

# Study and Simulation of Incond Based Maximum Power Point Tracking (MPPT) Algorithm for Photovoltaic Systems

<sup>1</sup>Ankit Tamkoria, <sup>2</sup>Mr.Neelesh Kumar

<sup>1</sup>M.TECH Scholar, <sup>2</sup>Assistant Professor

<sup>1,2</sup>DIMAT Raipur, PIN-492101(C.G), INDIA

---

**Abstract:** The entire world is facing a challenge to overcome the hurdle of energy crisis. It is fairly evident that a need exist for developing alternative energy sources. Amongst all the available renewable energy sources, solar energy appears to be a viable option as it is easily and widely available. If used in a proper way, it has a capacity to fulfill numerous energy needs of the world. Hence there is great scope of work in field of solar photovoltaic aiming at improved and efficient performances. Solar PV modules convert solar energy into electrical form but are having high non-linear current-voltage relationship which implies that they can operate at only one single point for maximum power. So extraction of maximum power in itself becomes a challenge under varying set of conditions of irradiation and temperature. A step by step approach is followed to analyze and address the problem with high frequency switching DC-DC converters that act as an interface between the module and the load and adjust the switching duty ratio so as to match the load line with that of Maximum Power Point load line. Further there exist various control algorithms to modify duty ratio. Their study is done and one such technique Incremental Conductance (IncCond) is used to process current and voltage of PV array to get the duty ratio. The results are obtained for changing radiation as well. In the present study, a review of Hill Climbing MPPT techniques, has been carried out with detailed flowcharts of algorithms and includes latest research papers published on MPPT techniques.

**Keywords:** Solar Energy, PV modules, Maximum Power Point Tracking (MPPT), Matlab/Simulink, Insolation, Incremental Conductance (IncCond) Technique.

---

## 1. INTRODUCTION

Solar energy is a clean and renewable energy resource for power generation. The power output from a solar photovoltaic system mainly depends on the nature of the connected load because of non-linear I-V characteristics. The PV systems connected directly to the load result in overall poor efficiency as such MPPT is to be introduced in PV systems to increase the efficiency of the system. Solar radiation, load impedance and module temperature are the three factors which affect the maximum power extraction from solar PV module. I-V curve of PV module is a function of insolation and temperature which affects output current and voltage. The increased temperature decreases the open circuit voltage (Voc) while increased intensity of solar radiation increases short circuit current (Isc). Therefore I-V and P-V curve changes according to the operating conditions which alters maximum power point accordingly as shown in Figure 1 and Figure 2 for different irradiation and temperature respectively.

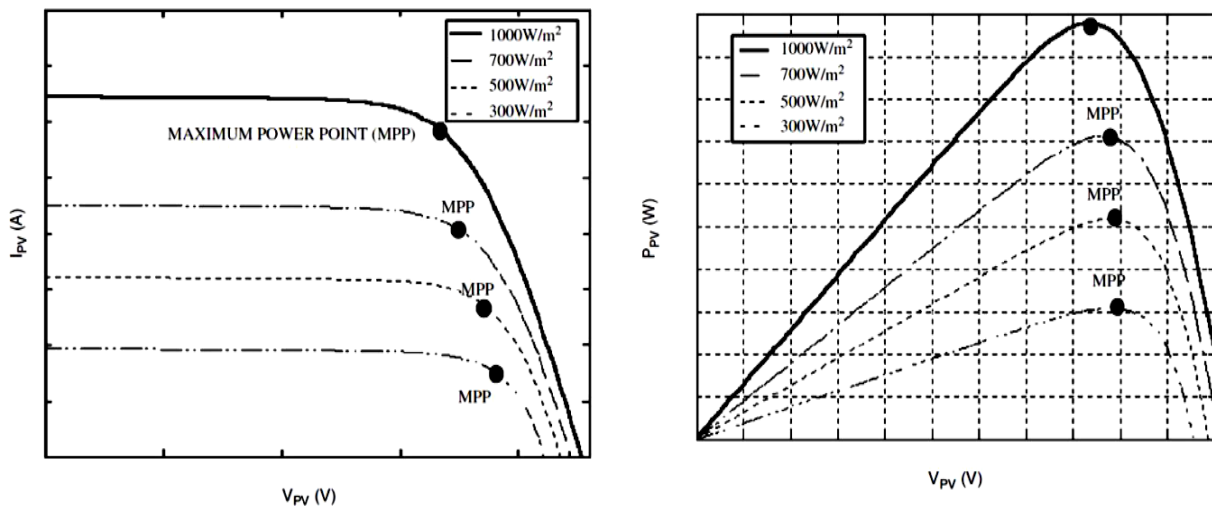


Fig.1: I-V and P-V characteristics for different irradiation level

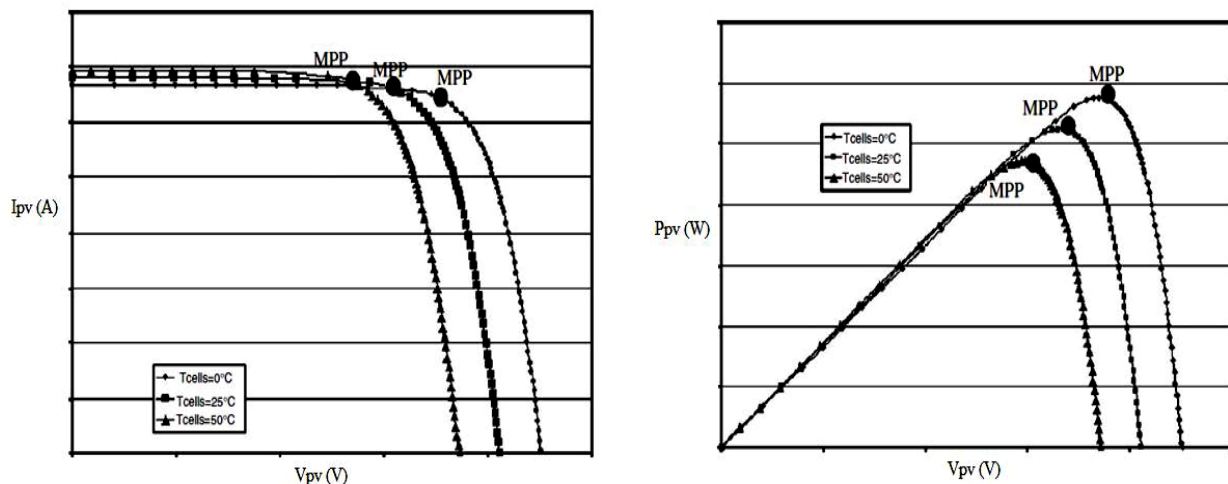


Fig.2: I-V and P-V characteristics for different temperature level

The concept of MPPT is to continuously monitor the terminal voltage and current and update the control signal accordingly to achieve maximum power point (MPP). A DC/DC converter with MPPT algorithm is used between PV module and load to extract maximum available power.

