

## Comparative Study of Maximum Power Point Tracking Algorithms with DC-DC Converters for Solar PV System

<sup>1</sup>Umashankar S., <sup>1</sup>Punna Srikanth, <sup>2</sup>D. Vijay Kumar  
and <sup>2</sup>D.P. Kothari

<sup>1</sup>*Power Electronics and Drives Division,  
SELECT, VIT University, Vellore, India*

*E-mail: umashankar.s@vit.ac.in, srikanth1987hyd@yahoo.co.in*

<sup>2</sup>*Power System Division, SELECT, VIT University, Vellore, India*

*E-mail: vijayakumar.d@vit.ac.in, dpk0710@yahoo.com*

### Abstract

This paper focuses on the comparative study of maximum power point tracking (MPPT) algorithm. It has been analysed with different combination of DC-DC converters. Due to poor efficiency of Photo voltaic (PV) systems some MPPT methods are proposed. All MPPT methods follow the same goal that is maximizing the PV system output power by tracking the maximum power on every operating condition.

In this paper maximum power point tracking techniques (Incremental conductance, and perturb and observe) for photovoltaic systems were introduced to maximize the produced energy. These techniques vary in many aspects as: simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects. Incremental conductance algorithm is used to track the MPP because it performs precise control under rapidly changing atmospheric conditions.

**Keywords:** PV system; Maximum power point tracking (MPPT); DC-DC Converter.

### Introduction

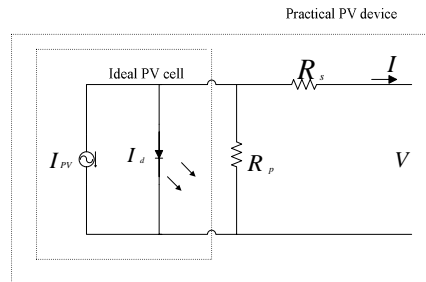
Unfortunately, PV generation systems have two major problems: the conversion efficiency of electric power generation is very low (9-16%), especially under low irradiation conditions and the amount of electric power generated by solar arrays

changes continuously with weather conditions. Moreover, the solar cell V-I characteristic is nonlinear and changes with irradiation and temperature. In general, there is a point on the V-I or V-P curve only, called the Maximum Power Point (MPP), at which the entire PV system operates with maximum efficiency and produces its maximum output power [4]. The location of the MPP is not known, but can be located, either through calculation models or by search algorithms. Maximum Power Point Tracking (MPPT) techniques [16] are used to maintain the PV array's operating point at its MPP.

As the MPP is always requested, and this point can be found in any position on I-V curve, depending on temperature and radiation levels, the natural DC-DC converters [13] to be applied as MPP Trackers are Buck, Boost, Buck-Boost and Cuk. The operating region of DC-DC converters are discussed in this paper.

## PV Cell

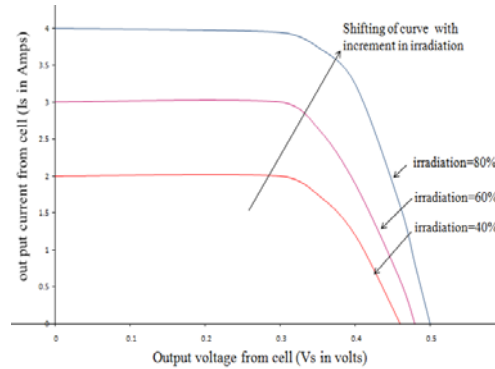
A photovoltaic system converts sunlight into electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules. Panels can be grouped to form large photovoltaic arrays. Fig.1 shows the equivalent circuit of the ideal photovoltaic cell. The basic equation for output current of module [2] is



