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IMPROVEMENT OF POWER QUALITY USING FUZZY CONTROLLER IN THREE-PHASE SOLAR PV INTEGRATED UPQC

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ABSTRACT

Project 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 swells conditions respectively. The proposed system combines both the benefits of clean energy generation along with. The steady state and dynamic performance of the system are evaluated by simulating in Matlab-Simulink under a nonlinear load. The system performance is then verified using a scaled down laboratory prototype under a number of disturbances such as load unbalancing, PCC voltage sags/swells and irradiation variation.

I.INTRODUCTION

With the advancement in semiconductor technology, there is an increased penetration of power electronic loads. These loads such as computer power supplies, adjustable speed drives, switched mode power supplies etc. have very good efficiency, and however, they draw nonlinear currents. These nonlinear currents cause voltage distortion at point of common coupling particularly in distribution systems. There is also increasing emphasis on clean energy generation through installation of rooftop PV systems in small apartments as well as in commercial buildings.

However, due to the intermittent nature of the PV energy sources, an increased penetration of such systems, particularly in weak distribution systems leads to voltage quality problems like voltage sags and swells, which eventually instability in the grid . These voltage quality problems also lead to frequent false tripping of power electronic systems, malfunctioning and false triggering of electronic systems and increased heating of capacitor banks etc. Power quality issues at both load side and grid side are major problems faced by modern distribution systems. Due to the demand for clean energy as well as stringent power quality requirement of sophisticated electronic loads, there is need for multifunctional systems which can integrate clean energy generation along with power quality improvement.

A three phase multi-functional solar energy conversion system, which compensates for load side power quality issues has been proposed in. A single phase solar pv inverter along with active power filtering capability has been proposed in. Major research work has been done in integrating clean energy generation along with shunt active filtering. Though shunt active filtering has capability for both load voltage regulation, it comes at the cause of injecting reactive power. Thus shunt active filtering cannot regulate PCC voltage as well as maintain grid current unity power factor at same time. Recently, due to the stringent voltage quality requirements for sophisticated electronics loads, the use of series active filters has been proposed for use in small apartments and commercial buildings. A solar photovoltaic system integrated along with dynamic

Journal of Engineering Sciences

Journal of Engineering Sciences
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voltage restorer has been proposed in . Compared to shunt and series active power filters, a unified power quality conditioner (UPQC), which has both series and shunt compensators can perform both load voltage regulation and maintain grid current sinusoidal at unity power factor at same time. Integrating PV array along with UPQC, gives the dual benefits of clean energy generation along with universal active. The integration of PV array with UPQC has been reported in . Compared to conventional grid connected inverters, the solar PV integrated UPQC has numerous benefits such as improving power quality of the grid, protecting critical loads from grid side disturbances apart from increasing the fault ride through capability of converter during transients. With the increased emphasis on distributed generation and micro grids, there is a renewed interest in UPQC systems .

Reference signal generation is a major task in control of PVUPQC. Reference signal generation techniques can be broadly divided into time-domain and frequency domain techniques. 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 [24]. 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). [26], 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. The performance of the proposed system is analyzed extensively under both dynamic and steady state conditions using Matlab-Simulink software. The performance is then experimentally verified using a scaled down laboratory prototype under various conditions experienced in the distribution system such as voltage sags/swells, load unbalance and irradiation variation.

II.PHOTOVOLTAIC INVERTER

The basic block diagram of grid connected PV power generation system is shown in Fig. 2.1. The PV power generation system consists of following major blocks:

1. PV unit
2. Inverter
3. Grid
4. MPPT

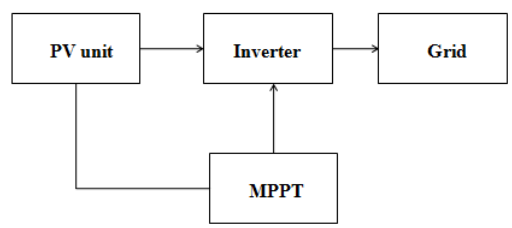

Fig.1 Schematic diagram of PV system

1. PV unit : A PV unit consists of number of PV cells that converts the energy of light directly into electricity (DC) using photovoltaic effect.
2. Inverter : Inverter is used to convert DC output of PV unit to AC power.
3. Grid : The output power of inverter is given to the nearby electrical grid for the power generation.
4. MPPT : In order to utilize the maximum power produced by the PV modules, the power conversion equipment has to be equipped with a maximum power point tracker (MPPT). It is a device which tracks the voltage at where

Vol 10, Issue 10, OCT/2019
ISSN NO:0377-9254

the maximum power is utilized at all times.

