ANALYZING THE PERFORMANCE OF SOLAR PHOTOVOLTAIC INTEGRATED UPFC

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Abstract: In traditional source current, the harmonics reduction techniques were found to be unreliable and also imbalanced with different load conditions. This certain unreliability problems in harmonics mitigation is caused by the non-linear loads. Normally, the harmonics and power quality problems are reduced by filters. These filters are very expensive to provide a dynamic response under various load conditions. The new Unified Power Flow controller (UPFC) with series and shunt compensator provides more secured power systems and good voltage stability at various load conditions. D-Q theory is used to produce the reference current from the AC source current. D-Q theories produce sinusoidal harmonics that is opposite to the load harmonics. This UPFC can absorb or inject the reactive power in the purpose of common coupling (PCC). D-Q theory followed by hysteresis current controller generates PWM pulses to shunt and series compensator. In this paper, the PI controller is used to maintain DC link voltage in the capacitor bank. The proposed technique has been simulated using MATLAB simulation under various loading conditions.

IndexTerms **– D-Q theory, Harmonics, Unified Power Flow controller, MATLAB.**

I. INTRODUCTION

The usage of semiconductor technology, there is an increased penetration of power electronic loads and these loads draw nonlinear currents. These nonlinear currents cause voltage distortion at point of common coupling particularly in distribution systems. In addition there is an increasing emphasis on clean energy generation through installation of rooftop PV systems in small apartments as well as in commercial buildings [1,2]. The intermittent nature of the PV energy sources, an increased penetration of such systems, particularly in weak distribution systems leads to power quality problems like voltage sags and swells, which eventually causes instability in the grid which may lead to many problems such as frequent false tripping of power electronic systems, malfunctioning and false triggering of electronic systems and increased heating of capacitor banks [3-7]. Hence these power quality issues at both load side and grid side should be rectified in modern distribution systems. The problems stated above reveals that the demand for clean energy as well as good power quality requirement of electronic loads needs multifunctional systems that can integrate clean energy generation along with power quality improvement.

The integration of clean energy generation in major research works were dealt with shunt active filtering. Thus shunt active filtering is not able to regulate PCC voltage as well as maintain grid current unity power factor at same time. Hence a unified power flow controller (UPFC), which has both series and shunt compensators is suggested in this research work that can perform both load voltage regulation and maintain grid current sinusoidal at unity power factor at same time. Hence, in this paper the integration of PV array with UPQC is clearly analyzed.

The solar PV integrated UPFC has numerous benefits compared to conventional grid connected inverters, such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. The reference signal generation is a major task in control of PV integrated UPFC system. Normally, the time-domain and frequency domain techniques are prescribed for reference signal generation. Time domain techniques are most commonly used because of lower computational requirements in real-time implementation. In this paper one of the time domain approach named synchronous reference frame theory (D-Q theory) is used for producing reference current from the AC source current.

II. SYSTEM CONFIGURATION AND DESIGN

2.1 Unified Power flow Controller (UPFC)

The UPFC is one of the most unique, versatile and complex FACTS device [8]. This UPFC has the combined features of the STATCOM and the SSSC. The UPFC has some of the special characteristics compared to other FACTS devices such as: its ability to pass the real power flow bi-directionally, maintaining well regulated DC voltage, workability in the wide range of operating conditions etc .The description of UPFC is depicted in Figure 1. In UPFC, two Voltage Source Inverters (VSI) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer in transmission system. The DC terminals of the two VSIs are coupled together with a DC link and this creates a path for active power exchange between the converters.

Compared to STATCOM or SSSC different range of control options are available in UPFC. The asymmetrical three phase voltage V_{se}, of controllable magnitude and phase angle is injected from the series converter in series with the line to control active and reactive power flows in the transmission line. Hence, this converter will exchange active and reactive power with the line. The reactive power is electronically provided by the series converter and the active power is transmitted to the dc terminals. The shunt converter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor V_{dc} as constant. Hence it is very clear that, the net real power absorbed from the line by the UPFC is equal only to the losses of the two converters and their transformers. The remaining capacity of the shunt converter can be used to exchange reactive power with the line so as to provide a voltage regulation at the connection point.