Maximum power point tracking can be achieved by using buck chopper with positive feedback of measurement speed and algorithm for controlling duty cycle. By using highly efficient MPPT with the DC/DC converter to charge batteries from PV modules, the cost of PV power generation reduced by 30%.

A great deal of research has been done to improve the efficiency of the PV modules. A number of methods of how to track the maximum power point of a PV module have been proposed to solve the problem of efficiency and products using these methods have been manufactured and are now commercially available for consumers. As the market is now flooded with varieties of these MPPT that are meant to improve the efficiency of PV modules under various insolation conditions.

Many MPPT techniques have been proposed in the various literatures; examples are the Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods, Constant Voltage Tracking Method etc.

In this paper array is simulated and dc-dc boost converter based MPPT tracker is used for tracking maximum power for STC and varying irradiation and relative efficiency of Incremental Conductance (IncCond) Technique under rapidly changing irradiation is calculated.

## 2. MODELING OF SOLAR PV MODULE

The working principle of all solar cells is based on the photovoltaic effect. In general, the photovoltaic effect means the generation of potential difference at the junction of two different materials in response to visible or other radiation.

When the cell is illuminated, electron-hole pairs are produced by the interaction of the incident photons with the atom of the cell. The electric field created by the cell junction causes the photon-generated electron-hole pair to separate, with electrons drifting to the n-region of the cell and the holes drifting into the p-region.

This movement of charges generates a photocurrent which depends mainly on the intensity and wavelength of the incident light. Scientific base for solar PV electric power generation is solid-state physics of semiconductors Silicon is a popular candidate material for solar PV cells because: It is a semiconductor material. Technology is well developed to make silicon to be positive (+ve) or negative (-ve) charge-carriers, essential elements for an electric cell or battery, Silicon, is abundant in supply and relatively inexpensive in production. Micro- and nano-technologies have enhanced the opto-electricity conversion efficiency of silicon solar PV cells

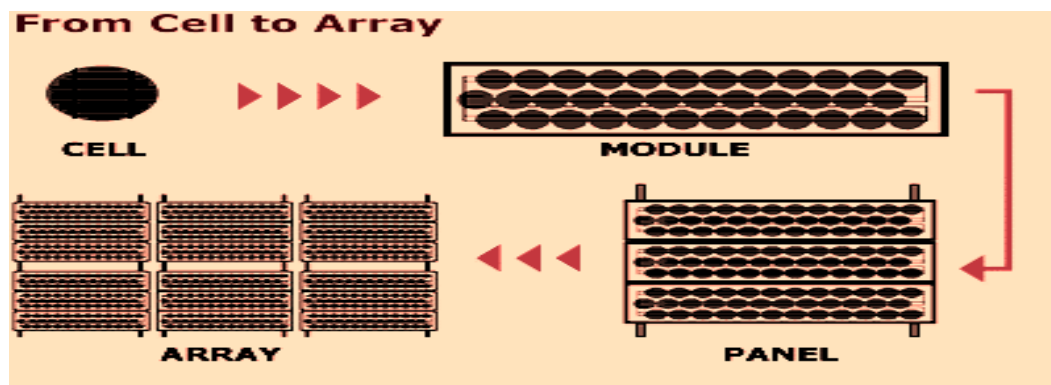


Fig.3: Cell To Array

The equivalent circuit model of the solar cell is shown in the fig. 3 in order to simulate the electrical behaviour of the PV cell. A solar cell can be modelled as a DC current source in parallel with the diode to represent the current escaping due to diffusion and charge recombination.

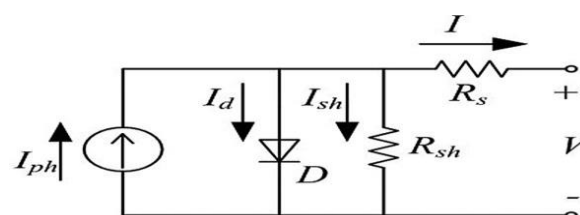


Fig.4: Model of a PV cell

Two resistances  $R_s$  and  $R_{sh}$  are included to account for the contact resistance, internal resistance and resistance of the shunt leakage path respectively.

$$I = I_{ph} - I_d - I_{sh} \quad (1)$$

$$I_d = I_o \left( e^{\frac{q(V+IR_s)}{AKT}} - 1 \right) \quad (2)$$

And

$$I_{sh} = \frac{(V + IR_s)}{R_{sh}} \quad (3)$$

Substituting in (1) from (2) and (3),

We get final equation as

$$I = I_{ph} - I_o \left( e^{\frac{q(V+IR_s)}{AKT}} - 1 \right) - \frac{(V + IR_s)}{R_{sh}} \quad (4)$$

Where  $I_{ph}$  is photocurrent,  $I_d$  is current of parallel diode,  $I_{sh}$  is shunt current,  $I$  is output current,  $V$  is output voltage,  $D$  is parallel diode,  $T$  is cell's working temperature,  $I_o$  is the reverse saturation current of the diode,  $q$  is the electron charge ( $1.602 \times 10^{-19}C$ ),  $A$  is the curve fitting factor, and  $K$  is Boltzmann constant  $1.38 \times 10^{-23} J/K$ .

Since a typical PV cell produces less than 2W at 0.5V approximately, the cells must be connected in series configuration on a module to produce enough high power. A PV array is a group of several PV modules which are electrically connected in series and parallel circuits to generate the required current and voltage. The equivalent circuit for the solar module arranged in  $N_p$  parallel and  $N_s$  series. The terminal equation for the current and voltage of the array becomes as follows.

$$I = N_p I_{ph} - N_p I_s \left( e^{\frac{q(\frac{V}{N_s} + IR_s)/N_p}{AKT}} - 1 \right) - \frac{(\frac{N_p V}{N_s} + IR_s)}{R_{sh}} \quad (5)$$

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as

$$I_{ph} = [I_{sc} + K_i(T_c - T_r)]\lambda \quad (6)$$

Where  $I_{sc}$  is the cells short-circuit current at a 25 C, 1kW/m<sup>2</sup>,  $K_i$  is the cell's short-circuit current temperature coefficient,  $T_r$  is the cell's reference temperature, and the solar insolation in kW/m<sup>2</sup>. On the other hand, the cell's saturation current varies with the cell temperature, which is described as

$$I_s = I_{rs} \left( T_c / T_r \right)^3 e^{\left[ \frac{qE_g \left( \frac{1}{T_r} - \frac{1}{T_c} \right)}{kA} \right]} \quad (7)$$

Where  $I_{rs}$  is the cell's reverse saturation current at a reference temperature and a solar radiation,  $E_g$  is the bang energy of the semiconductor used in the cell.

### 3. SIMULATION OF PV MODULE IN MATLAB

The model which is simulated has a data sheet as given in Table 1

**Table.1: Simulated PV Module Datasheet**

Rated Power	37.08
Voltage at Maximum Power	16.56
Current at Maximum Power	2.25
Open circuit Voltage	21.24
Short Circuit Current	2.55
Total number of cells in series	36
Total number of cells in parallel	1
Temp. Coefficient of $I_{sc}$	(0.065+0.015)%/C
Temp. Coefficient of $V_{oc}$	-(160+20)mV/C
Temp. Coefficient of Power	-(0.5+0.05)%/C

The PV module exhibits highly non-linear characteristics. It is simulated in MATLAB using the basic blocks and interconnecting them to give certain power and current under a given set of temperature, irradiation. The PV module simulated has a datasheet given in table 1.

