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INTEGRATION OF PHOTOVOLTAC ENERGY FOR IMPROVING POWER QUALITY OF UPQC

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This work carried out on improving power purity of Unified Power Quality Conditioner added to Photovoltaic unit. This effort describes the unified power quality conditioner formation and elaborates concept unreformed voltage outline of a distribution system. This practice brings out a complex alignment of UPQC that comprise a DC/DC converter, to support the converter a Photovoltaic unit is used at the DC link. This study used for discriminating between before and after injection, the amount of THD will be changed to a good value and source voltages are sinusoidal. In this described about result of UPQC giving excellent THD with of photovoltaic energy. The execution analysis presents the THD of Photovoltaic source. The working of the presented design is formulated and simulated in MATLAB workspace.

Keywords: power quality photovoltaic source unified power quality conditioner.

1. Introduction

The power grading problem is a complex scenario which is quite difficult to explore because it is not a same for area to the area and customer to customer. In the practical life each and every customer is different, their usage of electrical devices or appliances are different. The load on the system is varies minute-to-minute. In addition to dc loads, there are wide varieties of electronic gadgets with composite structure operated by power electronic converters. Due to instability in the system the appliances are may not work upto the expected specifications. Power system is exposed to the all-weather conditions, due to any severity of the problem faults can happen on the system. By the uneven or low voltages, the devices may fail or break down completely. Those devices can work abruptly and slowly inject the harmonics into the system. The rectification has to be done on either side is most necessary for upgrading the network. The Unified Power Quality Conditioner (UPQC) is an exclusive composition that binds series compensator as dynamic voltage restorer and shunt compensator as distribution static compensator with a common DC link, connected in a successive mode.

Shunt compensator quite effectively handle the current associated issues, reactive power compensation, improving power factor[1] and series compensator voltage associated disruptions. With the use of a DC link, the recompense can be done perfectly. The series compensator take measures for maintaining good voltage profile [2]. Here PV Energy is connected as a battery element parallel to the DC link for small time period. Photovoltaic is

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the process of producing electricity by transforming sun light into steady current using semiconductors material. Solar power generation utilizes the solar modules comprised of a number of solar cells. Depends upon the application, solar modules/array are arranged in different fashion with photovoltaic material.

PV used in wide variety of sectors such as solar water heating, Lighting distillation, pumping, transportations, furnaces, cooking etc [2]. Arrangements of shunt compensator, supercapacitors are employed to upgrading the power quality [3, 4]. Voltage source converter method is used in running both compensators. The shunt active filter compensates the voltage interruption supported by battery or some storage in the DC link [5]. Battery capacity governed by discharge rate as well temperature. The involvement of full bridge DC-DC converters in UPQC defined in paper [6]. UPQC is one of the power conditioner able to solve many problems related to current and voltage [7-9]. This paper submits the functioning of PV, UPQC with DC/DC converter, PV system. The functioning of the implemented model is simulated in MATLAB interface. This paper is arranged as: Section 2; describes the PV model description, explores the solar cell model and connecting equations Section 3; describes the PV based UPQC and DC-DC converter, explains the connection of among them Section 4; reveals about arrangement of series and shunt converters. Section 5; presents the result analysis. Sections 6; analyses the conclusions Sections 7; gives the appendix.

2. PV model description

Solar array/module is a type of nonlinear element which transforms photovoltaic energy to electrical energy. A PV module is a combination of strings, where the strings given by the voltage specification. Fig.1 presents that the modelling of a single diode PV cell contains of a photo voltaic current source.

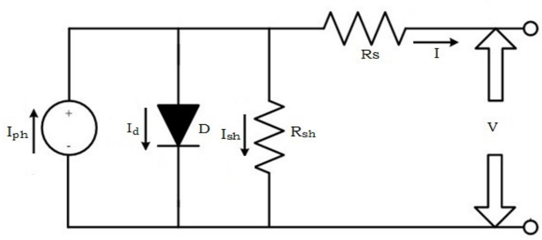

Fig.1: Modelling of a single diode PV cell [10].

The modelling of a PV cell shows, a diode showing the junction with resistances R_s and R_{sh}. The value of R_s and R_{sh} represent the series and shunt resistances respectively [10].

A PV array is consists of number of PV cells that have series and shunt combinations.The governing equation for current 'I' the above equivalent circuit is formulated using Kirchhoff''s current rule.

$$\mathrm{I} = \mathrm{Iph} - \mathrm{Id} - \mathrm{Ish} \tag{2.1}$$

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_o} * \left[\exp^{\left\{\frac{V+RsI}{aVt}\right\}} - 1\right] - \frac{V + IR_s}{R_{sh}} \tag{2.2}$$

In Equation (2.2) represents , I_{ph} - photovoltaic current, I_o - reverse current, a - ideal diode constant, V_t - thermal voltage, q is the electron charge, k - Boltzmann constant, T - temperature of junction

$$V_t = \frac{aKT_c}{q} \ln\left[\frac{I_{ph}+IR_s-I}{IR_s}\right] IR_s \tag{2.3}$$

yields voltage of one cell, which is multiplied by the number of cells connected in series to give full array voltage.

