Impact Factor (SJIF): 3.632

International Journal of Advance Research in Engineering, Science & Technology

e-ISSN: 2393-9877, p-ISSN: 2394-2444
Volume 3, Issue 5, May-2016

Load following mode Control of Solar PhotoVoltaics Generation for providing Ancillary service of reactive power in distribution system

Bhargav Balbhadra[1],Ajit Rathod[2]

[1]*Electrical Department, Parul institute of Technology*
[2]*Electrical Department, Parul institute of Technology*

Abstract —***In this paper, control of active as well as reactive power of solar PV generation with load following is discussed. Here a method to model solar PV and grid-connected inverter for the same is discussed. Controlling of active power in load following mode is possible only when there is enough generation is available during daytime, while controlling of reactive power can be achieved at day and night time also. This paper explores capability of static converters to supply both active and reactive power as per the demands. All the simulations are done in MATLAB, Simpowersystems.***

Keywords-Solar PV; Active-Reactive power control; Grid-integration; Ancillary service; Load following mode control; Distributed generation

I. INTRODUCTION

Increasing demand for energy, depletion of fossil fuels, energy security and threats like blackout has turned the world towards, more utilization of green, clean and sustainable energy. 69% of total required electricity is being generated through thermal power station which includes coal, gas & diesel based power plants in India. These thermal power plants are prominent source of carbon emission. Reduction in this carbon emission is essential for upcoming era. This can be partly achieved with the help of renewable distributed energy resources. Though there is not any particular definition of DG is defined as "*the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site of the meter*". Capacity range are also varying in different literature [2] suggests the capacity of DG may be 10-50 kWs. In [3] comparison of various Distributed generation in India is mentioned. Among all the renewable DERs solar PV's popularity due to several reasons as awareness for carbon footprint reduction, grid reliability, power system security, net metering policy.Solar PV is a device which directly converts sunlight in to electricity. When light shines on a solar cell, photovoltage is generated, this is capable to drive the current in external circuit, and therefore can deliver power [5]. Solar PV cells are the basic element of this device. Though output of a solar cell is very low, series and parallel connection are done in order to achieve eminent output. This combination is called solar PV module. Though output of a PV module depends on many variables like irradiance from sun, atmospheric temperature [5] a typical module available in the market is having output ranges from 100W to 300W per module. As DC (Direct Current) is generated from solar it can be used to feed loads like lightning or small DC motors, to use it for more sophisticated applications power conversion is required [5]. Due to availability of self-commutating devices like IGBT, MOSFET this power conversion ha became much more feasible. Power conversion devices may help to mitigate the effects due to *stochastic* nature of sun, and may help in finding Maximum Power Point (MPP) [5].

Electric system is dynamic in nature with generation and loads interacting with each other instantaneously over transmission, sub-transmission, and distribution levels. With all the dynamics taken in to account responsibilities of an electric utility is to provide proper voltage and frequency regulation. The prime task is to match generation and demand, In addition to this system need to have adequate inertial energy that may be called upon instantaneously to stabilize the dynamics during abnormal conditions. This stabilization requires both real and reactive power controls [1]. Rotating generation equipment like synchronous generators provides inertial component for both real and reactive power. While non-rotating generation sources like solar PV do not provide inertial energy inherently but may need to provide inertia by electronics means, to maintain synchronization with the existing system. These all additional features are required to provide ancillary services to the grid. According to Federal Energy Regulatory Commission (FERC) ancillary services are "those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system".

Commission has identified twelve ancillary services some of them are: reactive power and voltage control, loss compensation, scheduling and dispatch, load following, system protection, energy imbalance etc. Power Electronics interface required for interfacing of renewable energy integration to the grid is having capability to fulfill reactive power management through which voltage regulation is also possible.In this work an approach has been made to control active as well as reactive power of a solar PV [6]. Article is outlined as follows first of all mathematical modeling of solar PVin MATLAB has been discussed,controlling of active and reactive power of solar PV generation with load following mode is demonstrated with help of simulation results .

II. Solar PVmathematical modeling

As discussed in [6] solar PV can be modeled mathematically in MATLAB. Here most widely used single diode model taken in to account. A representation of the same is drawn in figure 1. To model the solar PV in MATLAB there are set of equations which can be modeled. They are given below.