Simulink model under varying temperature and irradiation, three step inputs are added namely 0.2,0.4,0.4 and are active for 1 s each such that we get results for  $200\text{W}/\text{m}^2$ ,  $600\text{W}/\text{m}^2$ ,  $1000\text{W}/\text{m}^2$ . For temperature variation a pulse signal of magnitude 10 and period 1s duty ratio 0.5 s is added to a constant signal 25.

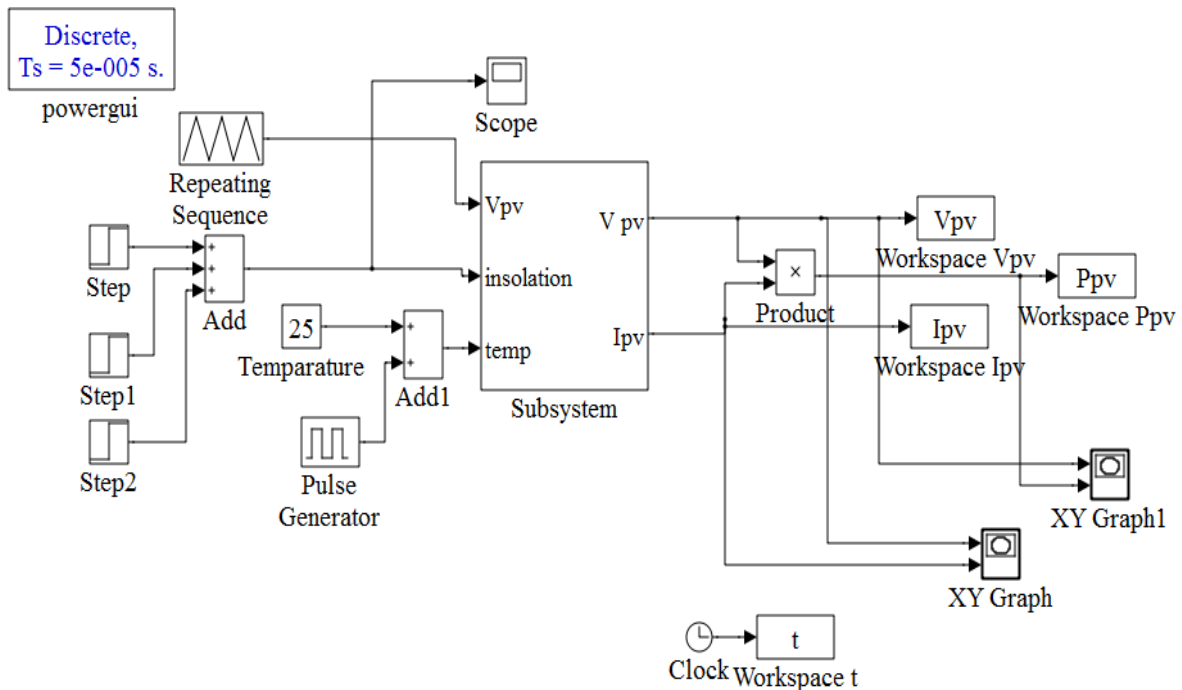


Fig.5: Simulink Model for diff temperature and Irradiation

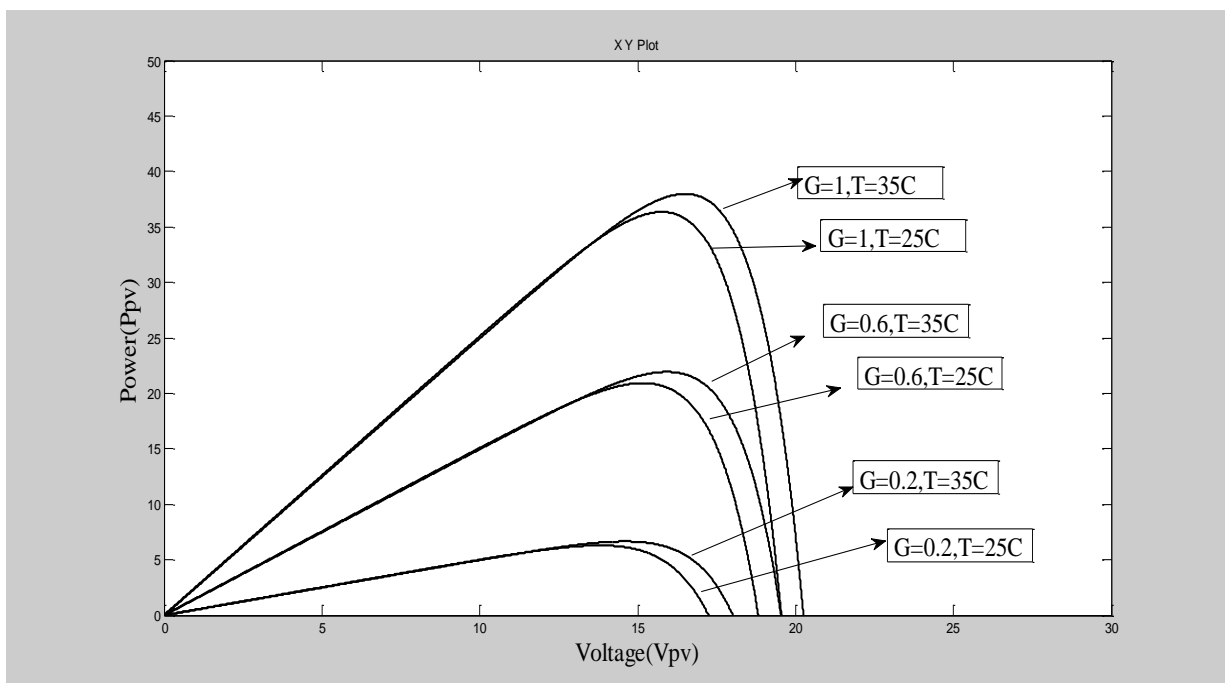
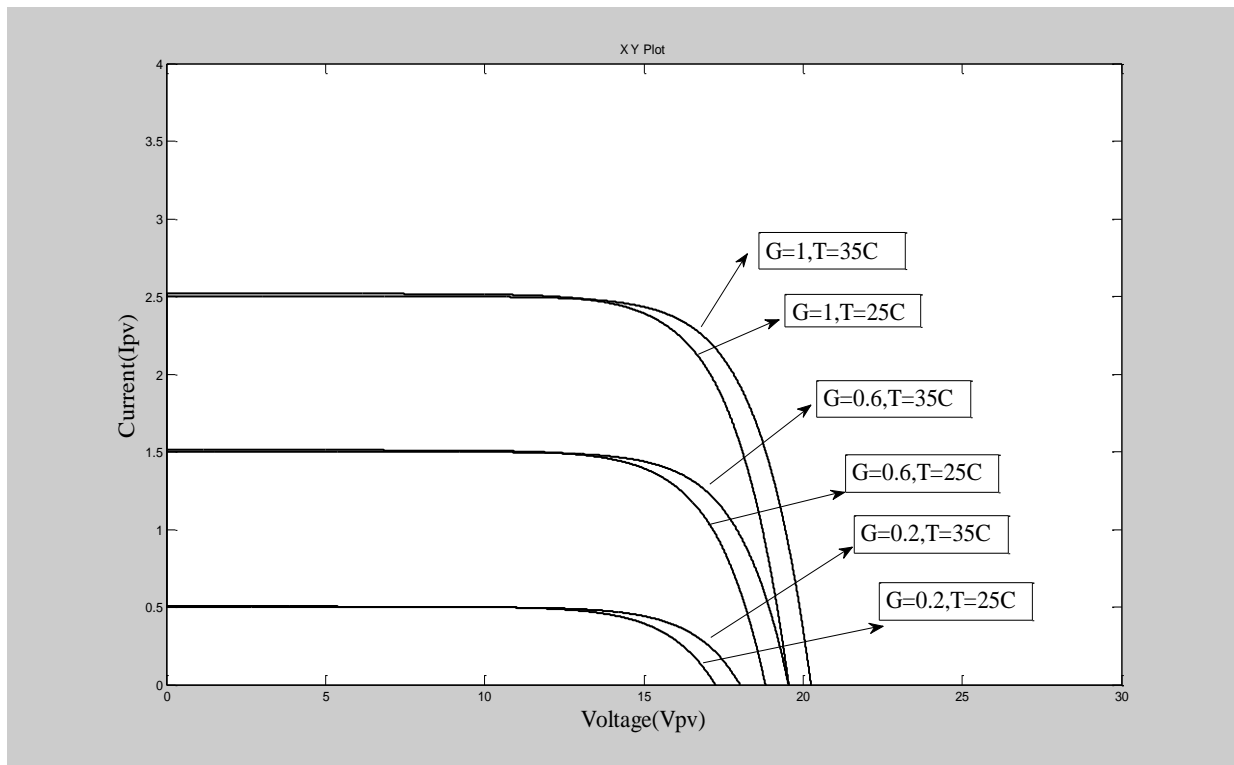


