Power Quality Improvement in a Grid Connected PV Cell using UPQC with Fuzzy Logic Controller

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Abstract:

In this paper, the design of combined operation of UPQC and PV-ARRAY is designed. The proposed system consists of UPQC connected back to back by a dc-link to which pv-array is connected. The UPQC system takes care of both current and voltage in inter-connected mode and islanding mode by injecting active power to grid. The Power Electronic Devices (PED) and Sensitive Equipments (SE) are normally designed to work in non-polluted power system, so they would suffer from malfunctions [when supply voltage is not pure sinusoidal. Thus this proposed operating strategy with flexible operation mode improves the power quality of the grid system combining photovoltaic array with a control of UNIFIED POWER QUALITY CONDITIONER. Pulse Width Modulation (PWM) is used in both three phase four leg inverters. A Proportional Integral (PI) and Fuzzy Logic Controllers are used for power quality improvement by reducing the distortions in the output power. The simulated results were compared among the two controller's strategies With pi controller and fuzzy logic controller.

Keywords: ***Logic controller, Controllers, Harmonics, reactive power Active power, Unified power quality controller, Total harmonics distortion.***

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I. INTRODUCTION

When the supply voltage is not pure sinusoidal the devices suffer from harmonics, inter harmonics, notches and neutral currents, the power quality should be improved [3]. The solution to PQ problem can be achieved [9] by adding auxiliary individual device with energy storage at its dc-link by PV-array. This auxiliary equipment has the general name of power conditioners and is mainly characterized by the amount of stored energy or stand alone supply time. That auxiliary equipment having both “shunt” and “series” inverter connected back to back by a dc-link is called the “unified power quality conditioner”. The Photo voltaic and UPQC is used to improve the power quality.

The UPQC is able to compensate voltage interruption and active power injection to grid because in its dc-link there is energy storage known as Distributed Generating (DG) source. The attention to distributed generating (DG) sources is increasing day by day. The important reason is that roll they will likely play in the future of power systems. Recently, several studies are accomplished in the field of connecting DGs to grid using power electronic converters.

The UPQC is a combination of series and shunt active filters connected in cascade via a common DC link capacitor. The UPQC is used to compensate [4] for supply voltage power quality issues such as, sags, swells, unbalance, harmonics, and for load current power quality [6] problems such as unbalance , harmonics, voltage dips , reactive current and neutral current.

A. *System Description of UPQC*

UPQC has two inverters shunt (or) D-Statcom and series (or) DVR voltage source inverters. Series inverter stands between source and coupling point [5] by series transformer and Shunt inverter is connected to point of common coupling (PCC) by shunt transformer. Shunt inverter operates as current source and series inverter operates as voltage source.UPQC is able to reduce unwanted distortions [1] and can compensate voltage interruption because of having PV-array as a source. Common interconnected PV systems structure is as shown in figure 1. In this paper it is proposed for UPQC, where PV is linked to DC link in UPQC as energy source [1] [9].

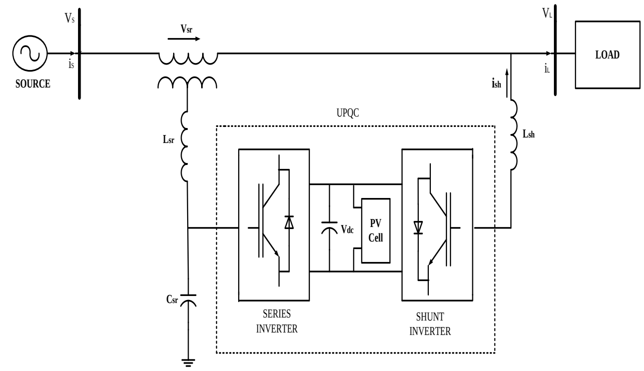

Fig 1. Configuration of proposed UPQC

B. *System Design*

The following are the important parts of the system design

Series inverter control
Shunt inverter control
Controlling strategy is designed and applied for two interconnected and islanding modes. In inter-connected mode, source and PV provide the load power together while in islanding mode; only PV is used to distribute power to the load. By disconnecting voltage interruption, system [1] comes back to interconnected mode.

