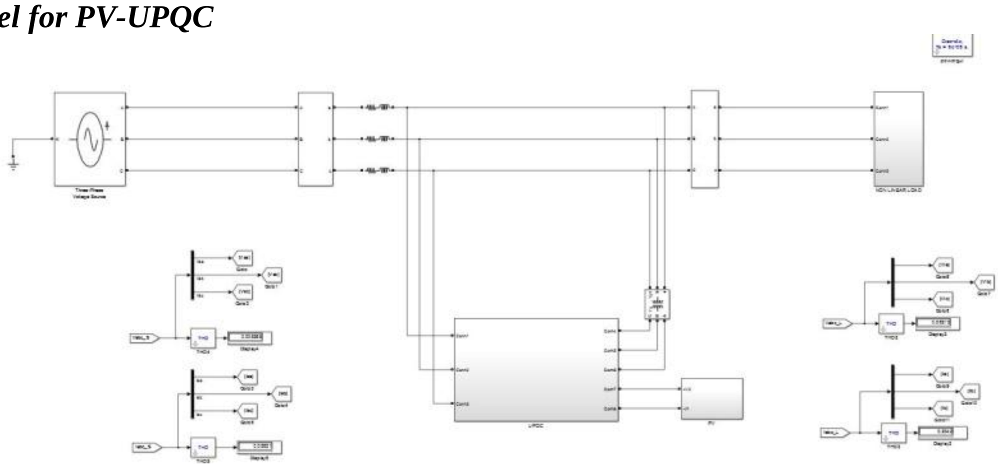

Fig 11 Simulink model for PV-UPQC

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E. Mitigation of Voltage Harmonics under a Non-linear load

Mitigation of Voltage Harmonics Using UPQC is shown in fig 12, 13 and 14. The signs indicated are Source Voltage of phase-a (Vsa), Source Voltage of phase-b (Vsb), Source Voltage of phase-c (Vsc), and Load Voltage of phase-a (Vla), Load Voltage of phase-b (Vlb), Load Voltage of phase-c (Vlc), and Compensating voltages of phase-a, b, c are V*ca, V*cb, V*cc respectively.

