2018 International Conference On Advances in Communication and Computing Technology (ICACCT)
Amrutvahini College of Engineering, Sangamner, Ahmednagar, India. Feb 8-9, 2018

Maximum Power Point Tracking for Photovoltaic Systems

Chandrakant D. Bhos
Symbiosis Institute of Technology,
Symbiosis International (Deemed University)
Lavale, Pune-411057, India
bhos.chandrakant@rediffmail.com

Paresh S. Nasikkar
Symbiosis Institute of Technology,
Symbiosis International (Deemed University)
Lavale, Pune-411057, India
paresh.nasikkar@sitpune.edu.in

***Abstract*— Photovoltaic system works with highest efficiency at an operating point of maximum power on power-voltage (P-V) and current-voltage (I-V) curve. But any mismatch in a photovoltaic array leads to differences in the I-V characteristics of the PV modules. It can lead to significant energy losses known as mismatch losses. An electronic circuitry is required to maintain the system stable at this maximum power point in spite of any disturbances, called as maximum power point tracking (MPPT) system. This paper describes few of the mostly used MPPT methods along with working principles. Limitations of these are presented in the latter section.**

Keywords—photovoltaic, mppt, solar.

I. INTRODUCTION

An increase in the population results in scarcity of land and electricity. Power engineers should meet Society's demand of a clean, cost effective and uninterrupted power supply. The renewable energy resources are nowadays widely used for electricity generation throughout the world to meet this demand. This is due the fact that the renewable energies do not generate the harmful gases and hence don't affect the ozone layer and hence the environment. Also fossil fuel has many drawbacks. The price of fossil fuels is always changing and these fuels will come to end after some years. But such problems are not faced by renewable energies and these are freely obtained from the nature. The two important renewable energy resources are the wind and the solar energy. These energies are widely available in abundant amount and these are free from the drawbacks which are prominent in nonrenewable sources. Therefore they are one of the best alternative options to conventional energy sources. Out of all types of renewable energies, the solar energy is mostly a better option and hence solar energy is widely utilized in industrial electrical generation or stand-alone applications. Due to its cleanliness, sustainability, ease of maintenance and low noise characteristics solar energy is very popular nowadays [15].

Solar energy can be extracted by two ways i.e. photovoltaic (PV) cells and solar thermal plants. PV cell directly converts the solar energy to an electrical energy and it has some advantages. But it has to meet some significant challenges like huge investment, energy fluctuation, less efficient energy conversion by PV module, and energy cost. Sun radiation is one of the important factor in generation capability of a photovoltaic power plant. There must be some control mechanism to use the PV panel because it posses non-linear characteristics. Moreover, various environmental factors like temperature, light intensity and radiation also contribute to changes in the output power and these are beyond the reach of us. A suitable MPPT method is necessary to increase the PV generation efficiency. MPPT predicts and tracks the MPP accurately at any values of environmental parameterss and then operates the PV system to run at the MPP point. An I–V (current–voltage) and P-V (power-voltage) characteristic of solar cell are non-linear and it changes according to irradiance and temperature values. This may disturb MPP and it in turn affects the available maximum power delivered to load. [3] [11].

II. MODELING OF PV CELL

P–N junction is formed in PV a cell which is similar to a diode. A modeling of a PV cell can be done as a parallel connection of a current source with a diode [11]. The PV cell acts like a diode in absence of a light. When the intensity of light incident on PV cell increases, it generates a current.

For an ideal cell, a model is so that the total current *I* is subtraction of the current generated by the photoelectricity (*Ipv*) effect and the diode current (*Id)*, according to the equation:

$$I = I_{pv} - I_d = I_{pv} - I_s(\exp(qV/kT) - 1) \quad (1)$$

where:
I_{pv} is PV current (A)
I_s is Saturation current (A)
q is Charge on Electron (1.60217×10^{-19} C)
V is Cell Voltage
k is Boltzmann constant (1.38065×10^{-23} J/K)
T is Temperature (K)

To achieve the required voltage and current, PV cells are connected in series connection and/or parallel way.

