Anmol Ratna Saxena[1*], Shyam Manohar Gupta[2]

J. Electrical Systems 10-3 (2014): 292-304

Regular paper

Performance Analysis of P&O and Incremental Conductance MPPT Algorithms Under Rapidly Changing Weather Conditions

JES Journal of Electrical Systems

In this paper, the comparative analysis of two maximum power point tracking (MPPT) algorithms namely Perturb and Observe (P&O) and Incremental conductance (InC) is presented for the Photo-Voltaic (PV) power generation system. The mathematical model of the PV array is developed and transformed into MATLAB/Simulink environment. This model is used throughout the paper to simulate the PV source characteristics identical to that of a 20 Wp PV panel. The MPPT algorithms generate proper duty ratio for interfacing dc-dc boost converter driving resistive load. The performances of these algorithms are evaluated at gradual and rapidly changing weather conditions where it is observed that InC method tracks the rapidly changing insolation level at a faster rate as compared to P&O. Depending upon the prevailing environmental conditions the MPPT algorithms finds a unique operating point to track the maximum available power. The algorithms find a fixed duty ratio by comparing the previous power, voltage and current thereby optimizing the power output of the panel. The main objective is to compare the tracking capability and stability of the algorithms under different environmental situations on par with other real world tests.

Keywords: Maximum Power Point Tracking (MPPT); Photovoltaic (PV); DC-DC Boost Converter; Perturb & Observe (P&O); Incremental Conduction (InC).

1. Introduction

The growing energy demand coupled with the possibility of reduced supply of conventional fuels, along with growing concerns about environmental conservation, has driven research and development in the area of alternative energy sources that are cleaner, renewable, and produce little environmental impact. Among the alternative sources, the electrical energy from photovoltaic (PV) cells is currently regarded as a natural energy source that is more useful, since it is free, abundant, clean, and distributed over the earth and participates as a primary factor of all other processes of energy production on Earth [1]-[2].

Generally PV panels are used in solar power generation system and PV cell is the key component which converts the solar energy into electrical energy by photovoltaic effect. But these PV cells have low power conversion efficiency and strongly depending on the weather conditions i.e. irradiations and temperature. Also the installation cost of the system is significantly high. PV Panel has nonlinear output characteristics. The power changes according to the change in illuminations so the unique maximum power point (MPP) also changes. For efficient use of a PV panel, it is necessary to extract the maximum power point at all instant of time. To find the MPP, the maximum power point tracking (MPPT) algorithms are used. The PV panel is interfaced with a dc-dc converter, which works as an intermediate circuit and locates between PV array and load. Dc-Dc converter continuously matches the load impedance with the panel's internal impedance by changing its impedance level such that the converter's operating point coincides with the MPP. When the load

* Corresponding author: A.R.Saxena, Dept. Of Electrical Engineering, Madhav Institute of Technology and Science, Gwalior, India, E-mail: anmol.mits@gmail.com

impedance and panel's internal impedance are in equilibrium at the given solar irradiations then the PV panel delivers maximum generated power to the load according to maximum power theory [1-4].

There are different techniques used to track the maximum power point. Few techniques are: Perturb & Observe (P&O), Incremental Conductance (InC), Constant Voltage (CV) method, Constant Current (CC) method, Artificial Neural Networks (ANN) method and Fuzzy Logic Control method etc [5]. The constant voltage (CV) method is a simplest control MPPT method which uses the fact that the operating voltage at MPP of PV panels (V_{mpp}) is linearly proportional to the open circuit voltage of PV panel (V_{oc}) with varying insolation level. The advantage of this method is its simplicity and low cost and no costly multipliers or digital controller are needed [6]-[7]. The constant current (CC) method is similar to the CV method and utilizes the fact that the current under various solar irradiation levels. In general, the constant voltage and current methods cannot track the MPP in time when the atmospheric conditions changes until the next sampling time is reached and it obtains the new reference value corresponding to the new MPP. However these methods are very simple to implement, fast and are cost effective. They are suitable for small power (a few hundred of watts) PV conversion systems where total cost is very low [8]. Development of microcontrollers has made the implementation of Fuzzy logic controller a reality. The Fuzzy logic MPPT controllers have the advantages of working with imprecise inputs, not needing an accurate mathematical model, and handling nonlinearity [9]. Another technique of implementing MPPT which are also well adapted for microcontrollers is Artificial Neural Networks (ANN). Neural networks commonly have three layers: input, hidden, and output layers. The number nodes in each layer vary and are user-dependent. The input variables can be PV array parameters like V_{oc} and I_{sc}, atmospheric data like irradiance and temperature, or any combination of these. The output is usually one or several reference signals like a duty cycle signal used to drive the power converter to operate at or close to the MPP [10]. Amongst above specified methods the P&O and InC is the most preferred MPPT algorithms because these methods requires less information to accurately track the MPP. However, the P&O has very less time complexity but on reaching very close to MPP it doesn't stop at the MPP and keeps on perturbations on both the directions and also does not take account of the rapid change irradiation level (due to which MPPT changes) and may calculate the MPP in the wrong direction. To avoid this problem the Incremental conductance method is proposed. The InC algorithm can track the MPP more accurately and shows better performance under rapidly changing irradiation level. It does not produce significant oscillations when it reaches at the MPP [11]-[15].

This paper studies about the comparative performances of two most preferably used MPPT algorithms namely Perturb & observe and Incremental Conductance are analyzed. These techniques are implemented through the boost Dc-Dc converter to extract and maintain the maximum power from the solar panel at the given solar irradiations. The comparison has observed under the gradually and rapidly changing climatic conditions and the setup has examined on different irradiation levels. The tests have done under slowly changing and rapidly changing climatic conditions. The performances of P&O and InC MPPT algorithms under these conditions have been discussed in the results and validate through experimental setup.