2.1.1 Photovoltaic cell and array modeling

A PV cell is a simple p-n junction diode that converts the irradiation into electricity. Fig.3.2 illustrates a simple equivalent circuit diagram of a PV cell. This model consists of a current source which represents the generated current from PV cell, a diode in parallel with the current source, a shunt resistance, and a series resistance.

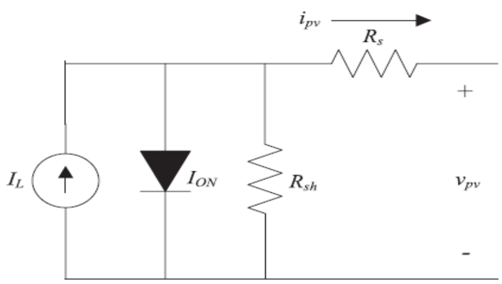

Fig.2 Equivalent circuit diagram of the PV cell

III.POWER QUALITY

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks.

Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: 'Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.' As we are all aware, container crane performance requirements continue to increase at an astounding rate.

IV.FUZZY LOGIC

As of late, the number and assortment of uses of Fuzzy logichave expanded fundamentally. The applications range from buyer items, for example, cameras, camcorders, clothes washers, and microwave stoves to mechanical procedure control, therapeutic instrumentation, choice emotionally supportive networks, and portfolio choice. To comprehend why utilization of Fuzzy logichas developed, you should first comprehend what is implied by fluffy rationale.

Fuzzy logichas two unique implications. In a tight sense, Fuzzy logicis a coherent framework, which is an augmentation of multivalve rationale. In any case, in a more extensive sense Fuzzy logic(FL) is verging on synonymous with the hypothesis of fluffy sets, a hypothesis which identifies with classes of items with un sharp limits in which enrollment involves degree. In this viewpoint, Fuzzy logicin its slender sense is a branch of fl. Indeed, even in its more limited definition, Fuzzy logicvaries both in idea and substance from conventional multivalve consistent frameworks.

In fluffy Logic Toolbox programming, Fuzzy logicought to be translated as FL, that is, Fuzzy logicin its wide sense. The essential thoughts fundamental FL are clarified plainly and sagaciously in Foundations of Fuzzy Logic. What may be included is that the essential idea hidden FL is that of a phonetic variable, that is, a variable whose qualities are words as opposed to numbers. As a result, quite a bit of FL might be seen as a technique for processing with words instead of numbers. In spite of the fact that words are intrinsically less exact than numbers, their utilization is nearer to human instinct. Besides, registering with words misuses the resistance for imprecision and along these lines brings down the expense of arrangement.

Another fundamental idea in FL, which assumes a focal part in a large portion of its applications, is that of a fluffy if-then administer or, just, fluffy tenet. Despite the fact that principle based frameworks have a long history of utilization in Artificial Intelligence (AI), what is

JES Journal of Engineering Sciences
Vol 10, Issue 10, OCT/2019
ISSN NO:0377-9254

lost in such frameworks is an instrument for managing fluffy consequents and fluffy forerunners. In fluffy rationale, this system is given by the math of fluffy standards. The math of fluffy guidelines serves as a premise for what may be known as the Fuzzy Dependency and Command Language (FDCL). Despite the fact that FDCL is not utilized expressly as a part of the tool kit, it is viably one of its chief constituents. In the vast majority of the uses of fluffy rationale, a Fuzzy logicarrangement is, actually, an interpretation of a human arrangement into FDCL.