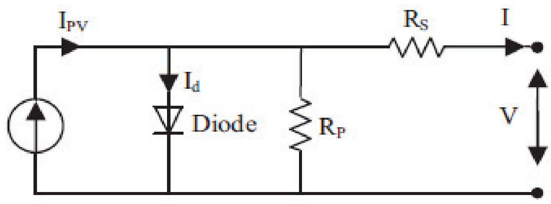

Fig.1. Simplified Model for a Photovoltaic Cell [11]

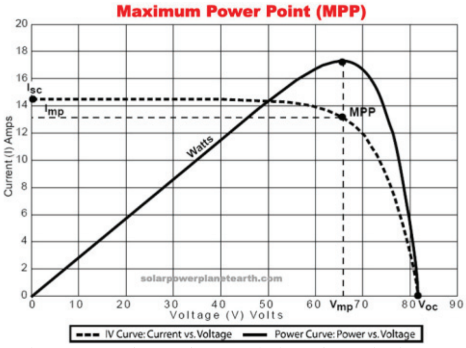

Fig. 2. IV and PV Characteristics of a typical PV system

Large output voltage is produced for the series connection of PV cells whereas large output current is produced for the parallel connection of PV cells.

A simplified circuit model shown above can be formed after expanding the equation. The corresponding associated equation is expressed below.

$$I = I_{pv} - I_s\left(\exp\frac{q(V + IR_s)}{N_s kTa} - 1\right) - \frac{V + IR_s}{R_p} \qquad (2)$$

where:
I_{pv} is PV current (A)
I_s is Saturation current (A)
q is Charge on Electron (1.60217×10^{-19} C)
k is Boltzmann constant (1.38065×10^{-23} J/K)
a is Constant of Diode ideality
Ns is Number of cells connected in series
T is Temperature (K)
Rs is series resistance (Ω)
Rp is parallel (shunt) resistance (Ω)

A photovoltaic (PV) module operates so that it has non-linear characteristics of I–V (current–voltage) and P–V (power–voltage). It can be noticed that there is only one point i.e. MPP where the PV module gives maximum power (Pmax) as shown in Fig. 2. MPP point also varies with the varying radiation and temperature.

III. MPPT METHODS

The solar PV systems can be categorized as stand alone systems or a grid connected systems. A conceptual view of generalized solar PV system is shown in figure3 which consists of the MPPT connected to a DC-DC converter which is fed by a PV panel. Inverter is used for AC loads and it can be also connected to a grid.

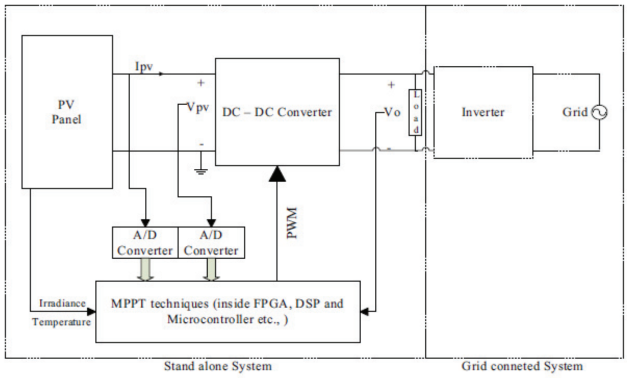

Fig. 3. Conceptual Block Ddiagram of a PV System [12]

The DC–DC converter drives a load as per the terminal voltage (V) which is generated by a PV cell as shown in Fig. 3. The MPPT circuit is used to track the MPP which can improve the performance of the system. MPPT generates the duty cycle to get PWM signal which drives the converter. The impedance of the PV panel and that of the load is matched through a converter. MPP is achieved by MPPT algorithm which provides the maximum power to the load. The operating point is changed according to this and it leads to more power delivery from the PV array. Thus from Fig. 3, it can be seen that voltage V_{mpp} or current I_{mpp} are found by MPPT technique and a PV array should operate at these values of V_{mpp} and I_{mpp}. It is used to harness the maximum power P_{mpp} for a given values of temperature and radiation.

A number of MPPT methods are developed by the researchers. They can be categorized as direct method and indirect method. Open-circuit and short-circuit methods are considered as indirect methods. These methods are generally based on mathematical relationships. These methods also require that a PV panel should be prior evaluated, or they use database which is not applicable for all operating environmental conditions. Therefore, these methods generally fail to obtain the exact value of maximum power at any available values of cell temperature and irradiance. However, the direct methods are able to operate at any environmental condition.

