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Improvement of Power Quality using Fuzzy Logic Controller in Grid Connected Photovoltaic Cell using UPQC

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ABSTRACT

In this paper, the design of combined operation of UPQC and PV-ARRAY is designed. The proposed system is composed of series and shunt inverters connected back to back by a dc-link to which pv-array is connected. This system is able to compensate voltage and current related problems both in inter-connected mode and islanding mode by injecting active power to grid. The fundamental aspect is that the power electronic devices (PE) 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

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1. INTRODUCTION

One of the important aspects is that, power electronic devices and sensitive equipments are designed to work in non-polluted power systems. So, they would suffer from malfunctions when the supply voltage is not pure sinusoidal. As these devices are the most important cause of harmonics, inter harmonics, notches and neutral currents, the power quality should be improved. The solution to PQ problem can be achieved 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" (UPQC) [1]. Renewable energy resource that is Photo voltaic with UPQC is greatly studied by several researchers as a basic device to control the power quality. The work of UPQC is reducing perturbations which affect on the operation of sensitive loads [2].

UPQC is able to reduce voltage sag, swell, voltage and current harmonics using shunt and series inverters. In spite of this issue, 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. Here, grid's interface shunt inverters are considered more where the reason is low sensitiveness of DGs to grid's parameters and DG power transferring facility using this approach. Although Distributed Generating needs more controls to reduce the problems like grid power quality and reliability, PV energy is one of the distributed generation sources which provides a part of human required energy nowadays and will provide in the future scope [3]. The greatest share of applying this kind of energy in the future will be its usage in interconnected systems. Now a days, so many countries like European has caused interconnected systems development in their countries by choosing supporting policies. In this paper, UPQC and PV combined system has been presented. UPQC introduced in has the ability to compensate voltage swell and sag, harmonics and reactive power.

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

2. SYSTEM DESCRIPTION OF UPQC

UPQC has two inverters shunt (or) D-Statcom and series (or) DVR voltage source inverters which are as 3-phase 4-leg. Series inverter stands between source and coupling point 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 current's harmonics, to compensate reactive power, voltage distortions and can compensate voltage interruption because of having PV-array as a source. Common interconnected PV systems structure is as shown in Figure 1 [4]. In this paper a new structure is proposed for UPQC, where PV is connected to DC link in UPQC as energy source [5].

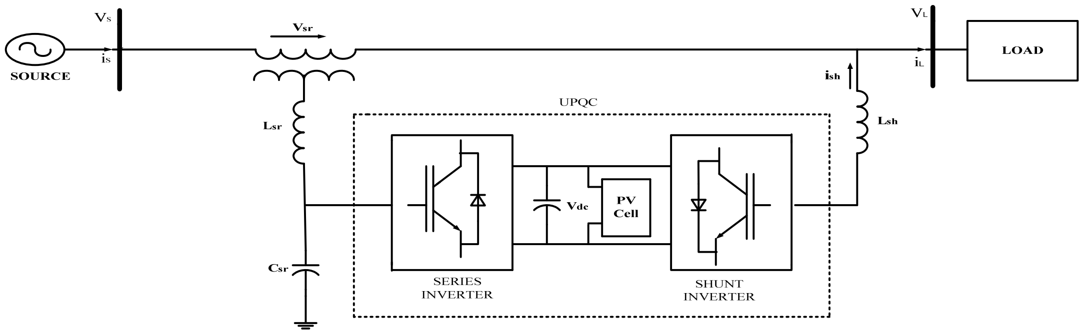

Figure 1. Configuration of proposed UPQC

3. SYSTEM DESIGN

The controlling design of proposed system is composed of two following parts:

a) Series inverter control

b) 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 transfers the power to the load. By removing voltage interruption, system comes back to interconnected mode.

