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# IMPROVEMENT OF POWER QUALITY USING SOLAR PV INTEGRATED UNIFIED POWER QUALITY CONDITIONER

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***Abstract*-This paper presents, the use of unified power quality conditioner (UPQC) to eliminate power quality issues. The solar PV panel with boost converter is integrated at the DC-link of UPQC. For extracting maximum power from PV panel the boost converter operates. The UPQC consists of the combination of shunt and series inverter. The voltage related power quality problems, such as voltage flicker, swell and sag are eliminated by series inverter. For eliminating the current related problems, such as current harmonics the shunt inverter is used in UPQC. Hence the UPQC performs the multi task, i.e. the voltage related problem as well as current related problems. The performance of solar PV integrated UPQC is simulated using power simulation software.**

***Keyword*- Power quality, solar PV, boost converter, UPQC, voltage harmonics, current harmonics.**

## I. INTRODUCTION

In distribution power system, with the increase in the use of electronic based load the power quality has many issues [1, 2]. The small industrial endowment and residential load consist of supersensitive electronic loads. These loads are highly non linear in nature [3, 4]. Due to this, the harmonics are injected in distribution system. This results into voltage distortion in low voltage distribution system that has comparatively higher supply impedance [5]. The voltage fluctuation leads to the failure or damage of an equipement. Most of the equipment in the residential areas of low voltage are television, air-conditioning, laptop system are protected by usage of voltage stabilizers. There is a requirement for systems to eliminate voltage and current harmonics

For eliminating all the problems related to power quality, the custom power devices are used [6-8]. There are various custom power devices such as, dynamic voltage restorer (DVR), distribution static compensator (DSTATCOM) and unified power quality conditioner (UPQC). DVR is series connected device which eliminates the voltage related problems such as voltage swell/sag. The DSTATCOM is connected in parallel and eliminates the load related power quality issues [9]. UPQC is the combination of series and shunt compensators. Further classification of UPQC depends on its topologies, position of shunt compensators and control techniques. The classification of UPQC is explained in [10].

According to location of shunt compensator UPQC has many types. If the shunt compensator is located at the load side then it is called as (UPQC-R) right shunt UPQC. If it is connected to grid side,then it is (UPQC-L) left shunt UPQC. Again UPQC can be classified as a three different ways based on injection of voltage by the series compensator. If the voltage injected by the series compensator is minimum then it is known as UPQC-P. If the supply current is orthogonal to injected voltage, it is named as UPQC-Q. Net VA rating of UPQC is minimized by voltage injection angle known as UPQC- S. Some other classification of UPQC like UPQC-DG where DC link of UPQC is integrated with distributed energy source [11]. The utility of UPQC is increased due to integration of distributed energy sources.

Most of the research related with integration of PV with custom power devices are working with voltage source converter(VSC). This VSC connected in shunt, injects the active power [12]. A singular topology of integration of PV and UPQC by reducing the variety of switches is determined in [13]. The compensation of current and voltage is done by UPQC, which improves the quality of power in distribution system. In single phase system, for improving the quality of power the single phase UPQC is used which is explained in [12-14]. The performance of UPQC with PV is explained in [15-18].

solar photovoltaic system supplies the active power and UPQC eliminates harmonics. Hence integration of UPQC and solar Photovoltaic cell is preferred for single phase. It is ideal solution for commercial and residential areas as it reduces voltage fluctuations in the distribution system. Because of integration of UPQC and PV it reduces the total cost of installing different individual stabilizers for different loads such as, television, air conditioning etc. An overview concerning numerous factors of UPQC system is explained in [19].

In this paper, the performance of solar PV integrated UPQC is analyzed. The solar PV panel is integrated at the DC link of UPQC through boost converter. The maximum power is tracked from the PV panel by the boost converter. The harmonics and load reactive power is compensated by shunt compensator which is connected to load side.

This paper consist, section I as introduction, section II consist of configuration and design of UPQC, section III includes design of PV-UPQC, section IV shows the simulation results and finally the conclusion.

