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THREE-PHASE SOLAR P V INTEGRATED UPQC USING FUZZY LOGIC

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ABSTRACT:

This paper deals with the design and performance analysis of a three-phase single stage solar photovoltaic integrated unified power quality conditioner (PV-UPQC) The PV-UPQC consists of a shunt and series connected voltage compensators connected back to back with common DC-link. The shunt compensator performs the dual function of extracting power from PV array apart from compensating for load current harmonics. An improved synchronous reference frame control based on moving average filter is used for extraction of load active current component for improved performance of the PVUPQC. The series compensator compensates for the grid side power quality problems such as grid voltage sags/swells. The compensator injects voltage in-phase/out of phase with point of common coupling (PCC) voltage during sag and swell conditions respectively. The DC voltage is maintained constant using Fuzzy Logic Controller. The shunt and series reference signals derived from the control algorithm and sensed signals are injected into FLC to generate switching signals., 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.

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

Reference signal generation is a major task in control of PV- UPQC. Reference signal generation techniques can be broadly divided into time-domain and frequency domain techniques [8]. Time domain techniques are commonly used because of lower computational requirements in real-time implementation. The commonly used techniques include instantaneous reactive power theory (p-q theory), synchronous reference frame theory (d-q theory) and instantaneous symmetrical component theory. The main issue in use of synchronous reference frame theory based method is that during load unbalanced condition, double harmonic component is present in the d-axis current. Due to this, low pass filters with very low cut off frequency is used to filter out double harmonic component. This results in poor dynamic performance . In this work, a moving average filter (MAF) is used to filter the d-axis current to obtain fundamental load active current. This gives optimal attenuation and without reducing the bandwidth of the controller . Recently, MAF has been applied in improving performance of DC-link controllers as well as for grid synchronization using phase locked loop (PLL).

In this paper, the design and performance analysis of a three- phase PV-UPQC are presented. An MAF based d-q theory based control is used to improve the dynamic performance during load active current extraction. The main advantages of the proposed system are as follows,

- Integration of clean energy generation and power quality improvement.
- Simultaneous voltage and current quality improvement.
- Improved load current compensation due to use of MAF in d-q control of PV-UPQC.
- Stable under various dynamic conditions of voltage sags/swells, load unbalance and irradiation variation.

SYSTEM DESCRIPTION AND DESIGN 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].

The structure of the PV-UPQC is shown in Fig.1. The PV-UPQC is designed for a three-phase system. The PVUPQC consists of shunt and series compensator connected with a common DC-bus. The shunt compensator is connected at the load side. The solar PV array is directly integrated to the DC-link of UPQC through a reverse blocking diode. The series compensator operates in voltage control mode and compensates for the grid voltage sags/swells. The shunt and series compensators are integrated to the grid through interfacing inductors. A series injection transformer is used to inject voltage generated by the series compensator into the grid. Ripple filters are used to filter harmonics generated due to switching action of converters. The load used is a nonlinear load consisting of a bridge rectifier with a voltage-fed load.

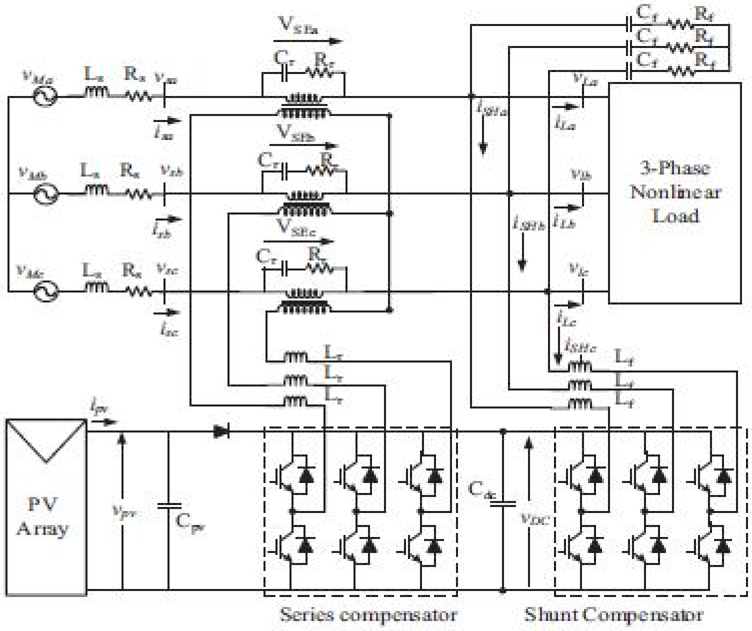

Fig. 1. System Configuration PV-UPQC

CONTROL OF PV-UPQC

The main subsystems of PV-UPQC are the shunt compensator and the series compensator. The shunt compensator compensates for the load power quality problems such as load current harmonics and load reactive power. In case of PVUPQC, the shunt compensator performs the additional function of supplying power from the solar PV array. The shunt compensator extracts power from the PV-array by using a maximum power point tracking (MPPT) algorithm. The series compensator protects the load from the grid side power quality problems such as voltage sags/swells by injecting appropriate voltage in phase with the grid voltage.