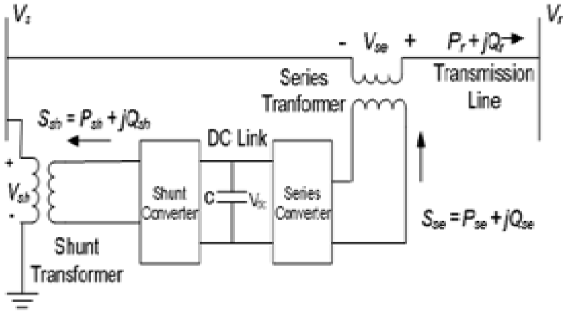

Figure 1. Schematic diagram of UPFC

2.2 Reference Current Generation by D-Q theory

The Figure 2 represents the electrical scheme of a Shunt Active Power Filter (SAPF) for a three-phase power system, which can compensate current harmonics. To identify the harmonic and reactive current of the SAPF and also to inject the balance current of the active filter into a system, the SAPF is coupled with the nonlinear load in parallel. The three phase source voltages and currents are represented as V_S^a, V_S^b V_S^c, and I_S^a, I_S^b I_S^c, , respectively. The three phase load currents and inductances are represented as I_L^a, I_L^b I_L^c, and L_1, L_2 and L_3, respectively. Then the proposed hybrid controller is used to evaluate the reference currents (I_{ca}, I_{cb} and I_{cc}) used by the inverter to produce the compensation currents (I_{ca}, I_{cb} and I_{cc}). Forcing the source current to be purely sinusoidal in a way by generating the equal and opposite current in polarity to the harmonic current strained by the load and injecting it to the point of common coupling is the basic principle of the shunt active filter. The SAPF does not want energy storage units i.e. it does not consume any active power wrapped up from the resource which is the strange characteristic of the SAPF. So it needs an effective compensation policy in order to achieve this function. Here, the instantaneous active and reactive current method is used with the proposed controller. With the help of the reference current generator the reference current signals are generated which are fed in to the hysteresis controller as the input. Following this, the gate signals for the SAPF are produced. The detailed analysis is described in the following section.

The instantaneous phase current and load current are represented as follows,

$$I_s(t) = i_L(t) - i_c(t) \quad (1)$$

$$i_L(t) = \sum_{n=1}^{\infty} I_n \sin(n\omega t + \Phi_n) \quad (2)$$

Then the compensation current of the shunt active filter is denoted as,

$$I_c(t) = i_L(t) - i_s(t) \quad (3)$$

Here, the active power filter finds the fundamental component of the load current and compensates the harmonic current and the reactive power. In this section, the reference currents are extracted by using proposed controller with the I_d-I_q method. Here, the reference currents are produced through the I_d-I_q current component of the nonlinear load. Initially, the active filter currents are obtained from the instantaneous active and reactive current of the nonlinear load. The three phase current components (a, b, c) are transformed into α-β-0 components by using Clark transformation. By using Park transformation, the α-β-0 components are transformed into the d-q components [9]. The transformation from α-β-0 components to d-q-0 components is denoted as follows:

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \frac{1}{v_{\alpha\beta}} \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\theta & \sin\theta \\ 0 & \sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (4)$$

Then the d-q components are decomposed into oscillatory components. The fundamental harmonic current of the positive sequence is transformed to dc quantities. It has the average current components and the higher harmonic current with the first harmonic of negative sequence of current are transformed to non dc quantities which undergo frequency shift in the spectra constituting the oscillatory.