3. Photovoltaic based UPQC and DC-DC Converter

As the trend is changed in the world of semiconductor mechanization, there is an expanded probing of power electronic burden in the realistic environment. This burden may be information technology related equipment, microprocessor based equipments, power converters, printers etc have expected caliber. However, those devices are basically in non-linear nature and they draw nonlinear currents create some disturbance due to voltage imbalance, improper working of the devices abruptly definitely voltage distortion in the distribution networks. There is also increasing priority on clean energy production by installing solar power plants with small to medium scale ranges [11-12].

Merging of photovoltaic unit with UPQC shown in Fig, 2, adds the dual advantages of clean, sound free, energy production.

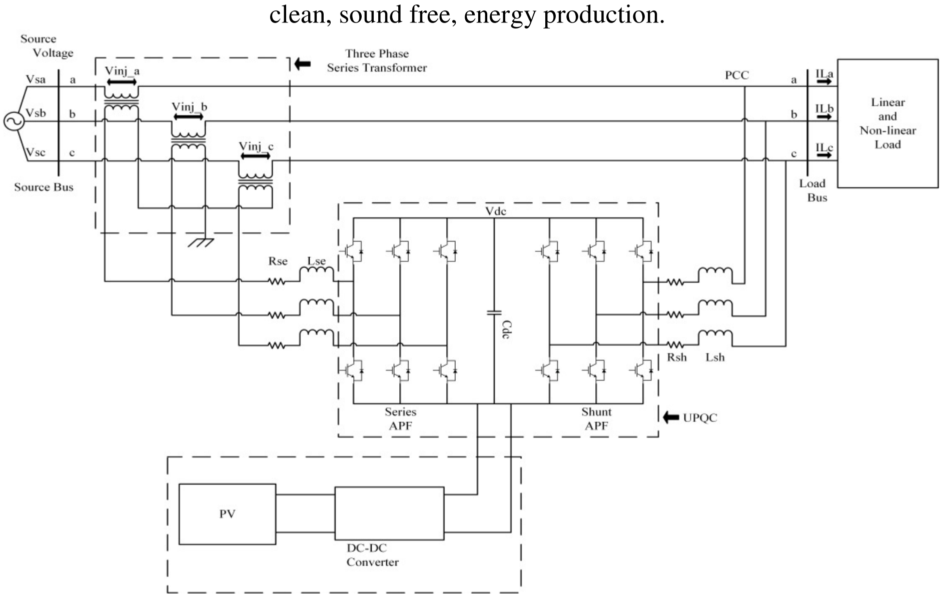

Fig.2: Circuit diagram of the PV based

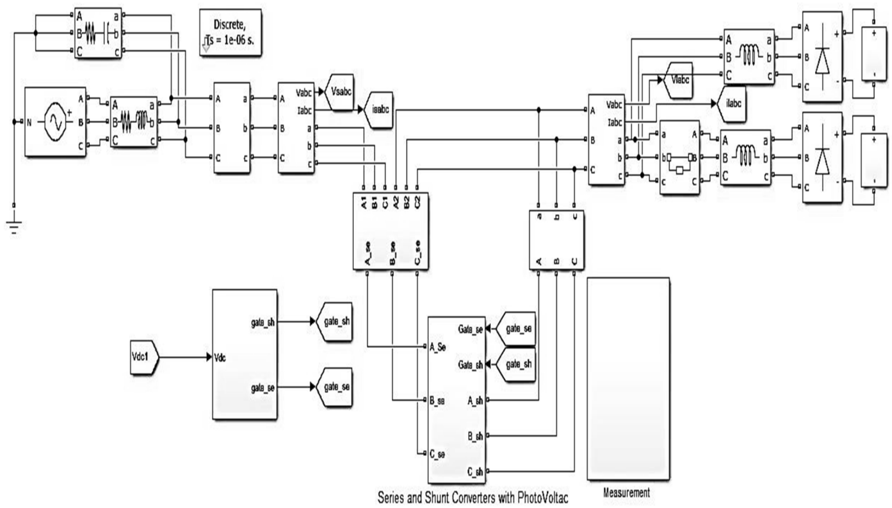

Fig.3: Simulink diagram of the enhanced UPQC with PV.

The shunt active power filter is employed for reactive power and maintains the voltages at the DC link voltage between both active power filters. The DC link with capacitor is same for both filters. The PV unit comprises of no. of cells arranged in series to increase the voltage at the DC link and the DC/DC converter is employed to give steady voltage at the DC link whatever the voltage at PV unit end. It adjusts the voltage depends on the voltage availability. The increase in voltage (sag) and decrease in voltage can be compensated by utilizing a dynamic voltage restorer, series active filter, UPQC, etc. In this work, synchronous reference frame approach for the PV based UPQC scheme with a DC/DC converter to manage voltage at the PV side is used and the system result is upgraded [13-14], simulink arrangement of the same shown in Fig.3.