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.

Control of Shunt Compensator

The shunt compensator extracts the maximum power from the solar PV-array by operating it at its maximum power point. The maximum power point tracking (MPPT) algorithm generates the reference voltage for the DC-link of PV-UPQC. Some of the commonly used MPPT algorithms are Perturb And Observe(P&O)algorithm, incremental conductance algorithm (INC). In this work, (P& O) algorithm is used for implementing MPPT. The DC-link voltage is maintained at the generated reference by using a PI-controller. To perform the load current compensation, the shunt compensator extracts the active fundamental component of the load current. For this work, the shunt compensator is controlled by extracting fundamental active component of load current using SRF technique. The control structure of shunt compensator is shown in Fig. 2. The load currents are converted to d-q-0 domain using the phase and frequency information obtained from PLL. of the load current (I_{Ld}) is filtered to extract DC component (I_{Ldf}) which represents the fundamental component in abc frame of reference. To extract DC component without deteriorating the dynamic performance, a moving average filter (MAF) is used to extract the DC component. The transfer function of moving average filter is given as,

$$MAF(s) = \frac{1 - e^{-T_w s}}{T_w s}$$

The reference grid currents are compared with the sensed grid currents in a hysteresis current controller to generate the gating pulses for the shunt converter.

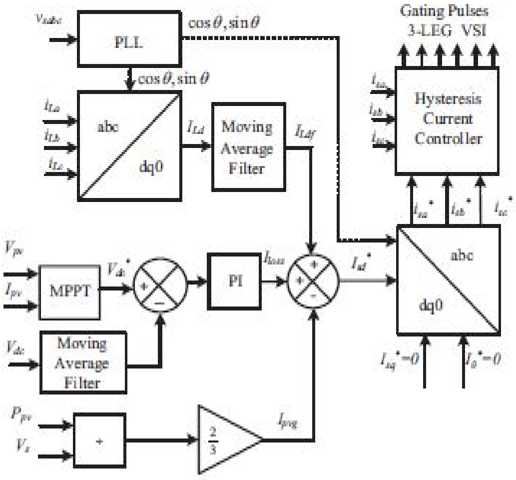

Fig. 2. Control Structure of Shunt Compensator

B. Control of Series Compensator

The control strategy for the series compensator are presage compensation, in-phase compensation and energy optimal compensation. .In this work, the series compensator injects voltage in same phase as that of grid voltage, which results in minimum injection voltage by the series compensator. The control structure of the series compensator is shown in Fig.3. The fundamental component of PCC voltage is extracted using a PLL which is used for generating the reference axis in dq- 0 domain. The reference load voltage is generated using the phase and frequency information of PCC voltage obtained using PLL. The PCC voltages and load voltages are converted into d-q-0 domain. As the reference load voltage is to be in phase with the PCC voltage, the peak load reference voltage is the d-axis component value of load reference voltage. The q-axis The PLL input is the PCC voltage. The d-component component is kept at zero. The difference between the load reference voltage and PCC voltage gives the reference voltage for the series compensator. The difference between load voltage and PCC voltage gives the actual series compensator voltages. The difference between reference and actual series compensator voltages is passed to PI controllers to generate appropriate reference signals. These signals are converted to abc domain and passed through pulse width modulation (PWM) voltage controller to generate appropriate gating signals for the series compensator.

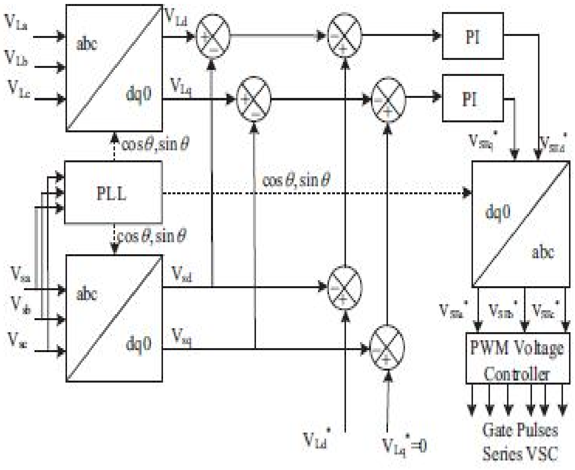

Fig. 3. Control Structure of Series Compensator

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:

