UGC Approved Journal

IJIREEICE

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

ISO 3297:2007 Certified

Vol. 5, Issue 7, July 2017

Three Phase Four Leg Static Compensator for Power Quality Improvement in PV Grid Connected System

Sri. C. R Sharada Prasad B.E, M.Tech[1], Sushma K P[2]

Associate Professor, E & E Department, UBDTCE College, Davangere, India[1]

Student, E &E Department, UBDTCE College, Davangere, India[2]

Abstract: Energy demand increases rapidly, utilization of renewable energy resources plays an important role in narrowing down the supply-demand difference. Introduction of more power electronic devices and non-linear loads pollutes the grid and create power quality problems. Both the scarcity of energy problem and power quality problem can be solved by using the grid connected PV system based four wire STATCOM. This paper demonstrates the power quality problem due to installation of solar panel with the grid. In this proposed scheme Static Compensator (STATCOM) is connected at a point of common coupling (PCC) to mitigate the power quality issue of Total Harmonic Distortion (THD). The STATCOM control scheme for the grid connected PV energy system for power quality improvement is simulated using MATLAB/SIMULINK in power system block set. The STATCOM is controlled on the basis of PQ based hysteresis control of STATCOM. Thus with such a control, a balanced linear load appears at the grid with the combination of STATCOM and 3-phase 4-wire linear/non-linear unbalanced load.

Keywords: Power quality (PQ), Static compensator (STATCOM), Point of common coupling (PCC).

I. INTRODUCTION

Electric utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Seventy five percent of total global energy demand is supplied by the burning of fossil fuels. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The Renewable Energy Source (RES) integrated at distribution level is termed as Distributed Generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and Power -Quality (PQ) issues [1]. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power. Due to the rapid growth of the power electronics technique, the photovoltaic (PV) power generation system has been developed worldwide. By changing the duty cycle, the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power, the term coined as Maximum Power Point Tracking (MPPT) [3]. There are many MPPT techniques like Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods, Fuzzy Logic Method, etc. In this paper the most popular of MPPT technique (Perturb and Observe (P&O) method has been implemented in MATLAB Simulink. The utilization efficiency can be improved (at the cost of a small increase in implementation cost) by employing this hill- climbing MPPT technique. This is a simple algorithm that does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement with analogue and digital circuits. The algorithm perturbs the operating point of the PV generator by increasing or decreasing a voltage by a small amount (step size) and measures the PV array output power before and after the perturbation. If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction. The number of perturbations made by the MPPT algorithm per second is known as the perturbation frequency or the MPPT frequency. Both active and reactive power control can be achieved with distributed generation units coupled through an Inverter [10]. The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network [11]. The causes of power quality problems are generally complex and difficult to detect when we integrate a photo voltaic system to the grid [2][8]. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to

IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the solar panel; 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase 4-wire system [5]. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously. The PQ [2] constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.
The topology of three- phase four-wire STATCOM [5] not only compensates power quality problems but also allows interface renewable energy sources with gird. The inverter stage of the active filter is based in two-level four leg inverter and its control is based in the theory of Instantaneous reactive power (p-q Theory)[4]. The filter is capable of compensating power factor, unbalance, and current harmonics.

II. GRID INTERCONNECTION OF PHOTOVOLTAIC SYSTEM

A solar cell is the most fundamental component of a photovoltaic (PV) system. The PV array is constructed by many series or parallel connected solar cells to obtain required current, voltage and high power. Each Solar cell is similar to a diode with a p-n junction formed by semiconductor material. When the junction absorbs light, it can produce currents by the photovoltaic effect. The equivalent circuit of a solar cell is the current source in parallel with a diode of a forward bias which represents dark current. The output terminals of the circuit are connected to the load. The current equation of the solar cell is given by

$$I = I_{ph} - I_D - I_{sh}$$

$$I = I_{ph} - I_0 \left[\exp\left(\frac{qV_D}{nkT}\right)\right] - \frac{V_D}{R_{SH}}$$

