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Analysis of Three-Phase Solar PV Inverters Using UPQC

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ABSTRACT: Increased energy demand, depletion of fossil fuels, and increased efforts to reduce CO₂ emissions are driving increased power generation from renewable energy sources. Today, solar power generation is on the rise due to the reliability and long-term availability of solar energy. The development of power electronic converters enables highly efficient power transmission. This analysis addresses the design and performance analysis of a three-phase, single-stage, photovoltaic integrated power quality conditioner (PV-UPQC). The PV-UPQC consists of voltage compensators in series with shunts connected back-to-back to a common DC link. An improved synchronous reference frame control based on a moving average filter is used to extract the active load current component and improve PVUPQC performance. A series compensator compensates for grid-side power quality issues such as grid voltage dips/spikes. A compensator injects a voltage in-phase or out-of-phase with the Point of Common Coupling (PCC) voltage during sag and swell. The proposed system combines the benefits of clean power generation with improved power quality. Steady-state and dynamic performance of the system are evaluated by Matlab-Simulink simulations under nonlinear loads. A scaled-down lab prototype is then used to validate the system performance under various disturbances such as load imbalance, PCC voltage dips/swells, and solar radiation variations.

KEYWORDS: Power Quality, Power system, series compensator, UPQC, Solar PV

I. INTRODUCTION

The production of electrical energy from renewable energy sources (RES) has grown a lot in recent decades, mainly due to increased demand for electricity, as well as the global intensive efforts to overcome the harmful environmental impacts caused by pollutant energy sources, such as oil, coal, natural gas, and others. Distributed generation (DG) systems based on RES have contributed to find new modern solutions for planning conventional power systems [13]. Inserted in this scenario, solar energy has emerged as a promising RES due to its abundance across the earth's surface. In particular, by means of photovoltaic (PV) cells, PV panels have been properly designed to produce energy by converting sunlight into electricity.

Normally, grid-connected PV systems can be deployed by means of single-stage (S-S) or double-stage (D-S) power conversion [9]. S-S PV systems are usually composed of only a grid-tied inverter (dc/ac converter). In this case, the PV array is directly connected to the dc-bus of the grid-tied inverter. On the other hand, in D-S PV systems, an additional dc/dc converter is placed between the PV array and the inverter. In this configuration, the maximum power point tracking (MPPT) is performed by the dc/dc converter. Considering SS-PV systems, the task to perform the MPPT is assumed by the grid-tied inverter, combined with the advantage of achieving more efficiency when compared to DS-PV systems [14]. In both the mentioned PV system topologies, the dc/ac converter controls the amplitude of the currents injected into the grid, in order to guarantee the balance between the power produced to the PV array and that absorbed by the grid.

In most applications, PV systems are connected to the electrical distribution system, as well as microgrids where local generation is carried out. Besides energy production, and according to a suitably adopted control strategy, PV systems can also carry out other roles in a microgrid, such as active filtering and/or reactive power compensation. In other words, PV systems can perform tasks similar to those performed by conventional parallel active power filters (P-APF).

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, 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 [10]. 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 [11]. 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.

The performance and efficiency of Solar PV Plant is depending on the power conversion stages through power electronics converter interfaced between PV plant and Grid. Although Solar PV system is reliable, the efficiency of Solar PV array is around 15-20%. Therefore, Solar panel should be operated in maximum power generating position every instant. MPPT Algorithms are widely used to extract maximum power from solar PV plant by electrically tracking PV in maximum power generating position. In transformerless PV plant, there is no galvanic isolation between inverter and utility grid. In transformer connected PV system, Low frequency transformer (acts as galvanic isolation) is connected in between PV inverter and Utility Grid which has less efficiency compared to transformer-less grid tied solar plant. Voltage source Inverter becomes most familiar for conversion of DC to AC Conversion process. The output of Inverter is modulated Sinusoidal wave which produces distorted currents with THD of 31%. To filter out distortion, LCL filter is used due to small size and high efficiency of active power transfer but LCL makes system unstable because of generation of resonance peaks. Passive damping technique is preferred to eliminate resonance peaks.

Solar cell-based photovoltaic power generation that is ready to direct conversion of solar energy to DC Electricity has the potential to be a clean energy source and it can be broadly pertinent renewable energy source accessible for forthcoming energy production. As a result of photovoltaic processing developments over the last few decades, the participation and role of electric utilities in PV has increased significantly. Observations on the inverter's DC side are needed thus to measure and sustain tracking, MPPT algorithms are used for the highest operating point at every instant. Numerous approaches have been found and discussed in this decade in order to reduce or to get rid of these measurements, the system's complexity is minimized, and it is more cost-effective.