3.1. 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. Series inverter control calculates the voltage reference values which are injected to grid by series controller. In order to control series controller of UPQC, load sinusoidal voltage control design and implementation strategy is proposed as shown in figure below:

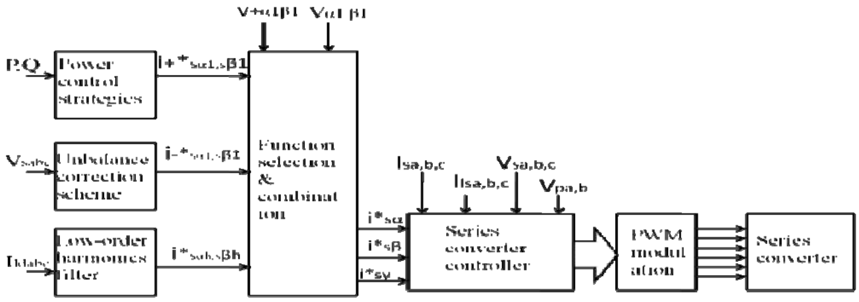

Figure 2. Block diagram of overall control structure with Series converter

The series converter is applicable for achieving multilevel control objectives [6]. Hence, the block "function selection and combination" is shown in Figure 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 for negative-sequence voltage compensation. For the power control strategy, which are used to obtain desired currents for active/reactive power transfer [7]. Due to the space limitation, they are not duplicated here. The active filter function is represented by the block "low-order harmonics filter". References is denoted by i*sαh,sβh,sγh can be obtained [8]. In order to track the desired reference signals, the rest of this section presents the main design aspects of the series and parallel converter control

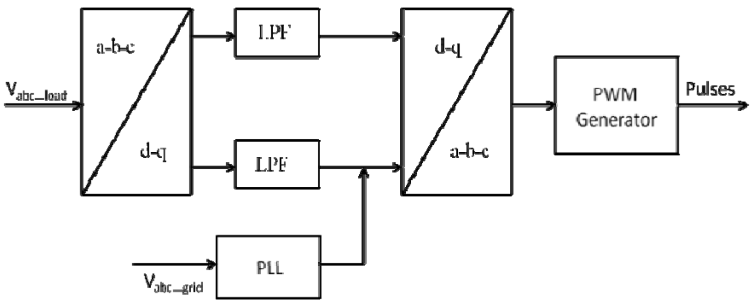

Figure 3. Control block diagram of series converter

3.2. Shunt Inverter Controlling

Shunt inverter undertakes two main operations. First is compensating both current harmonics generated by nonlinear load and reactive power, another is injecting 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 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.

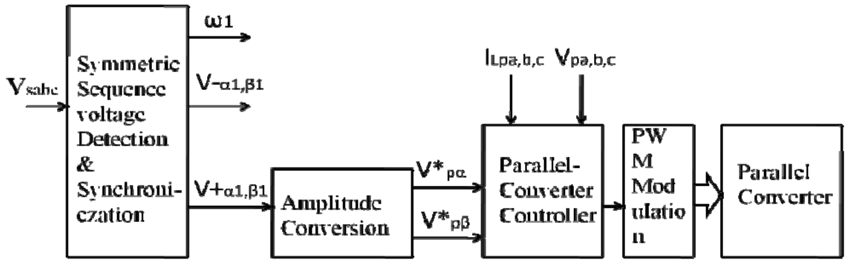

Figure 4. Block diagram of overall control structure with Parallel converter

As shown in Figure 4 , based on the fundamental positive sequence grid voltages (V+α1,V+β1) derived in the stationary frame, the amplitude conversion block first shapes the signals to per-unit quantities and then generates a set of reference signals (V*pα,V*pβ) with a specified amplitude for the parallel converter then give to PWM [4].

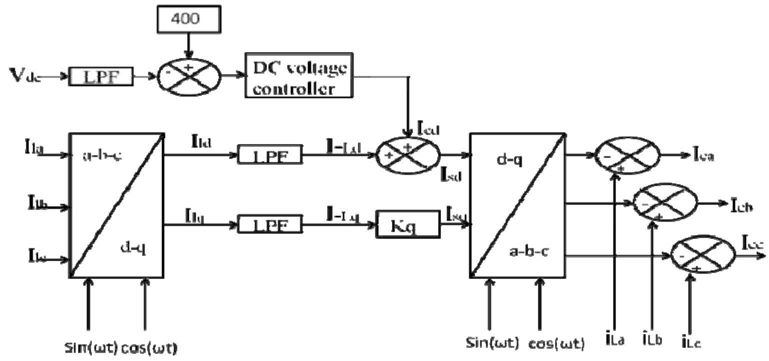

Figure 5. Control diagram of the parallel converter

4. MODELING OF PV MODULE

The PV cell is the basic unit of a photovoltaic module and it is the element in charge of transforming the sun rays or photons directly into electric power.