Where,

I_{ph} =Light generated current
I_D =Diode current
I_{sh} =Shunt current
I_0 =Saturation current
T=Temperature
V_D =Diode voltage
k =Boltzmann constant
R_{SH} =Shunt resistance
q =Electron charge

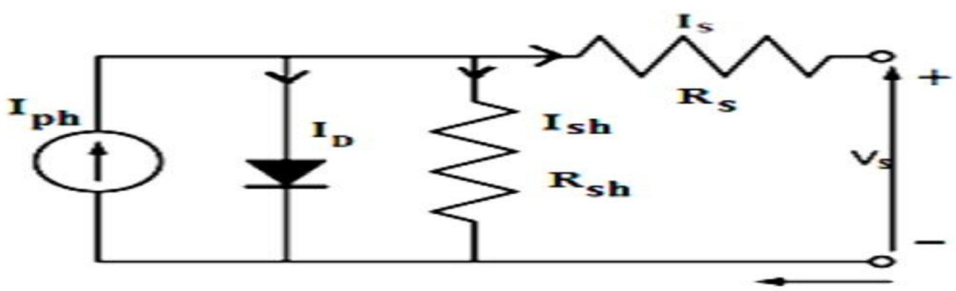

Fig 1. Equivalent Circuit of a Solar Cell

III. DESIGN OF PROPOSED MODEL

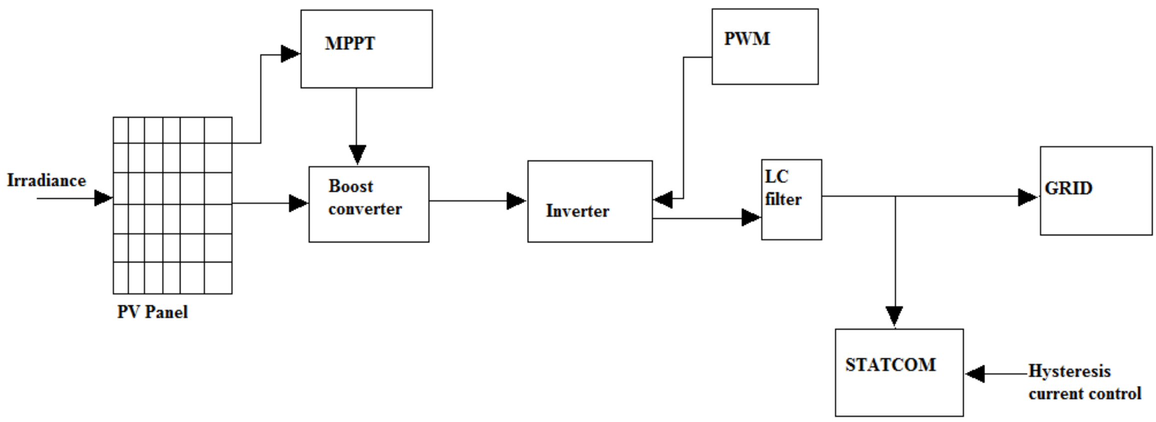

Fig.2 Proposed model

DOI 10.17148/IJIREEICE.2017.5722

PV Panels generate DC Voltage and this dc power is has to convert into AC power before exchange power with utility grid. There is a need of inverter to convert DC to AC before connecting to utility grid. Voltage and frequency of inverter output should be same as that of grid voltage and frequency. So that it can easily synchronized with grid.
Many inverter topologies are available. In this scheme
Voltage Source Inverter is selected with PWM (Pulse width modulated) (p-q theory) in phase. For three phase inverter 6 switching devices are used and its switching is controlled by PWM signals.

A. Static Compensator (STATCOM)

The three-phase four-leg STATCOM is based on four-leg voltage source converter. A STATCOM is built with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs. A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial photo voltaic system.
The STATCOM is a shunt-connected reactive-power compensation device that is capable of generating and/ or absorbing reactive power and in which the output can be varied to control the specific parameters of an electric power system. It is in general a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output terminals when it is fed from an energy source or energy-storage device at its input terminals. Specifically, the STATCOM, which is a voltage-source converter which when fed from a given input of dc voltage, produces a set of 3-phase ac-output voltages, each in phase with and coupled to the corresponding ac system voltage through a relatively small reactance (which is provided by either an interface reactor or the leakage inductance of a coupling transformer). The dc voltage is provided by an energy-storage capacitor. A STATCOM based control technology has been proposed for improving the power quality which can technically manages the power level associates with the commercial wind turbines. A STATCOM can improve power-system Performance like:

- The dynamic voltage control in transmission and distribution systems,
- The power-oscillation damping in power- transmission systems,
- The transient stability;
- The voltage flicker control; and
- The control of not only reactive power but also (if needed) active power in the connected line, requiring a dc energy source.