2. Mathematical Modeling of PV Panel

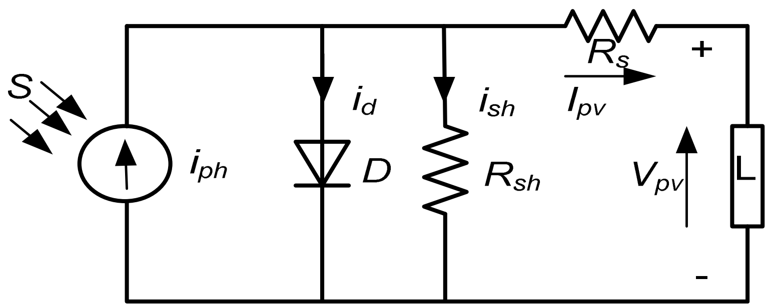


Fig. 1. The equivalent circuit of Solar cell

The PV panel is the combination of many PV cells connected in series and parallel fashion to provide the desired output voltage and current. This PV generator exhibits nonlinear insolation dependent *v-i* characteristics. The solar cell has extremely low output voltage (about 0.5-0.7V), so solar cells have to be connected in series and parallel combination according to the requirements of voltage and power ratings and in practical applications. The single diode model (Fig. 1), is the simplest equivalent circuit of PV cell, a current source in parallel with a diode [16]-[19].

On applying Kirchhoff's current law in the Fig. 1, the basic solar cell equation is given by

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

The term I_{ph} is the photocurrent, depends on the operating temperature and the solar irradiation (S) given by Eq.2.

$$I_{ph} = \frac{S}{1000}\left[I_{scr} + \beta\left(T - T_{ref}\right)\right] \tag{2}$$

I_d is the diode internal diffusion current which is defined by equation (3)

$$I_d = I_o\left[\exp\left(\frac{q(V_{pv} + I_{pv}.R_s)}{A.K.T}\right) - 1\right] \tag{3}$$

q is the charge of electron ($=1.61*10^{-19}C$), A is the diode ideality factor (or completion factor), K ($=1.38*10^{-23}J/K$) is Boltzmann's constant and T is the PV cell's operating temperature (or absolute temperature)in Kelvin (K).

The I_0 in the equation represents the dark saturation current or diode saturation current (or the holding current in opposite direction), which is always be present and produces when there is no light. I_0 is thermally generated, and changing the temperature affected on the generated current because of its temperature dependency as follows by equation (4)

$$I_O = I_{rs}\left(\frac{T}{T_{ref}}\right)^3 .\exp\left[\frac{q.E_g}{A.K}\left(\frac{1}{T_{ref}} - \frac{1}{T}\right)\right] \tag{4}$$

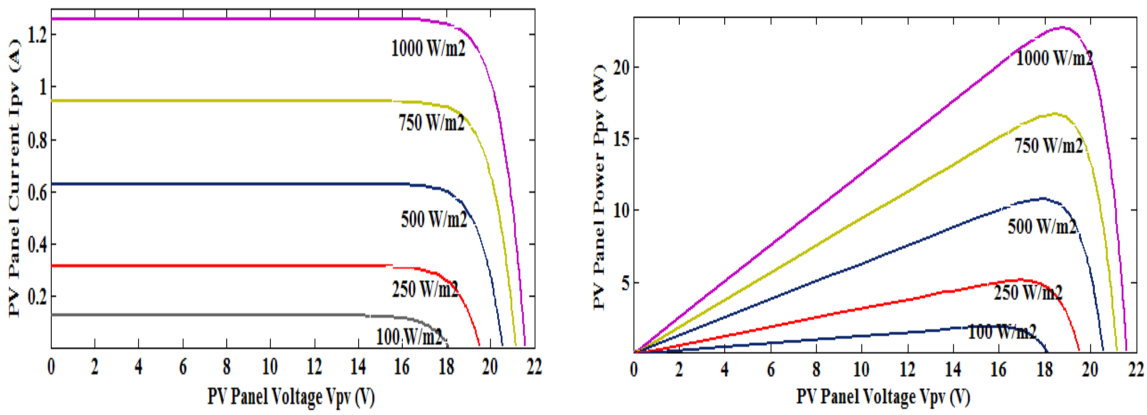
I_{rs} is the cell reverse saturation current in ampere (A) at T_{ref} and solar irradiation (S). E_g is the band-gap energy of semiconductor.

Finally the equivalent of an ideal relationship between the output current and voltage can be written as in Eq.5.

$$I = I_{ph} - I_o\left[\exp\left(\frac{q(V_{pv}+I_{pv}.R_s)}{A.K.T}\right)-1\right]-\frac{V_{pv}+I_{pv}.R_s}{R_{sh}} \quad (5)$$

The above equation is valid for the single diode model. Where R_s is the equivalent series resistance and R_{sh} is the equivalent shunt resistor of PV cell. Usually, the value of R_S is small & the value of R_{Sh} is very large, so under ideal conditions, these quantities are negligible.

Equation (5) was used in Matlab/Simulink to set up the PV electrical characteristics of solar module. The output *I-V* and *P-V* characteristics have been simulated at different solar irradiation levels at fixed temperature of 25°C. The 20W PV module has been used in this work. The V-I and V-P characteristics of the used panel at various insolation levels are shown in Fig. 2.