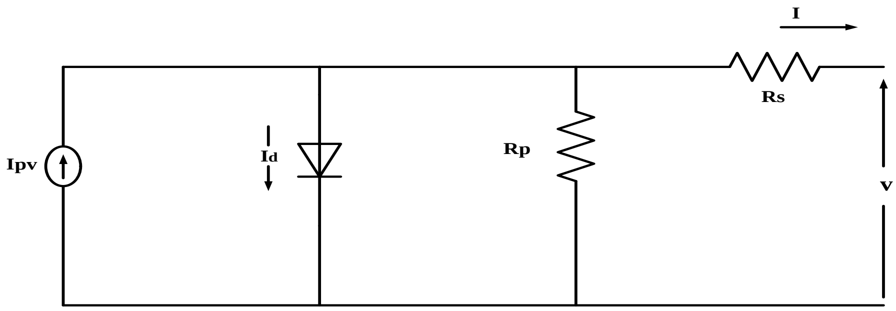

Figure 6. Equivalent circuit of a PV Cell

The equivalent circuit of a practical PV cell is shown in Figure 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, IPV=Current generated by the incident solar radiation
I0=Reverse saturation or leakage current of the diode
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 250C temperature. The other information like the light generated diode, saturation current, diode ideality constant, parallel and series resistance which are not noticed in manufacturer datasheet but necessary for the simulation purpose can be evaluated as follows [7].

The current produce by the event solar radiation is 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,
IPV, n is the light generated current at the nominal condition i.e. at 25oC and 1000W/m2
T Δ =Actual temperature-Nominal temperature in Kelvin
G=Irradiation on the device surface
Gn=Irradiation at nominal irradiation

The diode saturation current I0 and its addition on the temperature may be expressed as [4]:

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

Where Eg is the band gap energy of the semiconductor and Io, n is the nominal saturation current and is expressed as [3]:

$$Io,n = \frac{Isc,n}{\exp\left(Voc,n / aVt,n\right)-1} \qquad (4)$$

Where Voc, n=Nominal open circuit voltage of the PV module

Lastly the series and parallel resistance of the PV cell can be calculated by any iteration method.

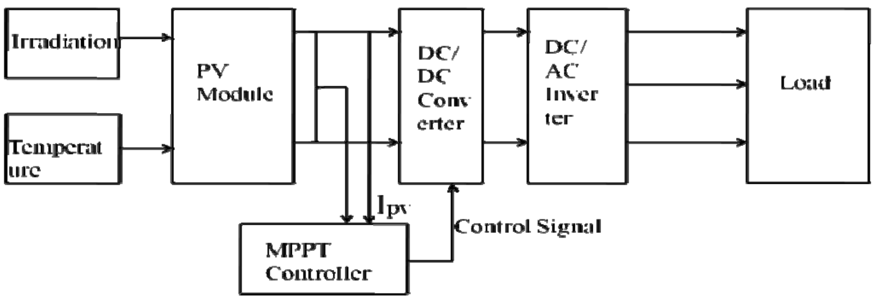

Figure 7. Complete block diagram of PV Module with MPPT Controller

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

5. 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. PV module has a single operating point where 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 most popular among the available MPPT techniques 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.

6. 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. Here if there is an improve in power, 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. In the proposed work each 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 converter as shown in Figure 8. The process of perturbation is repeated periodically until the MPP is reached. Hence at every instant of PV-array we are determining MPP and correspondingly capacitor-DC links voltage is charged.