II. SERIES INVERTER CONTROLLING

The duty of the series inverter is to compensate the voltage disturbance in the source side, grid which is due to the fault in the distribution line. It calculates the reference voltage values which are injected to grid by series controller. The series controller of UPQC [1] , load sinusoidal voltage control design and implementation strategy is proposed as shown in figure below:

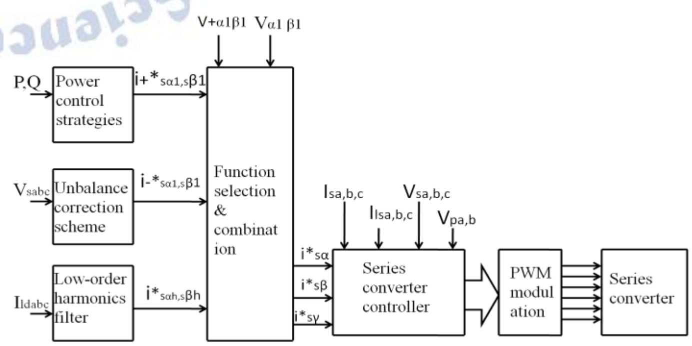

Fig2. Block diagram of overall control structure with Series converter

The series converter is applicable for achieving multilevel control objectives[6]. Hence, the block "function selection and combination" is shown in fig.2 is that different types of objectives can be integrated into the system by choosing appropriate reference signals i*sα,i*sβ,i*sγ. Details about the unbalance correction scheme, which is used to generate current reference [1] [4] for negative-sequence voltage compensation.

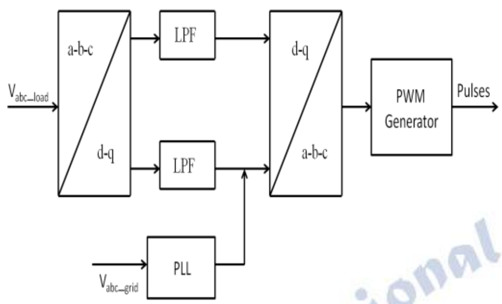

Fig 3. Control block diagram of series converter

A. *Shunt inverter controlling*

Shunt inverter undertakes two main operations. The current harmonics generated by nonlinear load and active power generated by Photo voltaic (PV) system. The shunt inverter controlling system should be designed in a way that it would provide the ability of undertaking two above operations. Shunt inverter control [9] calculates the compensation current for current harmonics and reactive Power when PV is out of the grid [7].

The power loss caused by inverter operation should be considered in this calculation. It has the ability of stabilizing DC-link voltage during shunt inverter operation to compensate voltage distortions[6]. The stabilization is maintained by DC-link capacitor voltage controlling loop in which fuzzy logic controller is applied. Shunt inverter control consists of the control circuit as shown in figure below.

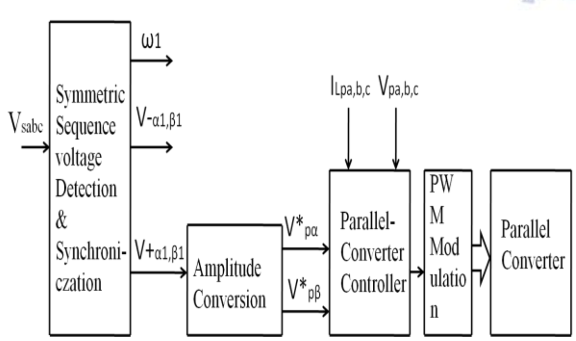

Fig 4. Block diagram of overall control structure with Parallel converter

As shown in Fig. 4 , based on the fundamental positive sequence grid voltages (V+α1,V+β1) derived in the stationary frame. The reference signals (V*pα,V*pβ) with a specified amplitude for the parallel converter then give to PWM[4].

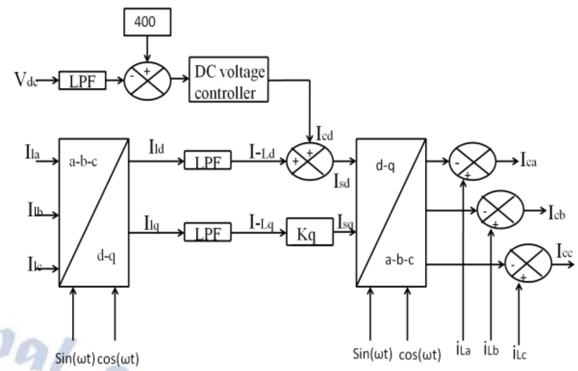

Fig 5. Control diagram of the parallel converter

III. MODELING OF PV MODULE

The Photo Voltaic Cell is used for transforming the sun rays or photons directly into electric power.

