International Journal of Applied Power Engineering (IJAPE)
Vol. 3, No. 1, April 2014, pp. 41~50
ISSN: 2252-8792

Modeling Simulation & Design of Photovoltaic Array with MPPT Control Techniques

Sangita R Nandurkar[1], Mini Rajeev[2]
[1] Assistant professor, Department of Electrical Engg, A.C P.C.E, Mumbai University, India
[2] Associate professor, Department of Electrical Engg, FCRIT, Mumbai University, India

Article Info

Article history:

Received Jan 25, 2014
Revised Feb 27, 2014
Accepted Mar 12, 2014

Keyword:

Boost converter
Maximum power point tracking (MPPT)
Modelling of PV array
Photovoltaic (PV) array

ABSTRACT

The Renewable energy is important part of power generation system due to diminution of fossils fuel. Energy production from photovoltaic (PV) is widely accepted as it is clean, available in abundance, & free of cost. This paper deals with modeling of PV array including the effects of temperature and irradiation. The DC-DC converter is used for boosting low voltage of the PV array to high DC voltage. Since the efficiency of a PV array is around 13% which is low, it is desirable to operate the module at the peak power point to improve the utilization of the PV array. A maximum power point tracker (MPPT) is used for extracting the maximum power from the solar PV array and transferring that power to the load. To track maximum power point (MPP) Perturb & Observe (P & O) algorithm is used which periodically perturbs the array voltage or current and compare PV output power with that of previous perturbation cycle which controls duty cycle of DC-DC converter. The entire system is simulated in MATLAB /SIMULINK and simulation results are presented.

Corresponding Author:

Sangita R Nandurkar,
Assistant professor, Department of Electrical Engg,
A.C P.C.E, Mumbai University, India.
Email: sangita.nandurkar@gmail.com

1. INTRODUCTION

The renewable energy sources (solar, wind, biomass etc) are important part of power generation. Electricity can be produced operating these sources in parallel with the grid. The photovoltaic(PV) system which ideally suitable for distribution generation is gaining importance today, since it offers many advantages such as requires less maintenance, noise free, pollution free and is more environmental friendly.[1] The photovoltaic system produces DC energy when solar insolation falls on photovoltaic array. The energy available at the terminal of a photovoltaic array can feed small loads such as lightning system, DC motors, but some application requires DC-DC converter, to process the energy from photovoltaic device. These converter are used to regulate the voltage and current at the load, to control power flow in the system and mainly to track maximum power point [2]

The amount of energy generated by photovoltaic array varies with change in environmental condition such as temperature and insolation which reduces the overall conversion efficiency of photovoltaic module. Therefore controlling maximum power point tracker (MPPT) at maximum power point (MPP) is essential in PV system. The amount of power generated by PV array depends on operating voltage of the array. Its I-V & P-V characteristics identify the unique operating point called MPP at which PV should operates and maximum power can be delivered to load operating at its highest efficiency. To enhance the performance of PV many techniques are available [4]-[7] which vary in many aspects such as simplicity, convergence speed, hardware implementation, sensors required & cost. The open circuit voltage method is based on observation that the voltage of the maximum power point is always close to a fixed percentage of the open circuit voltage. The main drawback in this method is energy generated by PV system is less, additional power components is required, static switch is needed which increases the cost of the algorithm. These drawbacks can be overcome by perturb and observe (P&O) method. It operates by periodically incrementing or decrementing the array terminal voltage or current and comparing the PV output power with that of previous perturbation cycle. The advantage of P &O method is easy to implement, control is simple and cost is less compared to other MPPT algorithm techniques.

The work presented here is about the modeling, simulation of PV array connected to DC load. The boost converter duty cycle is controlled by using P&O algorithm techniques. First section deals with modeling of PV array along with MPPT algorithm, followed by design of DC-DC converter, simulink model and results obtained are discussed in subsequent section.