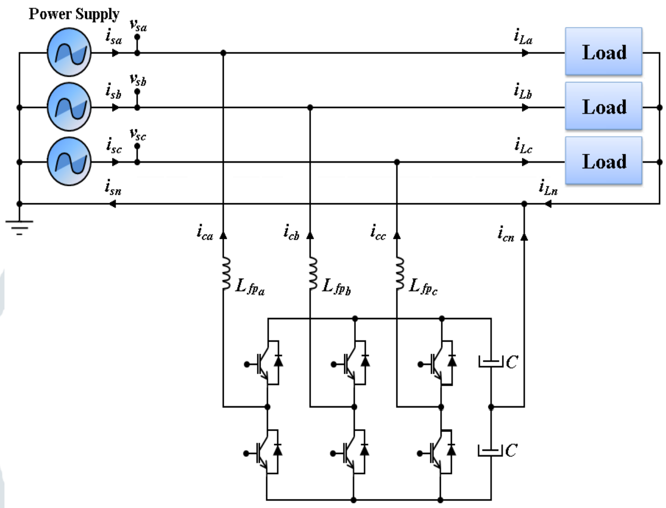

Figure 2. Block Diagram of Shunt active power filter

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{1}{V_{\alpha\beta}} \begin{pmatrix} V_\alpha & V_\beta & 0 \\ -V_\beta & V_\alpha & 0 \\ 0 & 0 & V_{\alpha\beta} \end{pmatrix} \begin{pmatrix} i_{l\alpha} \\ i_{l\beta} \\ i_{l0} \end{pmatrix} \quad (5)$$

$$i_d = \bar{i}_d + \tilde{i}_d$$
$$i_q = \bar{i}_q + \tilde{i}_q \quad (6)$$

In order to reduce the neutral current $P_{l\alpha\beta}$ is calculated by using dc and ac components of real and reactive power.

$$\frac{P_{l\alpha\beta}}{V_{\alpha\beta}} = \left(\frac{P_{l\alpha\beta}}{\sqrt{V_\alpha^2 + V_\beta^2}} \right) \quad (7)$$

The above equation describes the dc components' average values. Then the currents are compensated and the reference currents are follows,

$$\begin{bmatrix} i_{s\alpha}^{ref} \\ i_{s\beta}^{ref} \\ i_{s0}^{ref} \end{bmatrix} = \left(\frac{P_{L\alpha\beta}}{v_{\alpha\beta}} \right)_{dc} \frac{1}{v_{\alpha\beta}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} i_{s\alpha}^{ref} \\ i_{s\beta}^{ref} \\ i_{s0}^{ref} \end{bmatrix} = \left(\frac{P_{L\alpha\beta}}{\sqrt{v_\alpha^2 + v_\beta^2}} \right)_{dc} \frac{1}{\sqrt{v_\alpha^2 + v_\beta^2}} \begin{bmatrix} v_\alpha \\ v_\beta \\ 0 \end{bmatrix} \quad (9)$$

2.3 Solar Photovoltaic Integrated UPFC

A simplified schematic of a PV-UPFC is shown in Figure 3. The main features of PV-UPFC inverter are, it has two inverters, one connected in series with the line through a series insertion transformer and another connected in shunt with the line through a shunt coupling transformer. Primarily, the series-connected inverter tends to inject a controlled voltage in series with the line and thereby to makes the power flow to a desired value. Normally, the series inverter may exchange both real and reactive power while performing this duty. A voltage sourced-inverter can able to generate the needed reactive power at its AC terminals. However, it is incapable of handling real power exchange unless there is an appropriate power source connected to its dc terminals. In the same way, the series-connected inverter has its dc terminals connected to those of the shunt-connected inverter, which performs its fundamental act of delivering exactly the right amount of active power to meet the real power requirements of series inverter. It obtains this real power from its connection to the ac bus. The shunt inverter can also carry out a secondary function by generating reactive power for regulation of the local ac bus voltage.