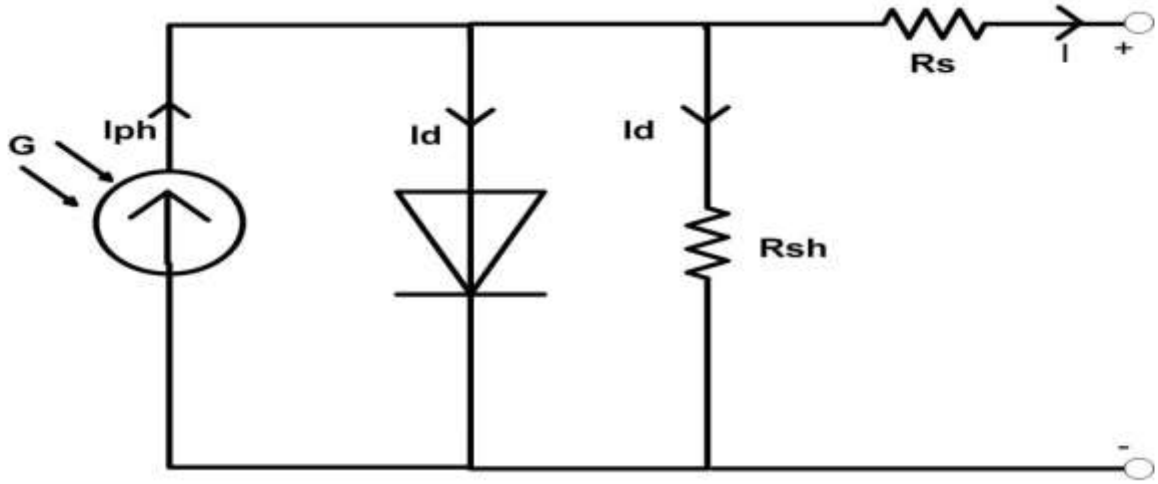


Figure 1. Electrical equivalent representation of solar PV

Table 1. Equations for mathematical modeling of solar PV

Sr.	Quantity	Equation
1.	Thermal voltage (V_t)	$V_t = \frac{k\,T_1}{q}$
2.	Diode current (I_d)	$I_d = \left[e^{\frac{(V+IR_S)}{dV_t nNs}} - 1\right] I_s N_p$
3.	Saturation current(I_s)	$I_s = I_{rs}\left(\frac{T_1}{T_2}\right)^3 e^{\left[\frac{qEg}{dk}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)\right]}$
4.	Reverse Saturation current (I_{rs})	$I_{rs} = \frac{I_{sc}}{\left[e^{\left(\frac{V_{oc}q}{kcT_{op}d}\right)} - 1\right]}$
5.	Photo current (I_{ph})	$I_{ph} = \frac{G}{G_{ref}}[k_i(T_1 - T_2)]$

6.	Shunt current (I_{sh})	$I_{sh} = \frac{V + IR_s}{R_{sh}}$
7.	Total current (I)	$I = I_{ph}N_p - I_d - I_{sh}$

All the necessary values can be found out from reference [5]

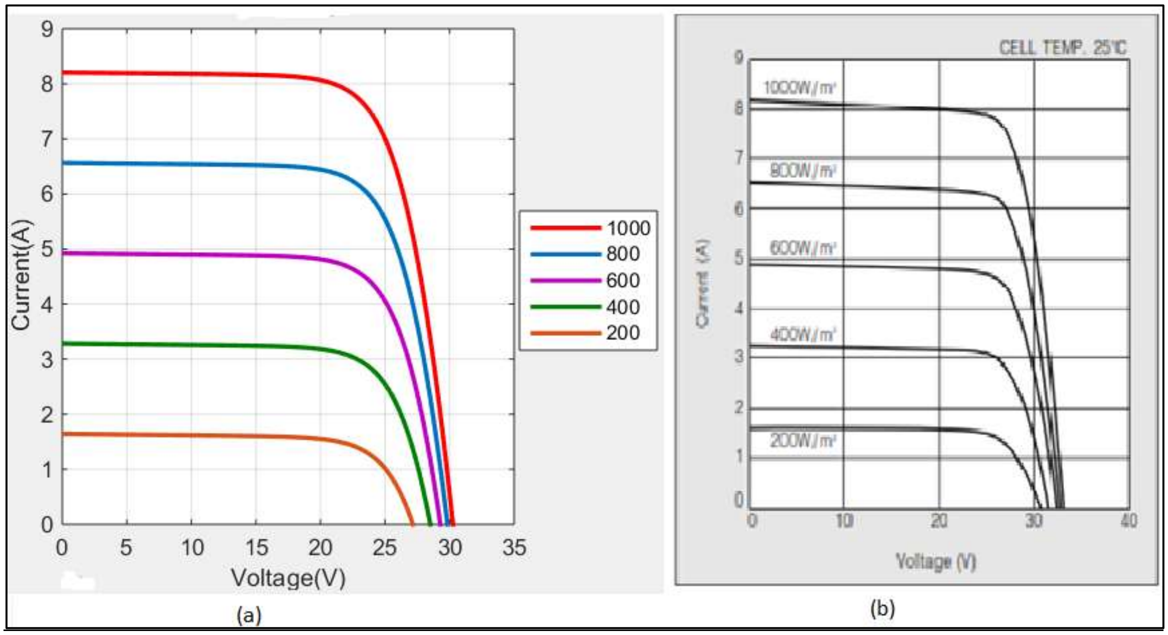


Figure 2. I-V characteristics of Kyocera KC200GT (a) Obtained from simulations (b) Given with datasheet

Above figure represents *I-V characteristics* for different irradiance level and constant Temperature of 25^0C, as depicted in the figure as irradiance of the sun decrease knee of the graph also decreases. It can be quoted undoubtedly that, "as voltage and current changes power of a solar panel changes". Which can be observed with help of below figure of*P-V curve.*