Fig.6: P vs V curve for diff temp and Irradiation

The above P-V curves are showing power obtained for  $200\text{W}/\text{m}^2$ ,  $600\text{W}/\text{m}^2$ ,  $1000\text{W}/\text{m}^2$ .

At 25C and 35C, the downward curve is at 35C and upper one is at 25C as array voltage coefficient of temperature is negative. We can conclude that as irradiation is increased the peak power derived from array also goes up.



**Fig.7: I vs V curve for diff temperature and Irradiation**

Similar analysis is done for the I-V curves as well showing power obtained for  $200\text{W/m}^2$ ,  $600\text{W/m}^2$  and  $1000\text{W/m}^2$ . At  $25\text{C}$  and  $35\text{C}$ , the upper curve is at  $35\text{C}$  and downward one is at  $25\text{C}$  as array current coefficient of temperature is positive.

#### 4. INCREMENTAL CONDUCTANCE BASED MPPT TECHNIQUE

Incremental method was used for the MPPT tracking of the PV array and is simulated in MATLAB/Simulink environment. Incremental conductance method is selected as this method shows some advantage like high tracking accuracy under rapidly changing irradiation condition as compared to P&O method, it reaches steady state faster and avoids continuous oscillation around the MPPT suitable for grid connected application, avoids waste of energy around MPP as with P&O method, it actually knows the direction in which to perturb the operating point to reach the MPP of PV array.

Duty cycle input to the boost converter is controlled by the MPPT algorithm by the MPPT control block using the incremental conductance method. The incremental conductance (IncCond) method is based on the fact that the slope of the PV array power curve (Fig.8) is zero at the MPP, positive on the left of the MPP, and negative on the right, as given by

$$dP/dV = 0, \text{ at MPP}$$

$$dP/dV > 0, \text{ left of MPP}$$

$$dP/dV < 0, \text{ right of MPP}$$

A less obvious, but effective way of performing the IncCond technique is to use the instantaneous conductance and the incremental conductance to generate an error signal

$$e = \frac{I}{V} + \frac{dI}{dV} \quad (8)$$

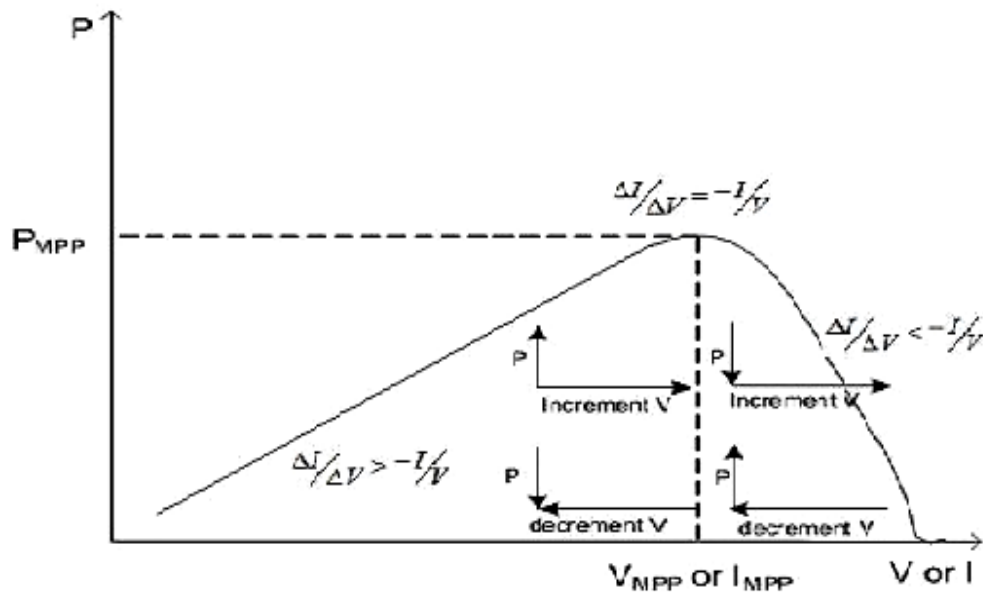


Fig.8: Principle of Incremental Conductance

From (8), we know that  $e$  goes to zero at the MPP. A simple proportional integral (PI) control can then be used to drive  $e$  to zero. Measurements of the instantaneous PV array voltage and current require two sensors. IncCond method lends itself well to DSP and microcontroller control, which can easily keep track of previous values of voltage and current and make all the decisions as per Fig. 9