2. SYSTEM CONFIGURATION

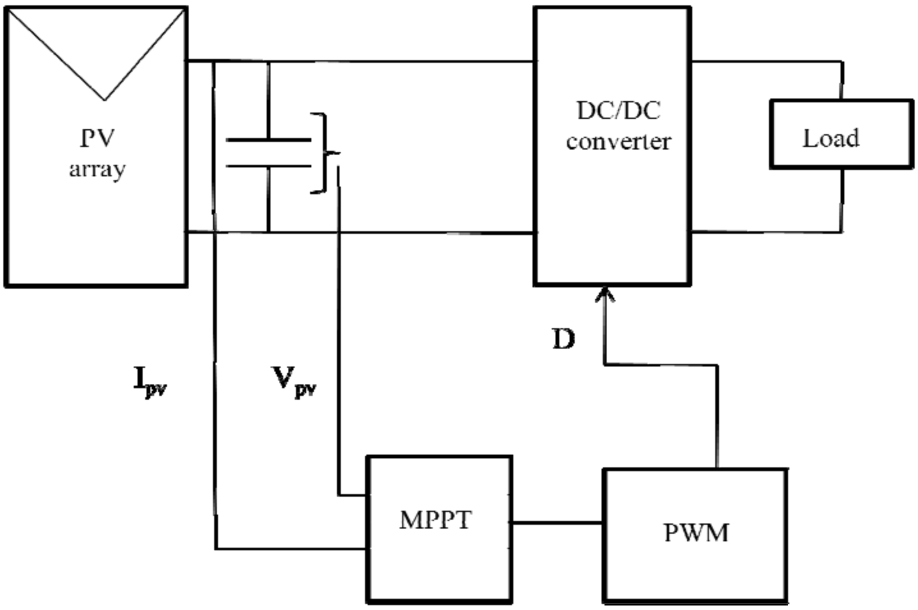

Fig.1 Schematic of the system

The above schematic as shown in Fig.1 present the configuration used in this paper. The PV array contain 5 modules of 250 W_p which is connected in series. The MPPT algorithm is used for extracting the maximum power from solar PV array and extracted power is supplied to load. The DC/DC converter used acts as an interface between PV array and load and serves the purpose of transfering maximum power from PV to load. By changing the duty cycle of the pulse width modulated (PWM) control signal of DC/DC converter, the load impedance seen by source varies and matches the peak power point with that of source, so as to transfer the maximum power. [1]-[2].

3. MATHEMATICAL MODELING OF PHOTOVOLTAIC ARRAY

3.1. Ideal photovoltaic cell

Solar PV is made of photovoltaic cells. Cells are grouped to from panels or modules and panels are grouped to from large PV array. The basic equation which mathematically describes the ideal PV cell is given by Eq. (1) [2]

$$I = I_{pv,cell} - I_{o,cell}\left[\frac{\exp\left({}^{qV}\!\big/_{AkT}\right)}{I_d} - 1\right] \quad (1)$$

Where:

$I_{pv,cell}$ is the current generated by the incident light, $I_{o\ cell}$ is the reverse saturation current of the diode, q is the electro charge valued at $1.602\text{x}10^{-19}$ C, k is Boltzmann's constant valued at $1.381\text{x}10^{-23}$ J/K, T is the junction temperature in Kelvin, A is diode identity constant, V is the voltage across PV cell & I is the output current of the ideal PV model.

3.2. Modelling of photovoltaic array

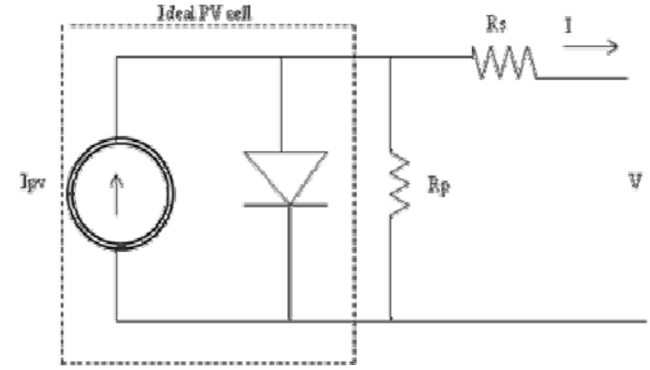

Fig.2 Equivalent circuit of practical PV cell

The basic PV equation does not represent the I-V characteristics as a practical PV module consists of several PV cells which require the additional parameters which is series resistance and parallel resistance (R_s & R_p) as shown in Fig.2. The modeling of PV module is based on mathematical equations of the solar cell which is given by Eq.2. [2].