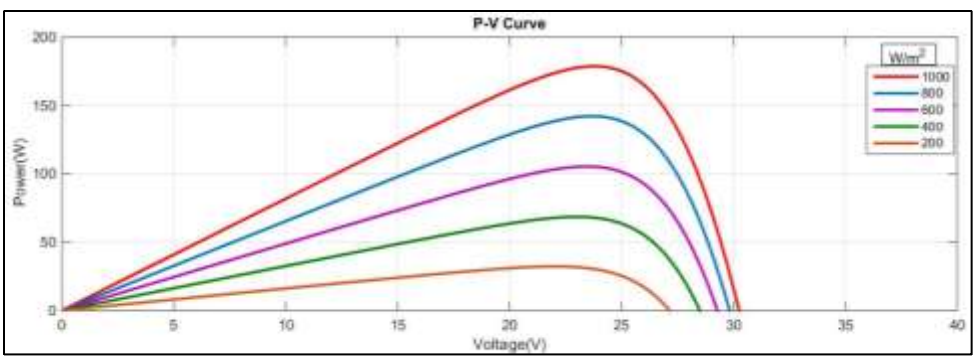


Figure 3. P-V curve of Kyocera KC200GT

III. Controlling of Active and Reactive Power with Load Following mode

A. Brief Introduction on Active and Reactive power

Before moving to controlling part a small discussion on active and reactive power is given here. Active power is the one responsible for useful work, while reactive power is being stored in the electromagnetic or electrostatic fields. In one complete cycle reactive power is being stored in in the above mentioned fields and in the next cycle it will be fed back to the source. Thus it is oscillating from load to source and viz. Power is nothing but multiplication of voltage and current if we talk for DC supply, while in AC supply which angle between those two quantities makes definition of power little bit complicated. In simple words *"active power is multiplication of voltage and component of current in phase with voltage"*, while *"reactive power is multiplication voltage and component of current 90^{0}out of phase"*.Now

B. Load following mode control P-Q control

Load following mode control is coming under the umbrella of ancillary services. As discussed above ancillary services Support the grid to have interruption less power transmission. Conventionally load following is achieved with help of peak load power plant. Abstract behind this concept is the same, which is utilization of solar PV generation as a peak load plant.

To demonstrate so called feature of load following control a small assumption is made over here that we are having enough generation which can be called upon while requirement of load following. In other words solar irradiance is assumed to be constant throughout the simulation. Figure 4 represents the basic diagram of proposed scheme. All the simulations are done in MATLAB/Simulink with help of SimPowerSystems' tool box.