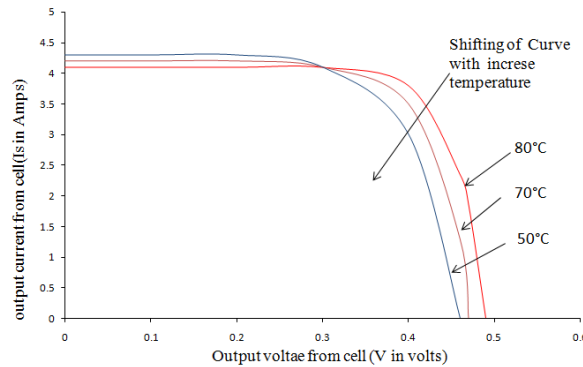
**Figure 1:** Single-diode model of the theoretical photovoltaic cell and equivalent circuit of a practical photovoltaic device including the series and parallel resistances.

$$I = I_{ph\ cell} - I_{0\ cell} \left[ \exp\left(\frac{qV}{akT}\right) - 1 \right] \quad (1)$$

Where  $I$  is the PV array output current,  $V$  is the PV output voltage,  $I_{pv,cell}$  is the cell photocurrent that is proportional to solar irradiation,  $I_{0,cell}$  is the cell reverse saturation current that mainly depends on the temperature,  $K$  is a constant. These techniques vary in many aspects as: simplicity, convergence speed, digital or analogical implementation, sensors required, cost, range of effectiveness, and in other aspects [3][4]. Fig.2, 3 shows basic idea of PV system with different increase in solar radiation [14] causes the output current to increase and the horizontal part of the curve moves upward. An increase in cell temperature causes the



**Figure 2:** Voltage Vs Current characteristics of PVA with Variation of Insolation.



**Figure 3:** Characteristics of PVA incorporating effect of Temperature.

Voltage to move leftward, while decreasing temperature produces the opposite effect. Thus, the I-V curves display how a photovoltaic module responds to all possible loads under different solar radiation and cell temperature conditions.

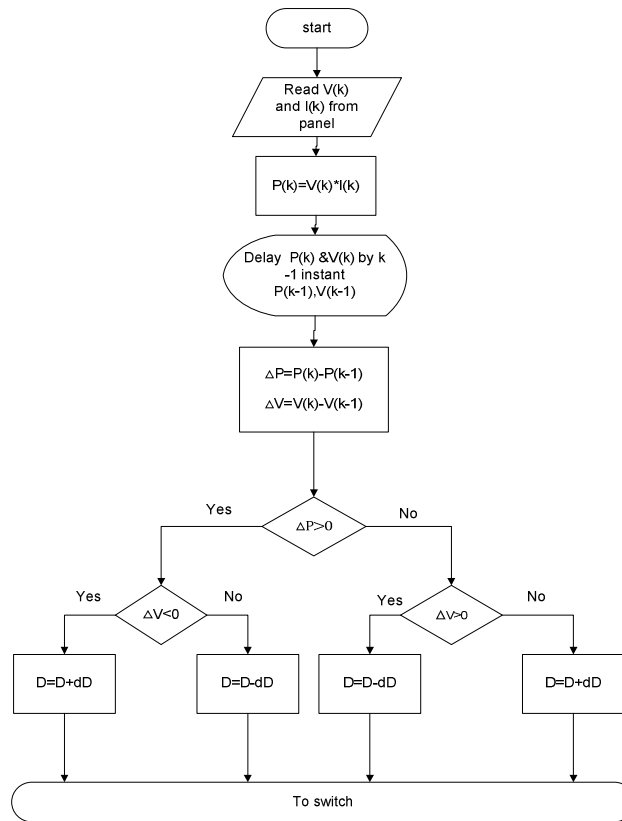
### MPPT Algorithms

Maximum power point trackers (MPPTs) play a main role in photovoltaic (PV) power systems because they maximize the power output from a PV system for a given set of conditions, and therefore maximize the array efficiency. Thus, an MPPT[18] can minimize the overall system cost. There are many MPPT methods available the most widely-used techniques are Perturb and Observe method and incremental conductance method described in the following sections. They also vary in complexity, sensor requirement, speed of convergence, cost, range of operation, popularity, ability to detect multiple local maxima and their applications [3][4]. Specifically the Power Point Tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the loads. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage

of high frequency circuits is that they can be designed with very high efficiency transformers and small components.