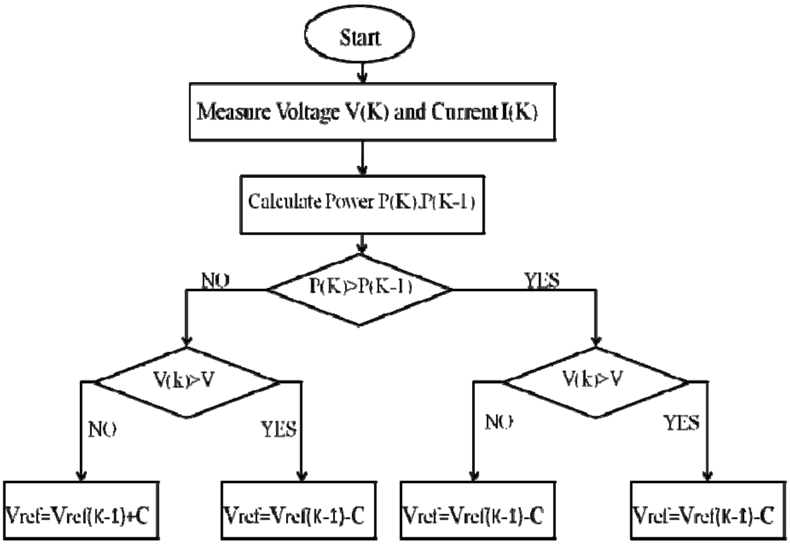

Figure 8. Algorithm for Maximum Power Point tracking by Perturb and Observe method

7. FUZZY LOGIC CONTROLLER

Fuzzy logic control mostly consists of three stages:

a) Fuzzification

b) Rule base

c) Defuzzification

During fuzzification, numerical input variables are converted into linguistic variable based on a membership functions. For these MPP techniques the inputs to fuzzy logic controller are taken as a change in power w.r.t change in current E and change in voltage error C. Once E and C are calculated and converted to the linguistic variables, the fuzzy controller output, which is the duty cycle ratio D of the power converter, can be search for rule base table. The variables assigned to D for the different combinations of E and C is based on the intelligence of the user. Here the rule base is prepared based on P&O algorithm.

In the defuzzification stage, the fuzzy logic controller output is converted from a linguistic variable to a numerical variable still using a membership function. MPPT fuzzy controllers have been shown to perform well under varying atmospheric conditions. 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:

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

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

8. 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 elaboration of this 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:

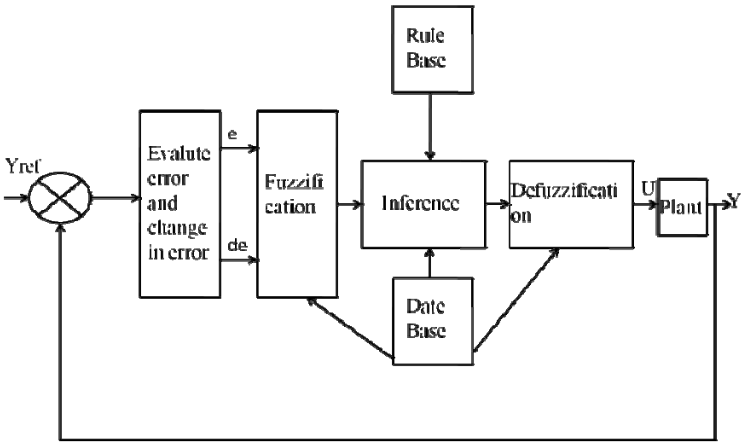

Figure 9. Basic structure of fuzzy control system

Table 1. Fuzzy Rules

code / error	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
PL= Positive Large

9. 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. Figure 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.