C. System Modeling

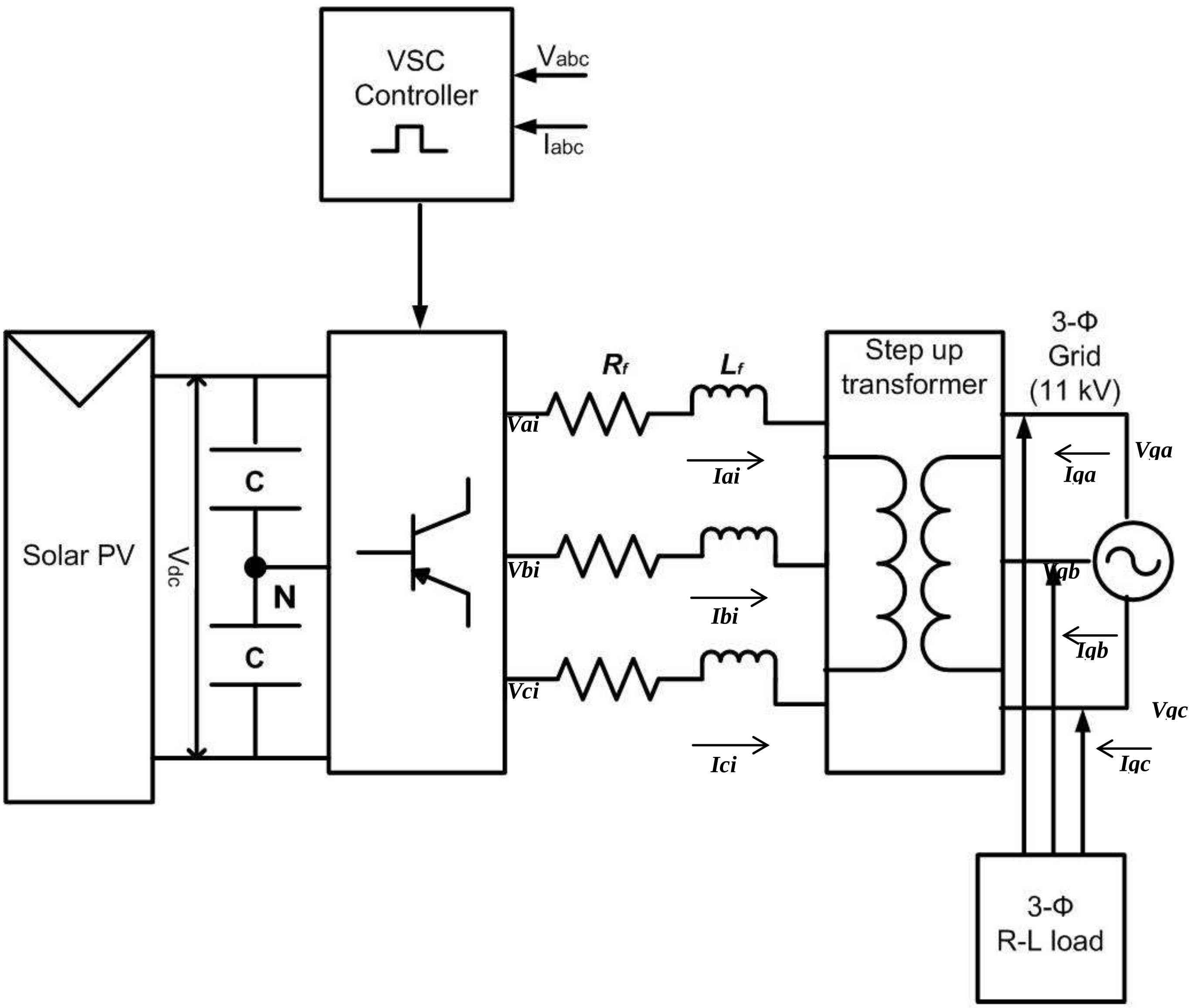


Figure 4.Demonstrative diagram of grid-integrated PV system scheme

Besides, in the transformer, values of the magnetizingbranch's resistance and inductance are generally very muchlarger than values of the primary and secondary winding'sresistance and inductance, respectively. As per the diagram while modeling the grid-connected inverter several measures need to be taken in to account. In above diagram $R_f$and L_f will work as a filter. Then a transformer is being shown which will boost up the voltages. According to the Kirchhoff's voltage law applied tothe circuit represented in Fig. we have below mentioned equations in *abc* frame are,

$$1. \quad \begin{bmatrix} v_{ai} \\ v_{bi} \\ v_{ci} \end{bmatrix} = R \begin{bmatrix} i_{ga} \\ i_{gb} \\ i_{gc} \end{bmatrix} + L \frac{d}{dt} \begin{bmatrix} i_{ga} \\ i_{gb} \\ i_{gc} \end{bmatrix} + \begin{bmatrix} v_{ga} \\ v_{gb} \\ v_{gc} \end{bmatrix}$$

Now, converting equation (1) in to *dq* frame we can have equation 2.

$$2. \quad \begin{cases} v_{di} = R\,(i_{gd}) + L\,\frac{di_{gd}}{dt} - \omega_g L\,(i_{gq}) + v_{gd} \\ v_{qi} = R\,(i_{gq}) + L\,\frac{di_{gq}}{dt} - \omega_g L\,(i_{gd}) + v_{gq} \end{cases}$$

Now three phase active and reactive power can be calculated as

$$3. \quad \begin{bmatrix} P_g \\ Q_g \end{bmatrix} = \frac{3}{2} \begin{bmatrix} v_{gd} & v_{gq} \\ v_{gq} & -v_{gd} \end{bmatrix} \begin{bmatrix} I_{gq} \\ I_{gd} \end{bmatrix}$$

From equation 3 references of direct axis and quadrature axis current for required amount of active and reactive power can be determined. Below figure depicts simulation diagram of above described grid connected PV system.