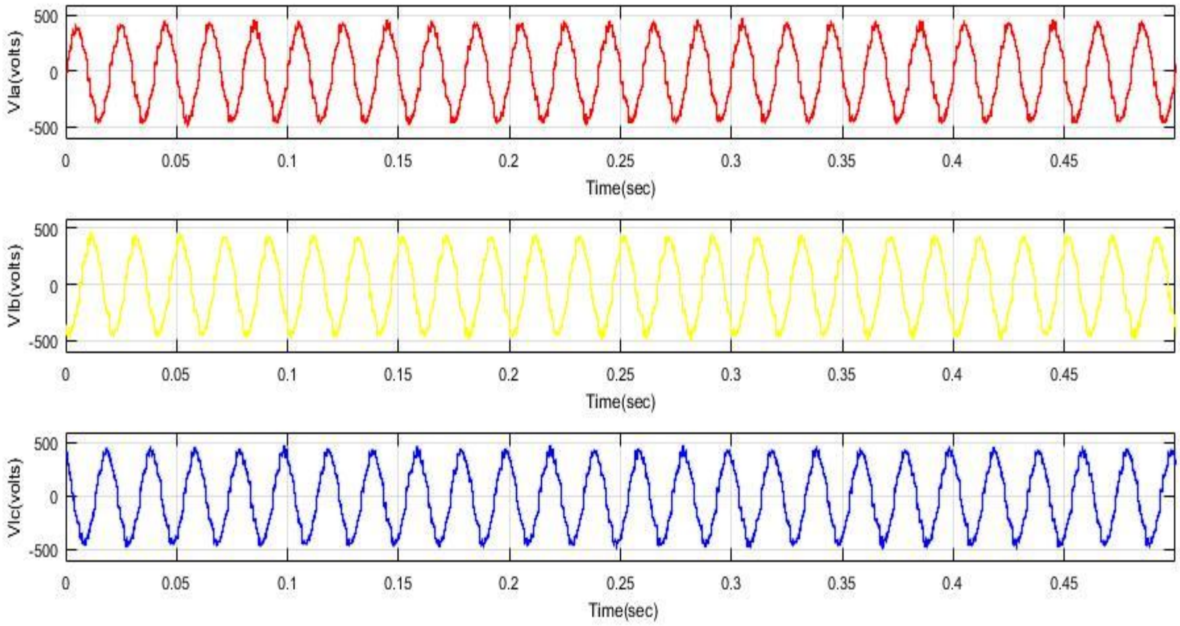

Fig 12 Load voltage waveforms

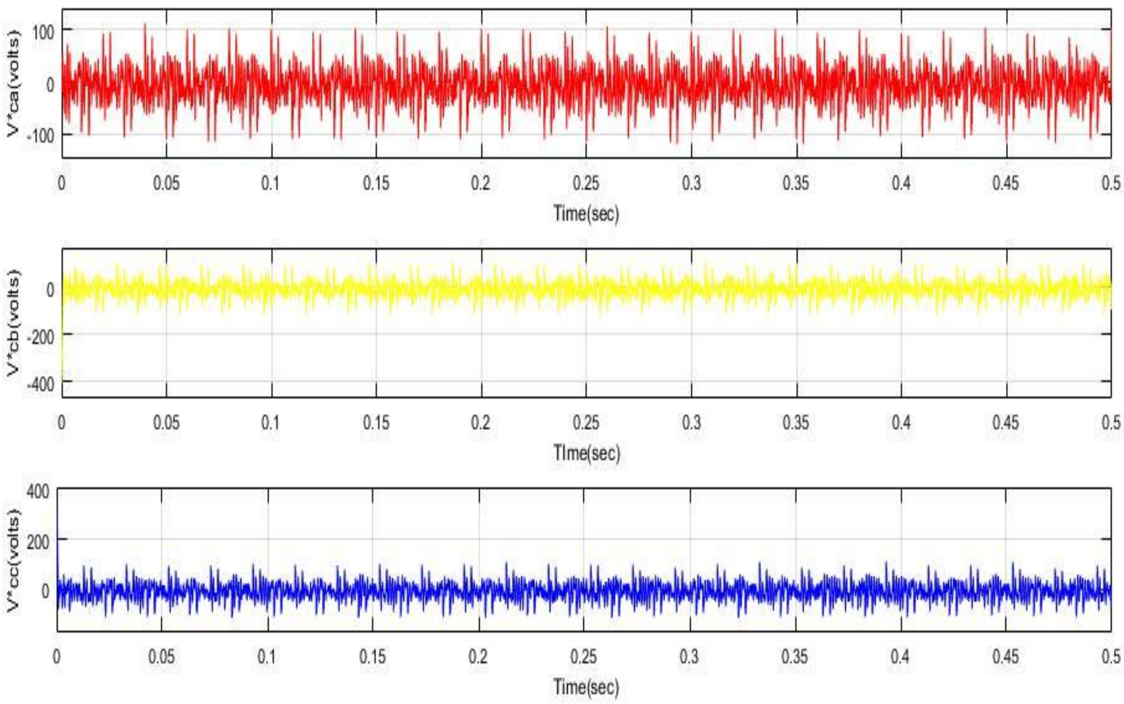

Fig 13 Compensating Voltage waveforms

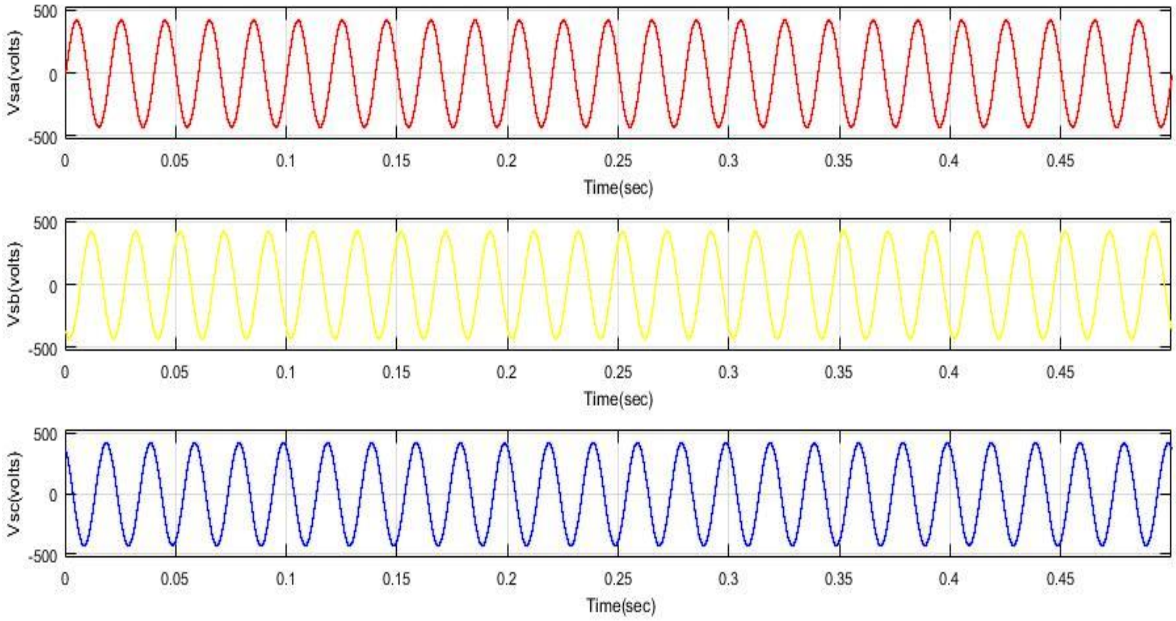

Fig 14 Source Voltage waveforms

F. Mitigation of Current Harmonics under a Non-linear load

Mitigation of Current Harmonics Using UPQC is shown in fig 15, 16, and 17. The signs indicated are Source Current of phase-a (Isa), Source Current of phase-b (Isb), Source Current of phase-c (Isc), and Load Current of phase-a (Ila), Load Current of phase-b (Ilb), Load Current of phase-c (Ilc), and Compensating Current signals of phase-a, b, c are I*ca, I*cb, I*cc respectively.