## II. CONFIGURATION OF UPQC AND PV-UPQC

### *A. CONFIGURATION OF UPQC*

The main two function of the UPQC is to eliminate voltage related problems and current related problems. The combination of two inverters i.e., series and shunt inverter with the DC link connected in between these two inverter is presented in UPQC. The voltage source is variable for series inverter for eliminating voltage variation, fluctuation in voltage, disturbances in supply voltage; whereas the current source is variable for shunt inverter for eliminating distortion in load current and reactive power [20-22].

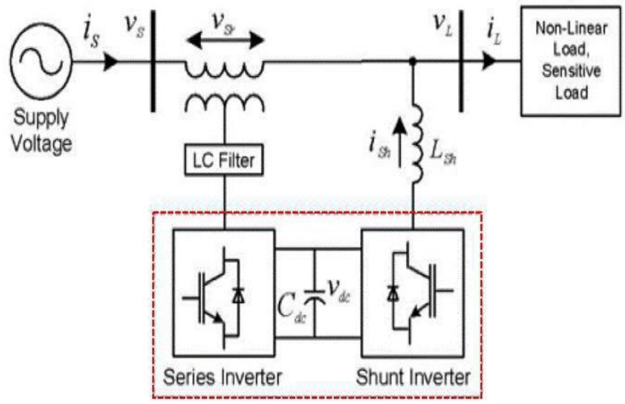


Fig.1. Unified power quality conditioner (UPQC)

Fig.1. represent the configuration of unified power quality conditioner (UPQC). The various components used in UPQC are as follows:

1. Series inverter- As shown in fig. 1. one of the inverters connected in series to the supply known as the series active filter. It behaves as a voltage source line which eliminates the voltage interruption.
2. Shunt inverter - The inverter connected in shunt to the supply line is known as shunt active filter. It eliminates the current related harmonics also minimize the reactive current in the load circuit.
3. DC link-The capacitor or inductor can be used as common DC link. As shown in fig. 4 the capacitor is used as DC link, which supplies the DC voltage.
4. LC filter- The output of the series active filter produces high switching ripples. The LC filter minimizes the ripples in a system. The LC filter acts as the low-pass filter.
5. $L_{sh}$ filter - The $L_{sh}$ filter act as a high-pass filter. The ripples during switching mode are minimized by $L_{sh}$ filter.
6. Injection transformer- The series injection transformer connected to series convertor. The voltage rating and also the current rating can be minimized by using suitable ratio.
   Apart from these all components of UPQC it also has coupling inductor connected in shunt which is connected in between network and shunt inverter.

### *B. CONFIGURATION OF PV-UPQC*

The integration of UPQC with PV for increasing the capability of UPQC and obtaining clean power is shown in fig.2. In this shunt inverter is near load side known as right shunt structure. Near the grid side series inverter is connected.

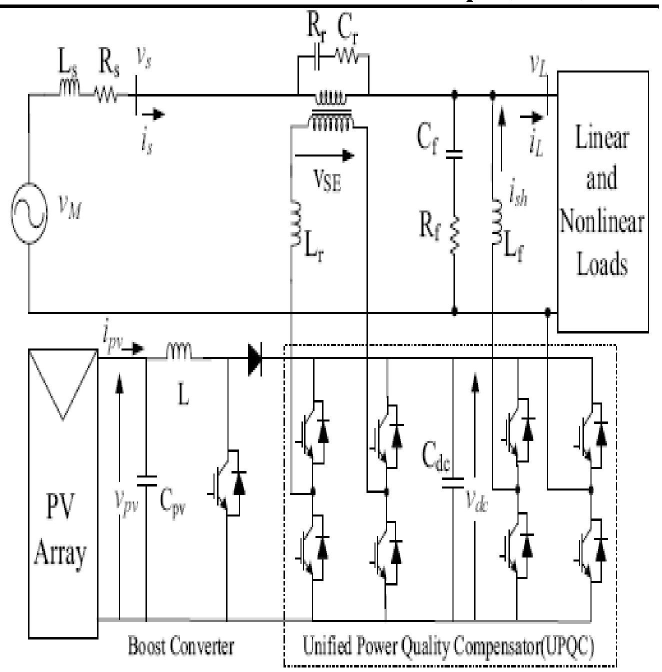


Fig. 2. Configuration of solar PV integrated with UPQC (PV-UPQC)