The most common methods are described here:

A. Perturbation and Observation (P&O) Method / Hill Climbing (HC):

P&O is a widely used method to determine the MPP. This method increases or decreases the PV module operating voltage to perturb the system and its impact on the output power is observed. Fig. 4 describes the P&O .

The slope of the power–voltage curve decides the step size and is shown in Fig. 5. The slope is obtained using Eq.

$$\frac{dP}{dV_{pv}}(k) = \frac{P(k) - P(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \qquad (3)$$

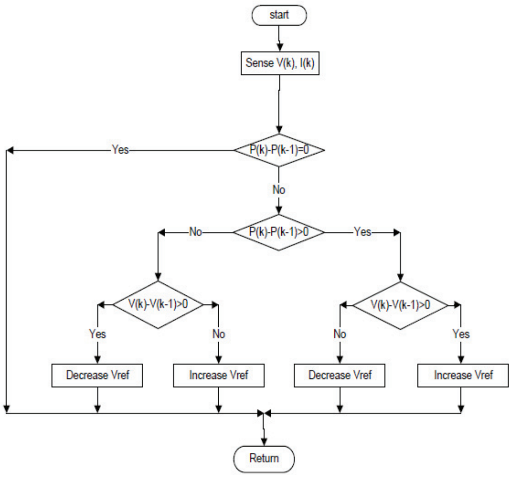

Fig. 4. Flowchart for P&O Algorithm [14]

where $dP/dV_{pv}(k)$ are actual derivatives of power and voltage
$P(k)$ and $P(k-1)$ are actual and previous power
$V_{pv}(k)$ and $V_{pv}(k-1)$ are actual and previous voltage
If $V < V_{mpp}$ the operating point shifts towards left and when $V > V_{mpp}$ the operating point shifts towards right of the curve shown in Fig. 5, where V_{mpp} is voltage at maximum power point.

B. Incremental Conductance (IC) Method:

In IC algorithm, the instantaneous and incremental conductance value is obtained and the PV array voltage is changed according to these values. The limitation of P&O method is that it fails to track the peak point variable if a system faces fast varying conditions. But this drawback is overcome in IC method because it rapidly tracks the control variable. From Fig. 5, the PV characteristic equation is represented as given in Eq. (4). At the MPP, the slope of the power curve of PV array is zero, whereas it is positive for the operation on the left side of MPP and negative for the operation on the right side of MPP.

$$\left.\begin{array}{ll} \dfrac{dP}{dV} = 0 & \text{at MPP} \\[2ex] \dfrac{dP}{dV} > 0 & \text{left of MPP} \\[2ex] \dfrac{dP}{dV} < 0 & \text{right of MPP} \end{array}\right\} \quad (4)$$

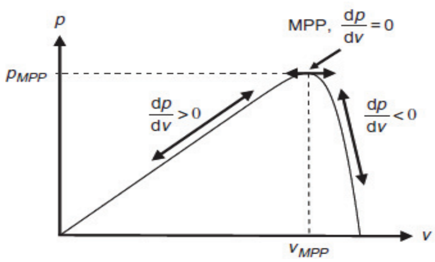

Fig. 5. Value of dP/dV at Different Positions on the P-V Characteristic [2]

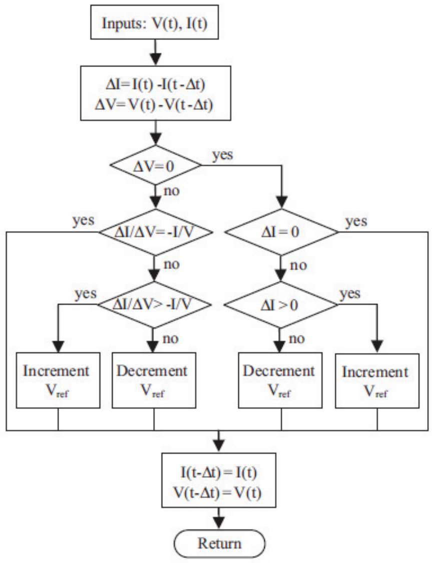

Fig. 6. Flowchart for Incremental Conductance [11]

Equation 4 can be expressed as,

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} = I + V\frac{\Delta I}{\Delta V} \quad (5)$$

After comparing (4) and (5), equation (4) can be rewritten as

$$\left.\begin{array}{ll} \dfrac{dI}{dV} = -\dfrac{I}{V} & \text{at MPP} \\[2ex] \dfrac{dI}{dV} > -\dfrac{I}{V} & \text{left of MPP} \\[2ex] \dfrac{dI}{dV} < -\dfrac{I}{V} & \text{right of MPP} \end{array}\right\} \quad (6)$$

The algorithm compares the immediate conductance (I/V) value with the Incremental Conductance ($\Delta I/\Delta V$) value and the operating point tracks MPP accordingly which is explained in Fig. 6.

