OVERVIEW OF MPPT TECHNIQUES FOR SOLAR ENERGY HARVESTING SYSTEMS

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Abstract:* The heart of solar energy harvesting system is Photo voltaic (PV) panel. High Cost and Low Conversion efficiency of PV panels are the major challenges of solar energy harvesting systems. To attain maximum efficiency, it is required to extract maximum possible power from the PV panel. Current to Voltage (I-V) characteristic of PV cell is non-linear and has a maximum power point (MPP). This MPP shifts dynamically due to irradiation conditions, temperature and electrical characteristics of the load. Maximum power point tracking (MPPT) is required to attain maximum conversion efficiency from PV panel. This paper presents overview of three maximum power point tracking algorithms- perturb-and observe (P&O), incremental conductance (INC), and fractional open circuit voltage (FV_{OC}). The techniques are studied to find out suitable technique for solar inverter used in smart grid projects at the lab.

***Index Terms* - Maximum power point tracking (MPPT), photo-voltaic (PV), incremental conductance (INC), perturb and observe (P&O), fractional open circuit voltage (FVOC).**

I. INTRODUCTION

Solar power is the cleanest and most reliable form of renewable energy sources, and it is looked upon as promising alternative for non-renewable sources of energy. PV panels work as a backbone of the system and convert the sunlight into electrical energy. The conversion efficiency of PV panels achieved till today is approximately 30%. This limitation of PV panels along with charge controllers and other devices make the Solar power harvesting system quite inefficient. As a result of this, till today the conversion efficiency and the costs per kilo-watt-hour (kWh) of solar energy harvesting systems are not competitive with petroleum energy sources.

The generation and conversion efficiency of PV system largely depends on the weather conditions in general and light intensity in particular. The I-V characteristic of PV cell is nonlinear, as shown in Fig. 1, which vary with the level of solar irradiation and temperature. This non-linear behavior makes the extraction of maximum power a complex task. The shift in MPP of solar cell can be compensated by MPPT controller.

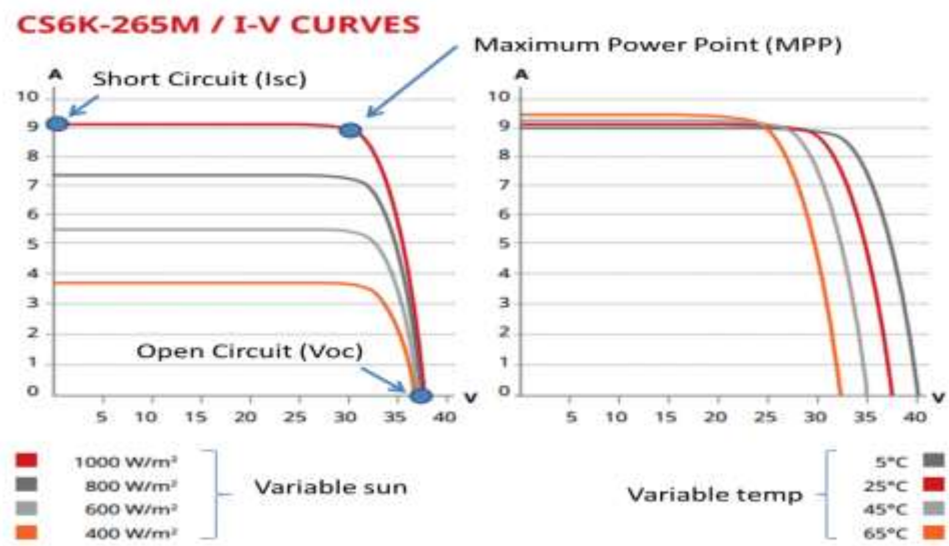

Figure 1: I-V characteristic of PV cell [13]

The MPPT controller monitors the output voltage and current delivered from the solar panel and accordingly determines the operating point that will extract maximum power to be delivered to the batteries. The MPPT controller dynamically shifts operating point allowing maximum power supply into the batteries by making the solar cell experience change in load while actually it is not possible to change [12]. The accurate tracking of MPP by MPPT controller can enhance the efficiency of the PV panels and in turn of solar energy harvesting system.

Many algorithms and techniques have been developed for tracking maximum power point of PV panel. These algorithms vary in effectiveness, complexity, convergence speed, sensors required and cost [4]. Three MPPT methods are reviewed and presented in this paper; the P&O method, the Incremental Conductance method and fractional open circuit voltage based on above parameters. The techniques are studied to find out suitable technique for micro solar inverter projects which are developed by students in laboratory for 1-5kWsystems. Various parameters of grid and inverters can be monitored at centralized system and controlled according to the requirement.

This paper is organized as follows. MPPT techniques under review are described in Section-II. In Section-III comparative study of different performance parameters of MPPT techniques is presented. Concluding remark is given in Section-IV.