### Perturb and Observe Algorithm

The Perturb and Observe algorithm[6-8] operate by periodically perturbing(i.e. incrementing or decrementing)the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. If the PV array operating voltage changes and power increases, the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the next perturbation cycle the algorithm continues in the same way.The flow chart of the Perurb and Observe algorithm shown in Fig.4.



**Figure 4:** Flowchart of Perturb and Observe (P&O) methods.

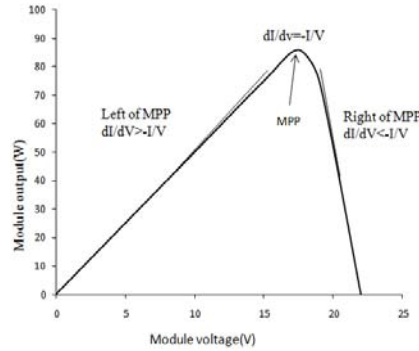
### Incremental Conductance Algorithm

The Incremental Conductance method[6-10] offers good performance under rapidly changing atmospheric conditions. Fig.5 shows that the slope of the PV array power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the right hand side of MPP.The basic equations of this method are as follows[1]

$$\frac{dI}{dV} = -\frac{I}{V} \text{ At MPP} \quad (2)$$

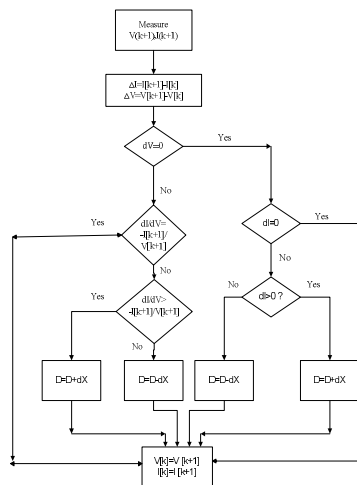
$$\frac{dI}{dV} > -\frac{I}{V} \text{ Left of MPP} \tag{3}$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ Right of MPP} \tag{4}$$



**Figure 5:** Basic idea of incremental conductance method on a P-V curve of a solar module.

Where I and V are PV array output current and voltage respectively. The left hand side of equations represents Incremental conductance of PV module and the right hand side represents the instantaneous conductance. From (2), (3) and (4) it is obvious that when the ratio of change in the output conductance is equal to the negative output conductance, solar array will operate at the maximum power point. In other words, by comparing the conductance at each sampling time, the MPPT will track the maximum power of the PV module. The flow chart of Incremental Conductance method shown in Fig.6. It makes use of instantaneous and incremental conductance to generate an error signal which is zero at MPP; however it is not zero at most of the operating points, but it make the error from the MPPs near to zero [3].



**Figure 6:** Flowchart of Incremental conductance method.

## Comparison

A common problem in Perturb and Observe algorithm[19] is that the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the output power oscillates around the maximum, resulting in power loss in the PV system. This is especially true in constant or slowly-varying atmospheric conditions. Furthermore, Perturb and Observe method can fail under rapidly changing atmospheric conditions. Incremental conductance method [5-8] is more efficient than Perturb Observe method [5-7] because panel terminal voltage is changed according to its value relative to the maximum power point voltage. Therefore, this method is independent on solar panel characteristics.

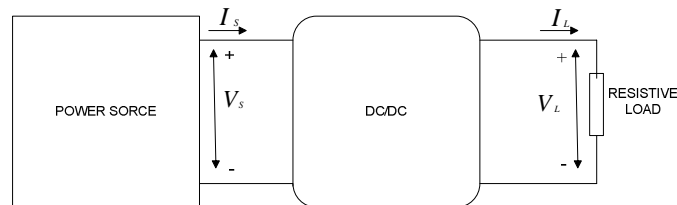
**Table I:** Overall MPP Tracking Efficiencies.