The three-phase four-leg STATCOM is based on four-leg voltage source converter [5]. It can compensate reactive currents, negative sequence currents and neutral currents of the power grid.

B. INSTANTANEOUS REACTIVE POWER THEORY

The P-Q theory was introduced by H.Akaqi in 1983. Time domain analysis has evolved a new manner to analyse and understand the energy flow in nonlinear circuit. The p-q theory is based on the set of instantaneous power defined in time domain. No restrictions are imposed on the voltage or current waveform and it can be applied on the three phase system with or without neutral. The p-q theory uses Clarks' transformation to converter from a-b-c coordinates to α-β-0 coordinates for both three phase currents and voltages and then defines instantaneous powers on these coordinates. The p-q theory uses Clarke transformation or α-β-0 transformation which consists of a real matrix that transforms three phase components into α-β-0 stationary reference frames. In this method reference current is generated from the instantaneous active and reactive power of the non-linear load. The three phase current or voltage waveforms from a-b-c coordinates system transforms to α-β-0 coordinates. It corresponds to an algebraic transformation, known as Clarke transformation, where coordinates α-β are orthogonal to each other, and coordinate corresponds to the zero-sequence component.

$$\begin{bmatrix} V_\propto \\ V_\beta \\ V_0 \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_{ca} \\ V_{cb} \\ V_{cc} \end{bmatrix}$$

$$\begin{bmatrix} I_\propto \\ I_\beta \\ I_0 \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} I_{ca} \\ I_{cb} \\ I_{cc} \end{bmatrix}$$

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

The α-β-0 coordinate system is again transformed to three phase a-b-c coordinates system. This corresponds to an algebraic transformation, known as Inverse Clarke transformation.

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} & \frac{-\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \\ i_0 \end{bmatrix}$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & 0 & \frac{1}{\sqrt{2}} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \\ \frac{-1}{\sqrt{2}} & \frac{-\sqrt{3}}{2} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_\alpha \\ V_\beta \\ V_0 \end{bmatrix}$$

The conventional instantaneous power on the three phase circuit can be defined as
Where p is equal to the conventional equation

$$p = V_\alpha . i_\alpha + V_\beta . i_\beta$$

The Instantaneous Reactive power q is defined as

$$q = V_\beta . i_\alpha - V_\alpha . i_\beta$$

The Instantaneous active power p and reactive power q are defined as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

P and q can resolved a mean value and an alternating value.

$$q = q^- + q^\sim$$
$$p = p^- + p^\sim$$

$p^-$and q^- are created from positive sequence components of the load current and $p^-$and q^- from the harmonic components of load current.
The oscillating components of p and the entire q should be supplied by the active power filter. So the required compensating currents can be calculated as
Compensating current $i_{c\propto}$ and $i_{c\beta}$ is obtain by the Instantaneous active power p and reactive power q

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}^{-1} \begin{bmatrix} p \\ q \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{V_\alpha^2 + V_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix}$$

Instantaneous active current on the α axis $i_{c\propto}^*$

$$i_{c\propto}^* = \frac{V_\propto}{V_\alpha^2 + V_\beta^2} p^- - \frac{V_\beta}{V_\alpha^2 + V_\beta^2} q$$
$$i_{c\beta}^* = \frac{V_\beta}{V_\alpha^2 + V_\beta^2} p^- + \frac{V_\propto}{V_\alpha^2 + V_\beta^2} q$$