II. OVERVIEW OF MPPT TECHNIQUES

In [1, 3, 4, 5, 10, 12] authors have presented review of approximately 30+ different techniques to achieve MPPT in PV systems. Following techniques are considered and presented in this paper keeping in mind solar inverters for home or for small scale industries, Laboratories etc.

1. Perturb-and-observe,
2. Incremental conductance,
3. Fractional open circuit voltage

A)Perturb-and-observe (P&O)

The simplest technique among all MPPT techniques is Perturb-and-observe algorithm. This technique is based on the simple mathematical condition, i.e, where P and V represent power and voltage at output of photovoltaic module respectively. From figure 2, it can be seen that when the PV array operate on the left side of MPP, increase in voltage increases power whereas when the PV array operates on the right of MPP, the power decreases on increasing voltage. Hence perturbation process is, if, the perturbation should be same and if, the perturbation should be reversed. The process should be repeated periodically until reached (maximum power point) [1], [3], [4], [9].

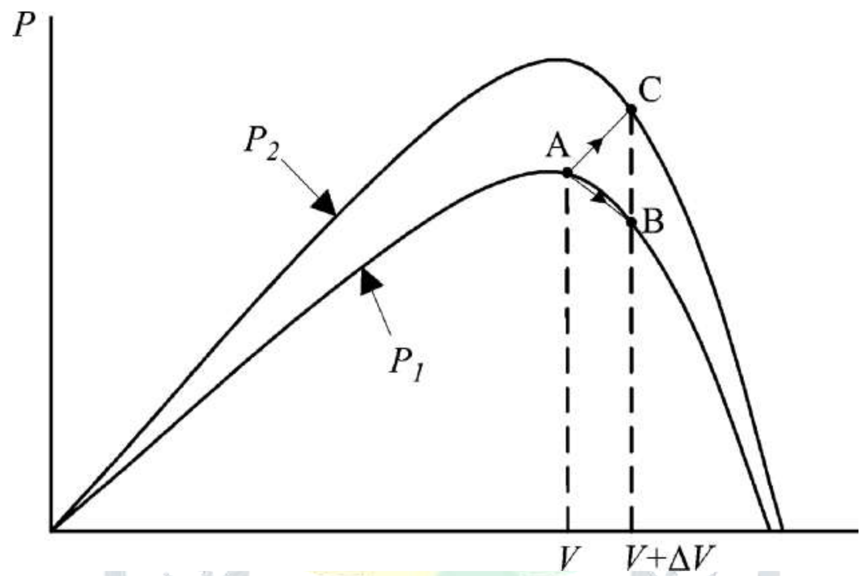

Figure 2: Divergence of P&O from MPP [4]

Under the constant atmospheric condition, because of small perturbation of ΔV in the PV voltage V under constant atmospheric conditions the operating point moves from A to B. According to P&O algorithm the perturbation should be reversed, since power decreases to B. similarly when the power curve move from P1 to P2 because of increase in irradiance the operating point will change from A to C. Now there is increase in power so again according to P&O algorithm the perturbation should be kept same which results in the divergence of operating point from Maximum Power Point [3], [4]. In sudden atmospheric change, P&O method does not respond well as illustrated in figure 2. In such situations, it is required to do some change in basic P&O technique to track MPP correctly even under rapid change in irradiance. For example, the three-points P&O algorithms [3]-[5]. In the smart grid power calculated by P&O controlling system can be monitored and tuned for the fast tracking. Various parameters can also be verified at central systems like irradiance, temperature, load, power.

B)*Incremental conductance (INC)*

In the Incremental conductance method, the basic fact is used, that the derivative of the PV module power is zero at MPP, positive at left of MPP and negative at right of MPP. This technique deals with the sign of derivative function (dP/dV) without a perturbation. So, this technique overcomes the limitations of P&O technique [5]. The basic mathematical relations for this technique are given below (shown in fig. 4):

$$\frac{dP}{dV} = 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{at MPP} \quad (1)$$

$$\frac{dP}{dV} > 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{at left of MPP} \quad (2)$$

$$\frac{dP}{dV} < 0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{at right of MPP} \quad (3)$$

Since,

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \quad (4)$$

For MPP putting $\frac{dP}{dV} = 0$, we get

$$I + V\frac{\Delta I}{\Delta V} = 0 \quad (5)$$

So,

$$\frac{\Delta I}{\Delta V} = -\frac{I}{V} \quad \ldots\ldots\ldots\ldots \quad \text{at MPP} \quad (6)$$

$$\frac{\Delta I}{\Delta V} > -\frac{I}{V} \quad \ldots\ldots\ldots\ldots \quad \text{at left of MPP} \quad (7)$$

$$\frac{\Delta I}{\Delta V} < -\frac{I}{V} \quad \ldots\ldots\ldots\ldots \quad \text{at right of MPP} \quad (8)$$

Where,

$\frac{I}{V}$ is instantaneous conductance

$\frac{\Delta I}{\Delta V}$ is incremental conductance

From equations (6), (7) and (8) we can say that the maximum power point of V array can be tracked by comparing the $\frac{I}{V}$ to $\frac{\Delta I}{\Delta V}$ as shown in the flowchart (fig.3).