The DC/DC converter with two full-bridges used [6], it can function in bi-directional mode. The converter has a wide voltage conversion range with simple control. The DC/DC converter decreases the nominal DC-link voltage down to the level of PV unit voltage in the charging mode. The operational voltage of the PV is in the range between 65-80V, while the dc link voltage is about 700V.The DC/DC converter amplifies the PV unit voltage up to the nominal DC link voltage in discharging mode. The PV voltage is regulate between 65-80V, while the DC link voltage changes up to about 700V. In the implemented technique, voltages at load side, source side and source current are received in under disturbed state by applying MATLAB interface. [15-19].

4. Control Scheme of Series and Shunt Converter

The presented control technique is used to find the 3 phase reference voltage at the load end of electrical power system network. This method has good response when non-linear and linear burden on power system network. Control scheme of series and shunt converter are described in following section.

I .Control method for Series Converter

The series compensator objective is to inject voltage in phase. It results in minimum injection voltage by the series compensator it. It is engaged to remove voltage harmonics. It is also used to maintain the same voltage and to also to balance in three-phase systems. Series Active Power Filter (APF) is used is to give the reference value for both voltage and currents. The control scheme of the series APF is depicted in Fig 4. The phase locked loop is employed to properly match with the supply voltage [15]. Three phase disturbed supply voltages are sensed and given to point of interconnection which generate two angles (sinθ, cosθ).

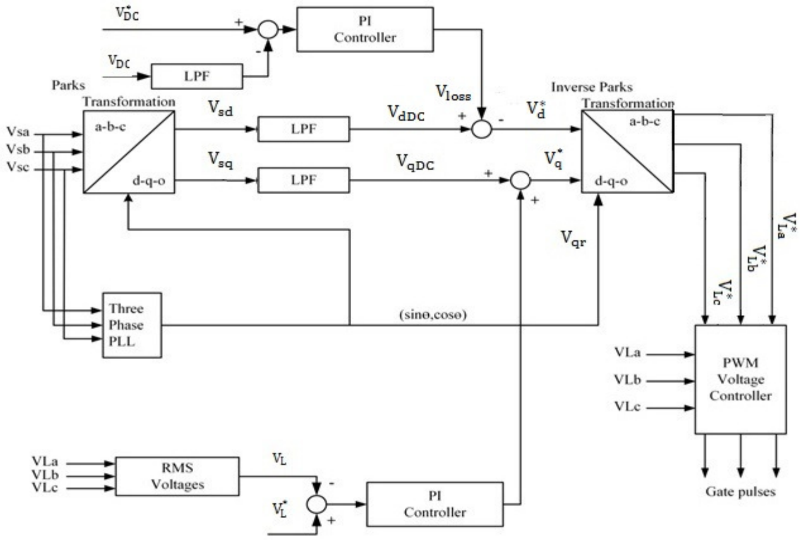

Fig.4: Control method of Series APF [15].

The source voltages V_{sa}, V_{sb}, V_{sc} are changed into d-q-0 from abc, given in equation (3.1).

$$\begin{bmatrix} V_{sd} \\ V_{sq} \\ V_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\Pi}{3}\right) & \cos\left(\theta+\frac{2\Pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta-\frac{2\Pi}{3}\right) & -\sin\left(\theta-\frac{2\Pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \tag{3.1}$$

The low pass filters are eliminates the harmonic components. The sections of voltages in V_{dh}, direct-axis and V_{qh}, quadrature-axis consists of ripple or harmonic components, fundamental component, are shown in equation (3.2) and (3.3).

$$V_{dh} = V_{dDC} + V_{dAC} \tag{3.2}$$
$$V_{qh} = V_{dDC} + V_{qAC} \tag{3.3}$$

To hold the DC bus voltage of the series filter, a proportional–integral (PI) controller is used and the output is taken as the voltage (V_{out}) for meeting the losses.

The reference of direct -axis and quadrature-axis are V^*_d, V^*_q are given by,

$$V^*_d = V_{dDC} - V_{out} \tag{3.4}$$

$$V^*_q = V_{qDC} + V_{qr} \tag{3.5}$$

Reference and actual source voltage will generate the three phase root mean square voltage. This will helps to create the suitable injected voltage for the compensation of voltage losses. Root mean square voltage and reference voltage from the PI controller are used to get required compensation reactive component of voltage. V_{qDC} is reactive component and with V_{qr} values are maintained to get the appropriate voltage at the converter of series APF, so that it can be needful to retain the root mean square voltage at point of inter connection due to root mean square voltage loss by load reactive power. The two reference voltage values (V^*_d, V^*_q) are used to produce the reference load voltages, to adjust the amount of voltage at series APF.