The DC/DC converter controls full output, while the DC/AC converter synchronizes and feeds required power to the grid in a two-stage topology, is one of many approaches for a sensor-less MPPT algorithm. However, such strategies necessitate at least one calculation, such as current or voltage on the DC side of the converter, as well as a large number of power switching instruments. Other methods, on the other hand, use a one stage converter topology, which has the benefit of reducing the number of conversion steps and power switching units. There has been a decrease in a number of sensing elements in one stage topology, and On the DC side of the converter, MPPT algorithms need at least one sensing component, which involves filtering the calculated values to have the DC quantities on average, necessitating more computing power from the controller.

There is various research works going on the power quality enhancement of PV systems such as elimination strategies or harmonic compensation. When the generated electrical power from the renewable energy resources is supplied to grid through the grid connected inverter, the inverter should be providing zero steady-state error, fast response, and robustness to disturbance. In addition to that the grid-connected inverter should effectively compensate the imbalance in the system, reactive power, and harmonic. Conventionally, the simple PI control is used to regulate the grid-connected inverter. The distortion caused by harmonics under the distorted grid cannot be adequately compensated using the PI controller.

II. LITERATURE SURVEY

Villalva, Marcelo Gradella, and Jonas Rafael Gazoli et. al., [1] explained the current ecological and climate conditions, particularly sun-oriented irradiance, temperature, and wind speed, are reported and analyzed. At around the same time, the prompt information from the plant including PV module temperature, electricity, current, and voltage are provided timely. The power reduces as the surrounding temperature rises. Another Fuzzy Logic-based approximation is proposed to greatly reduce the power decline under halfway concealing conditions.

Sridhar, R., et al., [2] proposed the display and reconstruction of a photovoltaic model. The PV exhibit is displayed, and its voltage current characteristics, as well as the strength and voltage values, are recreated, taking into account the

temperature and sun's irradiance. This allows the PV framework's components to be successfully recreated and advanced. The natural components have an effect on the yield qualities of a PV exhibit, and the transformation productivity is poor. As a result, a maximum power point monitoring (MPPT) protocol is required to monitor the maximum potential in order to increase the generated vitality.

E. Vartiainen et. al., [12] explained the radiant irradiance on a sloping or leaning in a particular direction surface is usually estimated from hourly flat irradiance estimations using a slant irradiance model. It is also possible to calculate the slant irradiance by using a sky brilliance model to include the sky brilliance conveyance. Five slant irradiance models and six sky dissemination models are compared in this article, as well as hourly irradiance estimations on 24 slanted surfaces.

R. K. Agarwal, I. Hussain, and B. Singh, et.al [3] described 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.

Y. Singh, I. Hussain, B. Singh, and S. Mishra, et.al [4] described A single phase solar pv inverter along with active power filtering capability. 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.

M. Rauf and V. Khadkikar, et.al [7] explained a solar photovoltaic system integrated along with dynamic voltage restored. 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.

S. Devassy and B. Singh, et.al [5] described the integration of PV array with UPQC. 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 microgrids, there is a renewed interest in UPQC systems.

B. Singh and J. Solanki, et.al [15] introduced the 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.

B. Singh, C. Jain, S. Goel, A. Chandra, and K. Al-Haddad, et.al [6] described 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.

S. Golestan, M. Ramezani, J. M. Guerrero, and M. Monfared, et.al [8] described 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).

III. DESIGN AND ANALYSIS OF THREE-PHASE SOLAR PHOTOVOLTAIC INVERTERS USING INTEGRATED UPQC

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.