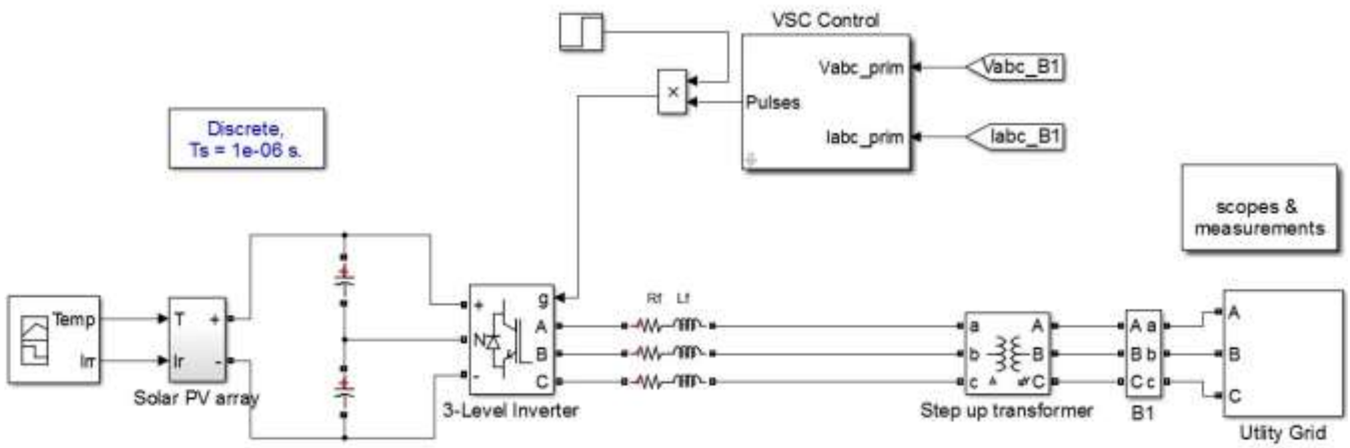


Figure 5. MATLAB modeling of P-Q control of solar PV generation

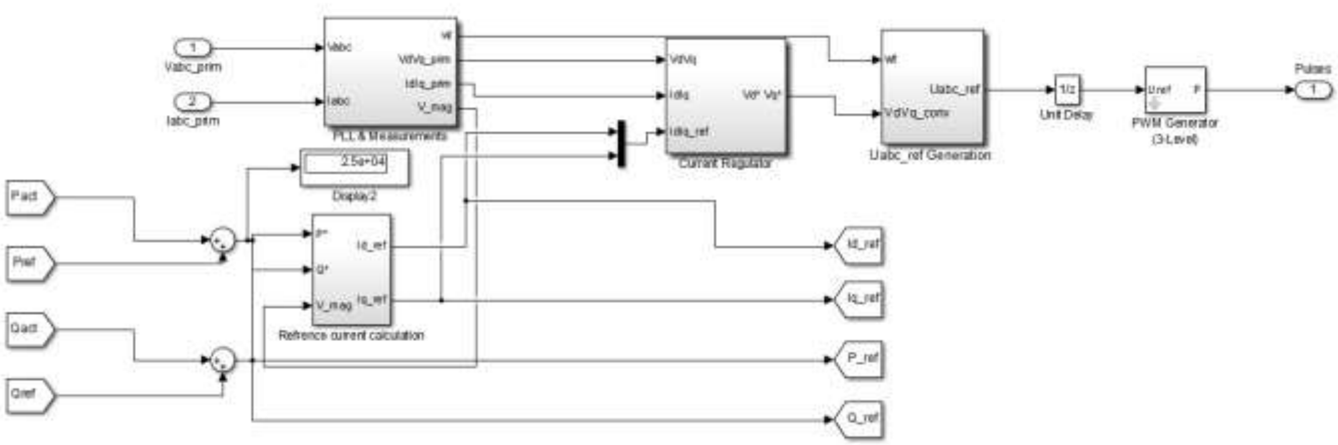


Figure 6. Subsystem under VSC control

For easy processing all the measured quantities first transformed into *per unit (pu)* equivalent. *Vabc_B1* denotes phase voltages while *Iabc_B1* denotes phase currents at Bus B1 this measured quantity will be converted it *pu* values under the block PLL and measurements. PLL stands for phase locked loop which helps to find out grid angle, which is necessary for grid integration. Also a *dq0* transformation is done under this block which converts three phase quantities in to two phase which makes reduction in time varying variables and also faster calculations can be achieved. Another block is current regulator under this block above mentioned equation 2 has been modeled. Under current regulator block error between measured and reference current will be found out and will be tuned with help of PI controller. Thus PI controller will help to reduce steady state error obtained from measured and actual direct axis currents and measured and actual quadratral axis current. Then after two blocks are for U_abc generation and 3-level PWM generator will generate gating signals for 3-level inverter. Here sinusoidal PWM is used with modulating frequency of 20 kHz.

IV. SIMULATIONS RESULTS AND VALIDATIONS

To validate above proposed scheme two cases are taken in to account.

A. One-on-One P-Q control
B. Simultaneous P-Q control

For both the cases the base load value is kept at 20 kW and 20 kVAR, then it will be increased to peak demand of 5 kW and 5 kVAR. Due to change in active and reactive power references I_d and I_q references also changes as per above mentioned equation 3 so that change will be calculated and error is generated between I_d ref and I_d actual similar thing happens for I_q. Then PI controller will play its role to reduce the steady state error. It is clear from the equation 3that change in I_d leads to active power change and change in I_q leads to reactive power change.