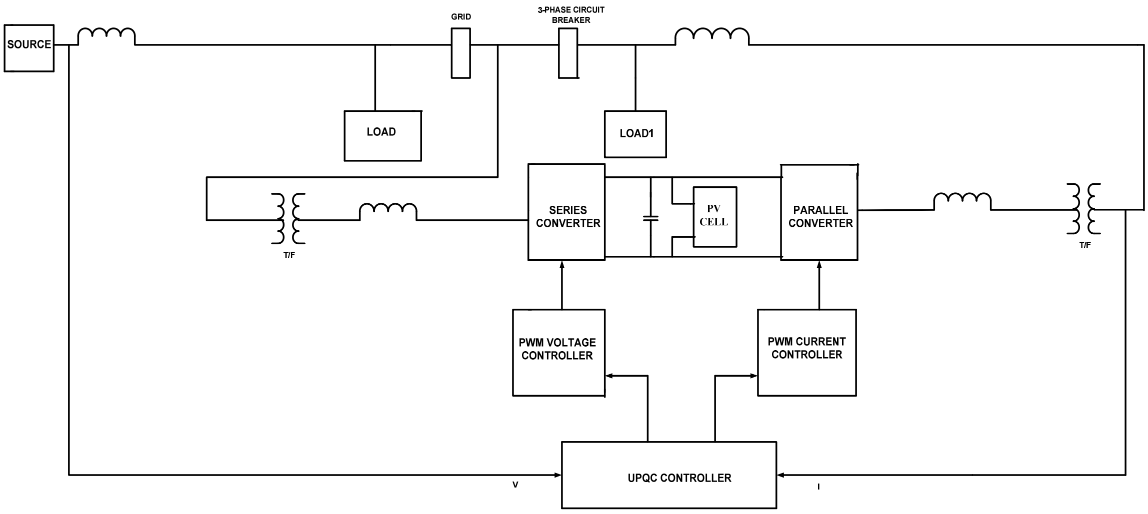

Figure 10. Grid interfacing converter ystem

10. RESULTS

10.1. Experimental Results of the Series-parallel System under Unbalanced Voltage Dips

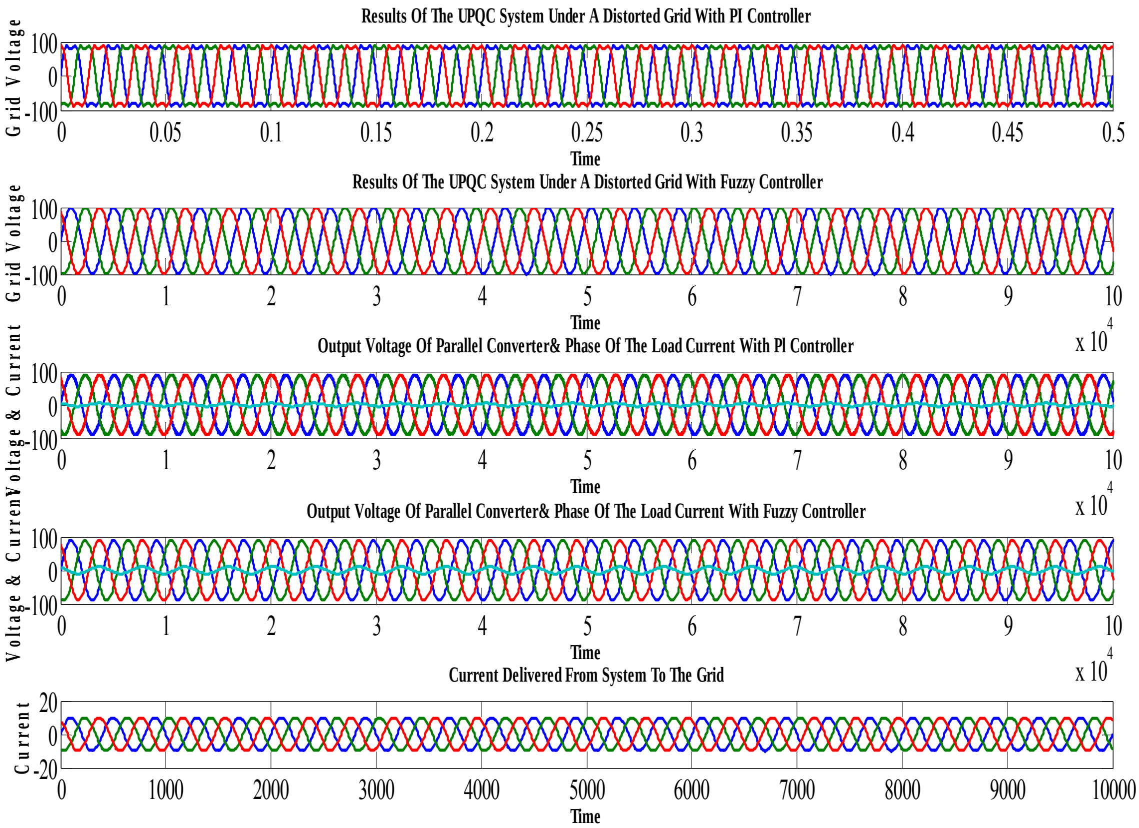

Figure 11. UPQC system under distorted condition

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 magnitude of output voltage of parallel converter is reduced by using fuzzy controller compared to PI controller.At 0.00045sec when PV out-ages, source current returns to sinusoidal mode after passing he transient state. It can understood that, before PV outages, 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, current and voltage are in same phase and UPQC compensates current harmonics and power factor. The THD factor in grid voltage side the difference is 7.03% by comparing both controllers.