To transform the reference load voltage (V^*_{Labc}) are into d-q-0, using Inverse Park transformation shown in equation (3.6).

$$\begin{bmatrix} V^*_{La} \\ V^*_{Lb} \\ V^*_{Lc} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} \tag{3.6}$$

ii. Control method for Shunt Converter

Shunt APF is focused to manage the DC link voltage and to remunerate the load current under non-linear loads. This control scheme of the shunt active power filter is shown in Fig 4.

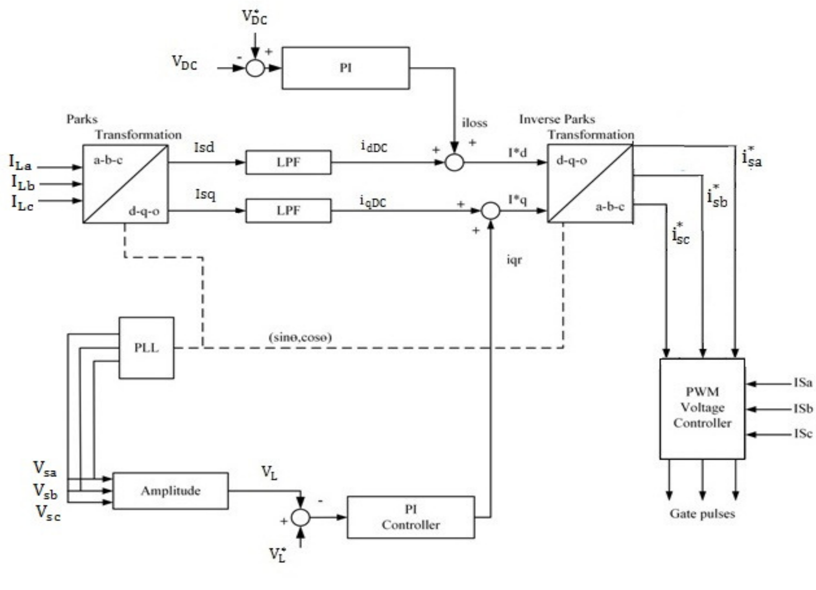

Fig.5: Control scheme of Shunt APF [15].

The source currents should be sinusoidal irrespective of the load conditions with the help of shunt APF by the current controller design. Three phase disturbed currents are sensed and added to point of common coupling which produce two quadrature unit vectors (sinθ, cosθ). The reference currents of direct axis, quadrature axis are I^*_d, I^*_q values are shown in equation in (3.7), (3.8).

$$i_d^* = i_{dDC} + i_{out} \tag{3.7}$$

$$i_q^* = i_{qDC} + i_{qr} \tag{3.8}$$

Where i_{dDC}, i_{qDC} direct-axis and quadrature-axis fundamental currents. i_{out} are the output of the PI controller. The load currents in the three phases are transformed into d-q-0 from abc using the mentioned equation (3.9).

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\Pi}{3}\right) & \cos\left(\theta + \frac{2\Pi}{3}\right) \\ -\sin\theta & -\sin\left(\theta - \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} \tag{3.9}$$

The two reference currents (i^*_d, i^*_q) are utilised to create the reference load currents, to correct the current magnitude at shunt APF. The reference source currents are produced by Inverse Park transformation given in equation 3.10.

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos\left(\theta - \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) & 1 \\ \cos\left(\theta + \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \tag{3.10}$$

The control process of the filter senses the current values and is investigated with the reference currents in a hysteresis current controller to produce switching pulses.

5. Result Analysis

The performance of PV based UPQC connected to non-linear load is analyzed by simulating a circuit in MATLAB environment.

(a) Voltage Sag compensation:

The supply currents are monitored normal and sinusoidal initially, shunt APF starts working at time t_1=0.1 sec. At time t_2=0.3 sec, series APF is comes into action. When load is switched on, sag is observed in the source voltage (V_S) during 0.3 sec to 0.38 sec. This sag over till time t_4=0.38 sec, as shown in Fig. 5(a). In this state, series APF is come up with the required voltage by injecting in phase remunerating voltage, shown in Fig. 5(b).The PV unit is providing the suitable power through the series compensator, So that the load side voltage is steady under normal conditions.