$$I = I_{pv} - I_o\left(\exp\left\{\left(\frac{q(V + I * R_s}{N_s * AkT}\right) - 1\right\}\right) - \frac{V + I * R_s}{R_p} \tag{2}$$

The light generated current (I_{pv}) depends linearly on solar radiation and is influenced by temperature is given by Eq. (3)

$$I_{pv} = \left[I_{sc} + K_i(T - T_{ref}) * \frac{G}{G_n}\right] \tag{3}$$

Module reverse saturation current (I_{rs}) at nominal condition and reference temperature is given by Eq.(4)

$$I_{rs} = \frac{I_{sc(n)}}{\left[\exp\left(\frac{q * V_{oc}}{N_s * AkT_r}\right) - 1\right]} \tag{4}$$

Module saturation current (I_0) is given by Eq. (5).

$$I_o = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 * \exp\left[\frac{qE_g}{Ak}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{5}$$

Basic output current of PV module of single diode is given by Eq.(6).

$$I = N_p * I_{pv} - I_o * N_p\left[\exp\left(\frac{q(V + I * R_s}{N_s * AkT}\right) - 1\right] \tag{6}$$

Where N_s and N_p is number of solar cells connected in series and parallel. Modeling of PV array is done based on datasheet parameters of SUN Module SW 250 mono versions 2.0 at 25°C & 1000 W/m^2 is given in Table I. Based on above parameters the PV module is modelled in Matlab /Simulink under standard test conditions (STC) of 25°C and 1000 W/m^2

TABLE -I. SUN-SW 250W$_P$ SOLAR MODULE PARAMETERS

Maximum power (P_{mpp})	250 W_p
Open circuit voltage (V_{oc})	37.8 V
Short circuit current (I_{sc})	8.28 A
Maximum power point voltage (V_{mpp})	31.1V
Maximum power point current (I_{mpp})	8.05A
Number of cell in series (N_s)	60
Short circuit temperature coefficient (K_i)	0.04 K
Open circuit temperature coefficient (K_v)	-0.30%/K

4. DESIGN OF DC-DC CONVERTER

A DC-DC converter acts as an interface between the PV and the load, and by varying the duty cycle the point of operation of the module is adjusted. DC-DC converter selected for design is boost converter, as it is used to boost up the PV array voltage and also maximum utilization of PV can be done by operating PV at MPP. The Boost converter design is done considering converter output voltage of 250 V (maximum) and maximum duty cycle of 50%, operating in continues conduction mode (CCM).

The minimum inductor size(L_{min}) is determined from Eq.(7) with inductor value 25% larger than the minimum inductor value, to ensure that inductor current is continues [3]

$$L_{\min} = \left(\frac{V_0 (1-D)^2 * D}{2} \right) * f_s * I_o \tag{7}$$

$L > 25\% \, L_{min}$

Where, V_0 is DC output voltage, D is duty ratio, f_s is switching frequency of converter, I_o is average output current. Considering maximum peak to peak ripple (ΔV_o) in output voltage is 1%., the minimum capacitance value (C_{min}) can be calculated using Eq.(8) [3].

$$C_{\min} = \frac{V_o * D}{R * \Delta V_o * f_s} \tag{8}$$

The switching frequency selection is trade-off between switching losses, cost of switch and efficiency of converter; hence it is decided to select 10 KHz as switching frequency. Based on design, values of L & C are calculated.

5. MAXIMUM POWER POINT TRACKING ALGORITHM

In this work P & O algorithm is selected as MPPT technique. This technique compares the power of the previous step with the power of the new step [4]-[6]. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached the power at the next instant decreases and hence the perturbation reverses. When the steady state is reached the algorithm oscillates around the peak point. In order to keep the power variation small, the perturbation size is kept very small. The flow chart of P&O MPPT algorithm is illustrated in Fig.3 whereas Table- II illustrates the behaviour of the P & O algorithm.

This algorithm can be described by the following statements.

If **dP/dV > 0**: the PV panel operates at a point close to MPP.