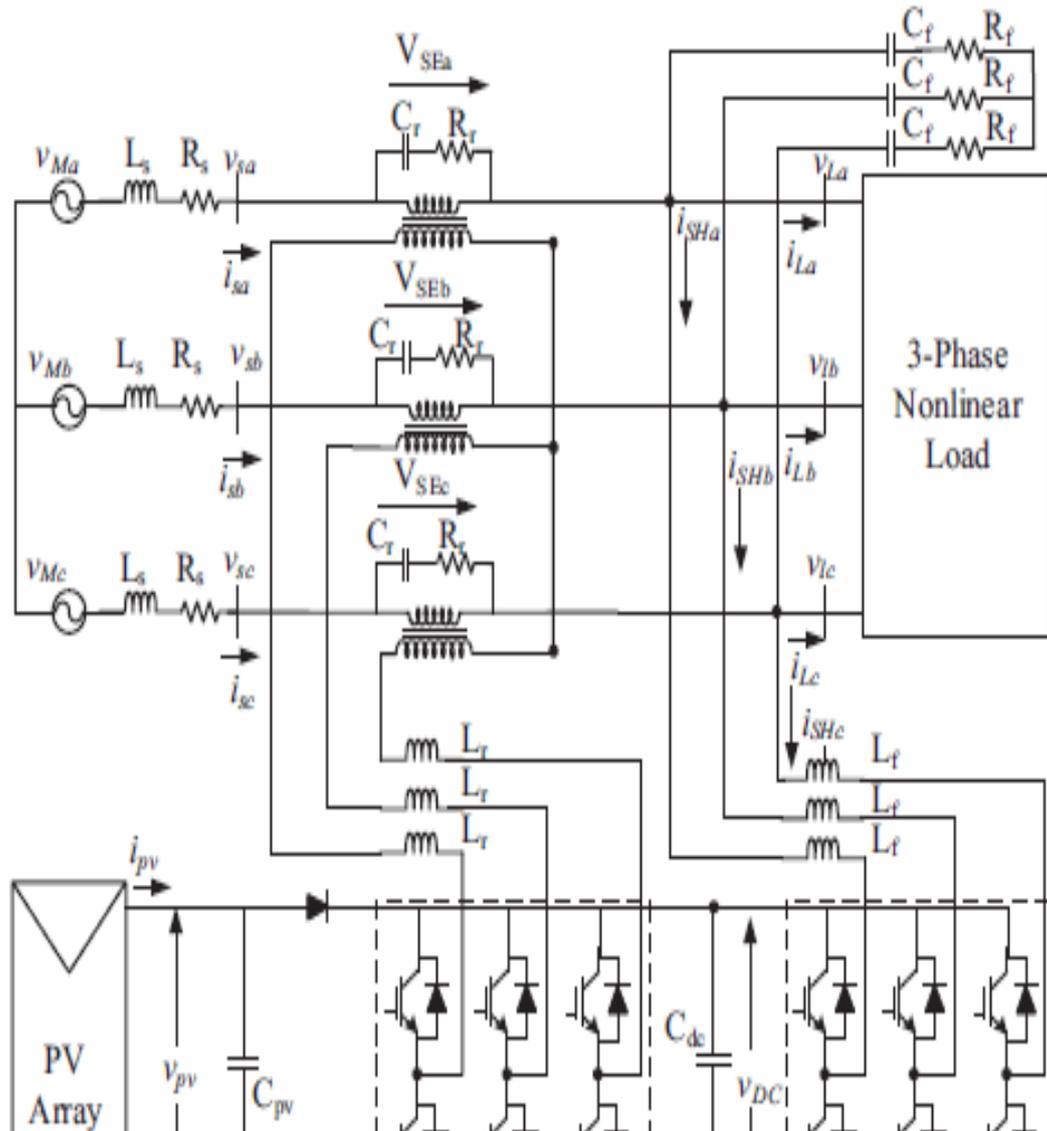


Fig. 1. System Configuration PV-UPQC

Series compensator

Shunt Compensator

- Stable under various dynamic conditions of voltage sags/swells, load unbalance and irradiation variation.



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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.

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. 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 detailed PV array specifications are given in Appendix A. The other designed components are the interfacing inductors of series and shunt compensators and series injection transformer of the series compensator.

The magnitude of DClink voltage V_{dc} 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. The DC-link capacitor is sized based upon power requirement as well as DC-bus voltage level. The interfacing inductor rating of the shunt compensator depends upon the ripple current, the switching frequency and DC-link voltage. 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. The rating of interfacing inductor of the series compensator depends on ripple current at swell condition, switching frequency and DClink voltage.

IV.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.