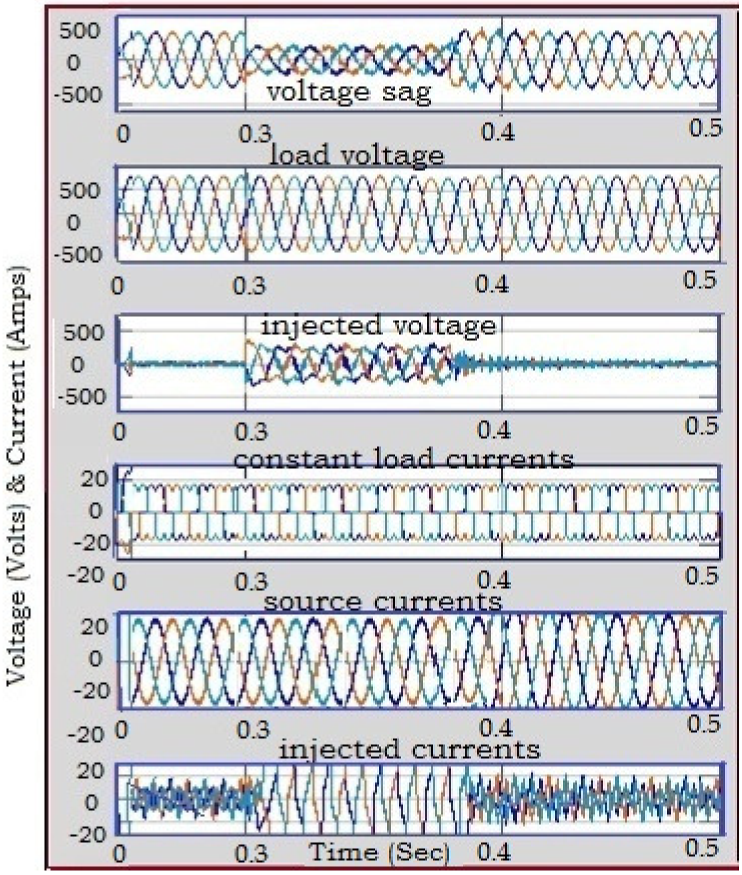

Fig.5(a): Sag condition.

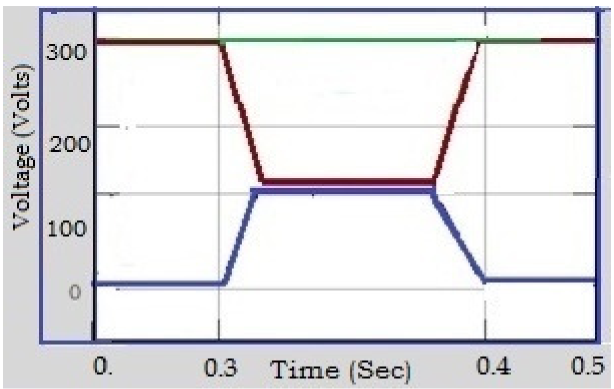

Fig. 5(b): Voltages injecting during sag condition showing: source voltage V_S (Pink), load voltage V_L (Green) and injected voltage I_{Inj} (Blue) in sag condition.

(b) Voltage Swell compensation:

In the initial conditions, it is monitored that the supply currents are normal and sinusoidal and the shunt APF is put into working. At time t_2=0.5 sec, series APF is comes into action. When load is on, a swell in the source voltage (V_S) is created during 0.5 sec to 0.58 sec on the system shown in Fig 6(a). In this state, the series APF injects an out of phase compensating voltage in the line through series transformers shown in Fig. 6(b).

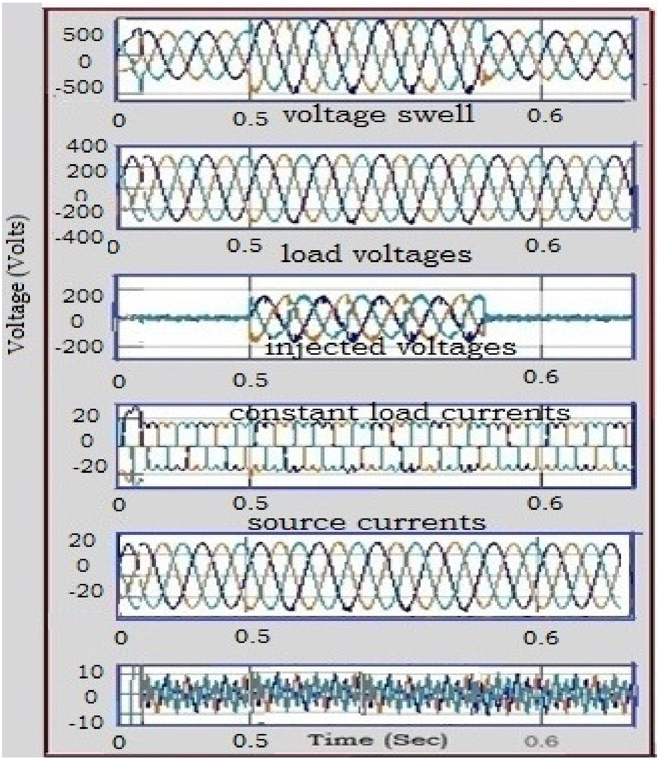

Fig.6(a): Swell condition.

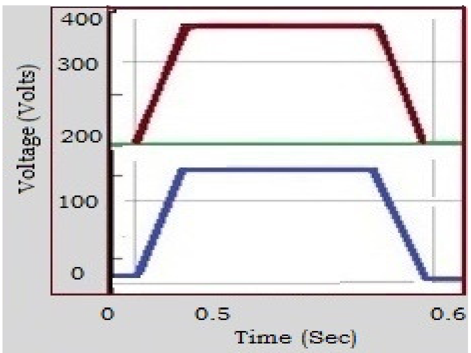

Fig.6 (b): Voltages injecting during swell condition showing: source voltage: V_S (Pink), load voltage V_L (Green) and injected voltage I_{Inj} (Blue) in swell condition.