10.2. Experimental Results of the Series-parallel System under Unbalanced Voltage Dips

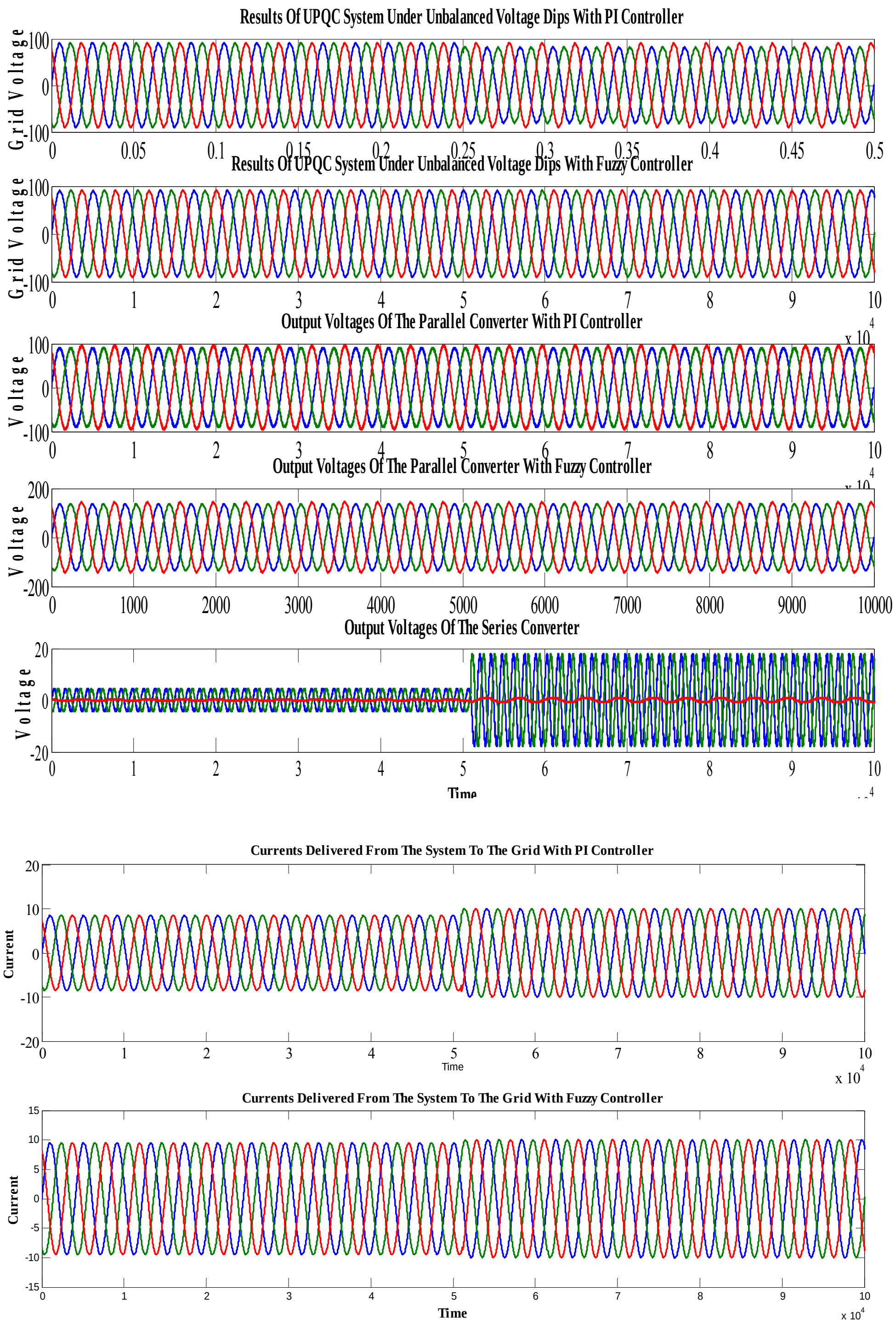

Figure 12. UPQC system under unbalanced voltage dips

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 0.0005 sec there is change in magnitude value in PI controller that will be reduced by applying fuzzy controller. THD factor in grid voltage side difference is 7.06% by comparing both controllers and also in series converter THD is 1.36% .