The series compensator has low rating in this configuration as it is used most commonly and the sinusoidal current flow through series inverter. For compensating the quality problems related to load are compensated by shunt inverter. The voltage of DC link and active power injection by PV array is upheld by shunt converter. But the UPQC does not have capability for compensating the interruption in voltage as it does not have storage for storing the energy. Hence the DC link is present in between the shunt and series inverter. The problems of power quality like, voltage fluctuation, voltage sag, voltage swell, harmonics, is compensated by the series inverter which operates in mode of voltage control. The integration of PV with DC link in UPQC through the boost converter is done [23-24]. MPPT algorithm is used to control i.e. taking more power from the solar panel.

For linear load a phasor diagram UPQC integrated with PV is shown in fig. 3. The 1 subscript shows the condition before sag and 2 subscript shows the condition during sag. At the time of sag, the injected voltage VSE is in phase to grid voltage. The current of shunt inverter $I_{sh}$ is combination of $I_{ash}$ (active current) and $I_{rsh}$ (load reactive current).For maintaining active power the sag current (IS2) is greater than that current which appear before sag.

## III. DESIGN OF PV-UPQC

The design configuration of UPQC integrated with PV consist a design in detail of series ad shunt inverter, PV array, boost converter. The parameters required for designing UPQC-PV are capacitor voltage of DC bus, capacitor size of DC bus, inductor value, PV array and boost converter. Further design of all above mentioned parameter is discussed below:

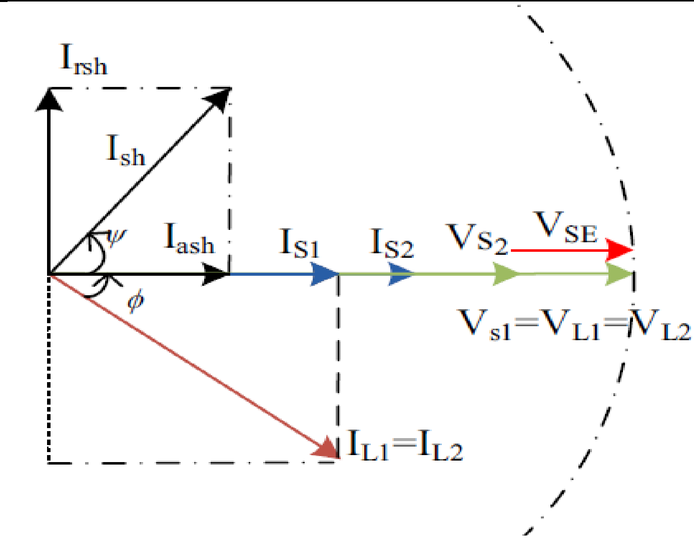


Fig.3. Phasor diagram of linear load for UPQC-PV

*A. Calculation of DC bus voltage*

The voltage source converter based on PWM (pulse width modulation) technique has the magnitude of DC bus voltage nearly equal to grid voltage peak value [21]. Hence magnitude of bus voltage can be determined by grid voltage peak value. For calculating the voltage of DC bus the equation is,

$$V_{dc} = \frac{\sqrt{2}V_s}{m} \quad (1)$$

$$= \frac{\sqrt{2}\times 230}{1} = 325.2691 \approx 325\text{V}$$

In this rms grid voltage is represented by $V_s$, m is modulation index considered as 1. In this system the voltage of grid is 230 V, the voltage of minimum DC bus is 325V.