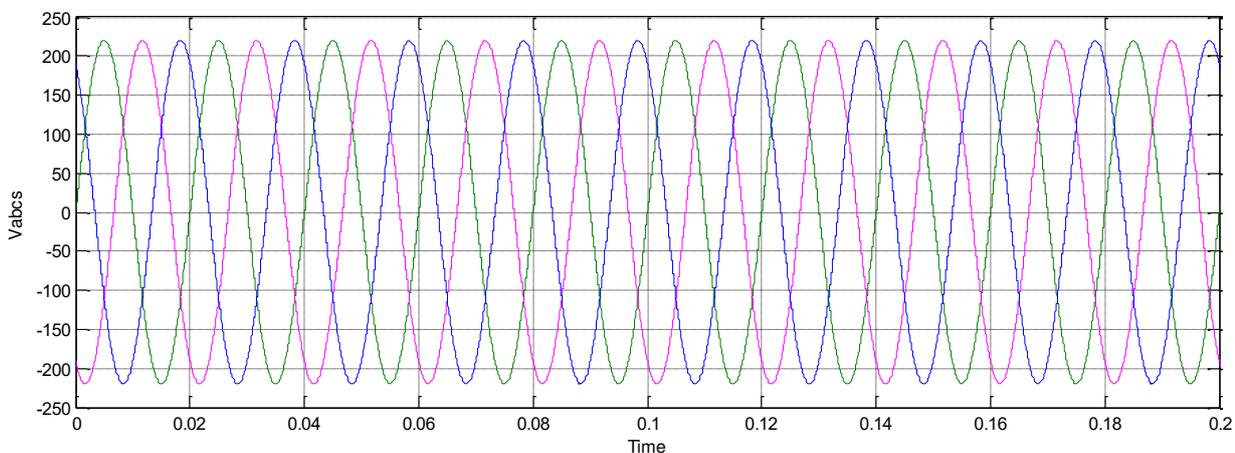


Fig. 2 Output Waveform Of Source Voltage



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Fig. 2 represents the source voltage wave form, it has 230V magnitude and three phase are maintain 120 degree phase shift with each other. It indicates the input voltage is given to the system.

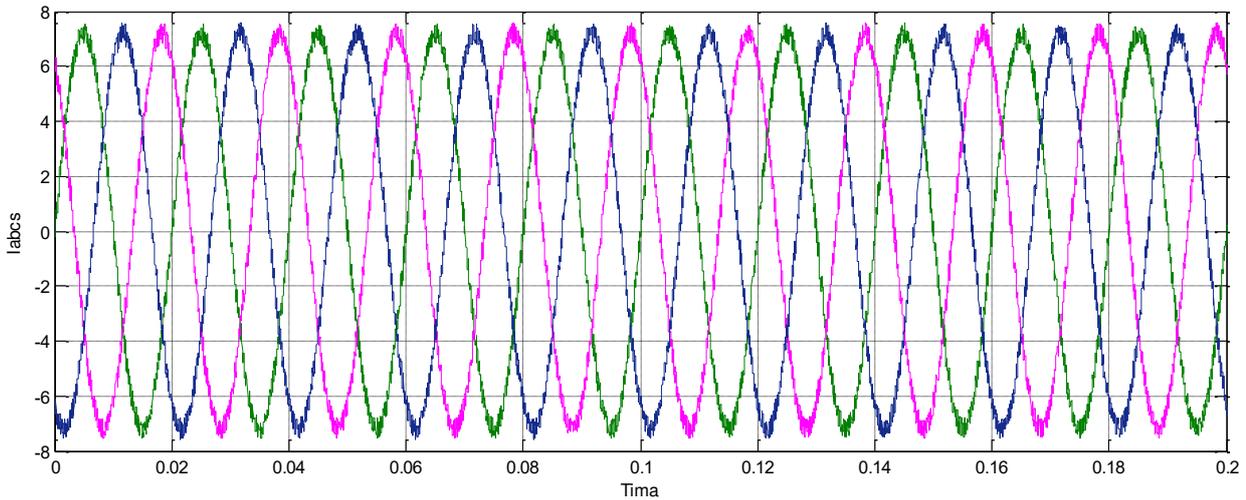


Fig. 3 Output Waveform Of Source Current

Fig. 3 represents the source current wave form, it has 7.5A magnitude and three phase are maintain 120 degree phase shift with each other.