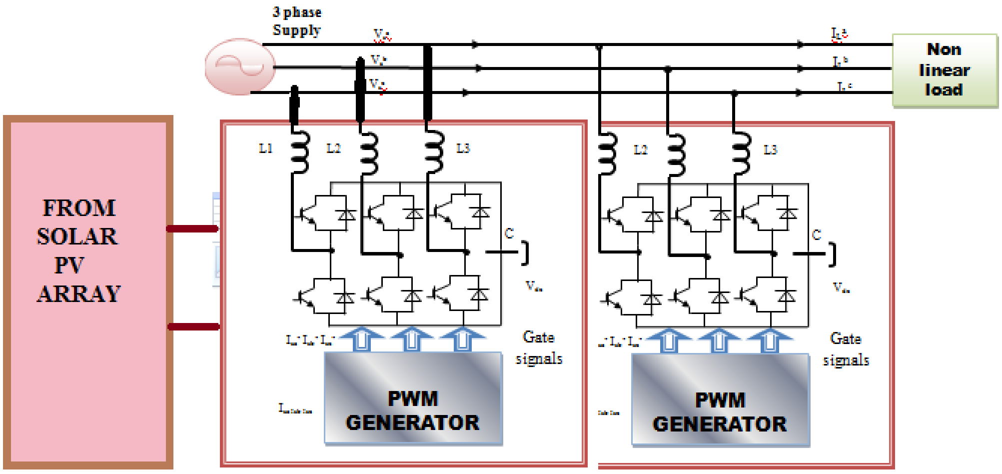

Figure 3. Circuit diagram of the proposed system

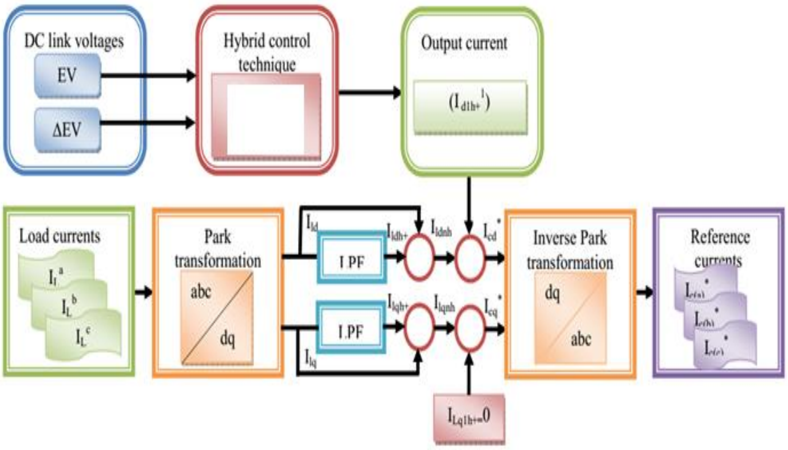

Figure 4. Implementation of D-Q theory

The UPFC thus offers the Power electronic systems have the capability of providing faster response compared to traditional mechanically based power system controls. Hence, to obtain the maximum capability of the UPFC, a system model with an equally faster response is required. It would be advantageous, if the time-varying equations can be transformed to a time invariant set. The calculation can be simplified with this approach for steady and transient conditions especially a huge power system is considered. R.H.PARK introduced the d-q transformation. In this paper the reference signal for solar PV-UPFC generated with D-Q axis theory. This D-Q axis control system enables the UPFC to follow the changes in reference values like AC voltage, DC link voltage, real and reactive powers through the line. By implementing a d-q axis controller it is possible to produce a relatively fast response and to reduce the interaction between real and reactive power flow. In this approach, the transformation of a three phase system to d-q model and d-q to 3-phase system quantities is done with Park's transformation. This can control real and reactive power individually and also regulating the local bus voltage. A basic control model for the UPFC is that the real power is influenced by the phase angle whereas reactive power is dependent on the voltage magnitude. BY referring the above concept, the series UPFC controller adjusts the angle of the series compensation voltage to control the real power flow in the transmission line and the amplitude of the series voltage is controlled by regulating the reactive power flow,. The real and reactive power flows in the transmission line are influenced by both the amplitude and the phase angle of the series compensating voltage.

III. RESULTS AND DISCUSSIONS

3.1 Simuation

The proposed UPFC work is implemented using MATLAB simulation and the shunt and series converter is developed with IGBT device. This system is developed with 100 V AC source voltage and this source voltage is given to the nonlinear load. In this system diode bridge rectifier and inductive loads are used as the nonlinear load. This nonlinear load induces heavy harmonics in the source current.