*B. Rating of DC bus capacitor*

Deciding the value of DC capacitor bus depends on ripple present in DC bus and power flow which is instantaneous in the capacitor of DC bus [21 22]. Hence the size of capacitor is shown

$$P_{PV-UPQC} = C_{dc} \times 2w \times V_{dc} \times \Delta V_{dc} \quad (2)$$

$$\text{Hence, } C_{dc} = \frac{P_{PV-UPQC}}{2w \times V_{dc} \times \Delta V_{dc}} \quad (3)$$

$$= \frac{1150}{2\times 314.1\times 450\times 8.5}$$

$$= 4.7 \text{ mF}$$

In this power dissipated of the system is represented as, $P_{PV-UPQC}$ , $w$ is the angular frequency, voltage of DC- bus is $V_{dc}$ and $\Delta V_{dc}$ is the ripple in voltage. Hence, the rating of capacitor is 4.7 mH.

*C. Rating of series inverter*

In the series mode, a series inverter based on VSC is connected to grid through series transformer. The voltage required to inject decides the exact rating of series transformer. Here, the design of series inverter is done according to compensating $\pm$ 30 voltage.

$$V_{SE} = X.V_{VSE} \quad (4)$$

$$= 230 \times 0.3 = 69V$$

The series inverter designed for mitigating the voltage swell/ sag. Also for keeping modulation index unity the turns ratio of series transformer is kept as,

$$K_{se} = \frac{V_{VSE}}{V_{SE}} \quad (5)$$

$$= \frac{230}{69} = 3.23 \approx 3$$

The series transformer VA rating can be obtained as shown below

$$S_{series} = V_{SE} \times I_{series} \quad (6)$$

$$= 1.96\ KVA$$

*D. Inductor interfacing in shunt inverter and series inverter*

The voltages of DC link, ripple current, switching frequency are the factors for selecting the inductor in shunt inverter.

$$L_{sh} = \frac{V_{dc}\times m}{4\times\alpha\times f_s\times I_{rp}} \quad (7)$$

$$= \frac{450\times 1}{4\times 1.2\times 1000\times 3.1} = 3.02\ mH$$

In this, the voltage of DC bus is $V_{dc}$, modulation index is $m$, $I_{rp}$ is the ripple current, $f_s$ is the switching frequency and $\alpha$ is overloading of shunt inverter.

The inverter connected in series to the grid through by using the interfacing conductor. Hence the estimation of parameter and design of the inductor is required.

$$I_{se} = \frac{K_{se}\times V_{dc}\times m}{4\times\alpha\times f_{se}\times I_{rp}} \quad (8)$$

$$= \frac{3\times 450\times 1}{4\times 1.2\times 10000\times 3.1} = 9.07\ mH$$

In this transformer ratio is indicated as $K_{se}$, bus voltage is $V_{dc}$ , modulation index is $m$, switching frequency is $f_{se}$, ripple current is $I_{rp}$ and $\alpha$ is maximum over loading.

*E. Solar PV panel*

The various energy sources which are Renewable like, sunlight, wind, biomass, flowing water gives clean energy. From all the renewable energy sources (RE), the energy acceptable option is solar energy. The output of solar PV panel is DC power. Further this power is increased as per requirement by boost converter. The DC power is converted into AC power by Inverter.

The UPQC has much capability for improving the quality of current and voltage at industrial power system. Hence, UPQC is one of the solutions for overcoming problems related to power quality. Due to some problems related to limitation of storage of power in Dc link, the UPQC cannot compensate the voltage and current harmonic as it has no storage of energy in DC link. For overcoming this limitation solar energy that is PV array is used for DC-link. The one of the advantage of PV-UPQC is that continuous power supply can be obtained for mitigating harmonics. The equivalent circuit diagram of PV panel is shown in fig. 4.