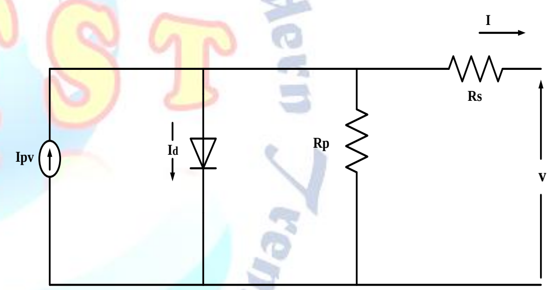

Fig 6. Equivalent circuit of a PV Cell

The equivalent circuit of a practical PV cell is shown in fig. 6. The characteristic equation of a PV cell is the output current produced by it and is expressed as

$$I = Ipv - Io\left(e\left(\frac{V + RsI}{Vta}\right) - 1\right) - \frac{V + RsI}{Rp} \qquad (1)$$

Where I_{PV}=Current generated by solar radiation

I_0= Leakage current

Vt =Thermal voltage of PV module with Ns

PV cell connected in series = NsKT/Q

K=Boltzmann constant=1.3806503 x 10-23J/K

Q=Electron Charge=1.60217646 x 10-19 C

T=Temperature in Kelvin a=Diode ideality constant (1<a<1.5)

PV cells connected in parallel increases the total output current of the PV module where as cells connected in series increases the total output voltage of the cell. The open circuit voltage/temperature coefficient (KV), the short circuit current/temperature coefficient (KI), and the maximum experimental peak output power (Pmax, e).These information are always given at standard test condition i.e. at 1000W/m2 irradiation and 25^{0}C temperature.

The current generated by solar radiation depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation[6]

$$Ipv = (Ipv,n + K1\Delta T)\frac{G}{Gn} \qquad (2)$$

Where,

I_{PV}, n is the light generated current

T Δ =Actual temperature-Nominal temperature in Kelvin

G=Irradiation on the device surface

Gn=Irradiation at nominal irradiation

$$Io = Io,n\left[\frac{Tn}{T}\right]^{3} \exp\left[\frac{qEg}{aK}\left(\frac{1}{Tn} - \frac{1}{T}\right)\right]$$

(3)

$$Io,n = \frac{Isc,n}{\exp\left(Voc,n \big/ aVt,n\right) - 1}$$

(4)

Where Voc, n=Nominal open circuit voltage of the PV moduleLastly the combination of series and parallel resistance of the PV [9] cell can be calculated by any iteration method.

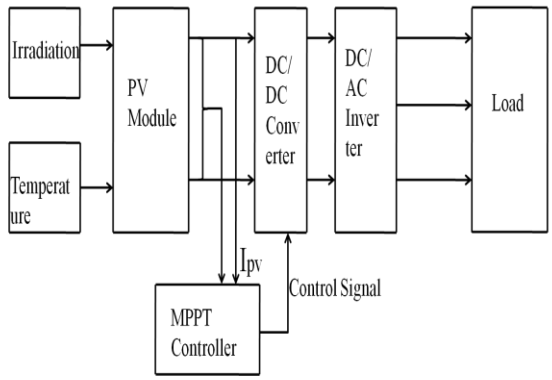

Fig 7. Complete block diagram of PV Module with MPPT Controller

Figure 7 shows the complete block diagram of a PV module with a MPPT controller and feed power to the load through a dc to dc converter. The output current and voltage of the PV module is taken as input by MPPT and its input is based on the control algorithm it gives appropriate command to the converter to interface the load with the PV module.

IV. MAXIMUM POWER POINT TRACKING

Maximum Power Point tracking controller is basically used to operates the Photovoltaic modules in a manner that allows the load connected with the PV module to extract the maximum power which the PV module capable to produce at a given atmospheric conditions. The single operating point of PV module has the values of the current and voltage of the cell result in a maximum output power. It is a big task to operate a PV module consistently on the maximum power point and for which many MPPT algorithms have been developed[5]. The leading technique of MPPT is Perturb and Observe (P&O) method. This method is having its own advantages and disadvantages. The aim of the present work is to improve the (P&O). MPPT controller and then the fuzzy control has introduced on it to improve its overall performance.