Sky conditions	Perturb and Observe		Incremental conductance	
	Days of data	MPPT efficiency	Days of data	MPPT efficiency
Clear	20	98.7	17	98.7
Partly cloudy	14	96.5	11	97.0
Cloudy	9	98.1	11	96.7
Overall	43	97.8	39	97.4
Simulator overall	99.3		99.4	

Incremental conductance method eliminates the problem that is seen in Perturb and Observe method. Therefore, oscillations that cause power loss are not occurred in Incremental conductance method. A summary of the MPPT efficiencies of two algorithms are shown in Table I.

## Choice of Converter for MPPT

When proposing a maximum power point tracker, the major job is to choose and design a high efficient converter which is supposed to operate as the main part of the MPPT. The cuk converters provide the opportunity to have either higher or lower output voltage compare with input voltage.



**Figure 7:** Converter acting as a Maximum Power Point Tracker.

Although buck and boost configuration is cheaper than cuk, some disadvantages

such as discontinuous input current, high peak currents in power components and poor transient response makes it less efficient. On the other hand, cuk converter has low switching losses and highest efficiency among non-isolated DC-DC converters [17]. It also can provide a better input and output current characteristic due to the inductor on the both input and output stage. The load voltage of converter can be obtained in terms of load current by the relation

$$V_{load} = I_{load}R_{load} \quad (5)$$

Where  $V_{load}$  is the load voltage,  $I_{load}$  is the load current and  $R_{load}$  is the load resistance. We shall assume the operation of a cuk converter

$$V_{load} = \frac{D}{1-D} V_{module} \quad (6)$$

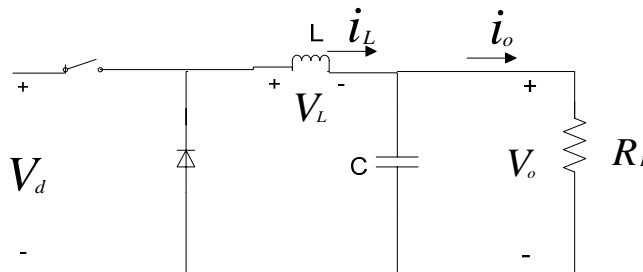
The average input power to the DC-DC converter equals the average output power thereby, we get a relation

$$I_{load} = \frac{1-D}{D} I_{module} \quad (7)$$

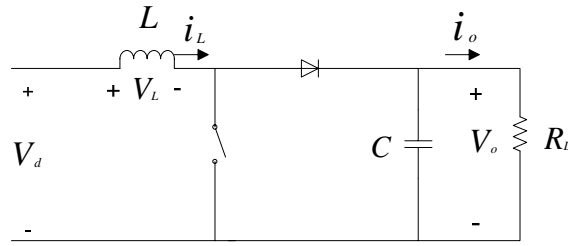
Combining the above two equations, we write

$$\frac{V_{module}}{I_{module}} = \frac{(1-D)^2}{D} R_{load} \quad (8)$$

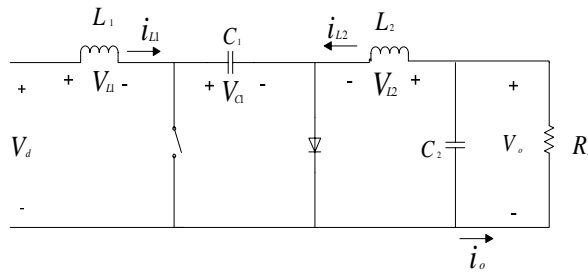
D here represents the voltage conversion ratio of the cuk converter. So, when seen from the source side, the effective resistance will be  $\left(\frac{1-D}{D}\right)^2 R_{load}$ . This is a function of D, which we can control to fix the operating point near the MPP. We have to note that the range of D is zero to one. The MPP can be found in any position on I-V curve, depending on temperature and radiation levels, the natural DC-DC converters to be applied as MPP Trackers are Buck-Boost, Cuk, because they have no non-operational region. TABLE-II summarizes the equations for DC-DC Buck, Boost, Cuk, converters. Comparative study on different schemes of switching converters is presented in the literature [11][13].The basic circuit diagram buck boost cuk converters are as shown in Fig.8, 9, and 10