If **dP/ dV < 0**: the PV panel operate at a point further away from MPP

Fig.3 Flow chart of P & O control technique [5]

Table-II [4]

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

6. SIMULATION RESULTS

The modeling of the photovoltaic module is realized with Matlab R2010a / Simulink and Fig.4 shows the simulink model of PV array. The input to module is temperature and solar insolation at standard test condition (STC) containing 60 solar cells connected in series of 250 W_p and such five modules are connected in series to from a solar array with voltage & current as output. The specifications of the resistance R_s and R_p of the PV array are 0.221 Ω & 415 Ω [2] .

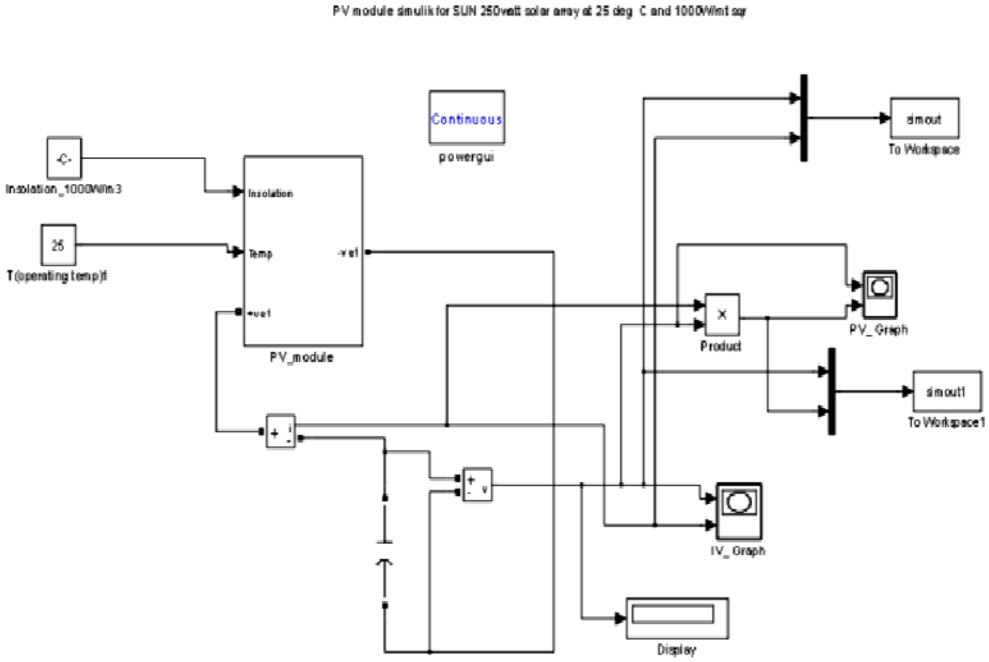

Fig.4 Matlab Simulink model of PV array