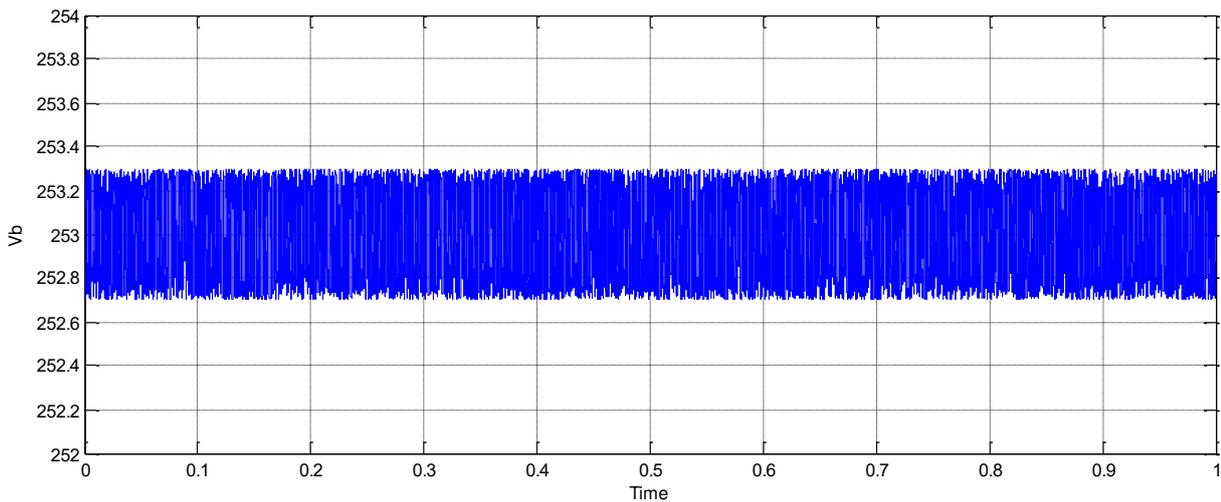


Fig. 4 Output Waveform Of Battery Voltage

Fig. 4 represents the battery output voltage wave form, it has 253V magnitude.

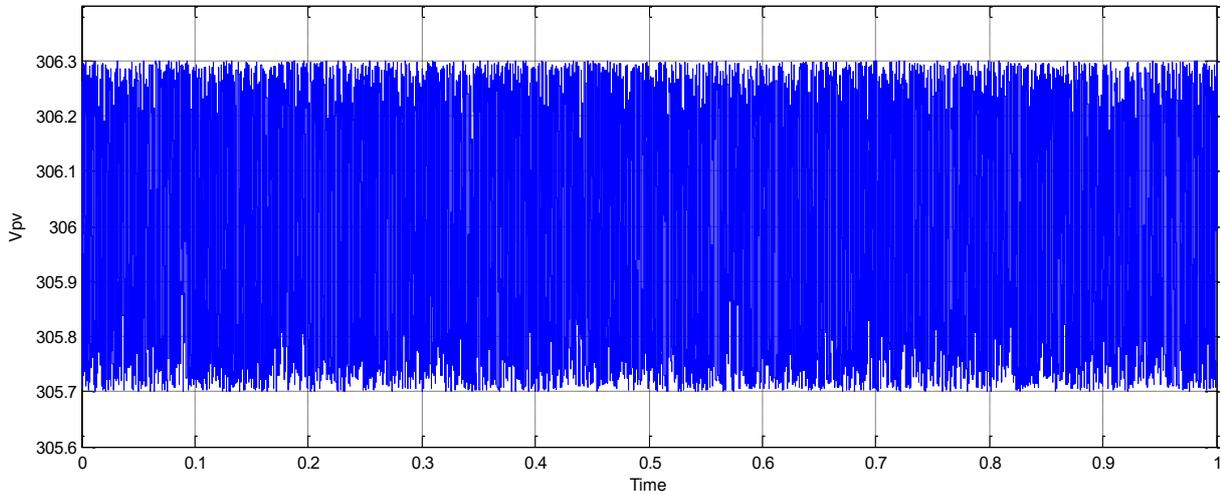


Fig. 5 Output Waveform Of PV Voltage

Fig. 4 represents the PV output voltage wave form, it has 306V magnitude.