V. PERTURB & OBSERVE TECHNIQUE (P&O) FOR MAXIMUM POWER POINT TRACKING

Currently the most popular MPPT algorithm is perturb and observe (P&O), where the current/voltage is repeatedly perturbed by a fixed amount in a given direction, and the direction is alternated only the algorithm detects a drop in power. If the enhancement of power is observed then the subsequent perturbation should be kept in the same direction to reach the MPP and if there is a decrease in power then the perturbation should be reversed. The perturbation of the controller gives a reference voltage which is compared with the instantaneous PV module output voltage and the error is fed to a PI controller which in turns decides the duty cycle of the DC/DC

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converter as shown in Figure 8.The process of perturbation is repeated periodically until the MPP is reached. So at every point of PV-array the MPP and correspondingly capacitor-DC links voltage are calculated.

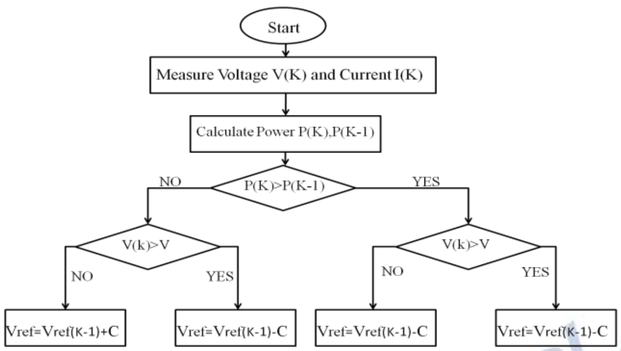

Fig 8. Algorithm for Maximum Power Point tracking by Perturb and Observe method

VI. FUZZY LOGIC CONTROLLER

The three stages of the controller are
1)Fuzzification.
2)Rule base .
3)Defuzzification.

During fuzzification, numerical input variables are converted into linguistic variable based on a membership functions. The inputs of MPP are considered w.r.t change in current E and change in voltage error C. When the value of E and C are found they are converted into linguistic variables. The output of fuzzy controller, which is the duty cycle ratio D of the power converter, is used for rule base table. The values allocated to D for the different combinations of E and C is based on the user. Depending on the values of P&O algorithm rule base is designed. In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function. However, their influence depends a lot on the intelligence of the user or control engineer in choosing the right error computation and coming up with the rule base table. The comparison for error E and change in code C are given as follows:

$$E = \frac{P(K) - P(K-1)}{I(K) - I(K-1)} \quad (5)$$

$$C = V(K) - V(K-1) \quad (6)$$

A. Fuzzy Controller

The general structure of a complete fuzzy control system is given in Figure. 9. The plant control 'u' is inferred from the two state variables, error (e) and change in error (Äe) The actual crisp input are approximates to the closer values of the respective universes of its course. Hence, the fuzzyfied inputs are described by singleton fuzzy sets. The detailed of the controller is based on the phase plan. The control rules base are designed to assign a fuzzy set of the control input u for each combination of fuzzy sets of e and de. The Table.1. is as shown in below

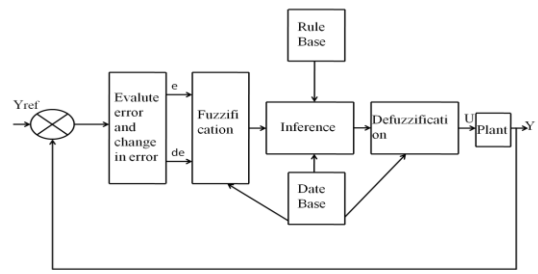

Fig 9. Basic structure of fuzzy control system

Table 1. Fuzzy Rules

error \ code	NL	NM	NS	Z	PS	PM	PL
NL	PL	PL	PL	PL	NM	Z	Z
NM	PL	PL	PM	PL	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

Here NL=Negative Large
NM=Negative Medium
NS=Negative Small
Z=Zero
PS=Positive Small
PM= Positive Medium

VII. EMPLOYED CONfiGURATION OF THE GRID INTERFACING CONVERTER SYSTEM

In this case, UPQC finds the ability of injecting power using PV to sensitive load during source voltage interruption. Fig. 1 shows the configuration of proposed system. In this designed system, two Operational modes are studied as Interconnected mode: where PV transfers power to load and source and Islanding mode: where the source voltage is interrupted and PV provides a part of load power separately.