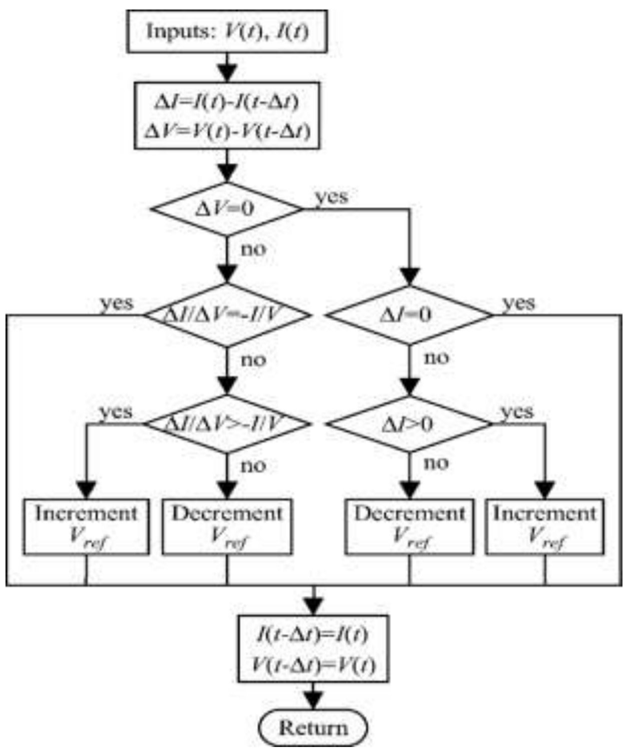

Figure *3*: Flow chart of Incremental Conductance method [2], [4]

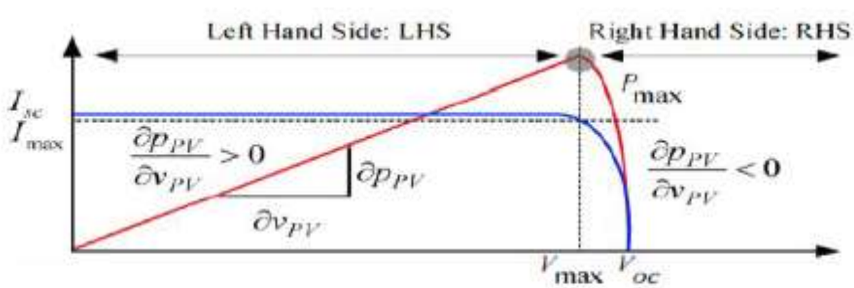

Figure *4*: I-V and P-V curve of PV module [6]

Here V_{ref} is reference voltage at which PV array is to be operated. At the instance of maximum power point V_{ref} must be equal to *VMPP*. And once maximum power point is tracked the operation is maintained at MPP until a change in occur or some change in atmospheric conditions. V_{ref} is continuously increasing or decreasing to maintain new MPP. To respond for a rapid change of atmospheric condition is the advantage over P&O. P&O technique oscillates around the same point whereas this technique determines when it has reached the MPP [1], [2], [4]-[6], [11].

C)*Fractional open circuit voltage (FVOC)*

There is a linear relation between the Maximum power point voltage (V_{MPP}) and the open circuit voltage. FVoc is based on this linear relation to track maximum power point.

$$V_{MPP} \approx K_1 V_{OC} \qquad (9)$$

Above equation (9) shows the linear relation between V_{MPP} and V_{oc} with constant factor K_1. Where, K1 is proportionality constant and the value of K1 is dependent on the characteristics of the PV Cell or Array of solar Panels being used. The ratio of VMPP and VOC will be up to 78% i.e. the value of K_1 is in between 0.77-0.78to calculate maximum power point voltage. VMPP calculation is easy using the known value of K1, with the help of above equation and with measured value of VOC periodically by shutting down the converters for a fraction of time to measure open circuit voltage which results the temporary loss of power.

Moreover, is not constant as PV panels degrade with the time. Degradation over the time causes a decrease in conversion efficiency so K1 value is not constant. Also, K1 varies with the various parameters like PV material temperature, light irradiation, and cell-to-cell mismatches within PV arrays. Thus, FV_{OC} needs a periodic pre-configuration.

The major disadvantage of FV_{OC} is the wastage of available energy while the power converter is disconnected from load. The problem of power loss can be overcome by using pilot cells from which VOC can be taken. And another problem is value of k1 is not constant, it varies according to the PV parameters.