A. One-on-One P-Q control

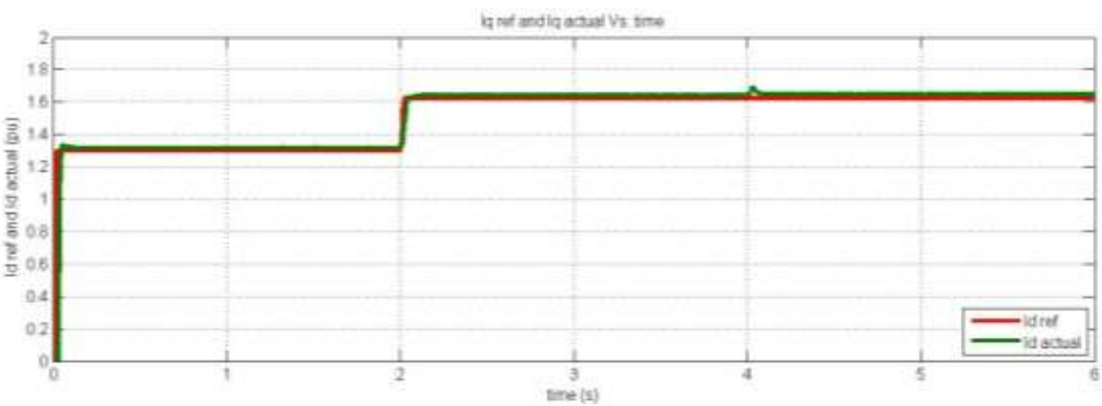


Figure 7. Tracking of I_d_ref and I_d_ref in One-on-One P-Q control

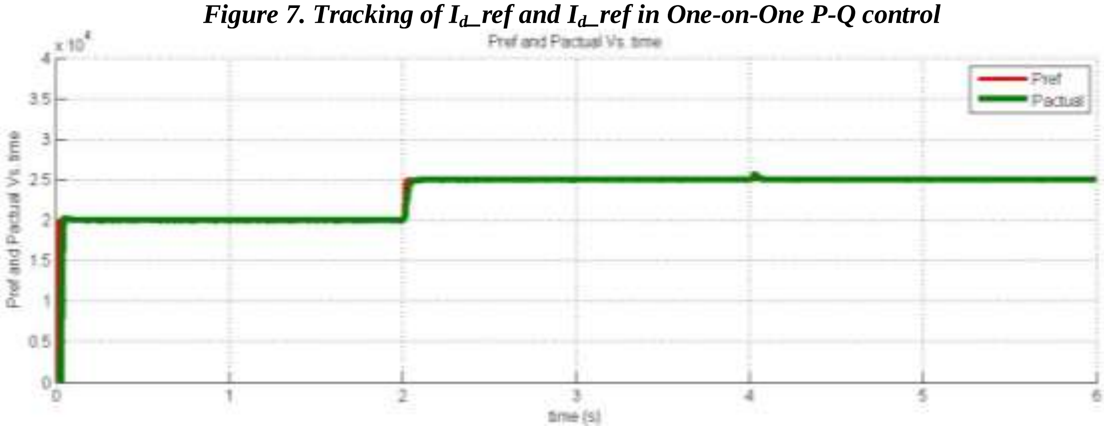
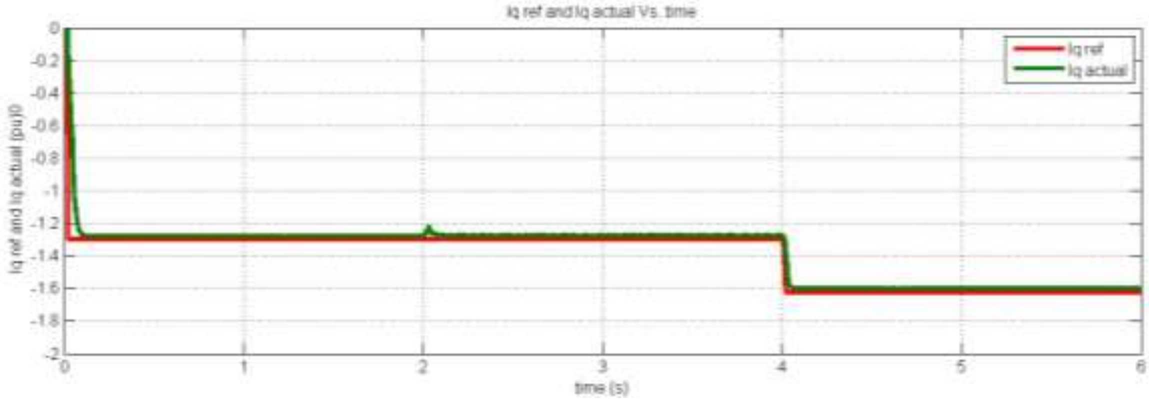


Figure 8. Tracking of active power to follow the load change in active power in One-on-One P-Q control

As shown in the above figure at time t = 2s a change in active power load from base to peak value is applied. It is clearly observable that both I_d and active power changes to follow the change in load. Similarly for change in reactive power I_q is changed from base value to peak value at t = 4s. Graphs are given in the figure below. Again here it is observable that as I_q changes reactive power supplied to the grid by means of inverter also changes. Thus this paper gives the idea of local reactive power supply to compensate the reactive power demand.

B. Simultaneous P-Q control

In this strategy both active and reactive power demands increased from base value to peak value at time t = 1s. For validation, again all the results are sketched below. All the figures clearly points towards effectiveness of control algorithm.