(a) Load compensation:

The execution of enhanced UPQC with PV for load unbalancing portrays in Figure 7, when the unbalance is created at load side. An unbalance is introduced by opening one of the phase of connected load during t=0.7 sec to 0.8 sec.

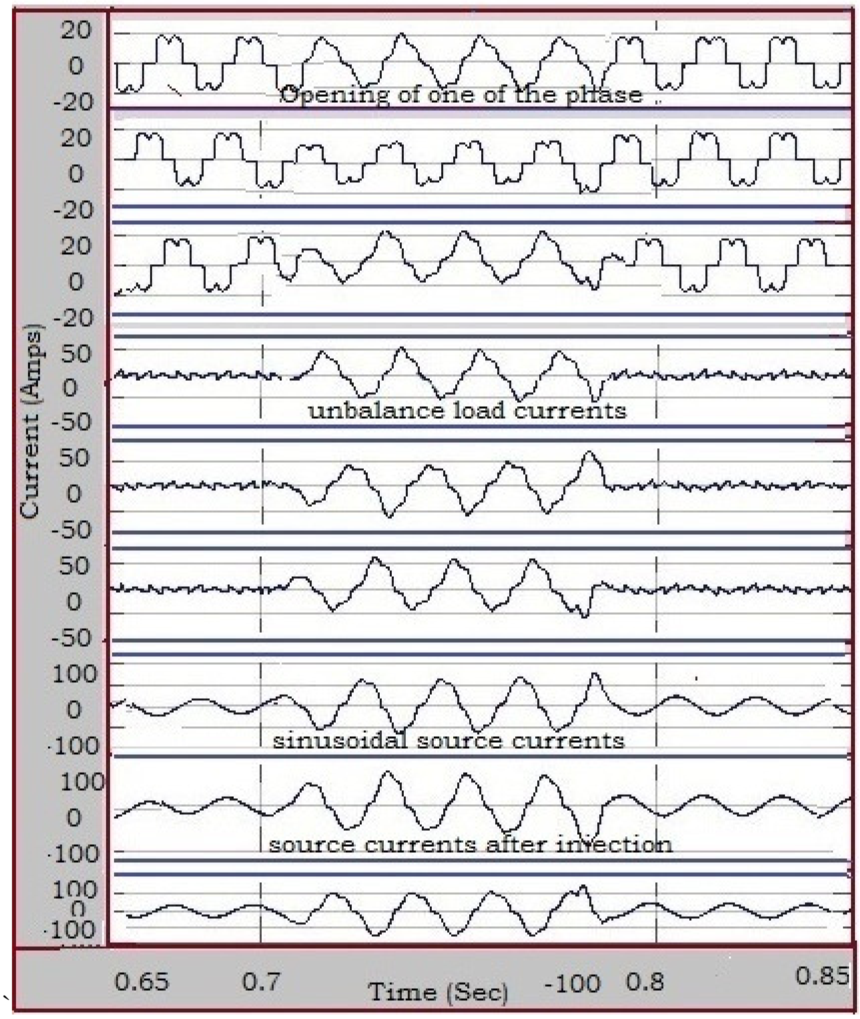

Fig.7: Showing unbalanced load currents.

(b) Harmonic compensation:

Fig.8:(a, b, c and d) shows the harmonic series of load current, source current, source voltage and load voltage, for the enhance UPQC integrated with PV. In Fig.8: (a) and (b), it can be watched that the total harmonic distortion of the phase ‘b’ of the load current is 29.85% and the source current is 2.46%. Fig.8: (c) Source voltage and (d) load voltages demonstrate the %THD of the source voltage and load voltage as 0.73% and 1.80% to accomplish the condition.