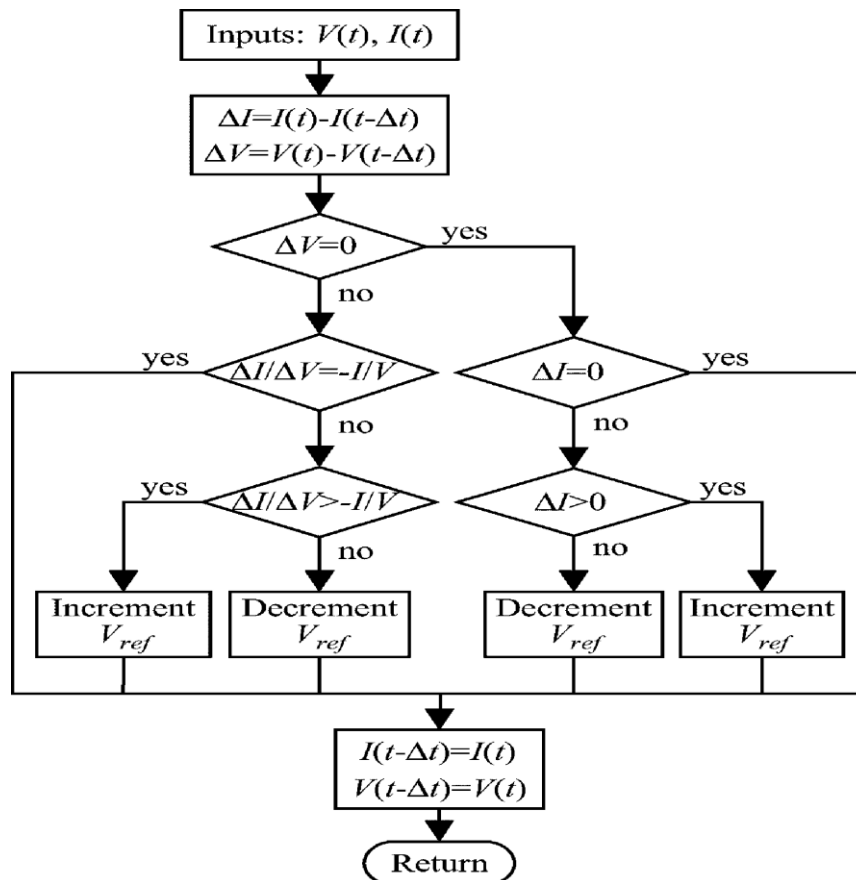
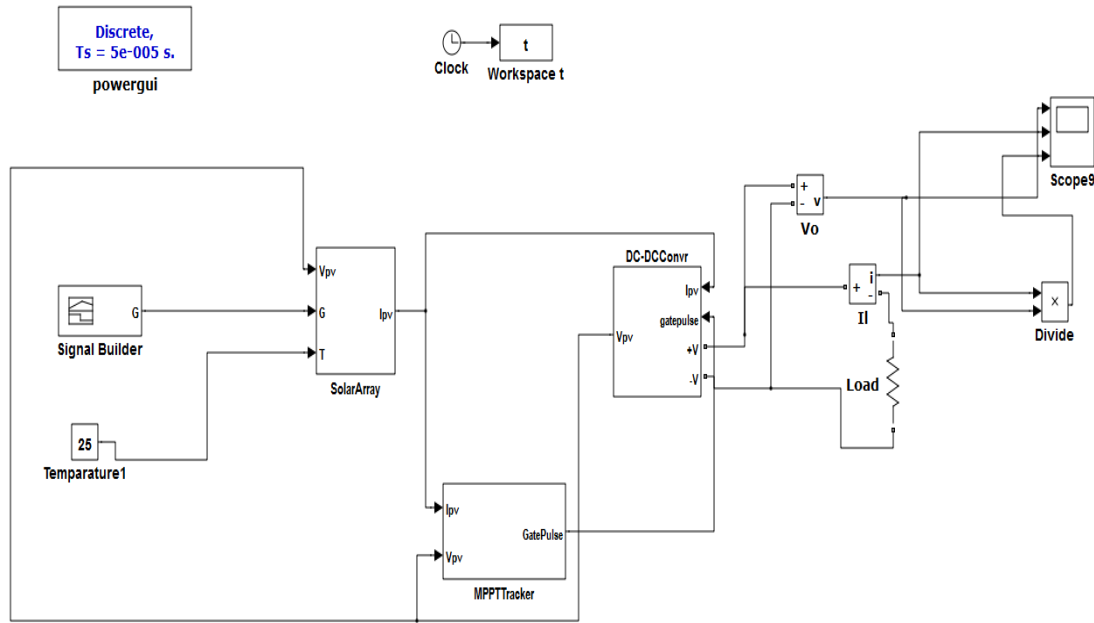


Fig.9: Flowchart of Incremental Conductance Technique

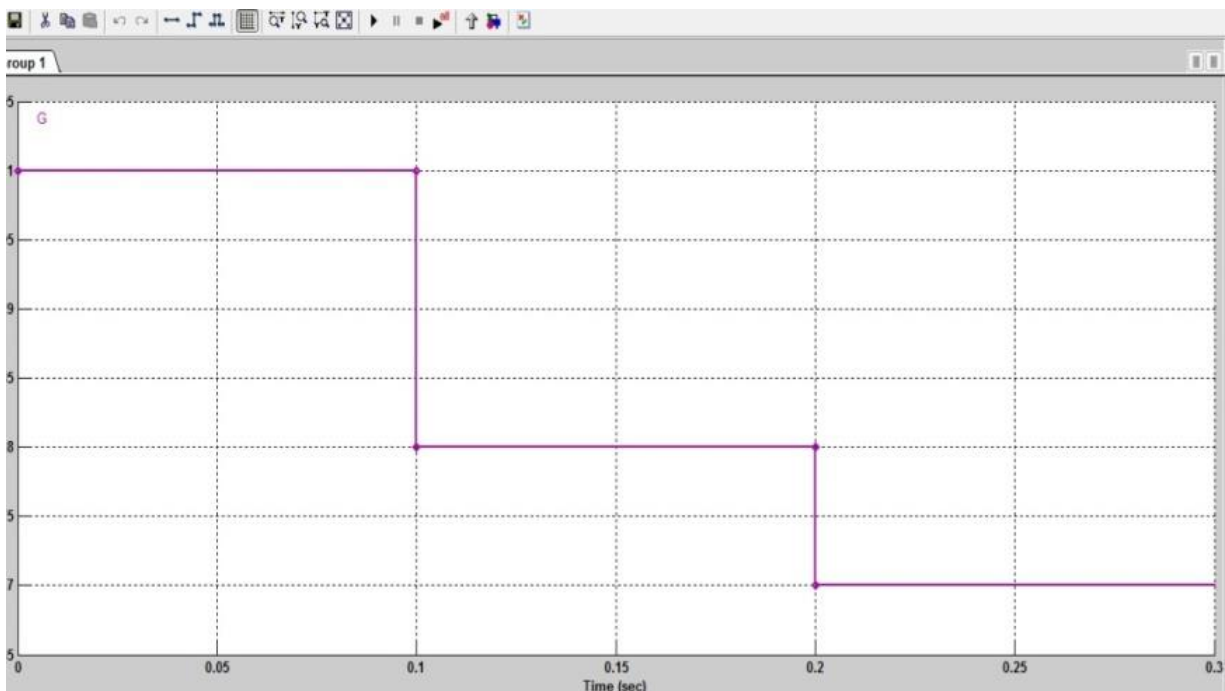
**5. SIMULATION OF MPPT ALGORITHM BASED PV ARRAY IN MATLAB**

Throughout the day the irradiation is not constant it is high in noon hours while low at start and end of the day. So MPPT tracker must take into account the varying conditions of irradiation. Same MPPT model is run for  $700W/m^2$ ,  $800W/m^2$ ,  $1000W/m^2$  and we observe that there is a decrease in efficiency of MPPT tracking giving best results for irradiation close to  $1000W/m^2$ . The results are summed up in the table 2.