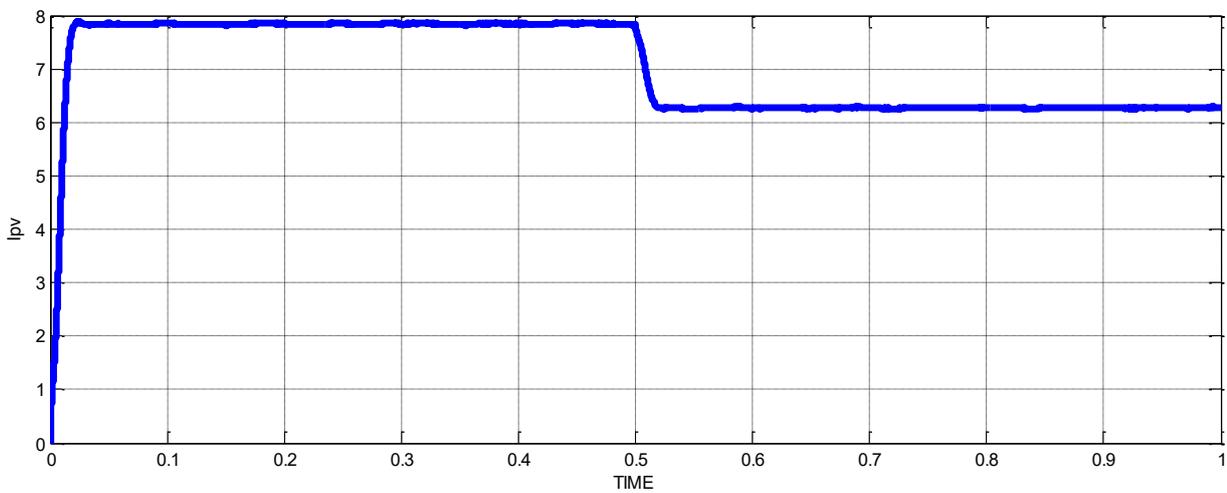


Fig. 6 Output Waveform Of PV Current

Fig. 6 represents the PV output current wave form, it has magnitude is varying from 8A to 6A. From initial value zero to 0.5sec it has 8A magnitude after 0.5sec the PV current magnitude is decrease to 6A due to change in irradiance of PV.

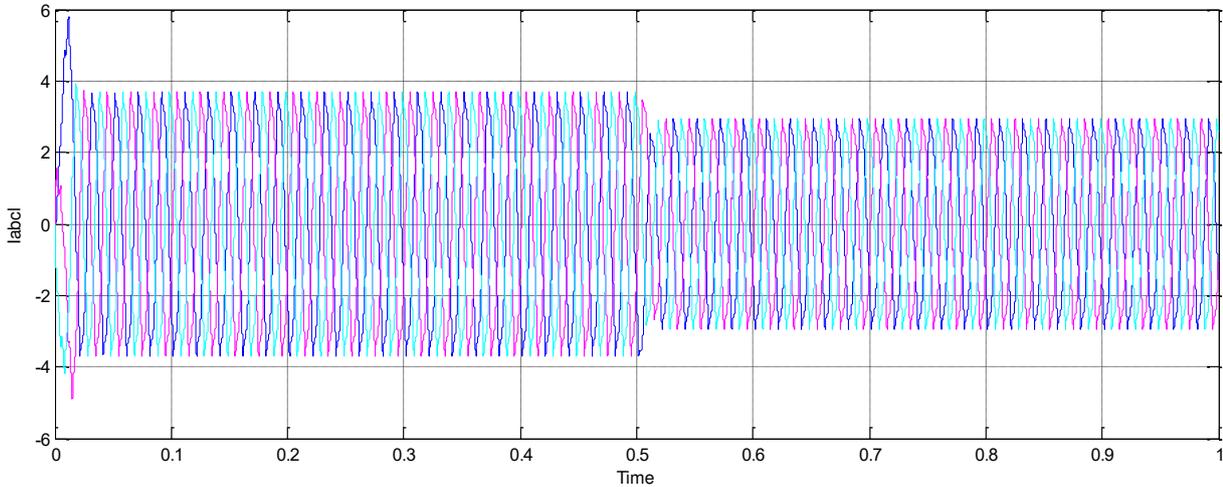


Fig. 7 Output Waveform Of Load Current

Fig. 7 represents the load current initially the load current has 4A from 0 to 0.5sec, after 0.5sec the load is varying due to change in load condition the load current also change. From the fig. 6 we can understand after 0.5sec the load is decreased so similarly the load current also decreased.