(a) (b)

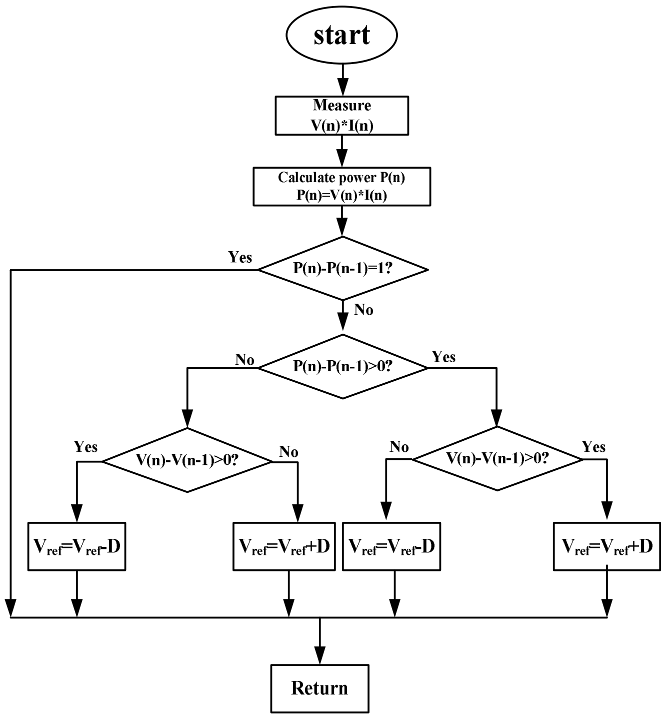
Fig. 2. The output characteristics of solar panel at different insolations (a) V-I characteristics (b) V-P characteristics

3. MPPT Control Algorithms

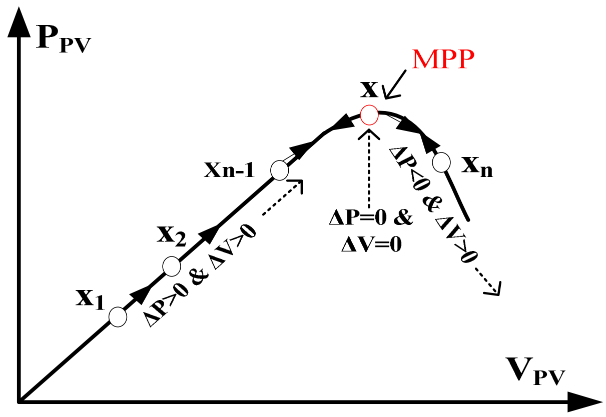
A. Perturb and Observe (P&O)

The flow chart of the P&O MPPT algorithm is given in Fig. 3(a) and the movement of operating point in the process of identifying MPP on PV is shown in Fig. 3(b). If the present operating point is to the left of MPP, the power varies against voltage as dP/dV>0 and if it is to the right side as dP/dV<0. If dP/dV>0 along with a small perturbation in operating voltage then that perturbation moved the panel's operating point toward the MPP and the algorithm continue to perturb the PV panel voltage in the same direction. If dP/dV<0 then perturbation in voltage changes in operating point moved away from the MPP. In this situation the algorithm reverses the direction of the perturbation. 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. It is observed that there some power loss due to this perturbation also the fails to track the power under fast varying atmospheric conditions. But still this algorithm is very popular and simple [20]-[22].

In this algorithm a slight perturbation is introduce in the system. This perturbation causes the power of the solar module changes. If the power increases due to the perturbation then the perturbation is continued in that direction. After the peak power is reached. If the power at the next instant decreases and hence after that the perturbation reverses Fig. 3.



(a)



(b)

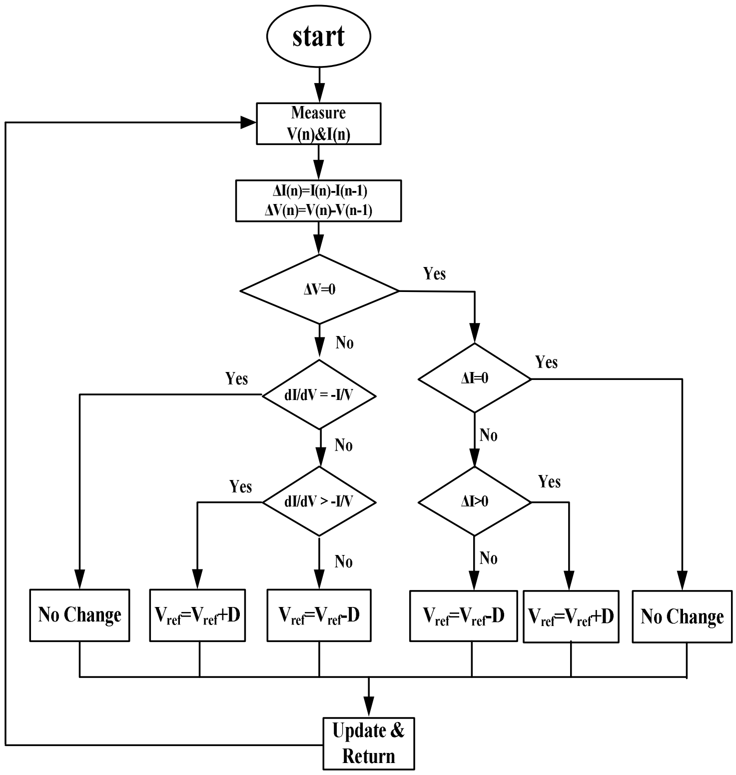
Fig. 3. Perturb & Observe Method (a) Flow Chart, (b) Principle of P&O on PV Characteristics

B. Incremental Conductance (InC)

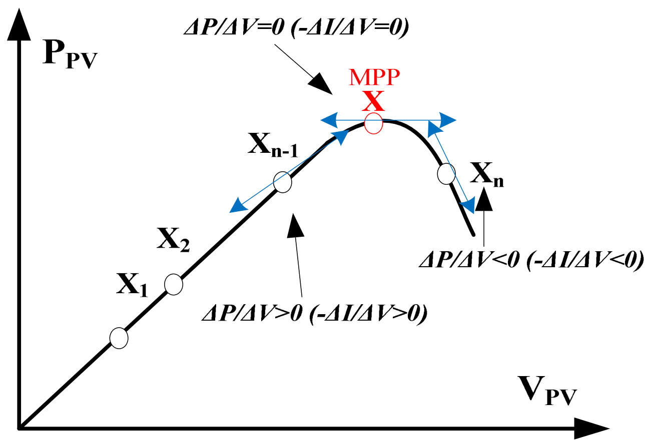
This MPPT algorithm is based on the fact that the power–voltage curve of a PV generator at constant solar irradiance and cell temperature levels has normally only one MPP. At this MPP point, the derivative of the power with respect to the voltage equals to zero which means that the sum of the Instantaneous conductance (*I/V*) and the incremental conductance (*dI/dV*) equals zero (Fig. 4). On the right-hand side of the MPP, the sum of the instantaneous and incremental conductance is negative, while on the left-hand side of the

MPP, the sum is positive. The INC algorithm compares the instantaneous conductance of a PV generator with its incremental conductance and decides whether to increase or decrease a control parameter accordingly. The condition in the flowchart (Fig. 4(a)) to keep the control parameter constant when $dI/dV = -I/V$ (i.e. $\Delta P/\Delta V = 0$). However, the assumption that the system operates at the MPP when $\Delta P/\Delta V = 0$ and can only be achieved when the weather conditions are stationary and the change in array voltage tends to zero [23]-[24].