**Fig.10: Simulink Model for varing Irradiation**

Fig. 11 is a signal which is given as G and varies from  $700W/m^2$ ,  $800W/m^2$ ,  $1000W/m^2$  for time intervals of 0.1s each, using signal builder block of simulink.



**Fig.11: Signal(G) as irradiation**



Fig.12 shows P-V curve for varying G and a shift of MPP to left when G is changed rapidly in step form. Fig. 13 represents I-V curve for above case

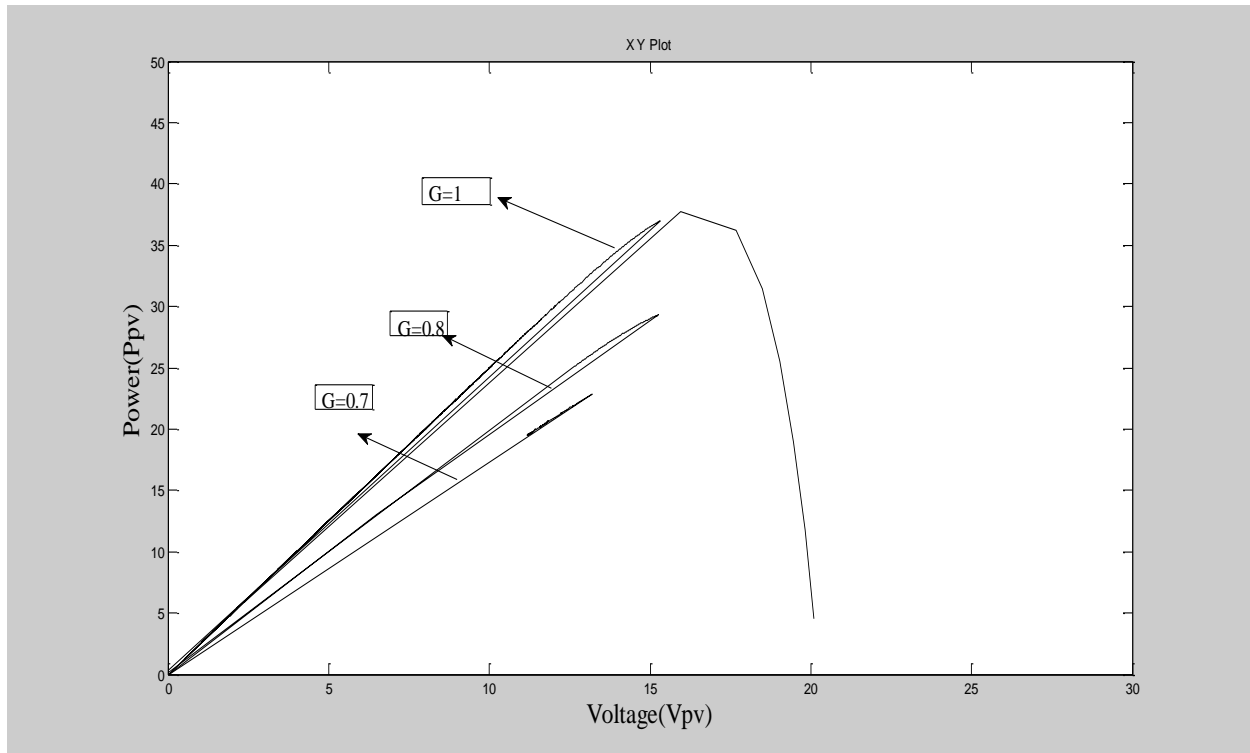


Fig.12: P-V curve for varying G

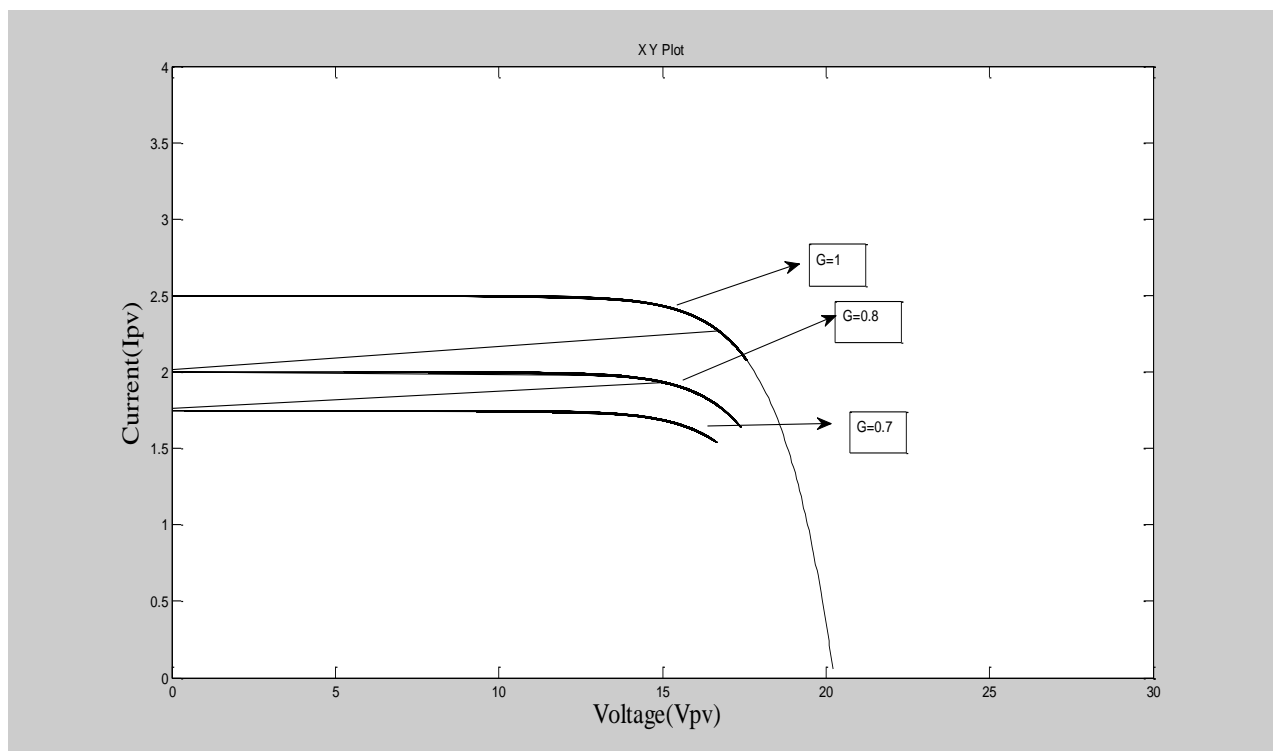


Fig.13: I-V curve for varying G

Fig. 13 is showing the array power output for change in G in step form. Earlier at G=1 the tracking occurs properly, while when G decreases from 1 to 0.8 to 0.7, we observe decrease in tracking efficiency which is summed up in table 5.2.