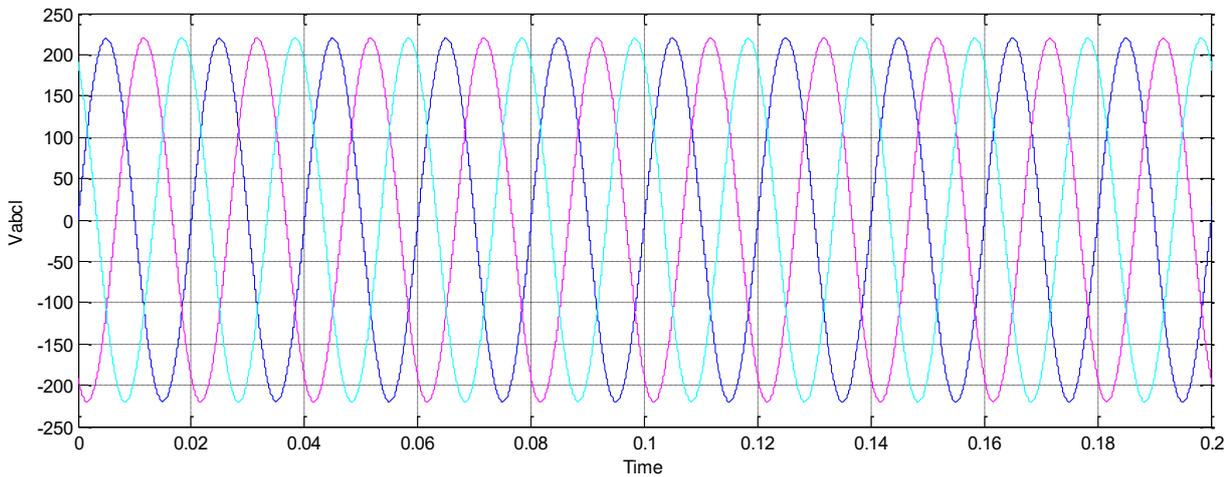


Fig. 8 Output Waveform Of Load Voltage

Fig. 8 represents the load voltage wave form it has 230V magnitude and three phase are maintain 120 degree phase shift with each other. The load voltage maintain equal magnitude in various load conditions also.

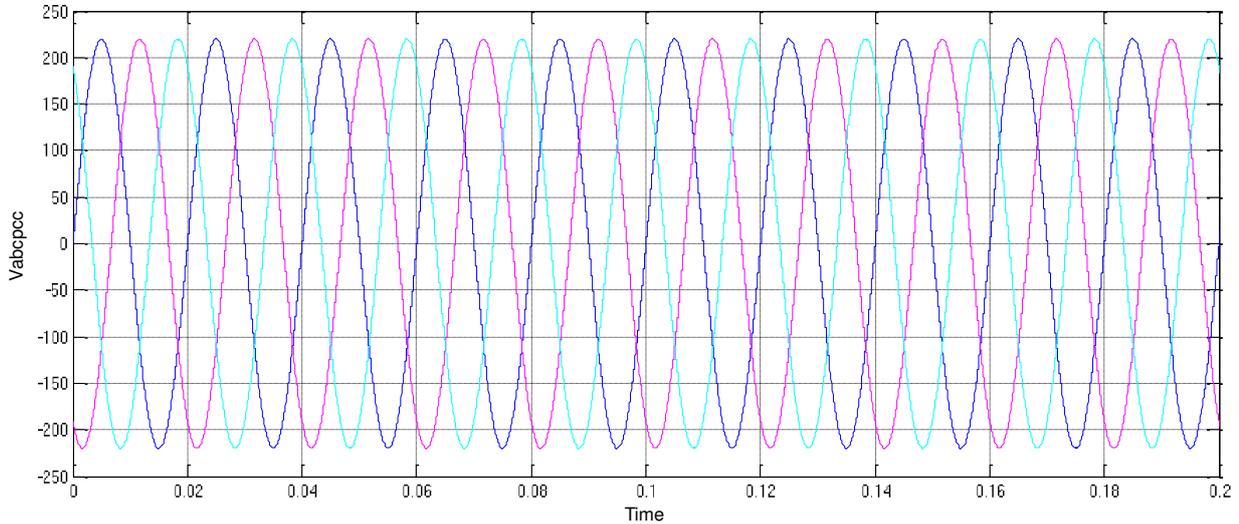


Fig. 9 Output Waveform Of PCC Voltage

Fig. 9 represents the PCC (point of common coupling) voltage wave form, it has 230V magnitude and three phase are maintain 120 degreed phase shift with each other. The Fig. 9 voltage taken from the hydro voltage and PV voltage coupling point.