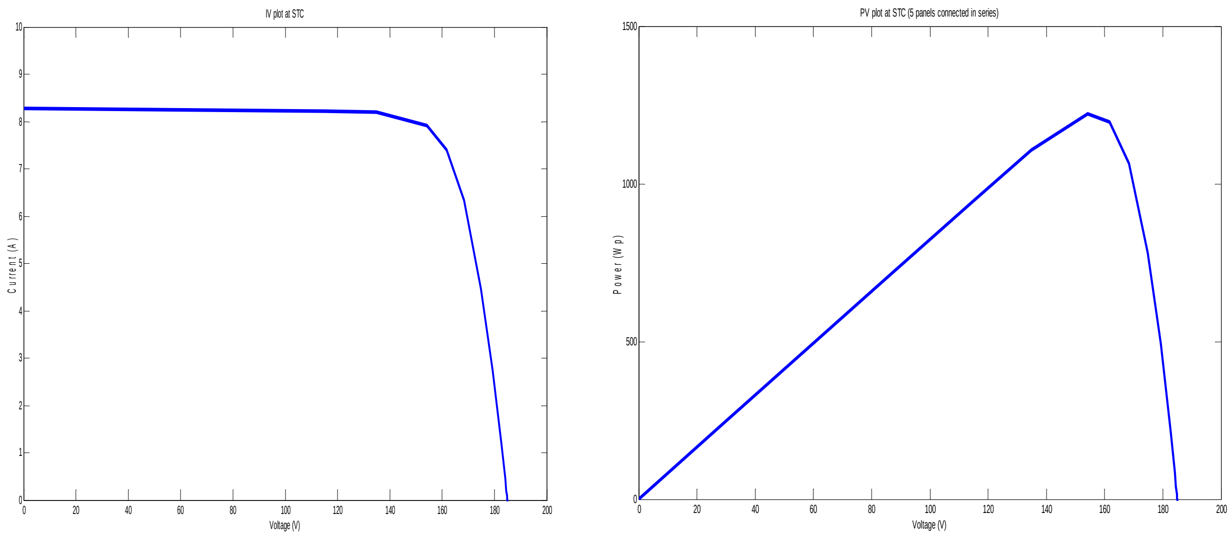

Fig.5 I-V & P-V characteristics obtained from PV array

Fig.5 shows the practical I-V & P-V characteristics of the PV array. The current and voltage at maximum power are respectively 8.05 A and 190 V. The maximum power obtained is 1250 W_p.

6.1. Simulation of PV with Temperature & insolation variation.

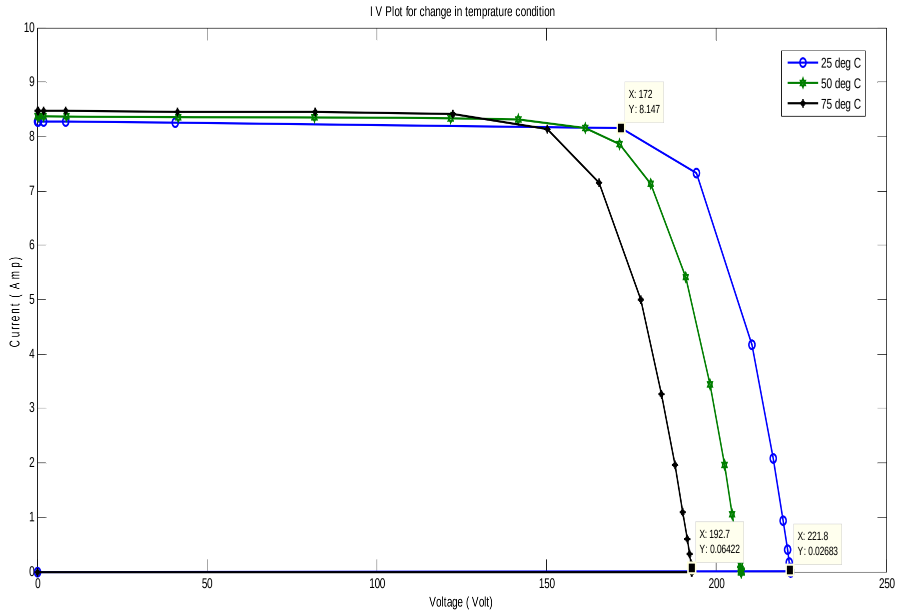

Fig.6 I-V plot form different Temperature condition

The temperature varies as 25ºC, 50ºC and 75ºC. The variation of the temperature has more impact on the output voltage of the PV whereas it affects the output current less. When the operating temperature increases, the PV current increases marginally but the PV voltage decreases drastically which results in net reduction in power output with rise in temperature.