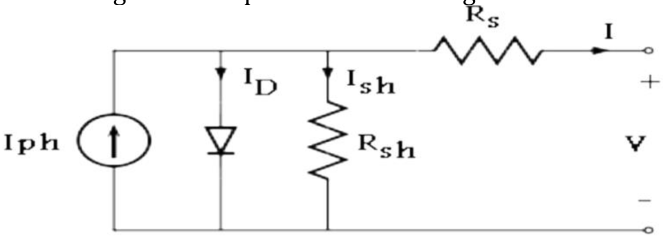


Fig. 4 Equivalent circuit diagram of a PV panel

An ideal photovoltaic system is modeled by a current source connected in parallel with a diode. As no PV cell is ideal, therefore series and shunt resistance are connected to solar cell. $R_S$ is connected is series with PV panel and value of Rs is very small. $R_P$ is the equivalent shunt resistance and it has a very high value.

Applying KCL to the above circuit,

$$I_{ph} = I_D + I_{sh} + I \tag{9}$$

From (9), we get photovoltaic panel current

$$I = I_{ph} - I_D - I_{sh}$$

$$= I_{ph} - I_o\left[\exp\left(\frac{V+I.R_s}{V_T}\right) - 1\right] - \left[\frac{V+I.R_s}{R_p}\right] \tag{10}$$

Where, Iph is the photon current, cell current is I, Reverse saturation current is I0,Cell voltage is V, Rpis the Parallel resistance, Rs is the Series resistance, VT is the Thermal voltage ( VT= KT/q), q is the Charge of an electron, T is the Temperature in Kelvin, K is the Boltzmann constant.

The ratio of peak power to input solar power is efficiency of a solar cell.

$$\text{Efficiency} = \left[\left(\frac{V_{mp}.I_{mp}}{I\left(\frac{KW}{m^2}\right)}\right).A(m^2)\right] \tag{11}$$

Where, $V_{mp}$= voltage at peak power,
$I_{mp}$= current at peak power,
I= solar irradiation,
A= area on which solar radiation fall

The specifications of PV array are as follows:

| Sr no. | Parameter | values |
|---|---|---|
| 1 | Open circuit voltage | 450 V |
| 2. | Maximum power voltage | 9.5 kW |
| 3. | Maximum power current | 4.8 A |
| 4. | Short circuit current | 26.5 A |
| 5. | modular string in series | 12 |
| 6. | String in parallel | 3 |

*F. Boost converter*

The converter which increases the rating of voltage is called as boost converter. The output voltage of the boost converter is always high than the input voltage. The switch used in the boost converter may be IGBT, MOFET, BJT.

The fig.5. Shows the boost converter consisting inductor, (Vg) Voltage source, Capacitor (C), Diode (D), switch controller (S) and load is resistive in nature(R). There are two states of operation in boost converter i.e. on state and off state. If the switch S is closed then it is on sate at that time the D is off and there is increase in inductor current.

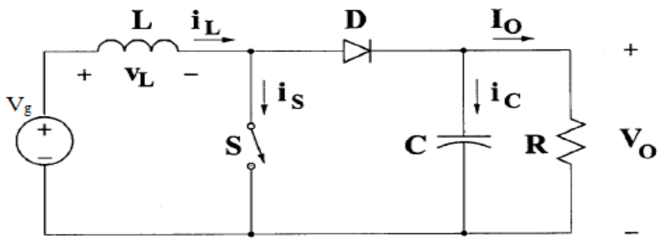


Fig. 5 Boost Converter circuit diagram

The OFF state of boost converter and its derivation are shown below:

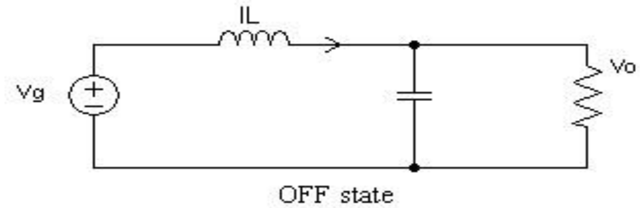


Fig. 6 OFF state of boost converter

In the OFF state the switch is open and the diode is forward biased. The boost converter in off state is shown in fig.6. At the time of OFF state the output voltage is equal to the sum of input voltage and inductor voltage.