s

Figure 9. Tracking of I_q_ref and I_q_ref in One-on-One P-Q control

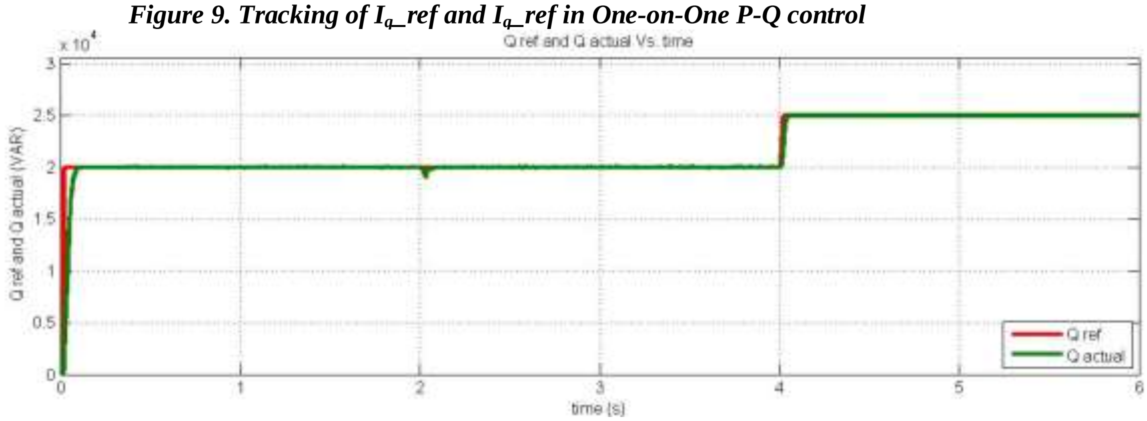


Figure 10. Tracking of reactive power to follow the load change in reactive power in One-on-One P-Q control

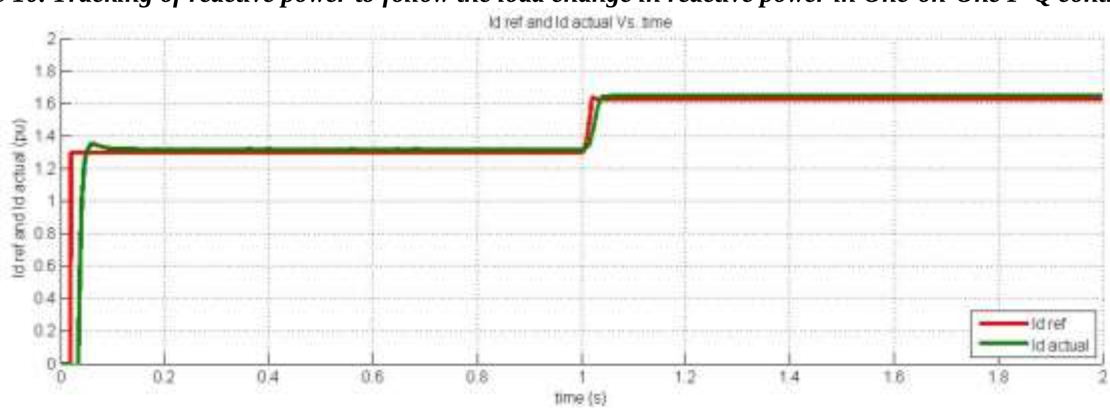


Figure 11 Tracking of I_d_ref and I_d_ref in Simultaneous P-Q control

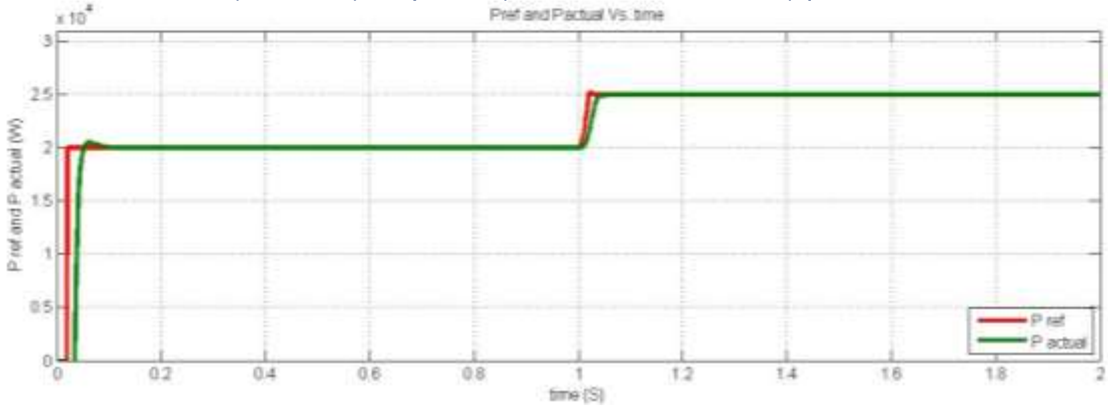


Figure 12 Tracking of active power to follow the load change in active power in Simultaneous P-Q control