III.SUMMARY OF THE COMPARISON OF MPPT TECHNIQUES

Three methods are compared on the basis of five performance parameters relevant to our survey. The same is presented in Table-1

Table *1*: Comparison of MPPT Techniques

Parameter	**Techniques**		
	P&O	INC	FV_{OC}
Tracking Efficiency	Reasonable	High	Medium
Algorithm Complexity	Low	High	Low
Hardware Complexity	Low	Low	Medium
Sensed Parameter	Current and Voltage	Current and Voltage	Voltage
Tracking Speed	Varies	Varies	Fast and Fixed
Periodic Tuning	No	No	Yes

As INC technique is based on the calculation of differential voltage and power, small change in the power changes the tracking. Hence it provides higher tracking efficiency than the P&O and FVoc algorithm.

Considering complexity, INC is highly complex as the differential power with respect to voltage needs to be calculated; on other hand FVoc have the medium hardware complexity due to its timing controller through which a PV cell is kept open for fraction of time. If the cell is kept open for longer duration, it will have reduced power delivered by PV cell and in turn will affect power efficiency.

FVoc is dependent on measurement of open circuit voltage hence only voltage sensor is required in it. On the other hand, in P&O and INC techniques power needs to be calculated hence current sensor is also required along with the voltage sensor.

Tracking speed of P&O and INC varies with weather conditions, but for FVoc it is fast and at fixed time intervals

FVoc requires periodic tuning of constant used for power calculation to compensate any changes in it due to aging or degradation of PV cell. In case of other techniques, there is no constant hence no such requirement of tuning.

IV.CONCLUSION

Three techniques for MPPT namely P&O, INC and FVoc are studied with respect to solar energy harvesting systems for solar inverter projects. If low cost solution with minimal complexity is required with moderate efficiency FVoc is better option than other two techniques. But it will call for periodic tuning. P&O technique can provide better efficiency than FVoc at the cost of little modification in basic P&O to handle inaccuracies due to oscillations. For large PV arrays, INC with complex hardware and large computational time can be used to obtain highest efficiency.

REFERENCES

[1] Jaen, C.; Moyano, C.; Santacruz, X.; Pou, J.; Arias, A., "Overview of maximum power point tracking control techniques used in photo-voltaic systems," Electronics, Circuits and Systems, 2008. ICECS 2008. 15th IEEE International Conference on , vol., no., pp.1099,1102, Aug. 31 2008-Sept. 3 2008

[2] Roshan, R.; Yadav, Y.; Umashankar, S.; Vijayakumar, D.; Kothari, D.P.,"Modeling and simulation of Incremental conductance MPPT algorithm based solar Photo Voltaic system using CUK converter,"Energy Efficient Technologies for Sustainability (ICEETS), 2013 International Conference on , vol., no., pp.584,589, 10-12 April 2013

[3] 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

[4] Esram, 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 2007

[5] D.P.Hohm and M.E.Ropp, “Comparative Study of Maximum Power Point Tracking Algorithms Using an Experimental, Programmable, Maximum Power Point Tracking Test Bed,” in Proc. Photovoltaic Specialist Conference ,2000, pp.1699-1702

[6] Suwannatrai, P.; Liutanakul, P.; Wipasuramonton, P., "Maximum power point tracking by incremental conductance method for photovoltaic systems with phase shifted full-bridge dc-dc converter," Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 2011 8th International Conference on , vol., no., pp.637,640, 17-19 May 2011.

[7] T.L. Kottas, Y.S.Boutalis and A. D. Karlis, “New Maximum Power Point Tracker for PV Arrays Using Fuzzy Controller in Close Cooperation with Fuzzy Cognitive Network,” IEEE Trans. Energy Conv., vol.21, no.3, September, 2006

[8] Hiyama, T.; Kitabayashi, K., "Neural network based estimation of maximum power generation from PV module using environmental information," Energy Conversion, IEEE Transactions on , vol.12, no.3, pp.241,247, Sep 1997

[9] 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

[10] Berrera, M.; Dolara, A.; Faranda, R.; Leva, S., "Experimental test of seven widely-adopted MPPT algorithms," PowerTech, 2009 IEEE Bucharest , vol., no., pp.1,8, June 28 2009-July 2 2009

[11] Safari, A.; Mekhilef, S., "Incremental conductance MPPT method for PV systems," Electrical and Computer Engineering (CCECE), 201124th Canadian Conference on , vol., no., pp.000345,000347, 8-11May 2011

[12] Gergaud O, Multon B, Ben Ahmed H. Analysis and experimental validation of various photovoltaic system models. 7th International ELECTRIMACS Congress, Montréal, Canada, 2002, pp. 1-6.

[13] Canadian Solar “CS6K- 270| 275| 280 P” PV Module Product Datasheet, April 2018