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

$$C = V(K) - V(K-1)$$

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 fuzzy fied 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

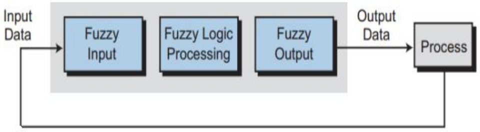

Figure 4. Basic structure of fuzzy control system

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

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 below

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IV. SIMULATION STUDIES

The steady state and dynamic performances of PV-UPQC are analyzed by simulating the system in matlab - Simulink software. The load used is a nonlinear load consisting of three phase diode bridge rectifier with R-L load. The solver step size used for the simulation is 1e-6s. The system is subjected to various dynamic conditions such as sag and swell in PCC voltage and PV irradiation variation. The detailed system parameters are given in Appendix.

A. Performance of PV-UPQC at PCC Voltage Fluctuations using fuzzy logic controler

The dynamic performance of PV-UPQC under conditions of PCC voltage sags/swells is shown in Fig.5. The irradiation(G) is kept at 1000W/m2. The various sensed signals are PCC voltages (vs), load voltages(vL), series compensator voltages (vSE), DC-link voltage (Vdc), solar PV array current (Ipv), solar PV array power (Ppv), grid currents (iS), load currents (iLa, iLb, iLc), shunt compensator currents ($iSHa$, $iSHb$, $iSHc$). Between 0.7s and 0.75s, there is voltage sag of 0.3pu and from 0.8s to 0.85s there is voltage swell of 0.3pu. The series compensator compensates for the grid voltage under these conditions by injecting a suitable voltage *VSE* in opposite phase with the grid voltage disturbance to maintain the load voltage at rated voltage condition.

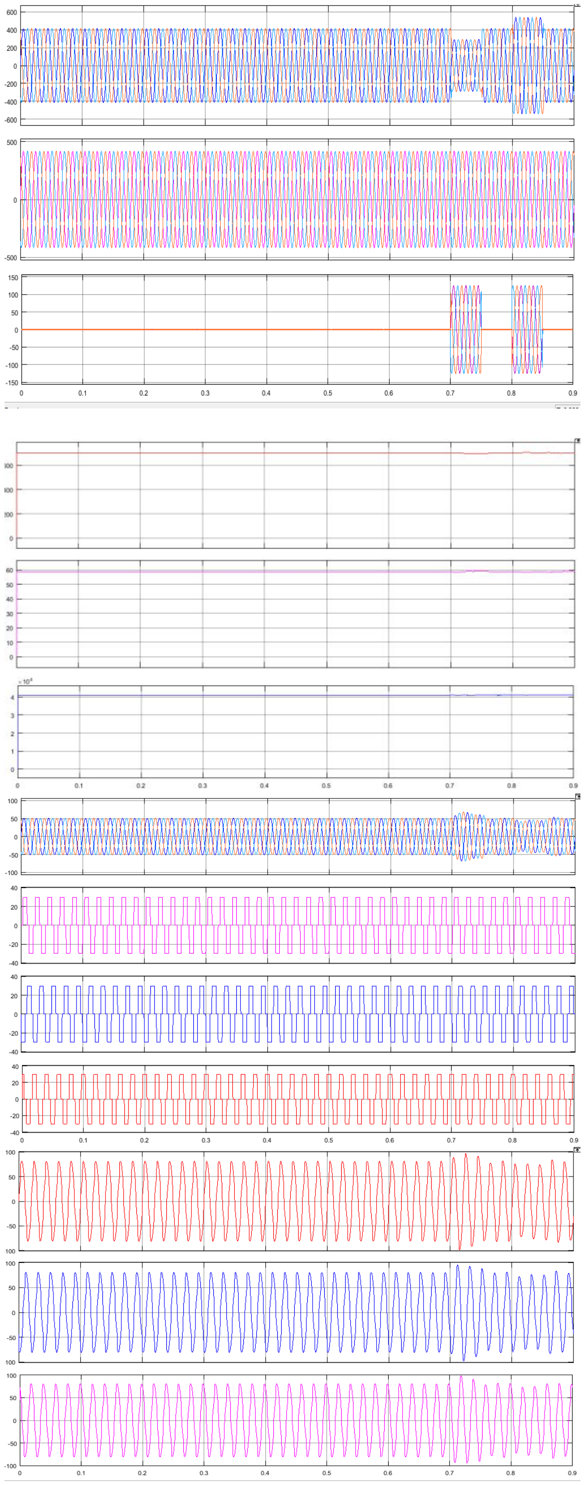


Fig. 5. Performance of PV-UPQC under Voltage Sag and Swell Conditions

B. Performance of PV-UPQC at Load unbalancing Condition using fuzzy

The dynamic performance of PV-UPQC under load unbalance condition is shown in Fig.5. At t=0.8s, phase ’b’ of the load is disconnected. It can be observed that the grid current is sinusoidal and at unity power factor. The current fed into the grid rises leading due to the reduction in the total effective load. The DC-link voltage is also stable and it is maintained near its desired regulated value of 700 V.