According to the principle of algorithm (in Fig. 4(b)), its increases the reference voltage (or decreases the duty ratio) if the operating point is to the LHS of the MPP and decreases the reference voltage (or decreases the duty ratio) otherwise.



(a)



(b)

Fig. 4. Incremental Conduction Method (a) Flow Chart, (b) Principle of InC on PV Characteristics

4. Results and Discussion

The MPP varies with insolations & temperature, so to maximum utilization and achieve maximum power it is necessary to match the provided load impedance to the internal impedance characteristics of PV panel such that the equilibrium operating point coincides with maximum power point. This condition is necessary for delivering the peak power from the PV panel (source) to the load according to maximum power theory. A Dc-Dc converter fulfills this work successfully without significantly affecting the efficiency of the system. An intermediate Dc-Dc converter converts the fixed load into a variable load in order to match the source and load impedances according to the requirements. In this paper the Boost Dc-Dc converter is used as an intermediate dc-dc converter. Boost Converter consists of the power switch, boost inductor *L*, filter capacitor *C*, output diode *D*, and load resistance *R,* Where the DC input source voltage is supplies by PV module. In Fig.5 the schematic of a PV panel interfaced to the boost converter with a resistive load is given [25]-[26].

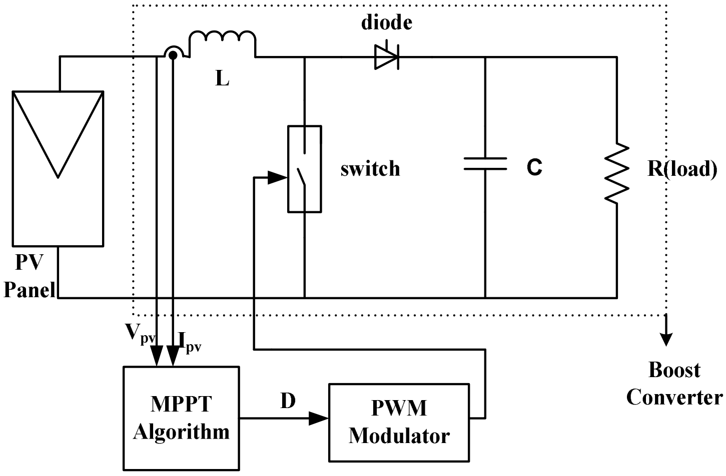


Fig. 5. PV Panel Interfaced with Boost Converter for MPP Tracking

The Boost converter adjusts its impedance value in order to match the load side impedance according to fix load by the given of duty ratio. The performance of the system also depends on the load provided to the converter. The study reveals that the boost converter can operate as a MPPT in a specific load range. When any value of the load within that range provides to the converter, than it is able to track the MPP and extract maximum power from the solar panel at given irradiations level [27].

The simulation studies are carried out using MATLAB/SIMULINK software. In-order to verify the theoretical concepts and simulation studies experimental prototype of the system is developed in lab which is shown in Fig. 6 and the various waveforms obtained by the experiments can be observed by the Fig.8. The details of the solar panel used are summarized in Table 1 while that of boost converter are summarized in Table 2. Experimentally obtained P-V characteristic of PV panel is shown in Fig. 7.

To compare the performance of the P&O and InC MPPT algorithms presented above, we have developed a simulink model by the help of the MATLAB/Simulink software. The simulink model consist a solar panel interfaced with a Boost converter with the MPPT controller, Fig. 9.