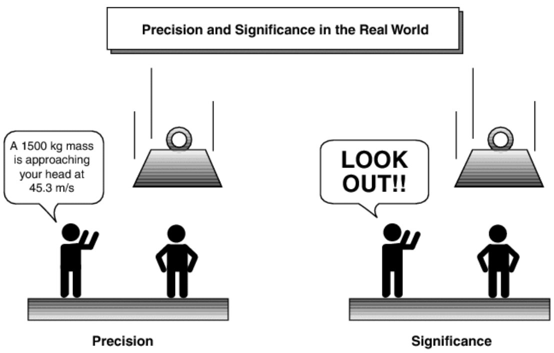

Fig.3 Fuzzy descriptions

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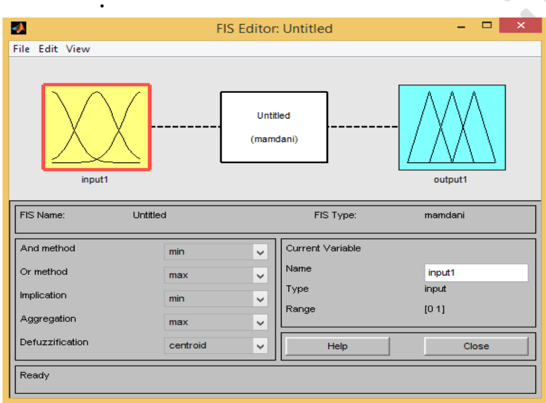

Fig.4 The FIS editor

V.PROPOSED MODEL AND CONTROL DESIGN

5.1 SYSTEM CONFIGURATION AND DESIGN

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.

A. Design of PV-UPQC The design procedure for PV-UPQC begins with the proper sizing of PV array, DC-link capacitor, DC-Link voltage level etc. The shunt compensator is sized such that it handles the peak power output from PV array apart from compensating for the load current reactive power and current harmonics. As the PV array is directly integrated to the DC-link of UPQC, the PV array is sized such that the MPP voltage is same as desired DClink voltage. The rating is such that, under nominal conditions, the PV array supplies the load active power and also feeds power into the grid. The other designed components are the interfacing inductors of series and shunt compensators and series injection transformer of the series compensator. The design of PV-UPQC is elaborated as follows.

1) Voltage Magnitude of DC-Link: The magnitude of DClink voltage Vdc depends on the depth of modulation used and per-phase voltage of the system. The DC-link voltage magnitude should more than double the peak of per-phase voltage of the three phase system [8] and is given as, $V_{dc} = 2 \sqrt{2} V_{LL} \sqrt{3} m$ (1) where depth of modulation (m) is taken as 1 and VLL is the grid line voltage. For a line voltage of 415 V, the required minimum value DC-bus voltage is 677.7 V. The DC-bus voltage is set at 700 V(approx), which is same as the MPPT operating voltage of PV array at STC conditions.

2) DC-Bus Capacitor Rating: The DC-link capacitor is sized based upon power requirement as well as DC-bus voltage level. The energy balance equation for the DC-bus capacitor is given as follows [8], $C_{dc} = 3kaV_{ph}I_{sh}t\ 0.5 \times (V^2_{dc} - V^2_{dc1}) = 3 \times 0.1 \times 1.5 \times 239.6 \times 34.5 \times 0.03\ 0.5 \times (700^2 - 677.79^2 = 9.3mF$ (2) where Vdc is the average DC-bus voltage, Vdc1 is the lowest required value of DC-bus voltage,a is the

JES Journal of Engineering Sciences

Vol 10, Issue 10, OCT/2019

ISSN NO:0377-9254

overloading factor, Vph is per-phase voltage, t is the minimum time required for attaining steady value after a disturbance, Ish is per-phase current of shunt compensator, k factor considers variation in energy during dynamics. The minimum required DC-link voltage is Vdc1 = 677.69 V as obtained from (2), Vdc = 700 V, Vph= 239.60 V,Ish=57.5 A, t= 30 ms, a = 1.2, and for dynamic energy change = 10%, k= 0.1, the value of Cdc is obtained as 9.3 mF. 3) Interfacing Inductor for Shunt Compensator: The interfacing inductor rating of the shunt compensator depends upon the ripple current, the switching frequency and DC-link voltage. The expression for the interfacing inductor is as, Lf = √3mVdc 12afshIcr,pp = √3 × 1 × 700 12 × 1.2 × 10000 × 6.9 = 800µH ≈ 1mH (3)