C. Fuzzy Logic Control (FLC)based MPPT:

In a binary set, variable has only two states i.e. true or false value. But in a fuzzy logic it has a set of multiple values. Fuzzy logic variable lies in a range between zero and one. It is based on the concept of partial truth. In a partial truth, the variable value is between complete true value and complete false value. Membership functions are used for operating fuzzy logic controller. It is not based on a mathematical model. It consists of three stages. These are fuzzification, inference mechanism based on rule base table and defuzzification. In a fuzzification step, according to the chosen membership function, input variables are transformed into linguistics variables. Then these linguistics variables are manipulated using rule base in the inference stage. The behavior of the controller is decided by it. In the last stage i.e. defuzzification, the numerical variables are obtained from the linguistic variable

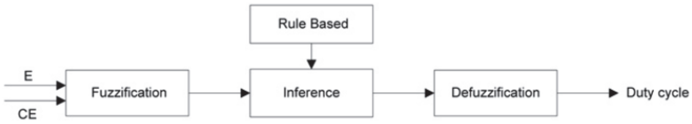

Fig. 7. Block diagram of FLC based MPPT [9]

using membership function. Two inputs are fed to FLC based MPPT and one output is obtained from it. [6][7][10]. Generally the inputs are taken as tracking error (E) and change in tracking error (ΔE), as given below,

$$E(n) = \frac{P(n) - P(n-1)}{V(n) - V(n-1)} \quad (7)$$

$$\Delta E(n) = E(n) - E(n-1) \quad (8)$$

for the sampling time n, immediate power P(n) of PV system and immediate voltage V(n).

The duty ratio is the final output variable which drives the converter. The fuzzy logic controller has advantages like fast convergence, works with in precise inputs and handles non linearity. However, as it is based on trial and error approach, it provides approximated outputs.

D. Neural Network (NN) based MPPT:

This technique is based on parameter approximations and it is generally used to solve more difficult problems. This technique has three layers. These are input layer, hidden layer, and output layer as shown in Fig. 8. The input layer has two neurons. These neurons are fed by the current and voltage variables from the PV system [4]. A duty cycle is obtained as a final output which drives the converters which are operated at the MPP or near to MPP. The input signals are propagated to the output layer in a hidden layer which is based on the transfer function applied on it. The hidden layers act to achieve the MPP.

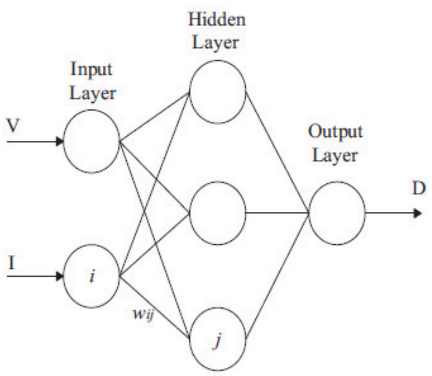

Fig. 8. Neural Network based MPPT [4]

IV. LIMITATIONS

Perturb and observe method generally fails to determine when it actually obtains the MPP and hence it shows oscillations around the MPP under steady state operation. Incremental conductance algorithm requires more computational time. Many of the algorithms are affected by the varying irradiance.

In any case if there is any shadow on any of the panels (as they are in series of parallel), then the power-voltage curve of the PV will have several peaks and it disturbs the operation of MPPT algorithm. Also they are affected by dust and hot spots on the solar panel.