In ON state the switch is closed and diode is reversed bias. The boost converter in on state is shown in fig.7. the voltage source charges the inductor and discharges the capacitor. Duty cycle D is calculated as $D = \frac{T_{on}}{T}$ and $T = \frac{1}{F}$.

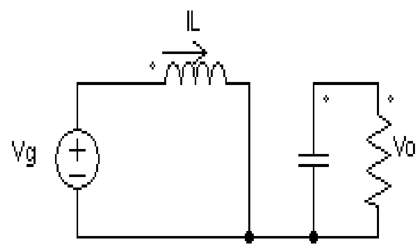


Fig. 7. ON state of boost converter

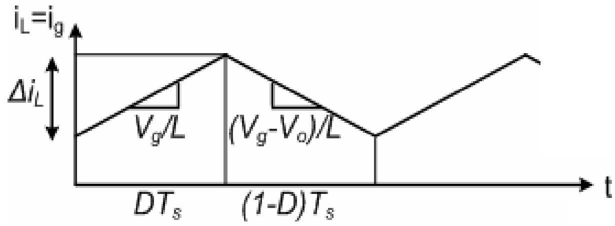


Fig.8 current waveform of inductor

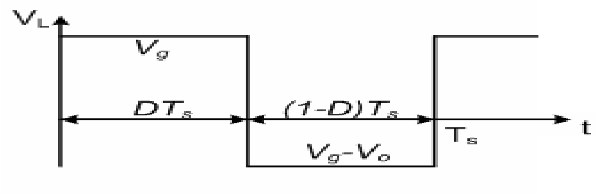


Fig 9. Voltage waveform ofinductor

The voltage equation for inductor is as follows:

$$V_g(DT_s) + (V_s - V_o)(1 - D)T_s = 0 \qquad (12)$$

Hence the output voltage can be obtained as,

$$V_o = \frac{V_g}{(1 - D)} \qquad (13)$$

*G. sinusoidal pulse width modulation*

One of the methods of PWM (pulse width modulation) is sinusoidal pulse width modulation (SPWM). Inverter converts DC to AC by use of switching circuits, sine wave is simulated by voltage square pulses on half cycle. The switching signal for the inverter is generated by using sinusoidal pulse width modulation technique. In this method there is comparison of modulating voltage that is sinusoidal $e_C$ of the required output frequency i.e. $f_o$ and triangular frequency $V_{tri}$.

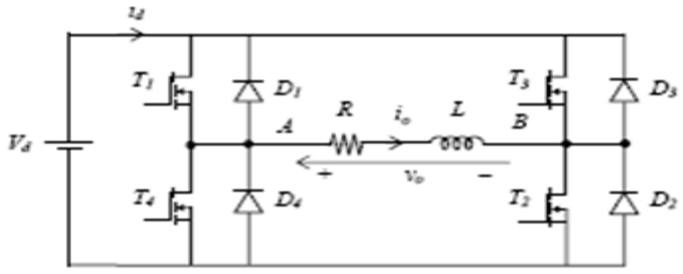


Fig.10 Full Bridge Inverter

In the full bridge inverter, switching scheme are as follows: When T1 transistor and T2 transistor are switched on and T3 transistor and T4 transistor are off at that time $e_C > V_{tri}$. When T3 transistor and T4 transistor are switched on and T1 transistor and T2 transistor are off at that time $e_C < V_{tri}$. The output waveform of the Sinusoidal pulse width modulation with modulating voltage sinusoidal $e_C$ and triangular frequency $V_{tri}$, is shown in fig 10.