**Figure 8:** Step down (buck) converter.



**Figure 9:** Step up (boost) converter.



**Figure 10:** Cuk converter.

**Table II:** Conversion Factor and Range of Operation of Converters.

DC-DC converter	$R_e(D, R_{load})$	Range $\theta$
Cuk converter	$\left(\frac{1-D}{D}\right)^2 R_{load}$	$0^\circ \leq \theta \leq 90^\circ$
Buck converter	$\frac{R_{load}}{D^2}$	$0^\circ \leq \theta \leq \tan^{-1}\left(\frac{1}{R_{load}}\right)$
Boost converter	$(1-D)^2 R_{load}$	$\tan^{-1}\left(\frac{1}{R_{load}}\right) \leq \theta \leq 90^\circ$

## Conclusion

This paper has presented a comparison of two Maximum Power Point Tracking techniques[9][12][15] and their efficiency performance at different weather conditions. The Incremental Conductance method is more efficient than Perturb and Observe method because panel terminal voltage is changed according to its value relative to the MPP voltage. Perturb and Observe method can fail under rapidly changing atmospheric conditions. Incremental conductance method eliminates the problem in Perturb and Observe method. The Incremental Conductance method offers good performance under rapidly changing atmospheric conditions. On the other hand; cuk converter has low switching losses and highest efficiency among non-isolated DC-DC converters. It also provides a better input and output current characteristic due



to the inductor on both input and output stage. Thus cuk converter configuration is a proper choice to be employed in designing the MPPT.

## References

- [1] Safari, A; Mekhilef, S "Simulation and Hardware Implementation of Incremental Conductance MPPT with Direct Control Method Using Cuk Converter," *Industrial Electronics, IEEE Transactions on*, vol.PP, no.99, pp.1-1, Odoi: 10.1109/TIE.2010.2048834.
- [2] H.S.Rauschenbach. "Solar cell array design handbook," Van Nostrand Reinhold, 1980.
- [3] Eram, T.; Chapman, P.L., "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," *Energy Conversion, IEEE Transactions on* , vol.22, no.2, pp.439-449, June 2007doi: 10.1109/TEC.2006.874230
- [4] V. Salas, E. Olias, A. Barrado, and A. Lazaro, "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems," *Sol. Energy Mater. Sol. Cells*, vol. 90, no. 11, pp. 1555–1578, Jul. 2006.
- [5] Zhou Yan; Liu Fei; Yin Jinjun; Duan Shanxu; , "Study on realizing MPPT by improved Incremental Conductance method with variable step-size," *Industrial Electronics and Applications, 2008. ICIEA 2008. 3rd IEEE Conference on* , vol., no., pp.547-550, 3-5 June 2008, doi: 10.1109/ICIEA.2008.4582575.
- [6] Femia, N.; Granozio, D.; Petrone, G.; Spagnuolo, G.; Vitelli, M.; , "Optimized one-cycle control in photovoltaic grid connected applications," *Aerospace and Electronic Systems, IEEE Transactions on* , vol.42, no.3, pp.954-972, July 2006, doi: 10.1109/TAES.2006.248205.
- [7] Wenkai Wu; Pongratananukul, N.; Weihong Qiu; Rustom, K.; Kasparis, T.; Bataarseh, I.; , "DSP-based multiple peak power tracking for expandable power system," *Applied Power Electronics Conference and Exposition, 2003. APEC '03. Eighteenth Annual IEEE* , vol.1, no., pp. 525- 530 vol.1, 9-13 Feb. 2003 doi: 10.1109/APEC.2003.1179263.
- [8] Chihchiang Hua; Chihming Shen; , "Comparative study of peak power tracking techniques for solar storage system," *Applied Power Electronics Conference and Exposition, 1998. APEC '98. Conference Proceedings 1998, Thirteenth Annual*, vol.2, no., pp.679-685 vol.2, 15-19 Feb 1998, doi: 10.1109/APEC.1998.653972.
- [9] Hohm, D.P.; Ropp, M.E.; , "Comparative study of maximum power point tracking algorithms using an experimental, programmable, maximum power point tracking test bed," *Photovoltaic Specialists Conference, 2000. Conference Record of the Twenty-Eighth IEEE* , vol., no., pp.1699-1702, 2000 doi: 10.1109/PVSC.2000.916230.
- [10] Hussein, K.H.; Muta, I.; Hoshino, T.; Osakada, M.; , "Maximum photovoltaic power tracking: an algorithm for rapidly changing atmospheric conditions," *Generation, Transmission and Distribution, IEE Proceedings-* , vol.142, no.1, pp.59-64, Jan 1995 doi: 10.1049/ip-gtd:19951577.