where m is depth of modulation, a is pu value of maximum overload, fshis the switching frequency , Icr,pp is the inductor ripple current which is taken as 20% of rms phase current of shunt compensator. Here, m=1, a=1.2, fsh=10kHz, Vdc=700V, one gets 800 µH as value. The value chosen is approximated to 1mH. 4) Series Injection Transformer: The PV-UPQC is designed to compensate for a sag/swell of 0.3 pu i.e 71.88 V. Hence, the required voltage to be injection is only 71.88 V which results in low modulation index for the series compensator when the DC-link voltage is 700V. In order to operate the series compensator with minimum harmonics, one keeps modulation index of the series compensator near to unity. Hence a series transformer is used with a turns ratio, KSE = VV SC VSE = 3.33 ≈ 3 (4) The value obtained for KSE is 3.33. The value selected is 3. The rating of series injection transformer is given as, SSE = 3VSEISEsag = 3 × 72 × 46 = 10kV A (5) The current through series VSC is same as grid current. The supply current under sag condition of 0.3 pu is 46 A and hence the VA rating of injection transformer achieved is 10 kVA. 5) Interfacing Inductor of Series Compensator: The rating of interfacing inductor of the series compensator depends on ripple current at swell condition, switching frequency and DClink voltage. Its value is expressed as, Lr = √3 × mVdcKSE 12afseIr = √3 × 1 × 700 × 3 12 × 1.2 × 10000 × 7.1 = 3.6mH (6) where m is the depth of modulation, a is the pu value of maximum overload, fse is the switching frequency, Ir is the inductor current ripple, which is taken to be 20% of grid current. Here, m=1, a=1.5, fse=10 kHz, Vdc=700 V and 20% ripple current, one gets 3.6 mH as selected value.

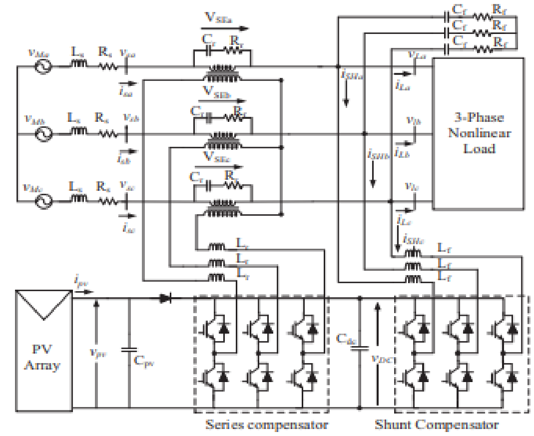

Fig 5 System configuration of PV-UPQC

5.2 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.

5.2.1 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 [28] 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.

Journal of Engineering Sciences
Vol 10, Issue 10, OCT/2019
ISSN NO:0377-9254

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 6.2. The load currents are converted to d-q-0 domain using the phase and frequency information obtained from PLL. The PLL input is the PCC voltage. The d-component of the load current (ILd) is filtered to extract DC component (Ildf) 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) = 1 – e−Tws Tws (7) where Tw is the window length of the moving average filter. As the lowest harmonic present in the d-axis current is double harmonic component, Tw is kept at half of fundamental time period. The MAF has unity DC gain and zero gain integer multiples of window length. The equivalent current component due to PV array is given as, Ipvg = 2 3 Ppv Vs (8) where Ppv is the PV array power and Vs is the magnitude of the PCC voltage. The reference grid current in d-axis is given as I∗ sd = Ildf + Iloss – Ipvg (9) I∗ sd is converted to abc domain reference grid currents. 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.