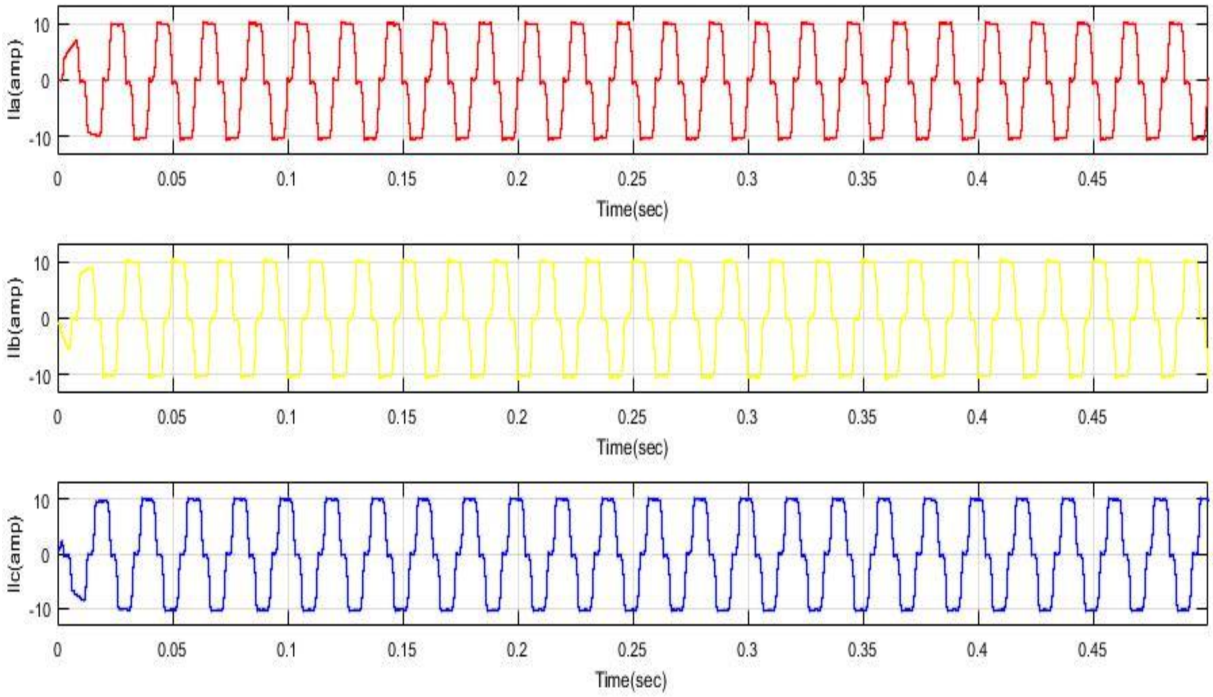

Fig 15 Load current waveforms

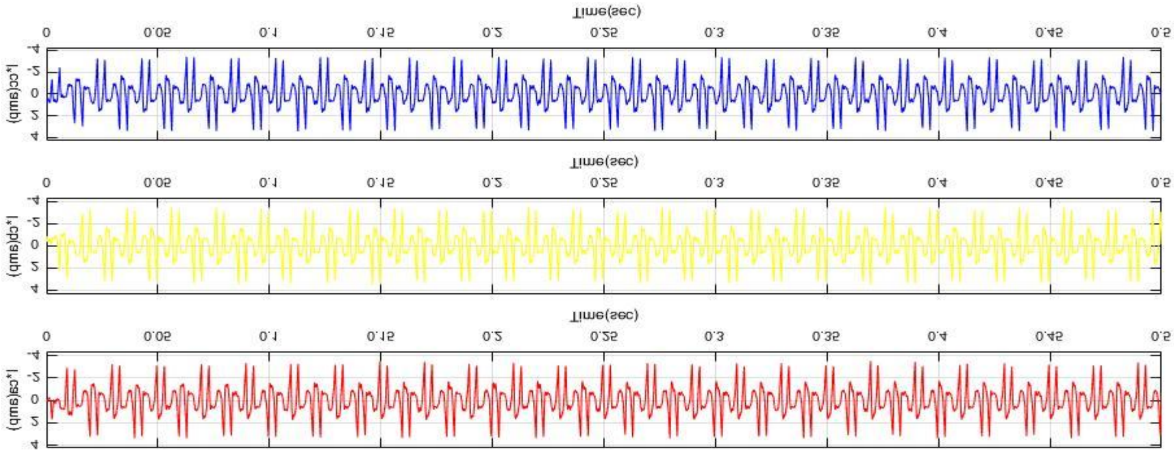

Fig 16 Compensating current waveforms

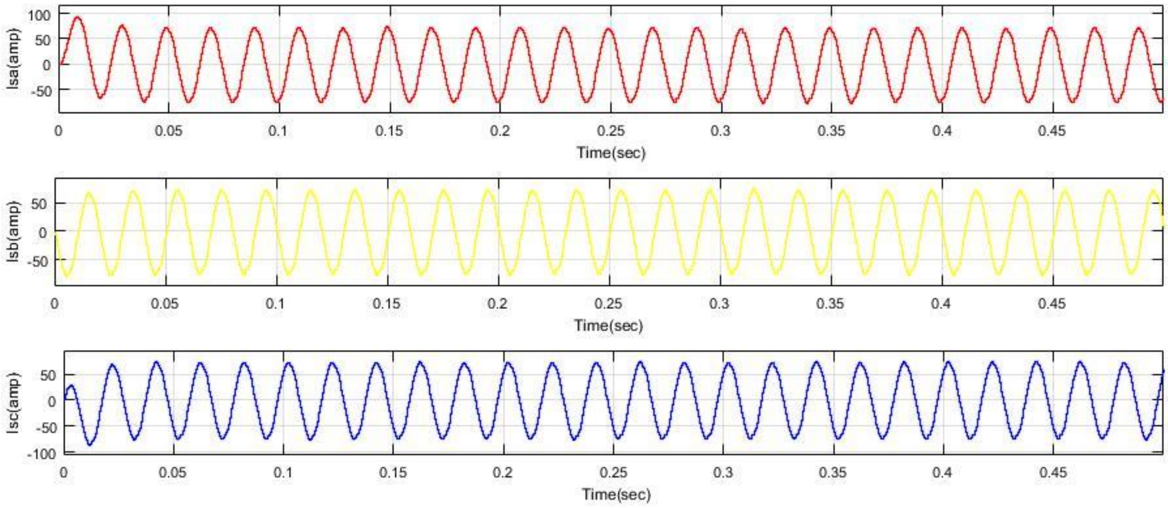

Fig 17 Source Current waveforms

G. *Comparison of %THD*

Table 1 Comparison of %THD

Control strategy	Load side	Source side
Voltage (%THD)	9.2%	0.5%
Current (%THD)	20.6%	2.8%

9. Conclusion

Due to prenominal increase of power demand, usage of non-conventional energy systems gradually increased. Due to integration of non-conventional sources with grid creates power quality issues. Hence Non-Conventional energy systems with PQ improvement systems such as DSTATCOM ,DVR, UPQC etc., affords an ultimate solution for clean energy with power quality enhancement. This paper presented the integration of PV to the grid by using UPQC. The performance of PV-UPQC has been tested under a Non-linear load. The PQ of the system is mainly affected with voltage sag/swell and Harmonics. Results are compensated using PV-UPQC. Proposed SRF based controlling for UPQC reduces the harmonics, Percentage of THD, Reactive power of the system. Power factor of the system is also improved.

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