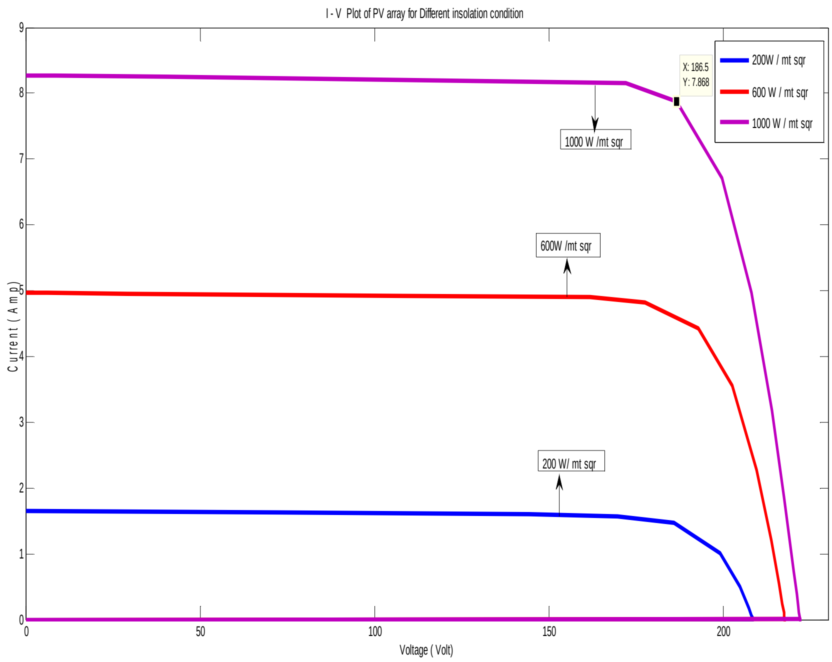

Fig.7. I-V plot form different solar insolation condition

When the irradiance varies from 200, 600 and 1000 W/m^2 with constant temperature it is observed that with increase in PV panel temperature, PV current and voltage increases. This results in net increase in power output with increase in irradiation at constant temperature.

6.2. Simulation of PV- Boost converter and MPPT control.

The simulink model of PV along with MPPT control & boost converter is shown in Fig.7.

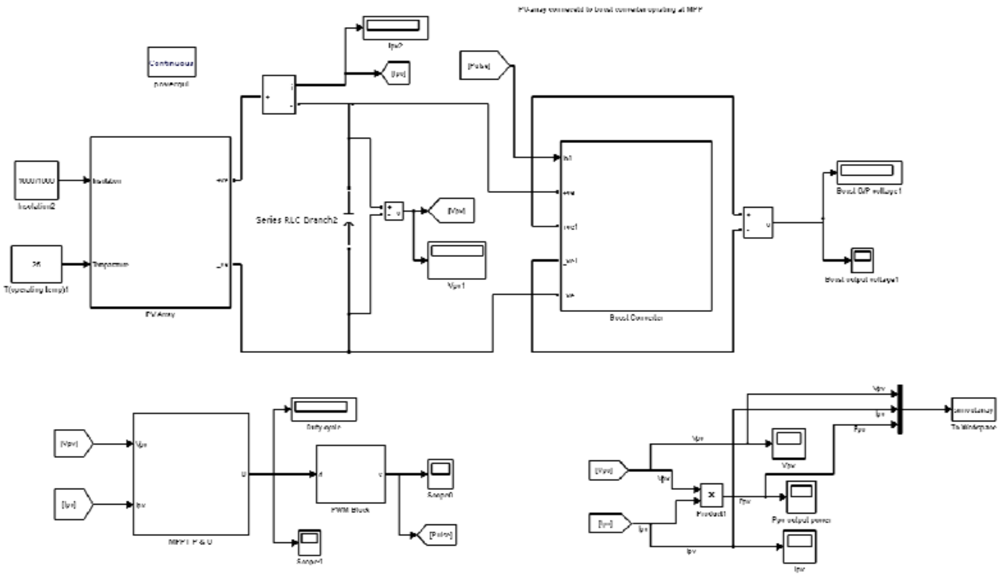

Fig.7 Simulink model of PV with Boost converter & MPPT Algorithm.