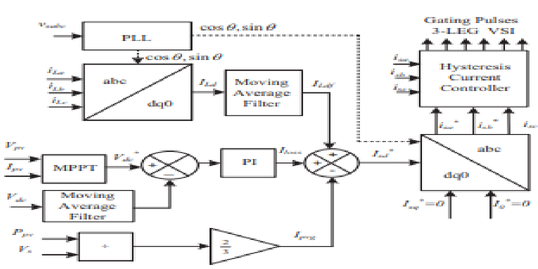

Fig 6 control structure of shunt controller

5.2.2. Control of Series Compensator

The control strategy for the series compensator are presage compensation, in-phase compensation and energy optimal compensation. A detailed description of various compensation strategies used for control of series compensator is reported in [29], [30] 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 6.3. 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 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

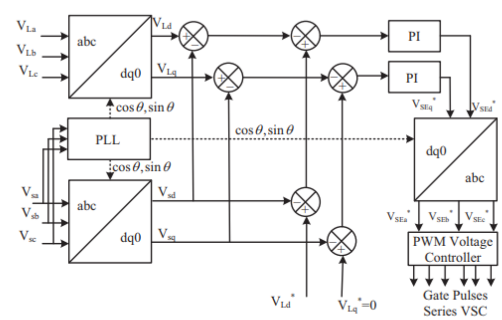

Fig7 control structure of series controller

VI.SIMULATION RESULT ANALYSIS

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 The dynamic performance of PV-UPQC under conditions of PCC voltage sags/swells is shown in Fig.7.1 .

6.1 SIMULINK MODEL OF PROPOSED SYSTEM

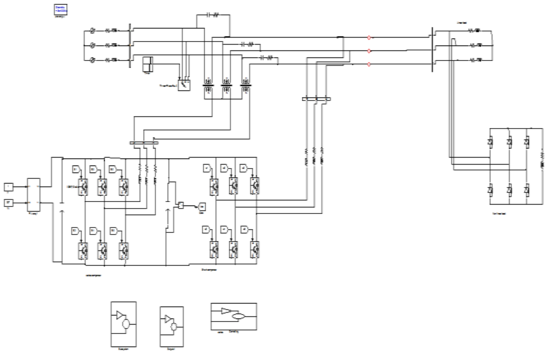

Fig 8 Simulink Model Of Proposed System

A. Performance of PV-UPQC at PCC Voltage Fluctuations

The dynamic performance of PV-UPQC under conditions of PCC voltage sags/swells is shown in Fig.7.1 . 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

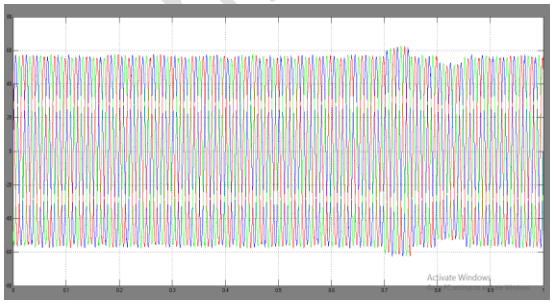

Fig 9 Shunt converter current

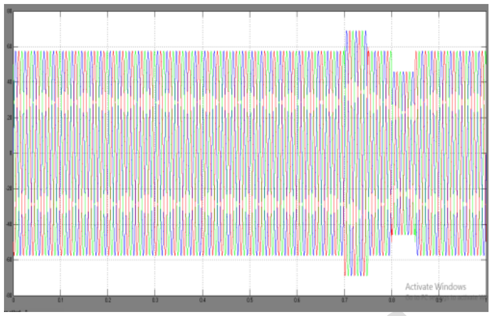

Fig 10 source currents under sag swell

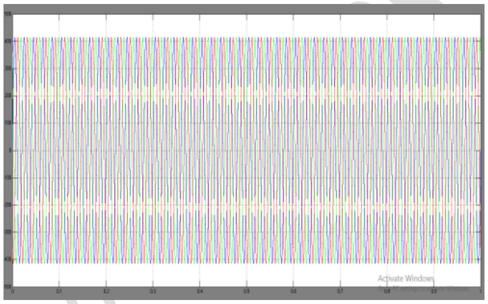

Fig 11 Load voltage after compensating sag and swell

B. Performance of PV-UPQC at Load Unbalancing Condition

The dynamic performance of PV-UPQC under load unbalance condition is shown in Fig7.5 to 7.8.. 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