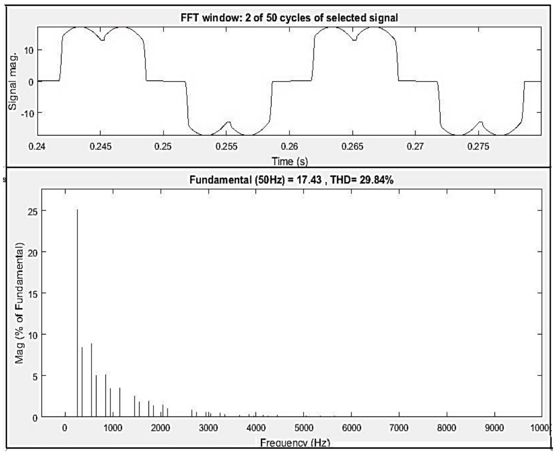

Fig.8 (a): Load current

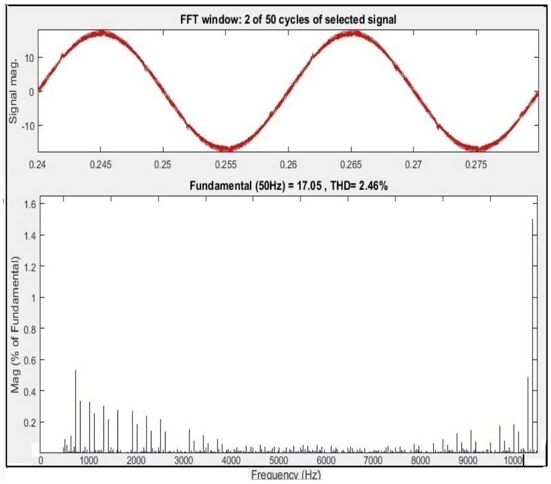

Fig.8 (b): Source current

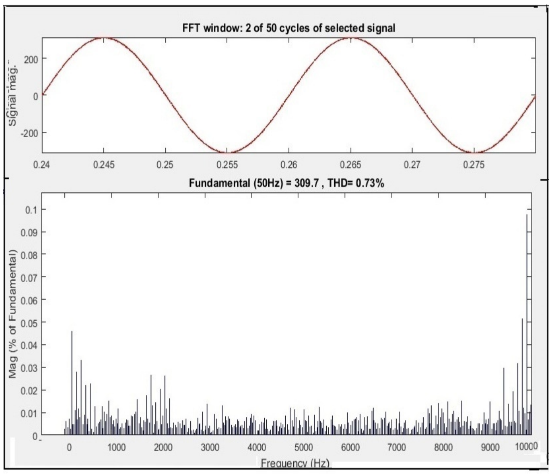

Fig.8 (c): Source voltage

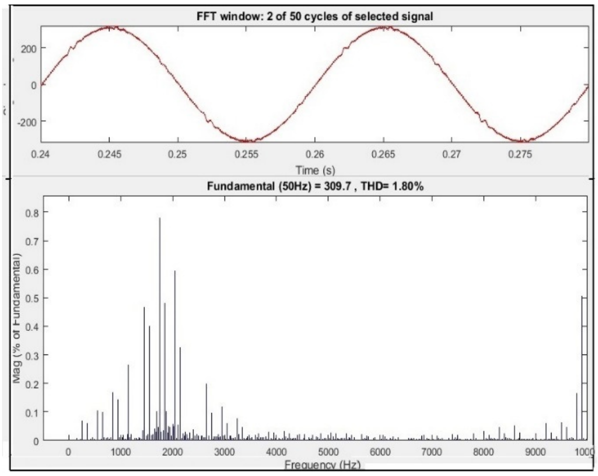

Fig.8 (d): Load voltage
Fig.8: Analysis of % THD values.

(C). Power factor correction: The power factor is gradually increased at source terminal after compensation of power, Fig.9. Hence no extra device is required.

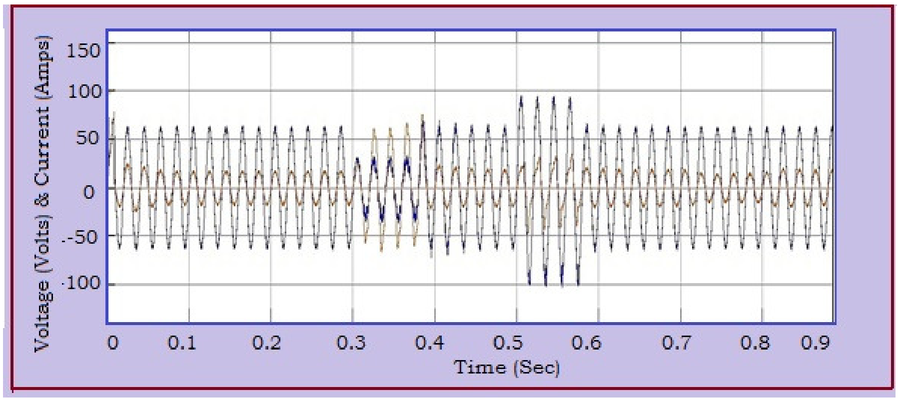

Fig.9: Waveform showing power factor correction

The overall performance of the part of the presented research work i.e., enhanced UPQC with PV for improving various PQ problems like sag, swell, load balancing, harmonic compensation and power factor correction are shown in Figure.10.