These limitations are summarized as follows:

TABLE I: Limitations of MPPT Methods

MPPT Method	**Limitations**
P&O	• Oscillations around MPP • affected by partial shading • affected by dust and hot spot
Incremental Conductance	• More computational time • affected by partial shading • affected by dust and hot spot
FLC	• Effectiveness of a system depends on knowledge of user and choice of the correct error computation and rule base table which depends on the chosen membership functions. • affected by partial shading • affected by dust and hot spot
Neural Network	• affected by partial shading • affected by dust and hot spot

V. CONCLUSION

An extensive literature review on various MPPT algorithms is described in this paper. It also had an insight on pros and corns of these methods. Based on an exhaustive analysis of the existing work, it is found that there is tremendous scope of new analytical studies that can shed more light on MPPT under partial shading and dust effect. Also there is a possibility of hybrid implementation of solar tracker and MPPT system. The observations in the paper can be used as a guide by the researchers for using a suitable MPPT method for the PV system model.

REFERENCES

[1] Abdelsalam Ahmed K, Massoud Ahmed M, Shehab Ahmed, Enjeti Prasad N. “High-Performance Adaptive Perturb and Observe MPPT Technique for Photovoltaic-Based Microgrids.”, IEEE Transactions on Power Electronics, 2011; 26(4):1010–21.
[2] Abdul Rahman NH, Omar A M, Mat Saat E H., “A Modification of Variable Step Size INC MPPT in PV System.”, Proceedings of the IEEE 7th International Conference on Power Engineering and Optimization; 2013.p.340–345.

[3] Amelia MT, Moslehpourb S,Shamloa M. "Economical Load Distribution in Power Networks that include Hybrid Solar Power Plants." Electronic Power Systems Res 2008; 78(7):1147–52.

[4] Bahgat ABG, Helwa N H, Ahmad G E, El Shenawy E T. "MPPT Controller for PV Systems using Neural Networks." Renewable Energy, 2005; 30(8):1257–68.

[5] Dincer Furkan. "The Analysis on Photovoltaic Electricity Generation Status, Potential and Policies of The Leading Countries in Solar Energy." Renewable and Sustainable Energy Reviews 2011; 15(1):713–20.

[6] Esram Trishan, Chapman Patrick L., "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques.", IEEE Transactions on Energy Conversion 2007; 22 (2): 439–49.

[7] Kottas Theodoros L, Boutalis Yiannis S, Karlis Athanassios D. "New MPPT for PV Arrays using Fuzzy Controller in Close Cooperation with Fuzzy Cognitive Network.", IEEE Transaction on Energy Conversion, 2006;21(3):793–803.

[8] Mellit A, Rezzouk H, Messai A, Medjahed B. "FPGA based Real Time Implementation of MPPT Controller for Photovoltaic Systems." Renewable Energy 2011; 36(5):1652–61.

[9] Mohd Zainuri M A A, Mohd Radzi M A, Soh A C, Rahim N A. "Development of Adaptive Perturb and Observe Fuzzy Control Maximum Power Point Tracking for Photovoltaic Boost DC–DC Converter." IET Renewable Power Generation, 2013; 8 (2):183–94.

[10] N. Patcharaprakiti and S. Premrudeepreechacharn, "Maximum Power Point Tracking using Adaptive Fuzzy Logic Control for Grid-Connected Photovoltaic System," in Power Engineering Society Winter Meeting, 2002. IEEE, 2002, pp. 372-377 vol.1.

[11] Reisi A R, Moradi M H, Jamasb S. "Classification and Comparison of Maximum Power Point Tracking Techniques for Photovoltaic System: A Review." Renewable and Sustainable Energy Reviews 2013; 19:433–43.

[12] S. Saravanan, Ramesh Babu N., "Maximum Power Point Tracking Algorithms for Photovoltaic System – A Review", Renewable and Sustainable Energy Reviews 57(2016)192–204

[13] Saravanan S, Ramesh Babu N. "Incremental Conductance based MPPT for PV System using Boost and SEPIC Converter.", ARPNJ Engineering Applied Science 2015; 10(7): 2914–9.

[14] Saravanan S, Ramesh Babu N. "Performance Analysis of Boost and Cuk Converter in MPPT based PV System." Proceedings of the International Conference on Circuit, Power and Computer Technology; 2015.p.1–6.

[15] Shahriar Bazyari, Reza Keypour, Shahrokh Farhangi, Amir Ghaedi, Khashayar Bazyari, "A Study on the Effects of Solar Tracking Systems on the Performance of Photovoltaic Power Plants", Journal of Power and Energy Engineering, 2014, 2, 718-728.