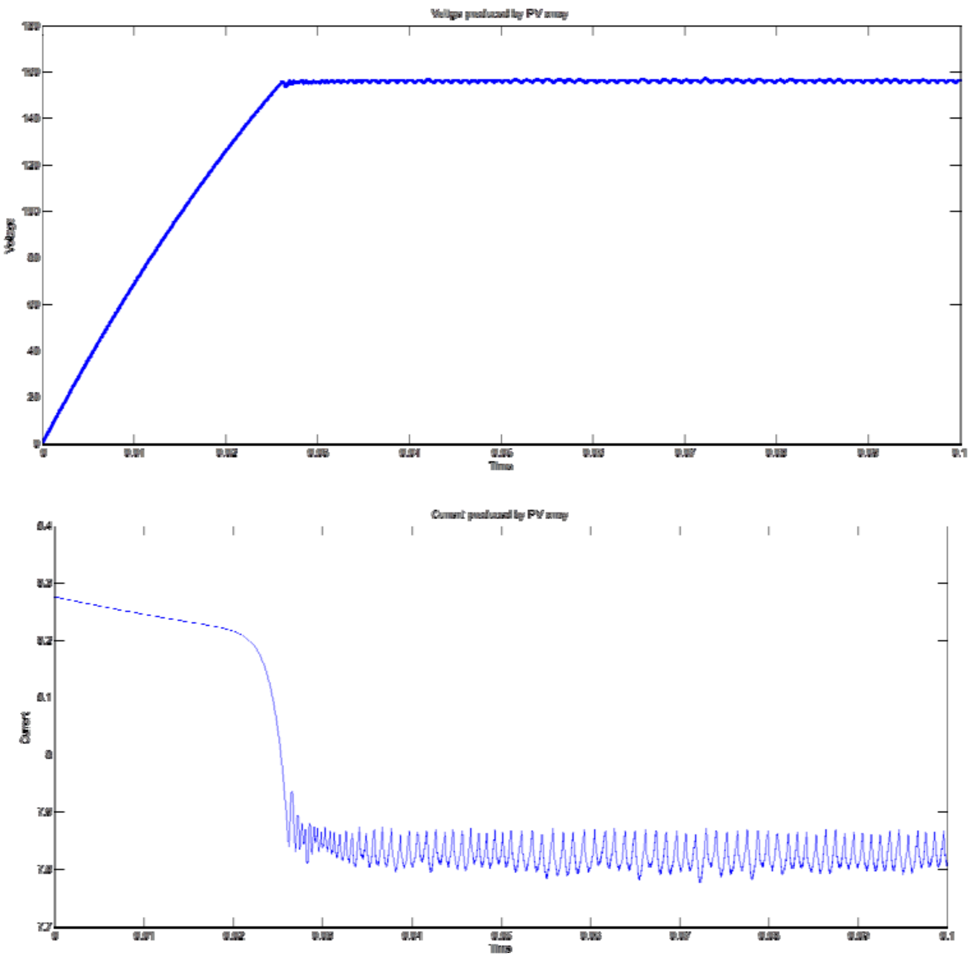

Fig.8 Output voltage and current response of PV array

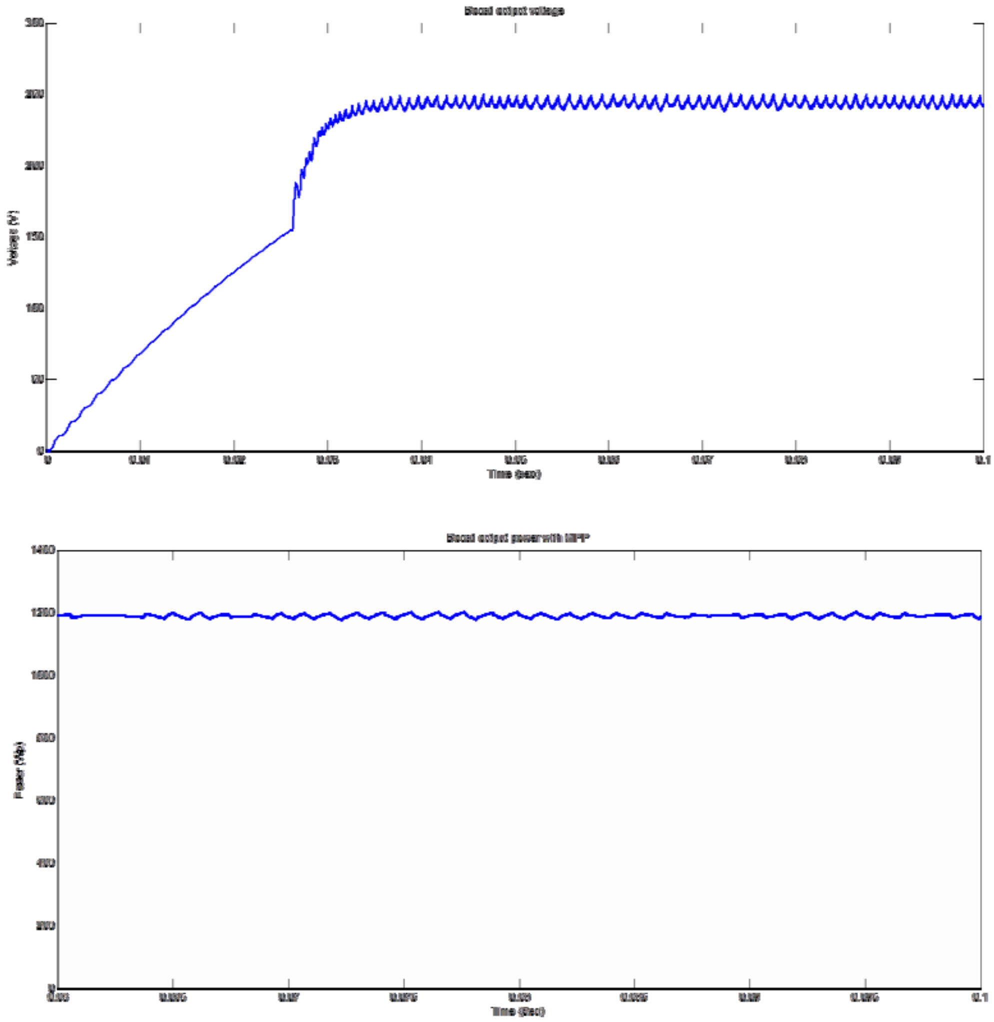

Fig.9 Output voltage and power response of boost converter.

The PV array model with MPPT control is tested at different temperature and insolation condition. It is observed that the output voltage generated by PV is 155.5 V and current is 7.76 A. Also the boosted output voltage is close to 250 V with slight oscillation as P& O algorithm is used. The boost converter duty cycle obtained is 0.36, which is less than 50 %.

7. CONCLUSION

The modeling, simulation & design of this system is done in matlab /simulink. The model is first tested without MPPT; it is observed that boosted output voltage is less than the 250V, as the PV array does not operate at MPP. Hence to improve the utilization of PV array the P&O MPPT algorithm is used. The algorithm is tested varying the temperature & insolation input condition of PV array. The result obtained shows that at different insolation & temperature condition, the MPPT algorithm always operates at MPP with slight oscillation, also the duty cycle of converter is controlled appropriately & obtained boosted output voltage is approximately 250 V which is desired. The presented PV array modeled will help to validated different MPPT algorithm. This system can be interfaced with grid by using different inverter control technique taking into account the different power quality issues.