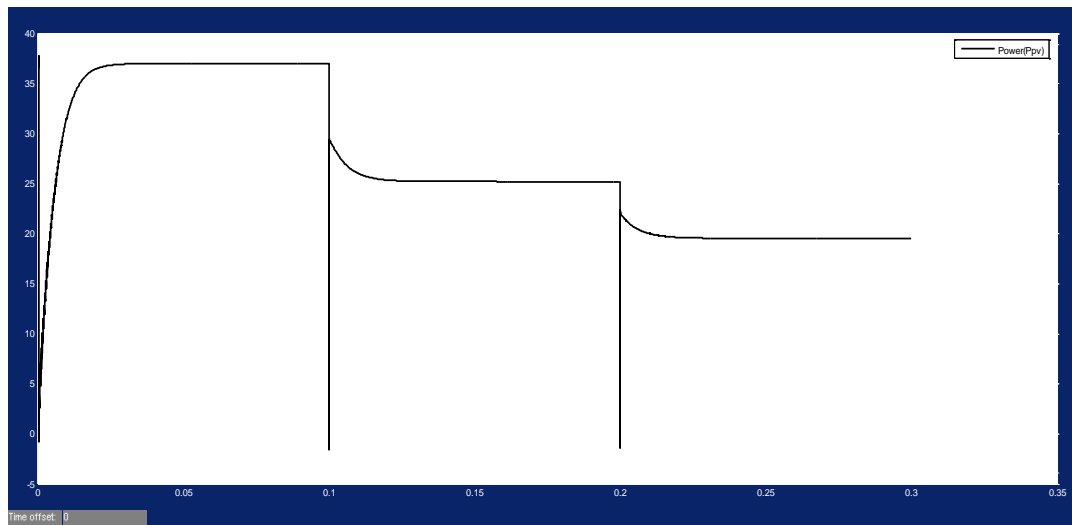


Fig.14: Array Power(Ppv)

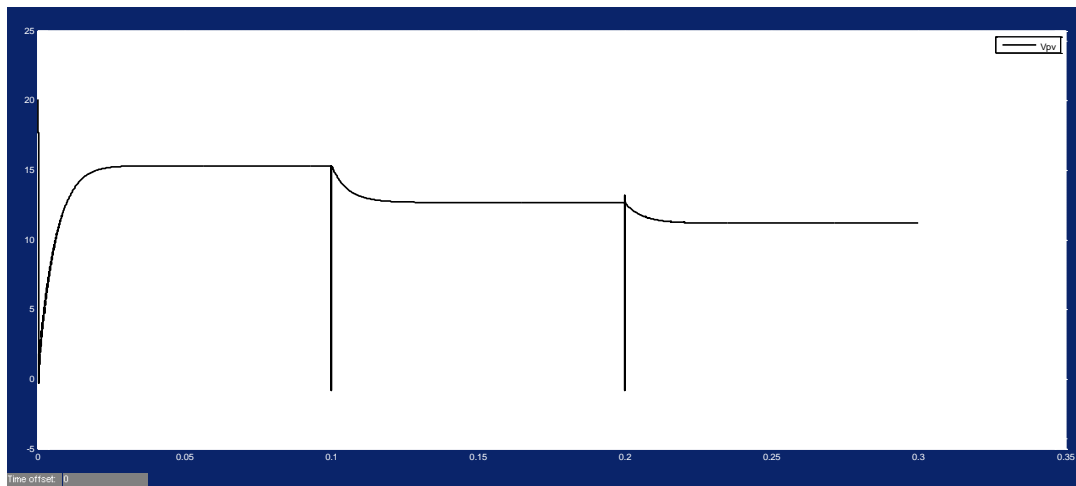


Fig.15: Array Voltage(Vpv)

Fig. 15 shows the output voltage, current and power for R load, showing variation w.r.t. variation in irradiation

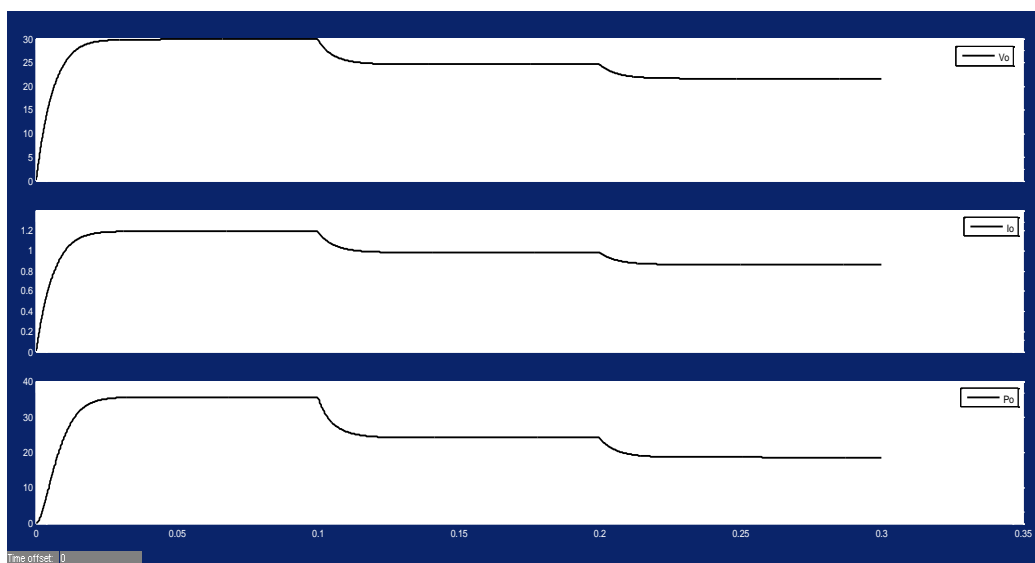


Fig.16: Output Voltage,Current and Power

Below fig. 16 is showing error variation for variable G and that 'e' is more oscillating for better MPP tracking while it oscillates less when the MPP tracking is poor.