The Instantaneous reactive currents are $i_{c\propto}^*, i_{c\beta}^*$ transformation into the three phase reference compensating currents $i_{ca}^*, i_{cb}^*, i_{cc}^*$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \frac{2}{\sqrt{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{3}{\sqrt{2}} \\ \frac{-1}{2} & \frac{3}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{c\propto}^* \\ i_{c\beta}^* \end{bmatrix}$$

 DOI 10.17148/IJIREEICE.2017.5722

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

The three phase reference compensating currents i^*_{ca}, i^*_{cb}, i^*_{cc} are given to hysteresis current controller

Harmonics are generated by nonlinear loads and are injected into power system. The calculated compensating three phase currents using instantaneous reactive power theory i^*_{ca}, i^*_{cb}, i^*_{cc} are used as reference currents for hysteresis current controller. The Hysteresis current controller will generate pulses given to the controller switches. Finally controller will generate compensating currents i^*_{ca}, i^*_{cb}, i^*_{cc} and injected into power system. Therefore reactive power demand in the power system decreases. By the way, with the reduction in reactive power demand, the Harmonics in the system are reduced. The value of THD is decreased and power factor is improved.

C. Hysteresis Band Current Controller

Hysteresis current control produces gating pulses to the switches in the inverter. The pulses are generated by passing the current error signal to the hysteresis band. This method gives an asynchronous control of the inverter switches. The main advantages of this method is its robustness and dynamic action. There are two limits in the hysteresis band, the upper band and the lower band. The upper and lower band constitute the total bandwidth of the hysteresis control. When the error current tend to exceed the upper band the upper switch is turned off and the lower switch is turned on in the respective branch.

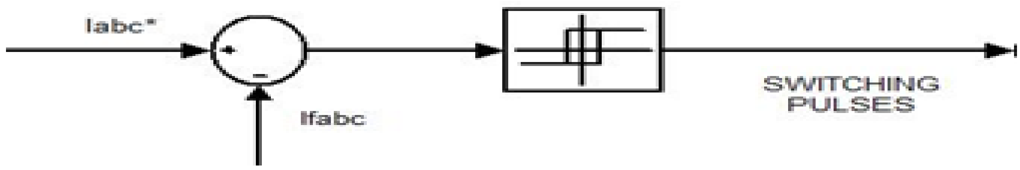

Fig 3. Hysteresis band current controller

By this the current again tracks back to the hysteresis band. When the current tend to exceed the lower band limit the upper switch is turned on and the lower switch is turned off. By this switching the current tends to lie within the hysteresis band and compensating current follows the reference current. Switching frequency can be obtained from the voltage waveform of the inverter. The voltage waveform in turn depends on the current error signal of hysteresis control by which the pulses are produced. Variable frequency is obtained from the hysteresis current controller. By changing the hysteresis band the frequency can be changed.

IV. SIMULATION RESULTS

For the simulation of real model, Matlab is very essential tool. Simulink model of without STATCOM is shown in fig 4.1.and waveforms of source side and load side without STATCOM as shown in fig 4.1(a) and fig 4.2(b). The total harmonic distortion of source and load side without STATCOM as shown in fig 4.1(c) and fig 4.1(d).