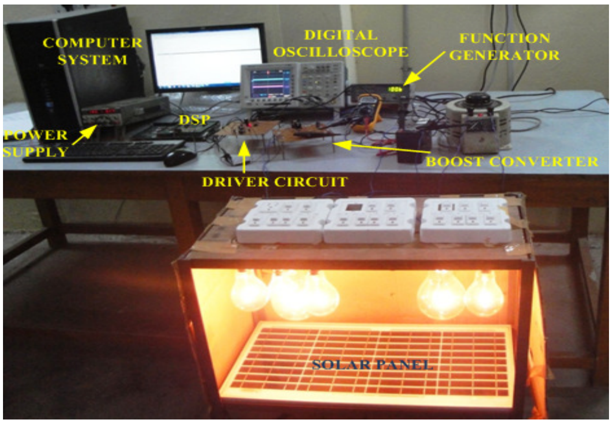


Fig. 6. Experimental Setup of Complete System

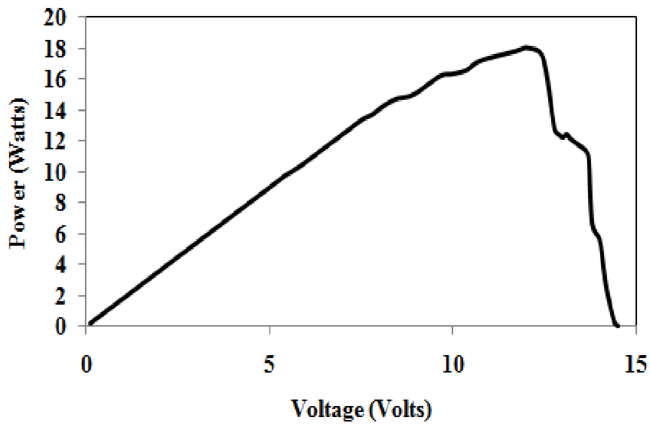


Fig. 7. Experimental Measured PV Characteristics

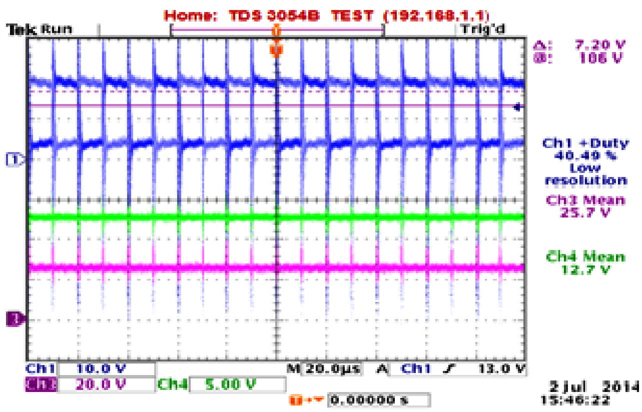


Fig. 8. Experimental Results showing Source Voltage, Load Voltage and Duty Ratio

Table 1: Parameters of PV Modules

Serial no.	Parameters	Value
1	Maximum Power (P_{max})	20 W
2	Voltage at P_{max} (V_{mp})	17.77 V
3	Current at P_{max} (I_{mp})	1.13 A
4	Open circuit Voltage (V_{oc})	22.04 V
5	Short circuit Current (I_{sc})	1.26 A
6	Tolerance	±5%

Table 2: Boost Converter Parameters

Serial no.	Parameters	Value
1	V_{in}	15 V
2	L	150 μH
3	C	250 μF
4	f_{sw}	20 kHz
5	R_{load}	10 Ω

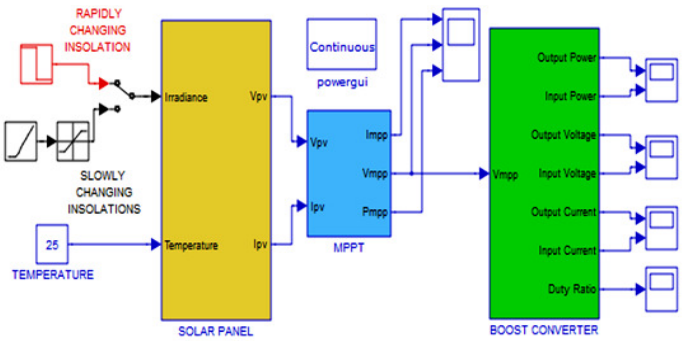


Fig. 9. Simulink Block Model of PV System

To provide the changing climatic conditions in simulation the step input and the ramp input are given as input on solar irradiation terminal. The simulation total time is 0.1 s. the ramp input provides to the system as gradually changing insolations from 1000 W/m^2 to 500W/m^2 (Fig. 10(a)), while the step input provides as rapidly changing climatic conditions from 1000 W/m^2 to 500 W/m^2 (Fig. 11(a)).

The temperature remains constant at 25^{o}C in this whole process. To analyze and compare the performances of the P&O and InC MPPT algorithms, we carried out a simulation test in which the photovoltaic generator is exposed at the same standard environmental conditions based on the appearance of a step of illumination. In Fig.10 to Fig.11, we report the dynamic response of the PV system driven by the two algorithms.

Fig. 10 compares the performances of the P&O and InC when the environmental conditions are changing gradually. Fig.10(b) shows of variation in duty cycles of P&O and InC. it is clearly seen that The initial settling time of P&O is about 0.01 s while the InC takes much less time 0.003 s for achieving the fix duty ratio, so the InC is achieving the MPP Three times faster than P&O. By this observation we can conclude that the InC starts to track the MPP more quickly than P&O. By observing the zoomed in window (Fig. 10(g)) the P&O oscillates around the line of the MPP which results in some power loss while in the InC there is no such oscillations. When the illumination level changes the InC finds the new MPP without taking any time whereas the P&O takes some time to find the new MPP. The voltage and power characteristics curves according to change in the conditions and MPPT tracking algorithms are reported from Fig.10 (e) and Fig.10 (f).

Fig. 11 compares the performances of the P&O and InC when the climate changes rapidly. Fig.11(b) shows of variation in duty cycles of P&O and InC. when the insolations varies rapidly the P&O confused to track the new MPP and takes some time to reach at the new MPP. Some-times P&O has failed to track the MPP and move in wrong direction. It is major draw-back of the P&O. In our case when the climate changes rapidly (Fig. 11 (b)&(c)) the P&O forgets its direction and takes some time to reach at the new MPP Whereas the InC shows better performance. The InC takes no time to track the new MPP.

After all the InC can work more accurately even the climate changes suddenly. The voltage and power responses with their respective algorithms are reported from Fig.11(d) to Fig.11(f).