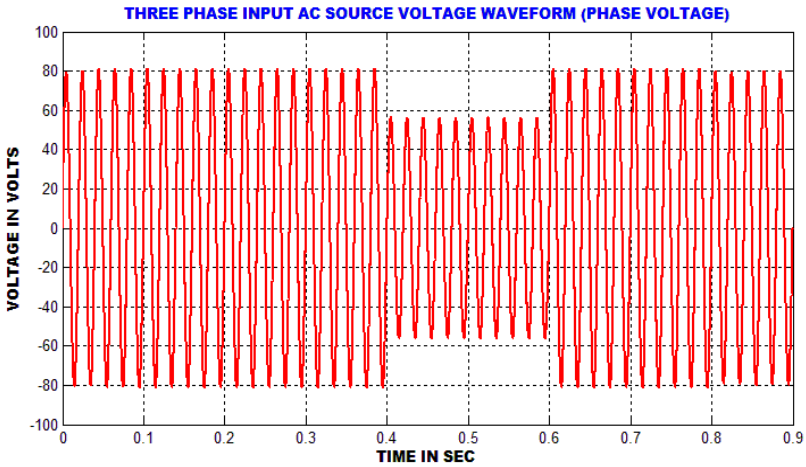

Figure 5. Input Source voltage to the nonlinear load

The Figure 5 shows the three phase AC voltage waveform, for testing under different voltage conditions whereas the source voltage has reduced from 0.4 to 0.6 sec to create voltage sag. Corresponding AC current waveforms are depicted in Figure 6. At this nonlinearity our proposed UPFC maintains voltage stability in order to prove the voltage compensation the proposed UPFC system reduces the harmonics and maintains voltage stability of the power system. The absorption and injection of series and shunt compensators of UPFC are shown in Figure 7. These figures clearly illustrate that enough compensation can be provided with the UPFC to maintain DC link voltage.

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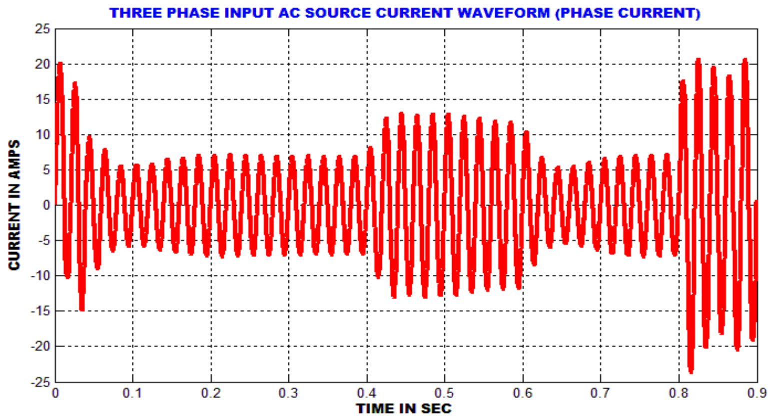

Figure 6. Input source current waveform with nonlinear load

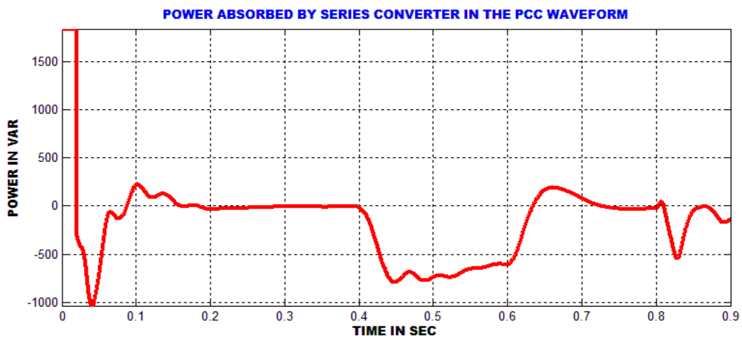

Figure 7. Series converter absorbed power waveform in UPFC

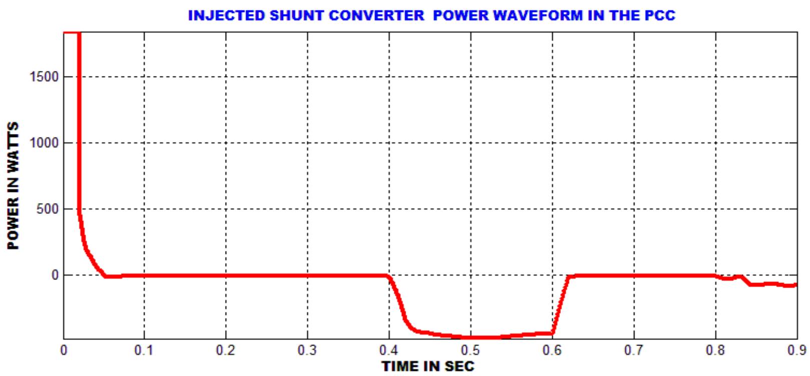

Figure 8. Shunt converter injected power waveform in the PCC

The Total harmonic Distorsion (THD) is analyzed with FFT analysis and it is shown in Figure 9 and its clear that the magnitude of fundamental harmonics is much reduced (nearly 2.5%) compared to earlier documented research article (26.31%) [10]. The D-Q theory based UPFC system reduce the source current harmonics, the current harmonics should obeys IEEE512 power quality standard. The Figure 10 illustrates the load voltage waveform, which clearly depicts the voltage sag causes by the input voltage between 0.4s 0.6s is nullified in output voltage. Hence, it is evidently proved that enough compensation is given by the UPFC to improve the power quality.