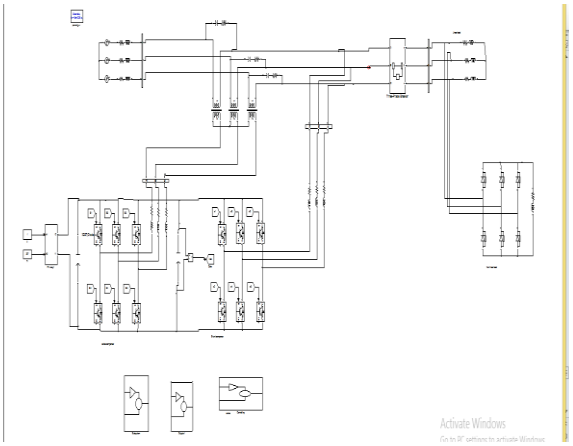

Fig 12 Simulink model under load change

Journal of Engineering Sciences
Vol 10, Issue 10, OCT/2019
ISSN NO:0377-9254

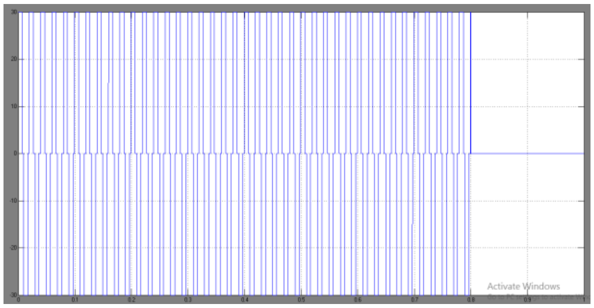

Fig 13 Load currents under load change

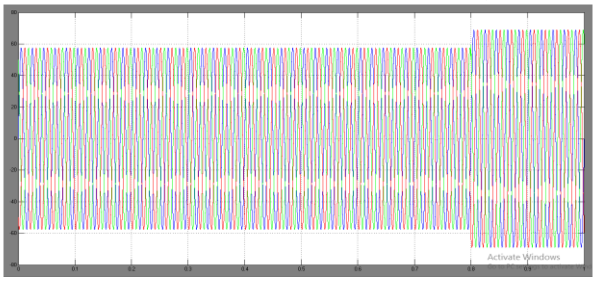

Fig 14 source current

C. Performance of PV-UPQC under Varying Irradiation

The dynamic performance of PV-UPQC under varying solar irradiation is shown in Fig.6. The solar irradiation is varied from 500W/m2 at 0.8s to 1000W/m2 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

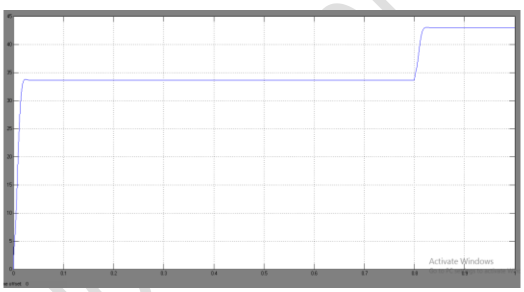

Fig 15 solar power under varying irradiation

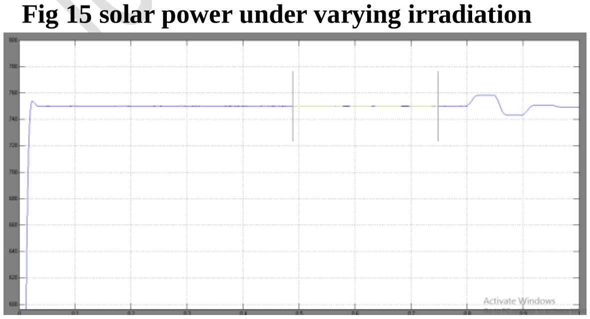

Fig 16 Vdc under varying irradiation

VII.CONCLUSION

The design and dynamic performance of three-phase PVUPQC have been analyzed under conditions of variable irradiation and grid voltage sags/swells. The performance of the system has been validated through simulation. The system is found to be stable under variation of irradiation, voltage sags/swell and load unbalance. The performance of d-q control particularly in load unbalanced condition has been improved through the use of fuzzy controller. It can be seen that PV-UPQC with fuzzy controller is a good solution for modern distribution system by integrating distributed generation with power quality improvement.

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