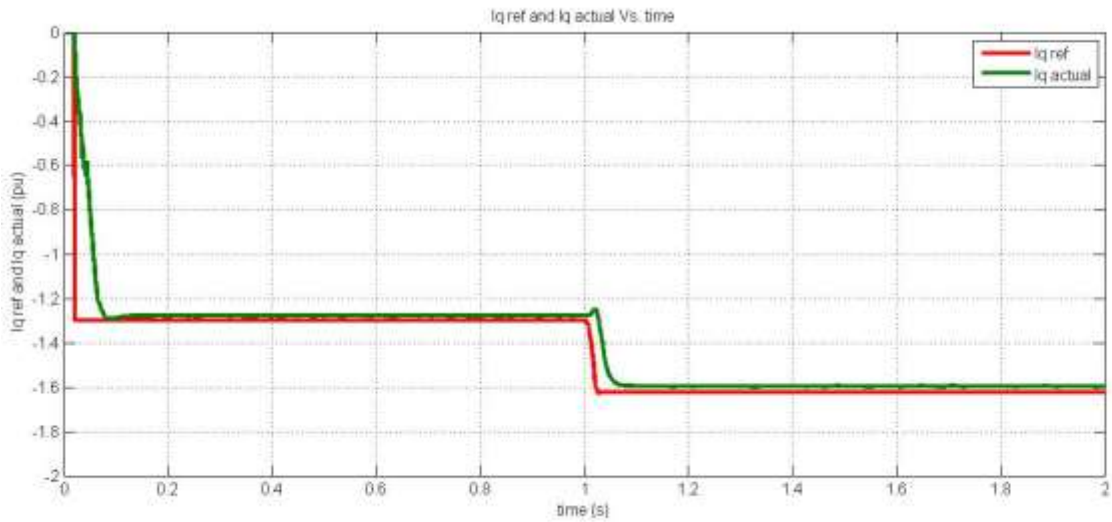


Figure 13. Tracking of I_q_ref and I_q_ref in Simultaneous P-Q control

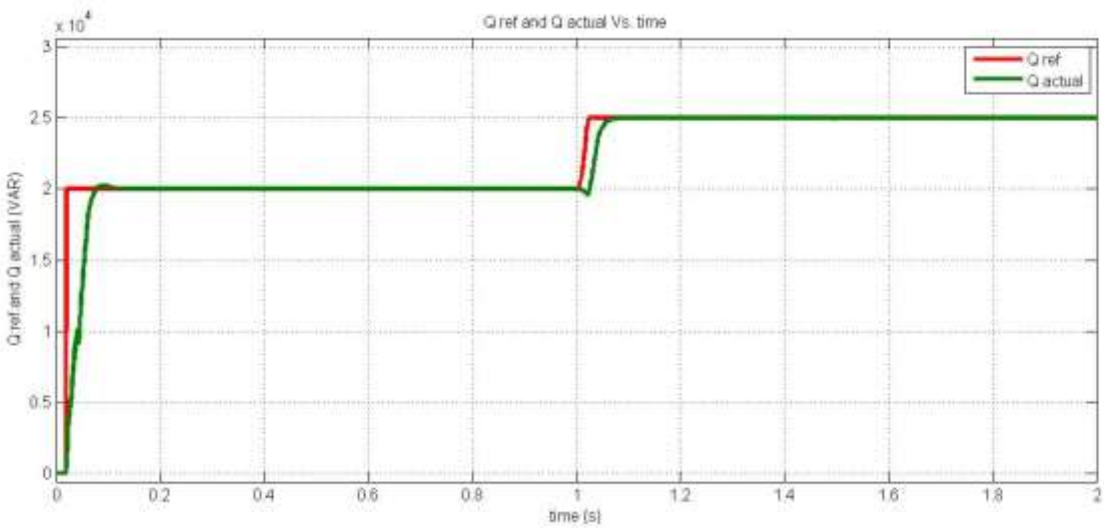


Figure 14. Tracking of reactive power to follow the load change in reactive power in Simultaneous P-Q control

V. CONCLUSION AND FUTURE WORK

In this work an ancillary service of load following with help of solar PV generation is achieved. Results clearly yield the effectiveness of control algorithm. Also two cases are displayed in one case both P-Q demands on the grid has been increased one by one. In other case both the demand has been applied simultaneously. In both the proposed cases inverter is capable of tracing reference and actual currents so the active and reactive power are being traced accordingly. In future work a volt/VAR control with droop control method can be applied, where motto is to maintain voltage at required bus with help of reactive power compensation, similarly droop control of active power and grid frequency can also be achieved.

REFERENCES

[1] P-Q and P-V control of solar Photovoltaic generators in distribution system, S.adhikari, F. LI, H.Li, IEEE Transactions on Smart Grid, March 2015

[2] T. Ackermann, G. Andersson and L. Soder, "Distributed generation: a definition," *Ele. Power Syst.Res.* Vol. 57, Issue 3, pp. 195-204, 20 April 2001.

[3] R. Banerjee, "Comparison of options for distributed generation in India," *Energy Policy*, Vol. 34, Issue 1, pp. 101-111, January 2006.

[4] Chetan Singh Solanki, "SOLAR PHOTOVOLTAICS: Fundamentals, Technologies and Applications 3rd ed.PHI Publications".

[5] M. G. Villalva, J. R. Gazoli, and E. R. Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays," IEEE Trans. Power Electron., vol. 24, no. 5, pp. 1198–1208, May 2009.

[6] L. Piegari and P. Tricoli, "A Control Algorithm of Power Converters in Smart-Grids for Providing Uninterruptible Ancillary services," 14th International Conference on Harmonics and Quality of Power (ICHQP), Sept. 2010.