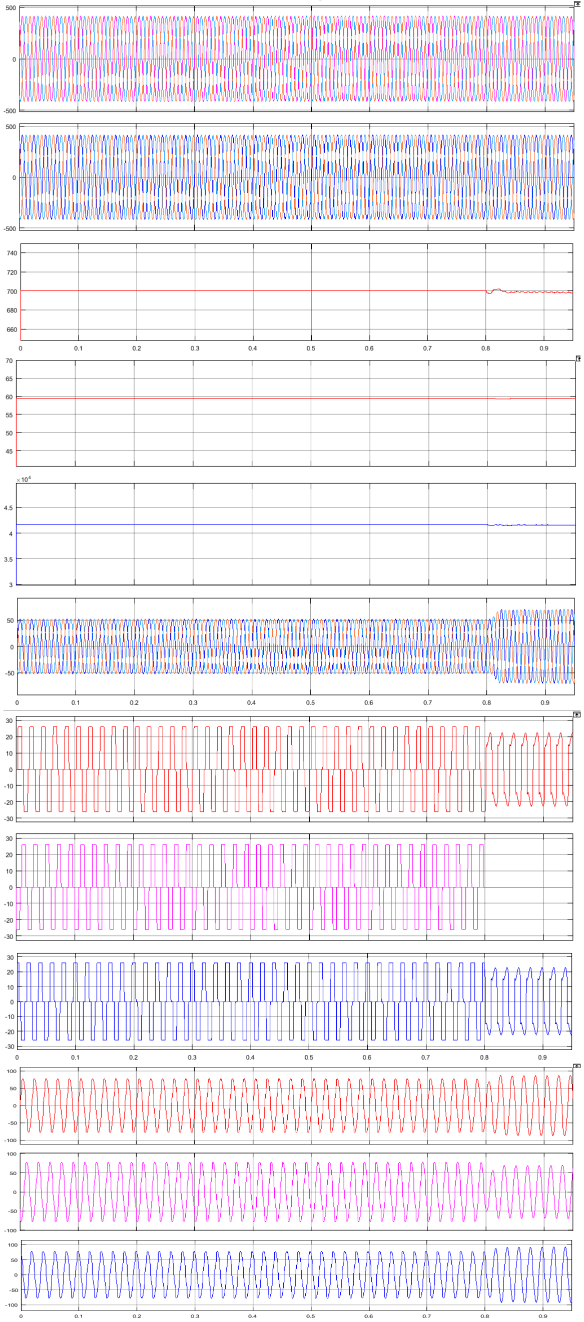
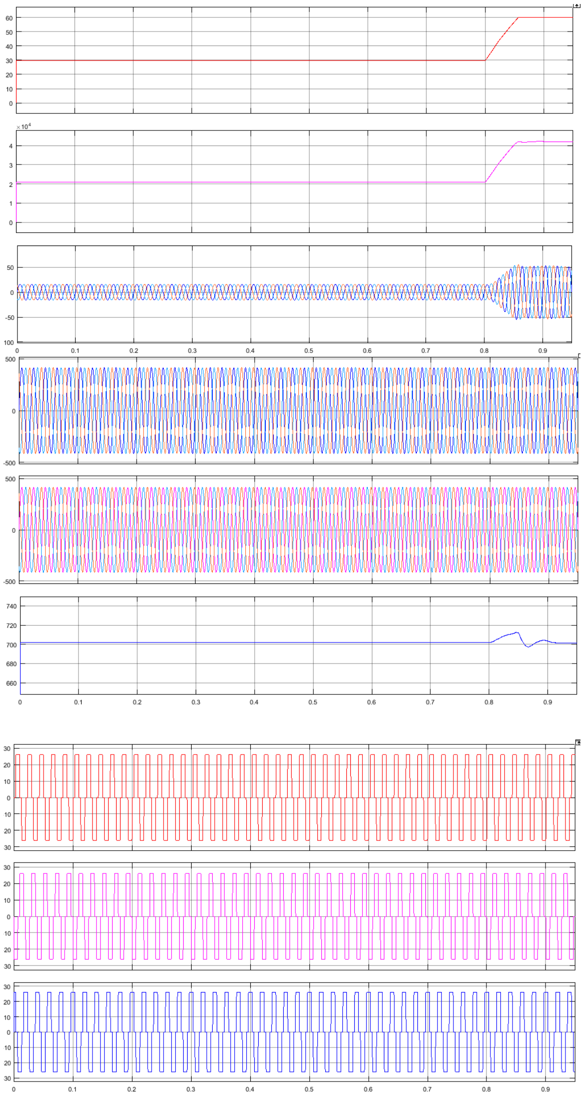