10.3. Output Voltages of the Parallel Converter Tested under a Single Phase Nonlinear Load

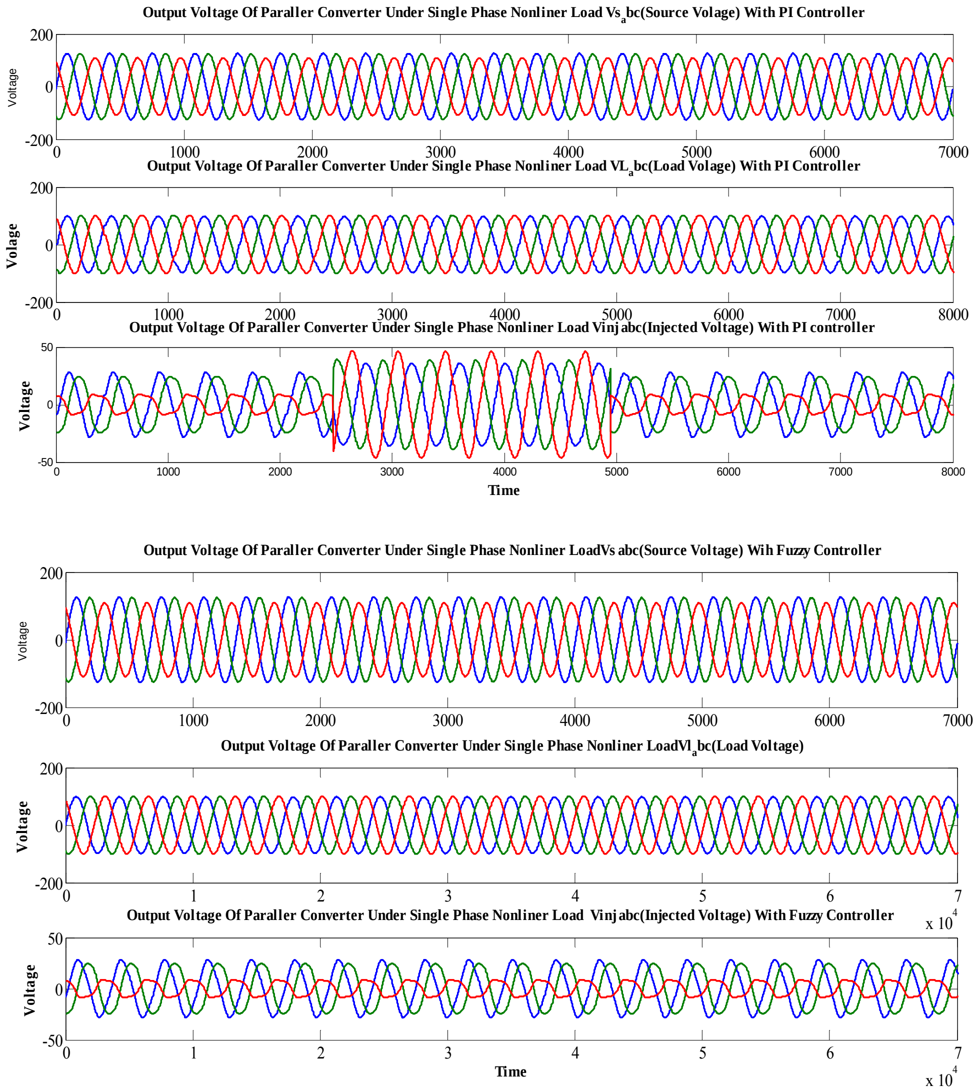

Figure 13. Output voltage of parallel converter under single phase non-linear load

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.

11. CONCLUSION

In this paper, the results of analyzing combined operation of UPQC and PV is explained. The designed system is composed of series and shunt inverters, PV module and DC/DC converter which can compensate the swell, voltage sag, interruption and reactive power and harmonics in both islanding and interconnected modes. The advantages of proposed 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, Fuzzy is more advantageous than PI controller 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, need less space to establish and finally most important thing we have to concern it is very less in cost compared to PI controller. The simulation 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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