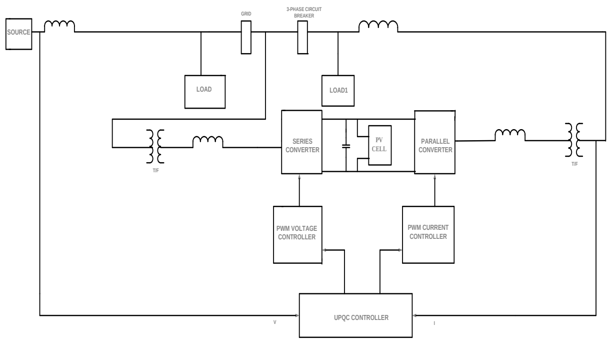

Fig 10. Grid interfacing converter ystem

VIII. RESULTS

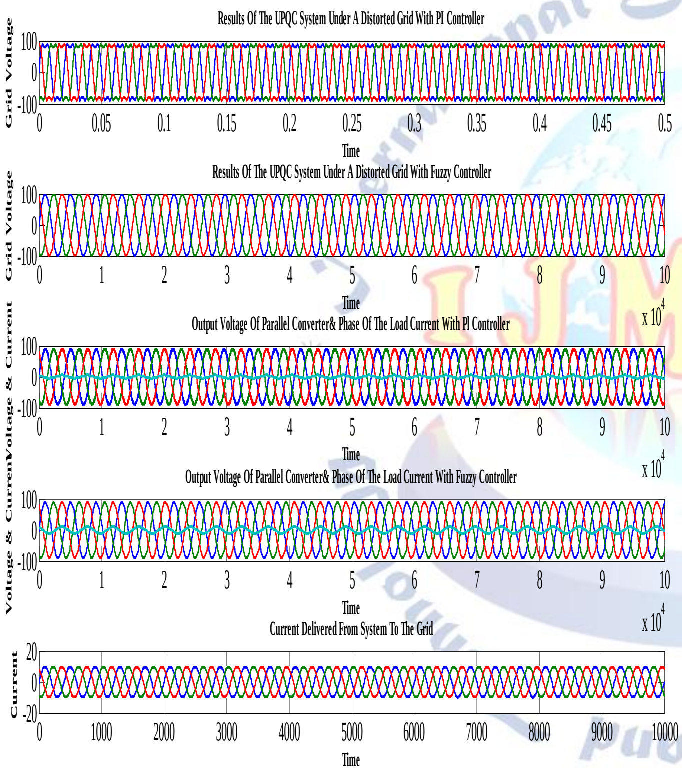

Fig 11. UPQC system under distorted condition

From the above figure 11 results under distorted grid voltage side a harmonics is obtained with PI controller. These harmonics are eliminated in grid voltage side by applying fuzzy controller so in turn pure sinusoidal wave is obtained. The output voltage of parallel converter is reduced by using fuzzy controller compared to PI controller. The source current returns to sinusoidal mode after passing the transient state at 0.00055sec when PV outages. When PV outages in advance, voltage has 180° phase difference with its current and PV injects current to source in addition to providing load that is islanding mode. After PV outages, it is seen that, the angle between current and voltage is zero and UPQC compensates current harmonics and power factor. The total harmonic distortion factor in grid voltage side the difference is 7.03% by comparing both controllers.