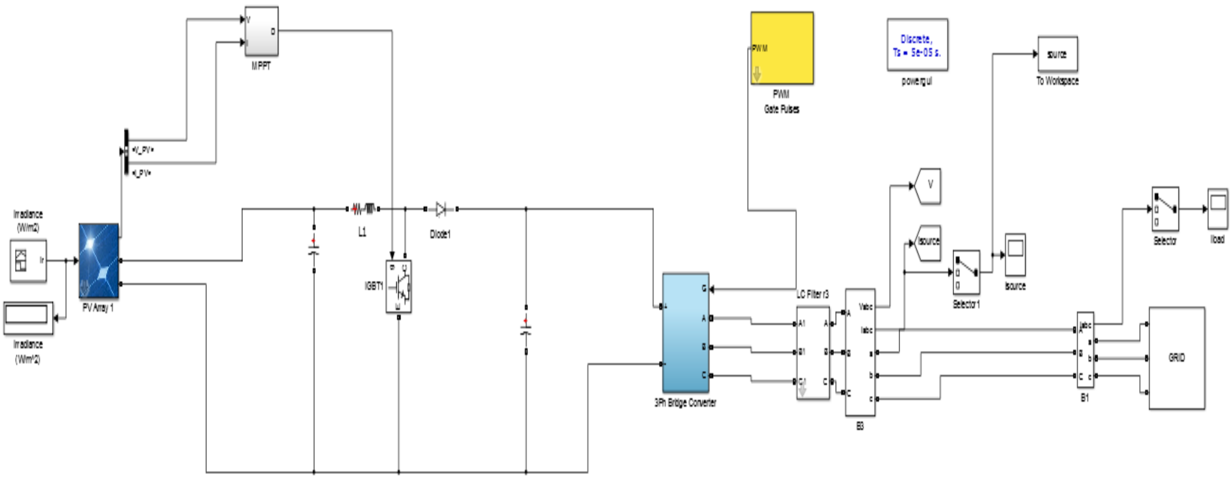

Fig 4.1. Simulink model without STATCOM

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

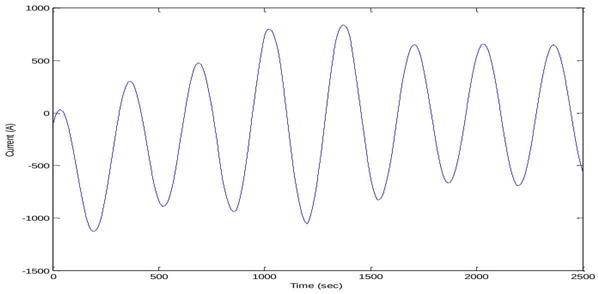

Fig 4.1(a) waveform of source side current without STATCOM

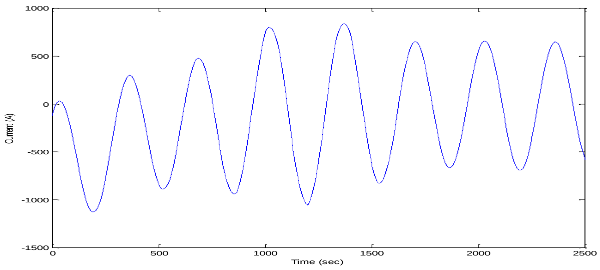

Fig 4.1(b) waveform of load side current without STATCOM

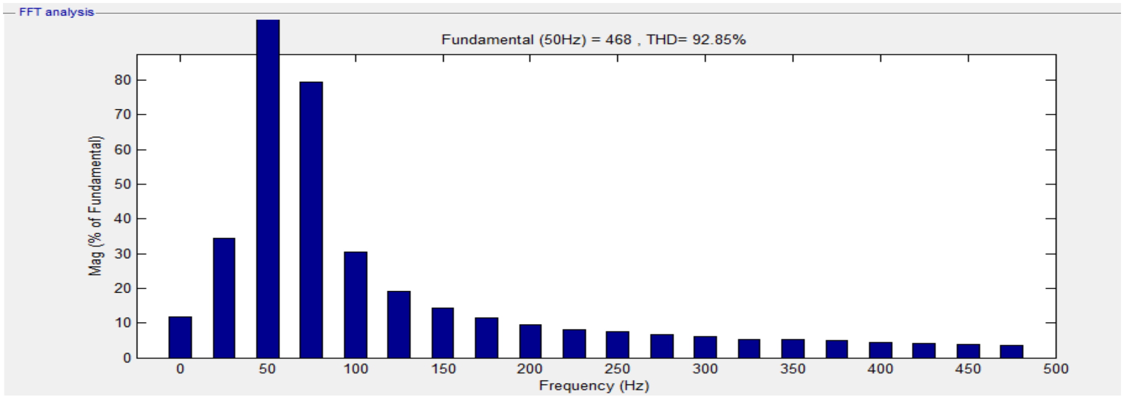