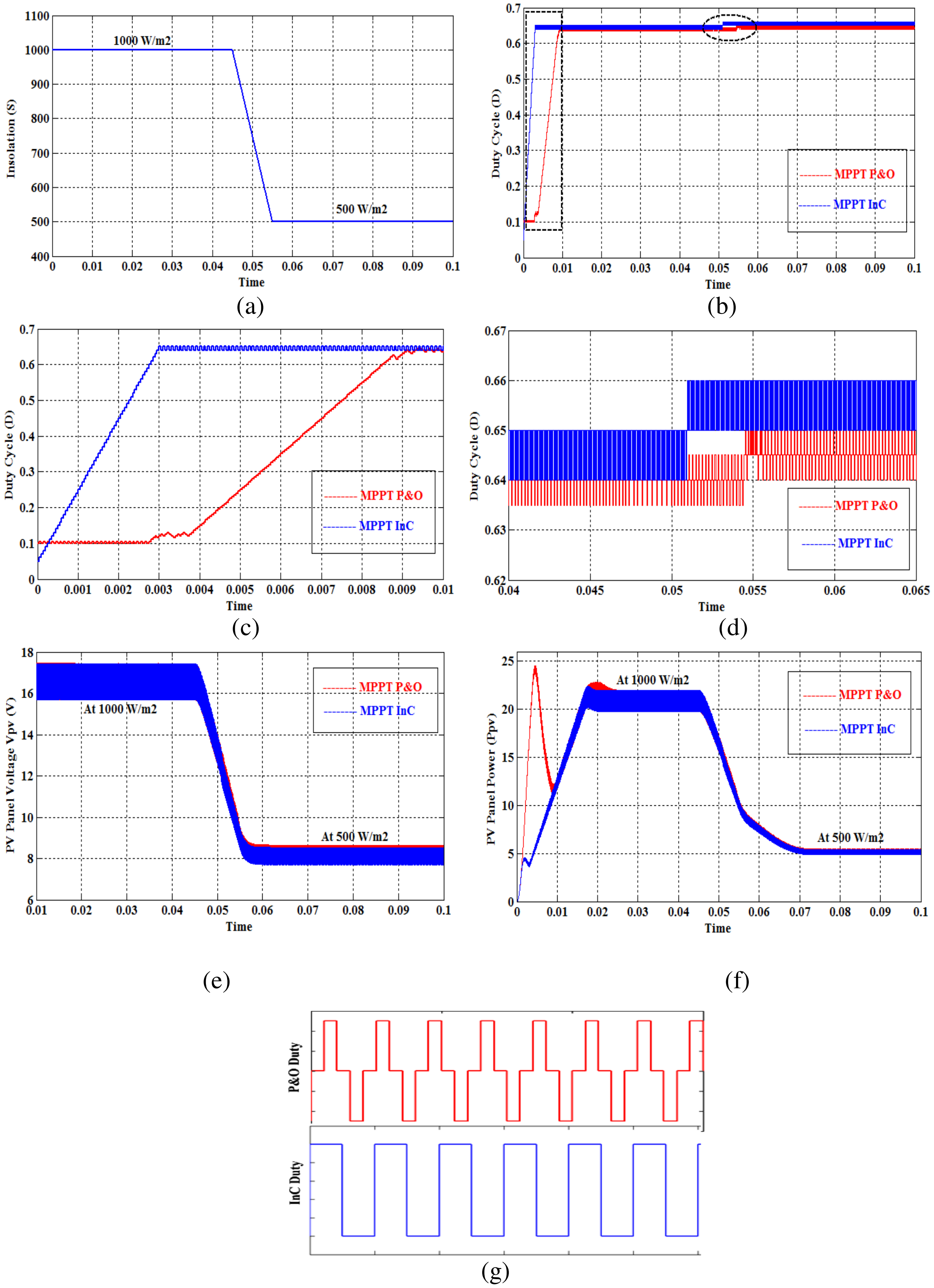


Fig. 10. Performances of P&O and InC under slowly changing climatic conditions (a) Irradiations Levels (b), (c) & (d) Duty ratio (e) Panel Voltage (f) Panel Power (g) Oscillations in Duty by the algorithms