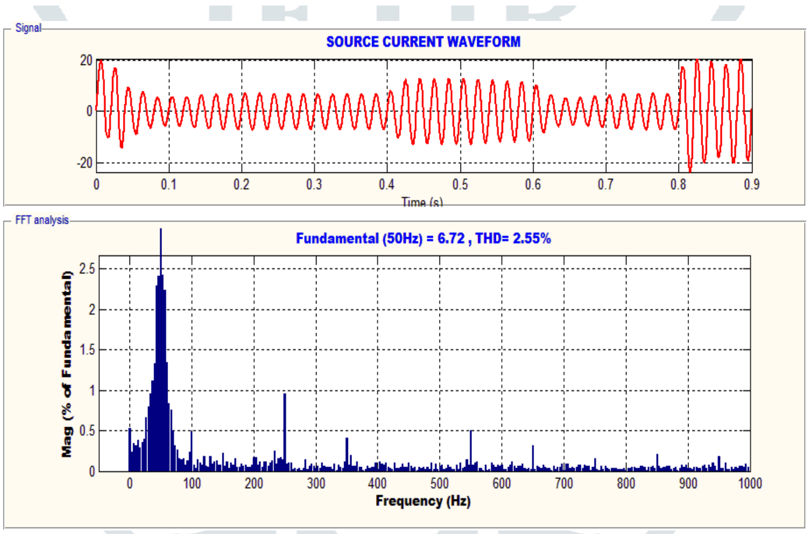

Figure 9. Input source current THD waveform using FFT analysis

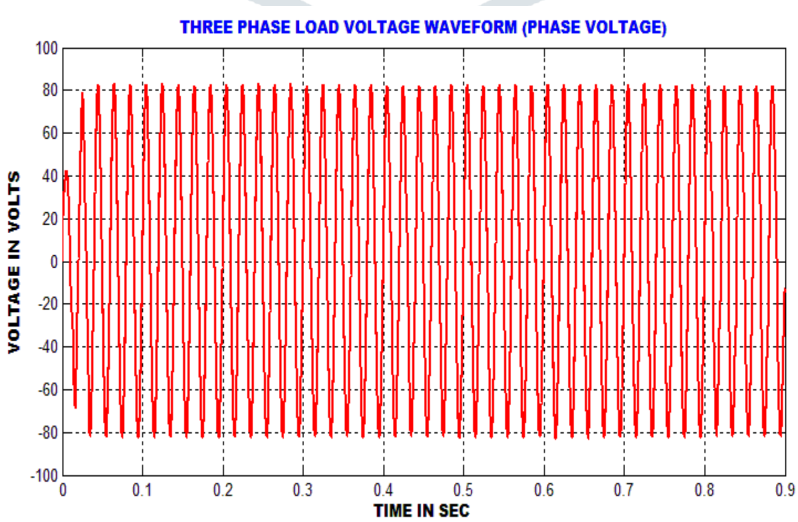

Figure 10. Load voltage waveform using UPFC system

IV. CONCLUSION

In this paper, an execution of photograph voltaic coordinated UPFC framework is broke down. A D-Q hypothesis is utilized to create reference flag. Furthermore, the reproduction model of the proposed framework is structured utilizing MATLAB simulink and the yield results were taken from the extension. The execution of the proposed plan is contrasted and the photograph voltaic incorporated UPQC framework in the prior research works and demonstrated that powerful consonant decrease can be performed with the proposed methodology. What's more the power factor likewise enhanced by this proposed methodology and attempted to be kept up close solidarity (UPF). The benefits of the proposed strategy are booked as pursues At ostensible burden, the compensator infuses receptive and consonant parts of burden flows, bringing about UPF. Nearly UPF is kept up for a heap change Fast voltage control has been accomplished amid voltage unsettling influences. Losses in the VSI and feeder are diminished impressively, and have higher list supporting capacity Hence the recreation results plainly uncover that the power quality is significantly enhanced with the proposed.

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