Fig 4.1(c) THD of source side current without STATCOM

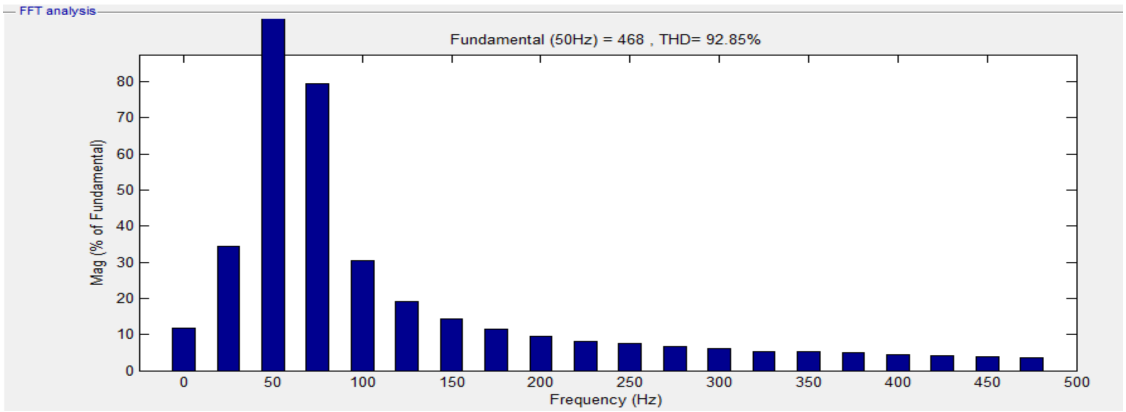

Fig 4.1(d) THD of load side without STATCOM

Simulink model with STATCOM is shown in fig 4.2. and waveforms of source side and load side with STATCOM as shown in fig 4.2(a) and fig 4.2(b). The total harmonic distortion of source and load side with STATCOM as shown in fig 4.2(c) and fig 4.2(d).