- [11] Tse, K.K.; Ho, B.M.T.; Chung, H.S.-H.; Hui, S.Y.R.; , "A comparative study of maximum-power-point trackers for photovoltaic panels using switching-frequency modulation scheme," *Industrial Electronics, IEEE Transactions on* , vol.51, no.2, pp. 410- 418, April 2004, doi: 10.1109/TIE.2004.825226.
- [12] Faranda, R.; Leva, S.; Maugeri, V.; , "MPPT techniques for PV Systems: Energetic and cost comparison," *Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE* , vol., no., pp.1-6, 20-24 July 2008, doi: 10.1109/PES.2008.4596156.
- [13] K.S.R. Rajeswararao, S. UmaShankar, N. Sudhakar, D.Vijaya Kumar, "Performance of a Controlled Capacitor Charging type converter Based on Switch Utilization Ratio", *International conference on Advances in Renewable Energy(ICARE 2010)*, Maulana Azad National Institute of Technology, Bhopal, June 24-26, 2010.
- [14] Kar, A.; , "A New Maximum Power Point Tracking Algorithm for PV Modules under Partial Shading and Rapidly Varying Illumination," *India Conference (INDICON), 2009 Annual IEEE* , vol., no., pp.1-4, 18-20 Dec. 2009, doi: 10.1109/INDCON.2009.5409472.
- [15] Hui, J.; Bakhshai, A.; Jain, P.K.; , "A hybrid wind-solar energy system: A new rectifier stage topology," *Applied Power Electronics Conference and Exposition (APEC), 2010 Twenty-Fifth Annual IEEE* , vol., no., pp.155-161, 21-25 Feb. 2010, doi: 10.1109/APEC.2010.5433678.
- [16] Lixin Pang; Hui Wang; Yuxia Li; Jian Wang; Ziyu Wang; , "Analysis of Photovoltaic Charging System Based on MPPT," *Computational Intelligence and Industrial Application, 2008. PACIIA '08. Pacific-Asia Workshop on* , vol.2, no., pp.498-501, 19-20 Dec. 2008, doi: 10.1109/PACIIA.2008.357.
- [17] Lu, J.; Stegen, S.; Butler, D.; , "High frequency and high power density transformers for DC/DC converter used in solar PV system," *Power Electronics for Distributed Generation Systems (PEDG), 2010 2nd IEEE International Symposium on* , vol., no., pp.481-484, 16-18 June 2010, doi: 10.1109/PEDG.2010.5545743.
- [18] Mutoh, N.; Ohno, M.; Inoue, T.; , "A Method for MPPT Control While Searching for Parameters Corresponding to Weather Conditions for PV Generation Systems," *Industrial Electronics, IEEE Transactions on* , vol.53, no.4, pp.1055-1065, June 2006, doi: 10.1109/TIE.2006.878328.
- [19] Fermia, N.; Granozio, D.; Petrone, G.; Vitelli, M.; , "Predictive & Adaptive MPPT Perturb and Observe Method," *Aerospace and Electronic Systems, IEEE Transactions on* , vol.43, no.3, pp.934-950, July 2007, doi: 10.1109/TAES.2007.4383584.