REFERENCES

[1] T. Chanitanya, Ch.Saibabu & J. Surya. "Modeling and simulation of PV array and its performance enhancements using MPPT techniques", *International Journal of Computer Science Communication Network*, Vol. 1. Pp. 9 – 16, 2011.

[2] M.G.Villalva, J.R. Gazoli & E. Rupert. “Modeling and circuit based simulation of photovoltaic arrays”, Brazilian Journal of Power Electronics, Vol/Issue: 14(1). Pp. 35- 45, 2009.
[3] N.Mohan,T. M.Undeland, and W.P.Robbins. *Power Electronics, Third edition,* India Willy. Pp. 185-248, 2010.
[4] Trashan Esram & Patrick L. “Comparison of photovoltaic array maximum power point tracking techniques”, *IEEE Transaction on Energy conversation*, Vol. 22. Pp. 1 -8, 2007.
[5] Hairul Zainudin & Saad Mekhilef. “Comparison study of maximum power point tracker techniques for PV systems”, *Proceeding of the 14th international Middle East power system conference (MEPCON' 10)*. Pp 750-755, 2010
[6] Ting-Chung Yu and Yu-Cheng Lin. “A Study on Maximum Power Point Tracking Algorithms for Photovoltaic Systems”, *International Journal 2010-2012.* Pp. 27-36, 2012.
[7] Yang Haizhu & Liu Jie. “Simulation study of MPPT strategy of Photovoltaic grid connected generation system based on single parameter control”, *International conference on Computing , Control & Industrial Engineering.* Pp. 152-155, 2010.