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

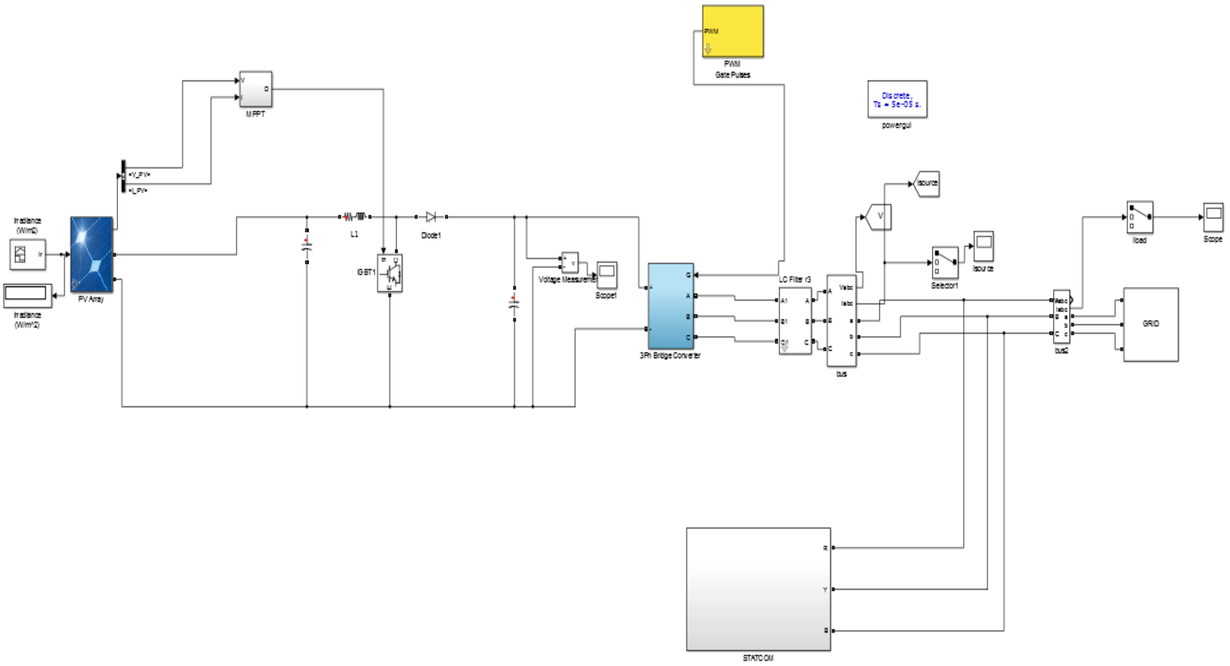

Fig 4.2 Simulink model with STATCOM

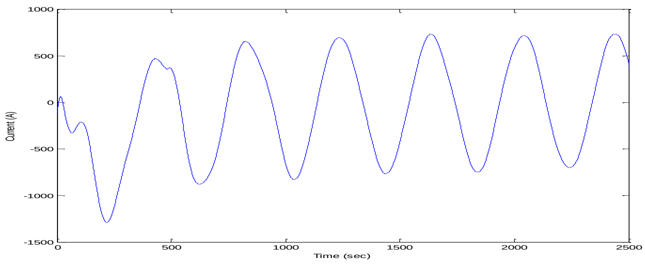

Fig 4.2(a). Waveform of source side current with STATCOM

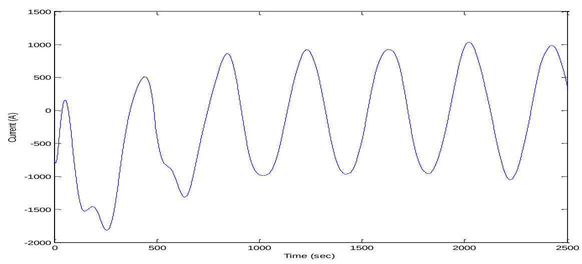

Fig 4.2(b) waveform of load side current without STATCOM

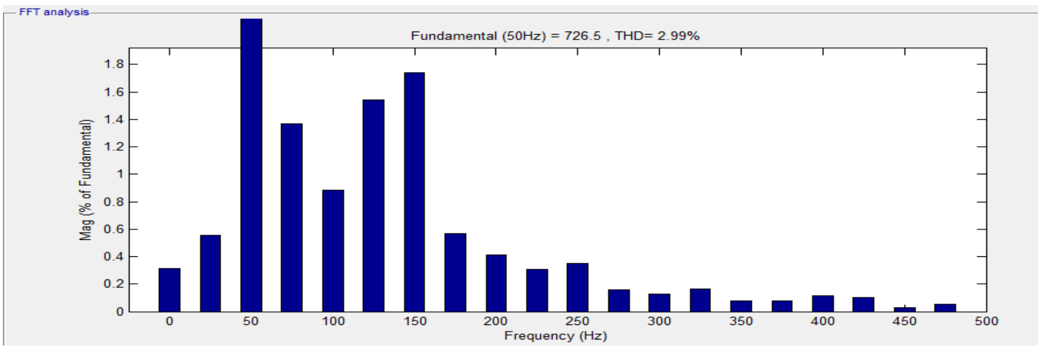

Fig 4.2(c) THD of source side current with STATCOM

UGC Approved Journal
IJIREEICE
ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
ISO 3297:2007 Certified
Vol. 5, Issue 7, July 2017