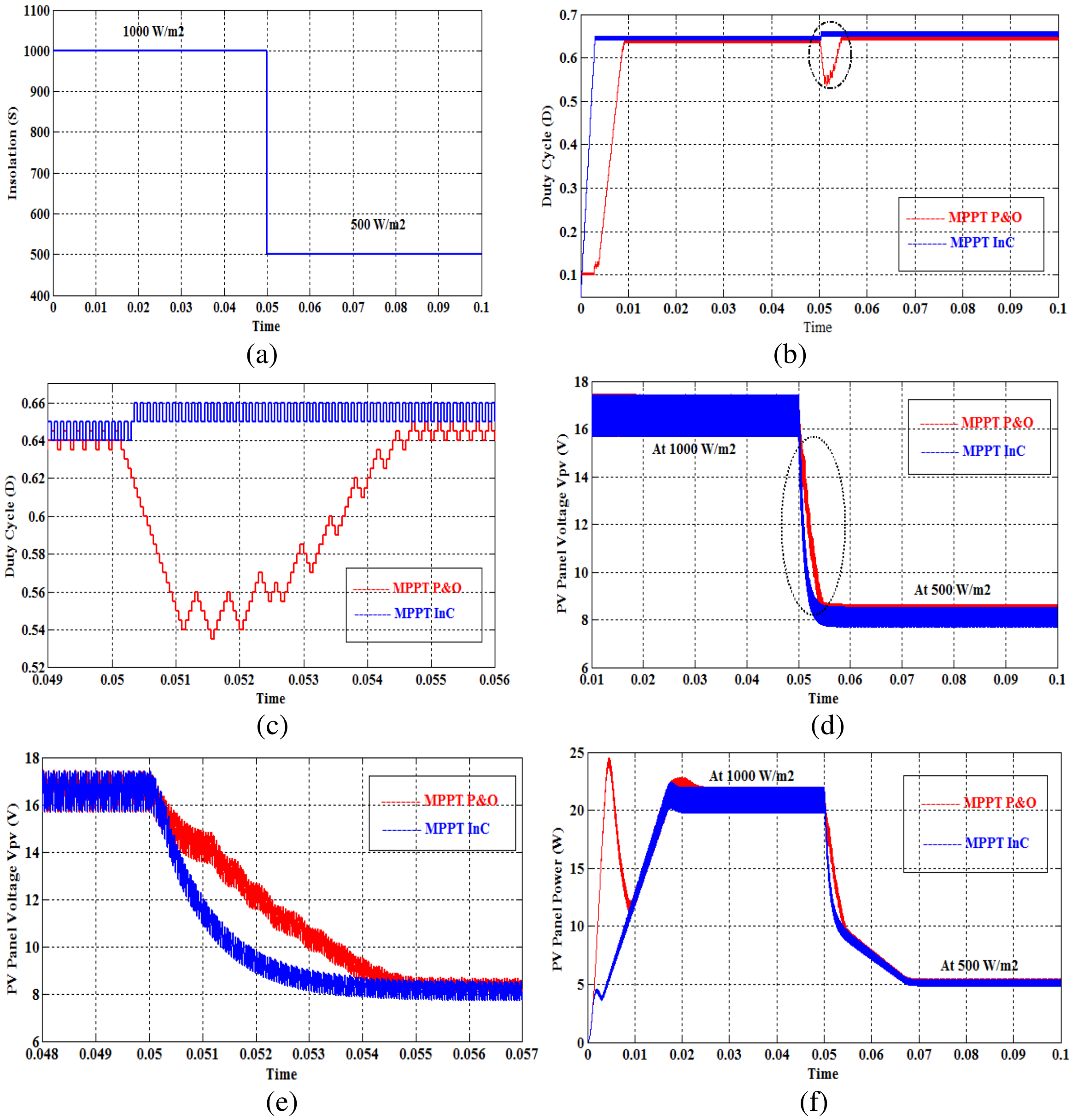


Fig. 11. Performances of P&O and InC under rapidly changing climatic conditions (a) Insolations (b)& (c) Duty ratio (d)&(e) Panel Voltage (f) Panel Power

If we conclude the comparison by the reported results, the InC MPPT algorithm performs better tends directly towards this MPP. we have highlight the fact that the advantages of the InC to the P&O algorithm by a faster achievement of the MPP which is carried out immediately in the good direction without additional oscillations when the MPP is reached in case of sudden change in temperature. In a first approach and at the contrary to the P&O algorithm, we can predict that the InC algorithm doesn't track in the wrong direction after a rapid change of the functioning conditions and doesn't present a strong oscillations about the MPP when it reaches it.

Finally, even if the overall better intrinsic performances of the InC algorithm can be shown by this study, we have to consider the simplicity of the P&O MPPT one, which makes it largely used according to the facility to implement in practical applications.

6. Conclusion

The presented studies in this paper were the comparative analysis of two MPPT algorithms, Perturb & Observe and Incremental Conductance and conducted through boost converter. The simulation results prove positively that the P&O and the Incremental Conductance MPPTs reach the intended maximum power point. In the slowly changing whether both algorithms perform without significantly changes. It has observed that the Incremental Conductance reaches at the MPP three times faster than P&O in all cases and shows better performance for rapid changes and a better stability when the MPP is achieved. It has observed that P&O shows oscillations around the MPP when it reaches in steady state position which results in some power loss. But in case of InC there are no additional oscillations at steady state condition. However the P&O MPPT are mostly used in practice due to their simplicity. The originality and the specificity of the presented results obtain during this research reside in the fact that external parameters as irradiation and fixed temperature were introduced, at first as linear functions (ramp input) and, at second as random (step input) ones describing more closely the actual applicative conditions. The effect of the changing weather on the voltage and power of the PV panel according to change in MPP has shown in the results section.

Acknowledgement

The authors sincerely acknowledge Director, MITS Gwalior, India for his support during this research work.

References

[1] Tariq, J. Asghar, “Development of an Analog Maximum Power Point Tracker for Photovoltaic Panel”, *PEDS. International Conference on*, 2005, vol. 1, no., pp. 251, 255.

[2] H. Al-Bahadili, H. Al-Saadi, R. Al-Sayed, M.A.-S. Hasan, “Simulation of maximum power point tracking for photovoltaic systems”, *Applications of Information Technology to Renewable Energy Processes and Systems (IT-DREPS), 1st International Conference & Exhibition on the* , 2013, vol., no., pp. 79,84.

[3] Lu Yuan, Cui Xingxing, “Study on maximum power point tracking for photovoltaic power generation system”, *Computer Science and Information Technology (ICCSIT), 3rd IEEE International Conference on*, 2010, vol. 9, pp. 180,183.

[4] G. Walker, “Evaluating MPPT converter topologies using a MATLAB PV model”, *Journal of Electrical & Electronics Engineering, 2001, Australia,* IEAust, vol. 21, No. 1, pp. 49-56.

[5] Beriber, D.; Talha, A, "MPPT techniques for PV systems," Power Engineering, Energy and Electrical Drives (POWERENG), 2013 Fourth International Conference on, vol., no., pp.1437, 1442, 13-17 May 2013.

[6] J. H. R. Enslin, M. S. Wolf, D. B. Snyman, and W. Sweigers, “Integrated Photovoltaic Maximum Power Point Tracking Converter”, *IEEE Transactions on Industrial Electronics,* Vol. 44, no. 6, Dec. 1997, pp.769-773.

[7] Murtaza, AF.; Sher, H.A; Chiaberge, M.; Boero, D.; Giuseppe, M.D.; Addoweesh, K.E., "A novel hybrid MPPT technique for solar PV applications using perturb & observe and Fractional Open Circuit Voltage techniques," MECHATRONIKA, 2012 15th International Symposium , vol., no., pp.1,8, 5-7 Dec. 2012.

[8] T. Noguchi, S. Togashi and R. Nakomoto, “Short-Current Pulse-Based Maximum Power Tracking Method for Multiple Photovoltaic-and-Converter Module System”, *IEEE Transactions on Industrial Electronics,* Vol. 49, No.1, Feb. 2002, pp.217-223.

[9] Simoes, M.G., N.N. Franceschetti, and M. Friedhofer, “A fuzzy logic based photovoltaic peak power tracking control” *Industrial Electronics, 1998. Proceedings. ISIE '98. IEEE International Symposium on*. 1998.

[10] Hiyama, T., S. Kouzuma, and T. Imakubo, “Identification of optimal operating point of PV modules using neural network for real time maximum power tracking control. Energy Conversion”, IEEE Transactions on, 1995. **10**(2): p. 360-367.