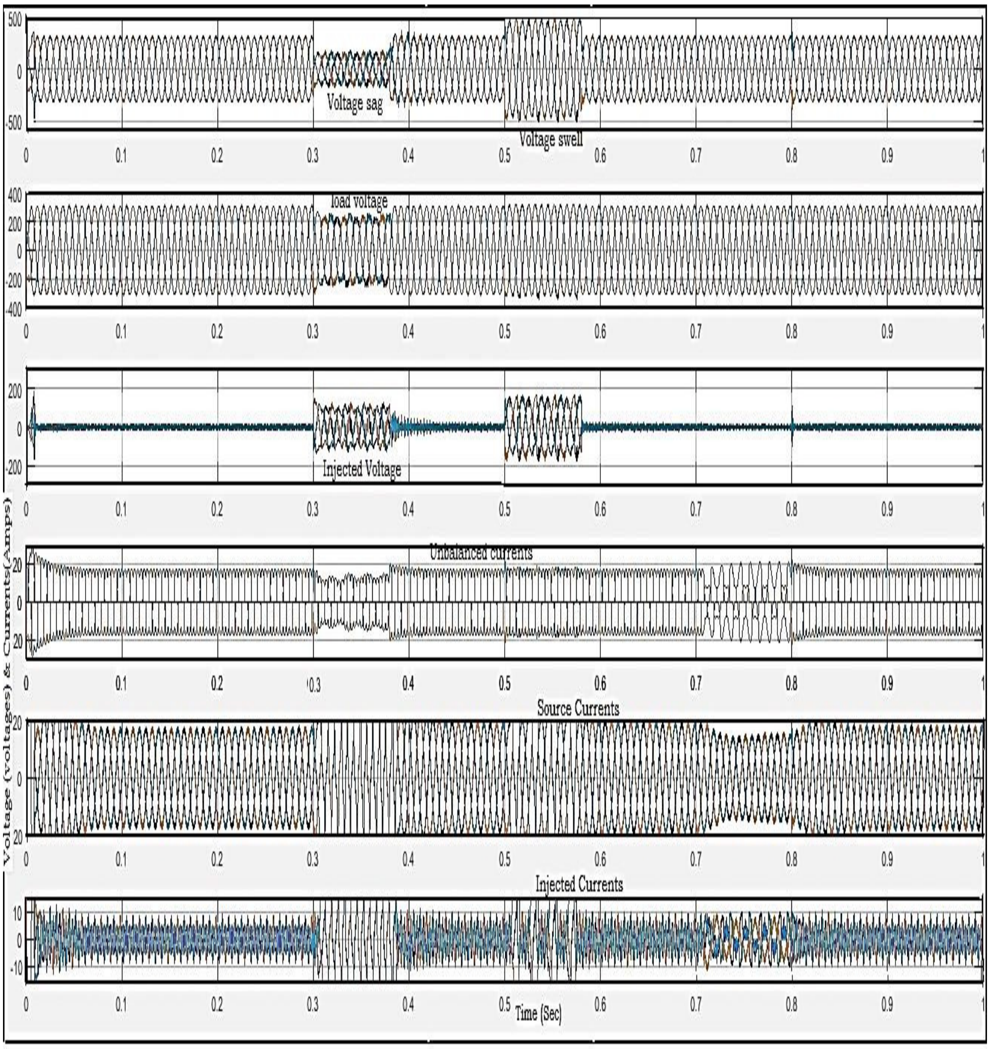

Fig.10**:** Waveforms showing the source voltage sag-swell and the unbalance in the load current.

Table.1: %THD values for UPQC with PV

Control Method	UPQC with PV	
	Parameter	
	Load voltage (V_L)	Source current (I_S)
THD (%)	1.8	2.46

The percentage total harmonic distortion values of the load current is 29.85% and for the source current is of 2.46%. The PF at source terminals is improved.

6. Conclusion

This work about interpretation of a PV based unified power quality conditioner. UPQC is one of the all-round devices for nullifying the power quality issues. The execution of the initiated scheme comprises of a DC/DC converter and a PV unit connected. The suggested method has the caliber to eliminate voltage sag and swells with corrected power factor. The proposed UPQC has attempted to eliminate the problems at the interconnection in the distribution system. For successful working conditions, the THD of source current is within the limits of IEEE 519-1992 admissible scale of 5%.The THD of the source current is 2.46%. The implemented scheme has proper working under linear, non-linear load. The functioning of presented system was recorded through simulation with MATLAB domain.

7. Appendix

Circuit and load parameters:			
Parameter	Value	Parameter	Value
Source Voltage (V_s)	440V	DC link capacitance (C_{dc})	4700uF
Frequency (f)	50Hz	Source resistance (R_{se})	0.01Ω
Load resistance (R_L)	10Ω	Source inductance (L_s)	40mH
Load inductance (L_L)	20mH	Shunt inductance (L_{sh})	10mH
DC link voltage (V_{dc})	700V	Series inductance (L_{se})	3.0mH
PV Model			
Number of cells connected in series (Ns)	200	Number of cells connected in series (Np)	5
Ideal diode constant (a)	0.00032	Boltzmann constant (k)	$1.38e\text{-}^{23}$
No.of Solar panels	23	series resistance (Rs)	0.0041
Short circuit current (Isc)	6.1A	Parallel resistance (Rp)	7.6927
Open circuit voltage (Voc)	35V		

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