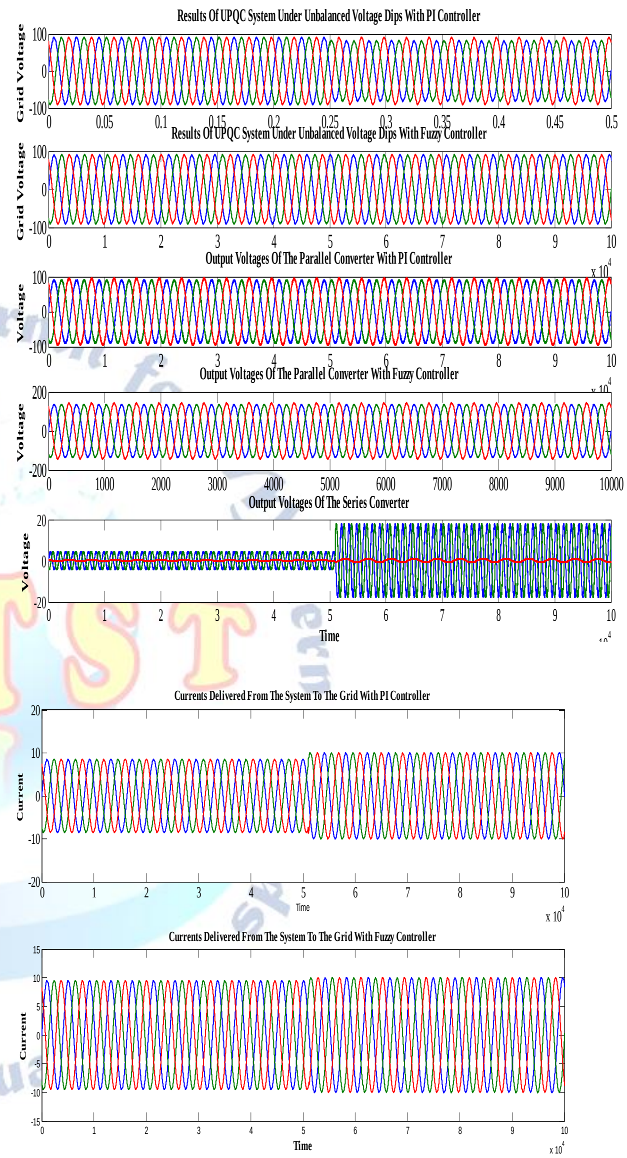

Fig 12. UPQC system under unbalanced voltage dips

From the above figure 12 results under unbalanced voltage dips in grid voltage side, voltage dips are obtained with PI controller that is eliminated by using fuzzy controller and a pure sinusoidal wave is obtained. The current delivered from the system to the grid at 0.0007 sec there is change in the value of PI controller that will be reduced by applying fuzzy controller. The value of THD across the grid voltage side difference is

7.06% by comparing both controllers and also in series converter THD is 1.45% .

Output voltages of the parallel converter tested under a single phase nonlinear Load

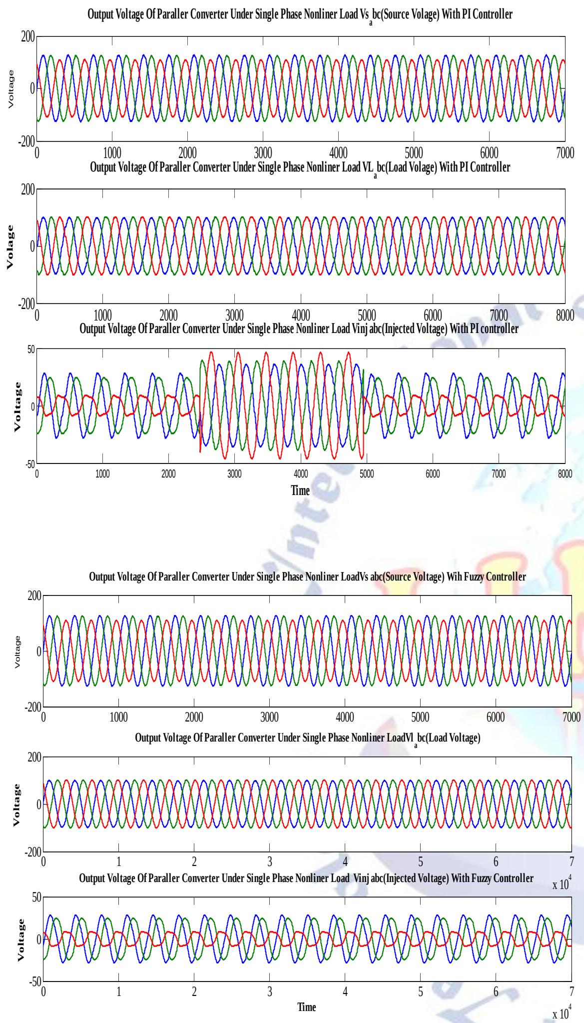

Fig 13. Output voltage of parallel converter under single phase non-linear load

From the above figure 13 result single phase nonlinear load at source voltage V s with PI controller at the time period during 2000sec to 4000sec there is voltage sag. This sag is reduced by applying fuzzy controller as shown in the above figure. When voltage (Vinjecj) is injected with PI controller at single phase nonlinear load the obtained voltage swell is eliminated by using fuzzy controller.

IX. CONCLUSION

In this paper, the results of analyzing combined operation of UPQC and PV is explained. The designed is used for both islanding and interconnected modes. The merits of the new system is reducing the expense of PV interface inverter connection to grid because of applying UPQC shunt inverter and also is the ability of compensating the voltage interruption using UPQC because of connecting PV array to DC link. In this proposed system, P&O method is used to achieve the maximum power point of PV array. Along with Advanced compensation of faulted voltage from source, when compared to PI controller fuzzy is more advantageous because of its faster response. The operation of fuzzy logic is much simpler when the fault occurs at the source due to its rule during the type of fault obtained in the source voltage, and most important thing we have to concern it is very less in cost compared to PI controller. The results obtained for the Grid interfacing using series and parallel converter system with conventional PI controller and Fuzzy logic controller are shown above.

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