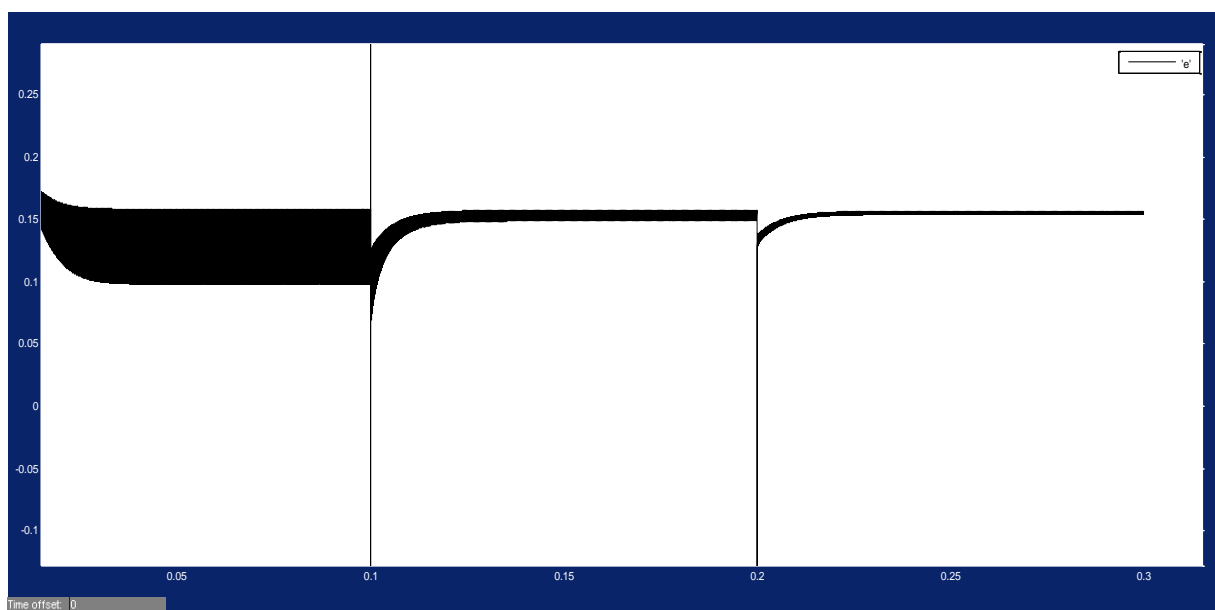


Fig.17: Error 'e'

Values of  $I_{pv}$  and  $V_{pv}$  are taken from PV array output and input of boost converter respectively.  $V_{pv}$  is fed back to solar array to form a closed loop system for simulation analysis.

$I_{pv}$  and  $V_{pv}$  are given unit delays each to get  $I_{pv-1}$  and  $V_{pv-1}$  then we calculate their differences which gives us  $dI$  and  $dV$ . Using division block we find  $dI/dV$ .

This value is added to  $I/V$  and value  $e = \frac{I}{V} + \frac{dI}{dV}$  is fed to discrete PI controller, for error processing, the output of which is compared with high frequency carrier wave to give PWM pulses to switch of boost converter. As 'e' tends closer to zero we get improved efficiency, ideally e should be zero for array to operate at Maximum Power Point.

Table.2: Comparison for varying irradiation

G(kW/m <sup>2</sup> )	P(theoretical)	P(actual)	Efficiency(%)
1	36	35.2	97.70
0.8	27.36	25.2	92.10
0.7	23.94	21.2	88.50

## 6. CONCLUSION

The solar PV module is studied and simulation in MATLAB is done for different set of conditions. Simulation is done for Incremental Conductance technique for fixed and varying set of conditions giving PV and IV curves. The basic target has been to extract the maximum power from a stand-alone PV system for which we are using boost chopper in open and closed loop mode, for obtaining load impedance matching.

In open loop mode we have preset the duty ratio of chopper and load resistance from theoretical calculations to observe maximum power point of module. In a nutshell a stand-alone PV system needs a boost chopper as an interface between itself and load, to increase the output voltage and to ensure that any condition of temperature and insolation we extract maximum power.

### REFERENCES

- [1] Hairul Nissah & Saad Mekhilef, "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems" Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010.
- [2] M.Lokanadham & K.Vijaya Bhaskar,, "Incremental Conductance Based Maximum Power Point Tracking (MPPT) for Photovoltaic System". International Journal of Engineering Research and Applications (IJERA) Vol. 2, Issue 2, Mar-Apr 2012.
- [3] N. Pandiarajan & Ranganath Muthu, "Mathematical Modeling of Photovoltaic Module with Simulink" International Conference on Electrical Energy Systems (ICEES 2011), 3-5 Jan 2011.
- [4] V.C. Kotak & Preti Tyagi, "DC To DC Converter in Maximum Power Point Tracker". International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 2, Issue 12, Dec 2013.
- [5] Soren Baekhoj Kjaer, "Evaluation of the "Hill Climbing" and the "Incremental Conductance" Maximum Power Point Trackers for Photovoltaic Power Systems". IEEE Transactions on Energy Conversion, Vol. 27, No. 4, December 2012.
- [6] Rahul Rawat & S. S. Chandel, "Hill Climbing Techniques for Tracking Maximum Power Point in Solar Photovoltaic Systems-A Review". Centre for Energy And Environment, National Institute Of Technology, Hamirpur, Himachal Pradesh-177005, India.
- [7] Kinal Kachhiya, "The MATLAB/Simulink model of solar PV module and MPPT algorithm". National Conference on Recent Trends in Engineering & Technology 13 & 14 May 2011.
- [8] Fan Zhang, Kary Thanapalan, Andrew Procter, Stephen Carr, and Jon Maddy "The Adaptive Hybrid Maximum Power Point Tracking Method for a Photovoltaic System". IEEE Transactions on Energy Conversion, Vol. 28, No. 2, June 2013.
- [9] Kun Ding, XinGao Bian, HaiHao Liu, and Tao Peng "A Matlab-Simulink-Based PV Module Model and its Application Under Conditions Of Nonuniform Irradiance".IEEE Transactions On Energy Conversion, Vol. 27, No. 4, December 2012.
- [10] Trishan ESRAM "The Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques". IEEE Transactions on Energy Conversion, Vol. 22, No. 2, June 2007.
- [11] Eftichios Koutroulis, Kostas Kalaitzakis "A Microcontroller-Based, Photovoltaic Maximum Power Point Tracking Control System". IEEE Transactions on Power Electronics, Vol. 16, No. 1, January 2001.
- [12] Weidong Xiao, "Overview of Maximum Power Point Tracking Technologies for Photovoltaic Power Systems". 2011 IEEE Transactions on Energy Conversion.
- [13] Hussein Al-Bahadili, Hadi Al-Saadi, "The Simulation of Maximum Power Point Tracking for Photovoltaic Systems". 2013 1st International Conference & Exhibition on the applications of Information Technology to Renewable Energy Processes and Systems.
- [14] A. Durgadevi, "Study and Implementation of Maximum Power Point Tracking MPPT) Algorithm for Photovoltaic Systems". IEEE Transactions on Energy Conversion 2011.
- [15] M. Godoy Simaes, N. N. Franceschetti, "This Work Presents the Development of a Solar Powered Public Illumination System Used for a Waste Recycle Campaign in The City of Sao Paul (Brazil)". IEEE Transactions on Energy Conversion 2000.
- [16] Michael E. Ropp "The Development of a MATLAB/Simulink Model of a Single-Phase Grid-Connected Photovoltaic System" IEEE Transactions on Energy Conversion 2000.