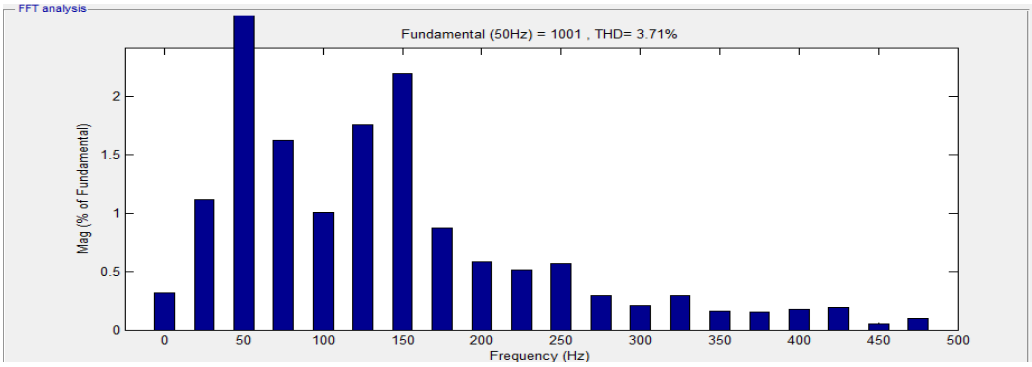

Fig 4.2(d) THD of load side current with STATCOM

IV. CONCLUSION

This paper presented Power Quality Improvement in grid connected PV system using three-phase four-wire STATCOM. The PQ based hysteresis current controller is used to generate the switching signal for inverter in such a way that it will cancel the harmonic current in the system. This scheme improves power factor and also make harmonic free source current in the distributed network at the point of common connection. Rapid injection or absorption of harmonic in the power system can be made possible through static compensator. This proposed model is implemented using MATlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system and performance of power system have been established.

REFERENCES

[1] Masoud Farhoodnea, Azah Mohamed, Hussain Shareef, Hadi Zayandehroodi, ―Power Quality Analysis of Grid-Connected Photovoltaic Systems in Distribution Networks‖, Przegląd Elektrotechniczny, (2013), ISSN 0033-2097, R. 89 NR 2A.
[2 Omran W.A., M. Kazerani, and M.M.A. Salama, ―A study of the Impacts of Power Fluctuations Generated from large PV Systems‖, IEEE PES/IAS Conference on Sustainable Alternative Energy (SAE), 2009.1-6.
[3] Seok-Ju, L., P. Hae-Yong, K. Gyeong-Hun, S. Hyo-Ryong, M.H. Ali, P. Minwon, and Y. In-keun, ―The Experimental Analysis of the Grid-Connected PV System Applied by POS MPPT‖, In International Conference on Electrical Machines and Systems 2007. 1786-1791.
[4] H. Akagi, Y. Kanazawa, and A. Nabae, ―Instantaneous reactive power compensators comprising switching devices without energy storage components‖, IEEE Trans. Ind. Applicat., vol. IA-20, pp. 625-630, [89] May/June 1984.
[5] 2014 International Conference on Power System Technology (POWERCON 2014)," Negative Sequence Current Feed-forward
Control for Three-phase Four-leg STATCOM under Unbalanced Loads,"Zhang Zhihao, **Wu** Jianwen.
[6] Zayandehroodi, H., A. Mohamed, H. Shareef, and M. Farhoodnea, ―A Novel Neural Network and Backtracking based protection coordination scheme for distribution system with distributed generation‖, International Journal of Electrical Power and Energy Systems, 43 (2012), No.1, 868-879.
[7] S. CHANDRAMOULU, K. SREEPAL REDDY," PQ Theory and ID-IQ Theory Controlled STATCOM for Grid Connected Wind Driven Induction Generator for Power Quality Improvement," ISSN 2348–2370 Vol.07, Issue.18, December-2015.
[8] Ashok Kumar L. Archana N. and Vidhyapriya R.," Power Quality Improvement of Grid Connected Wind Energy Systems Using Statcom-Battery Energy Storage System," ISSN 1819-6608 VOL. 10, NO. 21, NOVEMBER 2015.
[9] Chowdhury, B.H. ―Effect of Central Station Photovoltaic Plant on Power System Security‖, Conference Record of the Twenty First IEEE Photovoltaic Specialists Conference, 1990. 831-835 vol.
[10] Mr. Piyush M. Desai, 2Mr. S. S. Khule," Reactive Power Compensation Through Grid Connected PV System Using STATCOM," ISSN: 2494-9150 Vol-02, Issue 05, Aug 2016.
[11] C. K. Duffey and R. P. Stratford, ―Update of harmonic standard IEEE- 519: IEEE recommended practices, requirements for harmonic control in electric power systems‖, IEEE Trans. Ind. Applicat., vol. 25, pp. 1025-1034, Nov./Dec. 1989.

BIOGRAPHIES

Sri. C.R. Sharada Prasad, BE, M.Tech, Associate Professor, Electrical and Electronics Engineering, E & E Dept. UBDTCE, Davangere.

Sushma K.P, B.E, M.Tech (pursuing), Student, Power System Engineering, UBDTCE, Davangere.