Fig. 6. Performance PV-UPQC during Load Unbalance Condition

C. Performance of PV-UPQC under Varying Irradiation using fuzzy

The dynamic performance of PV-UPQC under varying solar irradiation is shown in Fig.6. The solar irradiation is varied from 500*W/m*2 at 0.8s to 1000*W/m*2 at 0.85s. It is observed that as irradiation increases, the PV array output increases and hence grid current rises as the PV array is feeding power into the grid. The shunt compensator tracks MPPT along with compensating for the harmonics due to load current. The harmonic spectra and THD load current and grid current are shown in Fig. 8 and Fig.9. It is observed that the load current THD is 29.46% and the grid current THD is 0.40% thus meeting the requirement of IEEE-519 standard [31].



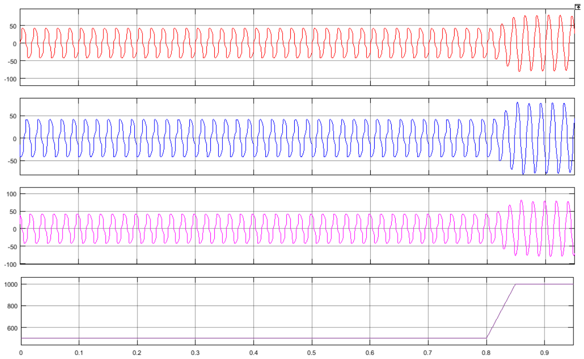


Fig. 7. Performance PV-UPQC at Varying Irradiation Condition

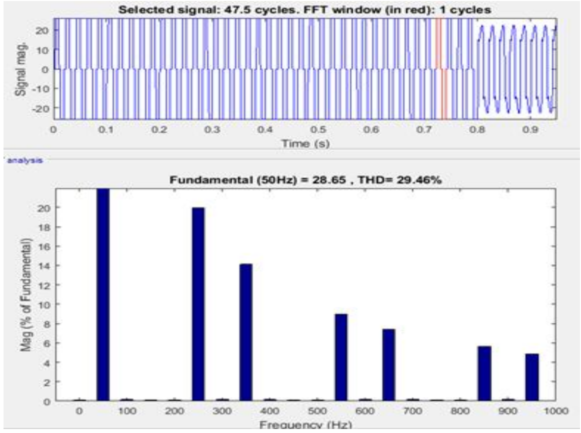


Fig. 8. Load Current Harmonic Spectrum and THD

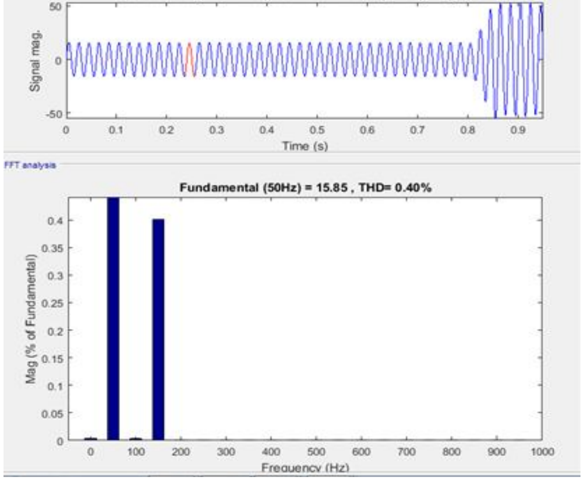
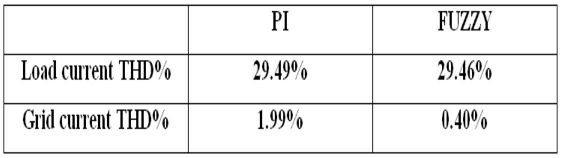


Fig. 9. Grid Current Harmonic Spectrum and THD

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 compare shown below.



	PI	FUZZY
Load current THD%	29.49%	29.46%
Grid current THD%	1.99%	0.40%

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