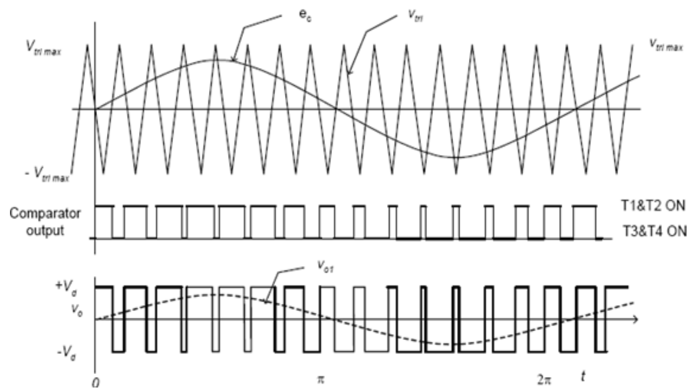


Fig 11. Sinusoidal pulse width modulation

IV. Simulation results

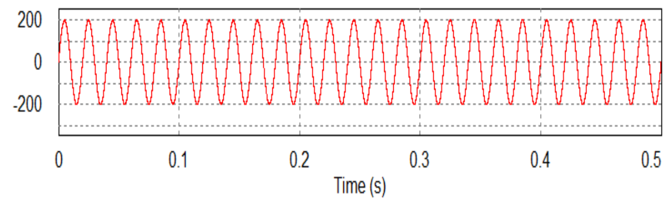


Fig.12 Voltage sag in system

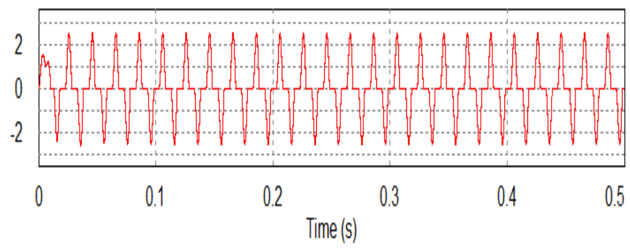


Fig. 13 Mitigation on voltage sag

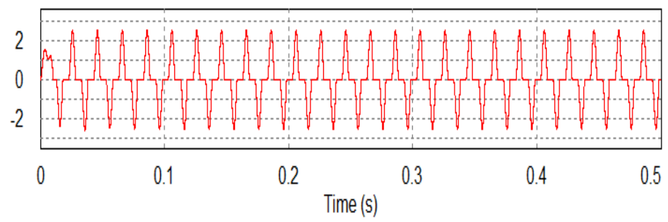


Fig 14 Current harmonics in system

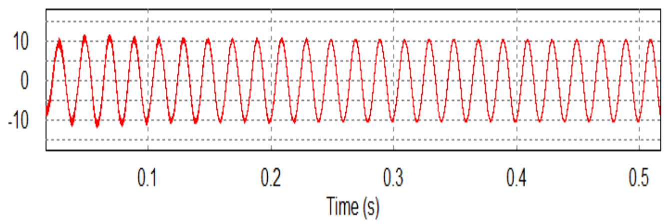


Fig.15 Mitigation of current harmonics

Fig. 12 shows the voltage sag in the system, as the non linear load are connected to the system. The voltage is 200 V that is the voltage sag is occurred. The expected voltage for single phase supply is 230 V. Hence the voltage sag is eliminated by series inverter; by injecting the required voltage in PV integrated UPQC. Therefore by compensating the voltage sag the output acquired is 230 V, as shown in fig. 13.

The main cause of harmonics present in load current is the non linear load. The output waveform of current is not sinusoidal due to harmonics present in it, as shown in fig. 14. However, the UPQC integrated with PV shows its best performance by compensating the harmonics in current, so as to obtain the sinusoidal current waveform as shown in fig. 15.

V. CONCLUSION

This paper shows the performance of UPQC by integrating solar PV panel. The continuous supply is given to the UPQC by the solar PV panel. So the current harmonics and voltage related problems are eliminated. The simulation is done on power simulation software. In this, the overall simulation of unified power quality conditioner integrated with solar PV is done. The output results of elimination of voltage and current harmonics is explained.

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