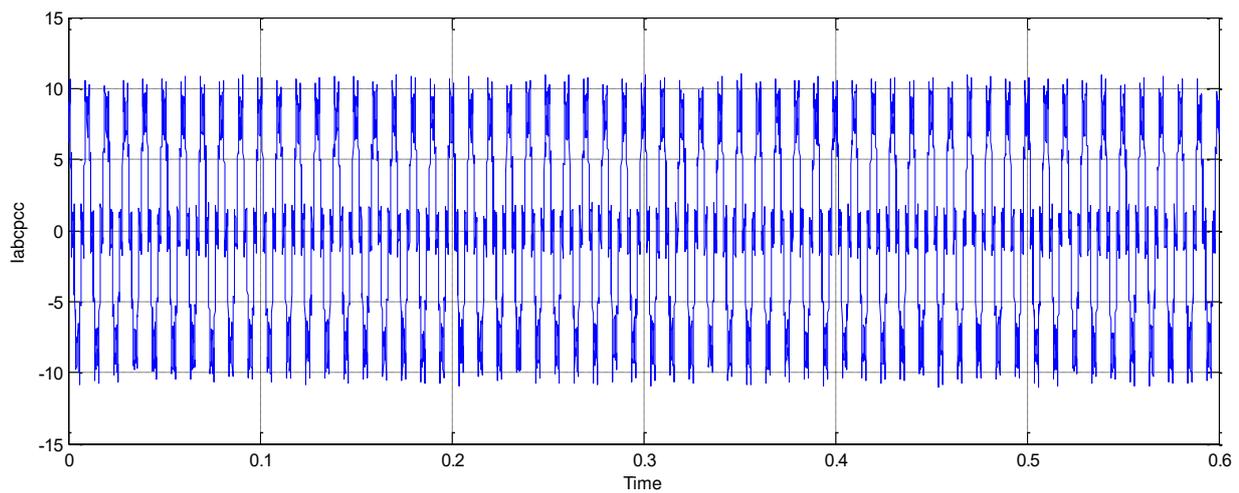


Fig. 10 Output Waveform Of PCC Current

Fig. 10 represents the PCC (point of common coupling) current wave form, the current is taken from the hydro voltage and PV voltage coupling point.

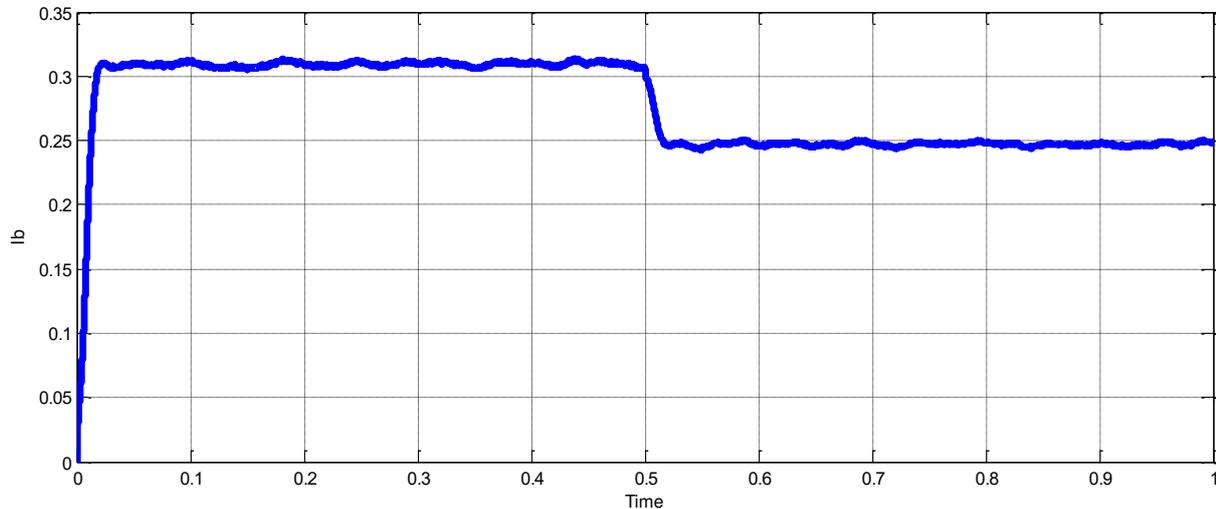


Fig. 11 Output Waveform Of Battery Current

Fig. 11 represents the battery output current, it has magnitude is varying from 0.3A to 0.25A. From initial value zero to 0.5sec it has 0.3A magnitude after 0.5sec the PV current magnitude is decrease to 0.25A due to change in load.

V. CONCLUSION

The design and dynamic performance of three-phase PV using integrated UPQC have been analyzed under conditions of variable irradiation and grid voltage sags/swells. The performance of the system has been validated through experimentation on scaled down laboratory prototype. It is observed that PVUPQC mitigates the harmonics caused by nonlinear load and maintains the THD of grid current under limits of IEEE-519 standard. 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 moving average filter. It can be seen that PV-UPQC is a good solution for modern distribution system by integrating distributed generation with power quality improvement.

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