[11] S. Zahra Mirbagheri, Saad Mekhilef, S. Mohsen Mirhassani, MPPT with Inc.Cond Method using Conventional Interleaved Boost Converter, *Energy Procedia,* Volume 42, 2013, Pages 24-32, ISSN 1876-6102.

[12] Sahu, T.P.; Dixit, T.V., "Modelling and analysis of Perturb & Observe and Incremental Conductance MPPT algorithm for PV array using Ċuk converter," Electrical, Electronics and Computer Science (SCEECS), 2014 IEEE Students' Conference on , vol., no., pp.1,6, 1-2 March 2014.

[13] Sera, D.; Mathe, L.; Kerekes, T.; Spataru, S.V.; Teodorescu, R., "On the Perturb-and-Observe and Incremental Conductance MPPT Methods for PV Systems," Photovoltaics, IEEE Journal of, vol.3, no.3, pp.1070,1078, July 2013.

[14] Banu, IV.; Beniuga, R.; Istrate, M., "Comparative analysis of the perturb-and-observe and incremental conductance MPPT methods," Advanced Topics in Electrical Engineering (ATEE), 2013 8th International Symposium on , vol., no., pp.1,4, 23-25 May 2013.

[15] Murtaza, AF.; Sher, H.A; Chiaberge, M.; Boero, D.; De Giuseppe, M.; Addoweesh, K.E., "Comparative analysis of maximum power point tracking techniques for PV applications," Multi Topic Conference (INMIC), 2013 16th International , vol., no., pp.83,88, 19-20 Dec. 2013.

[16] A. R. Saxena, M. Veerachar, "Robust digital deadbeat control for DC-DC power converter with online parameter estimation", *Proc. Joint Int. Conf. on Power Electron., Drives and Energy Syst. (PEDES) &* 2010 Power India, pp.1-5, Dec. 2010.

[17] Yu Ting-Chung, Chien Tang-Shiuan, "Analysis and simulation of characteristics and maximum power point tracking for photovoltaic systems", *Power Electronics and Drive Systems, PEDS. International Conference on*, 2009, pp. 1339,1344.

[18] M. Veerachary, T. Senjyu, K. Uezato, "Voltage-based maximum power point tracking control of PV system", *Aerospace and Electronic Systems, IEEE Transactions on* , 2002, vol. 38, no. 1, pp. 262,270.

[19] S.M. Gupta, A.R. Saxena, "Analysis of P&O MPPT Algorithm for PV System Interfaced With Boost Converter Under Changing Climatic Condition", *International Journal of Current Engineering and Technology*, *IJCET* , 2014, Vol.4, No.3, pp. 2189, 2195.

[20] F. A O Aashoor, F. V. P. Robinson, (2012), A variable step size perturb and observe algorithm for photovoltaic maximum power point tracking, *Universities Power Engineering Conference (UPEC),* 47th International , pp. 1,6.

[21] Mohd Zainuri, M.AA; Mohd Radzi, M.A; Soh, AC.; Rahim, N.A, "Development of adaptive perturb and observe-fuzzy control maximum power point tracking for photovoltaic boost dc-dc converter," Renewable Power Generation, IET , vol.8, no.2, pp.183,194, March 2014.

[22] Lian, K.L.; Jhang, J.H.; Tian, IS., "A Maximum Power Point Tracking Method Based on Perturb-and-Observe Combined With Particle Swarm Optimization," Photovoltaics, IEEE Journal of, vol.4, no.2, pp.626,633, March 2014.

[23] M. Veerachary and A. R. Saxena, "Design of Robust Digital Stabilizing Controller for Fourth-Order Boost DC-DC Converter: A Quantitative Feedback Theory Approach", IEEE Trans. on Ind. Electron., vol. 59, No. 2, PP. 952-963, Feb. 2012.

[24] Elgendy, M.A; Zahawi, B.; Atkinson, D.J., "Assessment of the Incremental Conductance Maximum Power Point Tracking Algorithm," Sustainable Energy, IEEE Transactions on, vol.4, no.1, pp.108, 117, Jan. 2013.

[25] Chauhan, J.; Chauhan, P.; Maniar T.; Jhosi, A, "Comparison of MPPT algorithms for DC-DC converters based Photovoltaic Systems," *Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on,* vol., no., pp.476,481 , 10-12 April 2013.

[26] M. A. Elgendy, B. Zahawi, and David J. Atkinson, "Assessment of the Incremental Conductance Maximum Power Point Tracking Algorithm", *IEEE Trans,* vol. 4, no. 1, jan 2013.

[27] M. Veerachary, "Maximum Power Point Tracking Algorithm For Non-Linear DC Sources", *Industrial and Information Systems, ICIIS, IEEE Region 10 and the Third international Conference on*, 2008, pp. 1,6.

[28] M. Veerachary, "Maximum power point tracking parameter selection for higher order converters used in photovoltaic applications", *Power Systems, ICPS, International Conference on* , 2009, pp. 1,6.

[29] N. Altin, T. Yildirimoglu, "LabVIEW/MATLAB based simulator for grid connected PV system", *Power Engineering, Energy and Electrical Drives (POWERENG), Fourth International Conference on* , 2013, pp. 1316,1321.

[30] M.A. Farahat, H.M.B. Metwally, Ahmed Abd-Elfatah Mohamed, "Optimal choice and design of different topologies of DC-DC converter used in PV system, at different climate conditions in Egypt", *Renewable Energy,2012,* Vol., no., 43, pp. 393,402, .

[31] J.A.B. Vieira, A.M. Mota, "Maximum power point tracker applied in batteries charging with PV panels", *Industrial Electronics, ISIE, IEEE International Symposium on*, 2008, pp. 202,207.

[32] A. R. Saxena, M. Veerachary, "Robust digital deadbeat control for DC-DC power converter with online parameter estimation", *Proc. Joint Int. Conf. on Power Electron., Drives and Energy Syst. (PEDES) & 2010 Power India,* pp.1-5, Dec. 2010.