Modelling and Simulation of MPPT Algorithms for PV Applications

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Abstract**—**This paper focuses on the mathematical modelling and simulation of Maximum Power Point algorithms to investigate tracking efficiency at different atmospheric conditions. This paper will review existing Maximum Power Point Tracking approaches. A 60W PV panel is modelled in MATLAB since panel current is taken as the input for maximum power point tracking. This paper presents a simulation-based comparative study between two most popular techniques perturb and observe (P&O) and incremental conductance (InCond) to optimize the energy conversion efficiency of PV system.

Keywords**—***Photovoltaic; Maximum PowerPoint Maximum; Maximum power point Tracking ; Perturb and Observe ;Incremental Conductance ;*

1. INTRODUCTION

Concerns over environmental effects such as e climate changes, global warming, depletion of fossil fuels and increase in fuel prices are making renewable energies more attractive. Among the various renewable energy sources, solar energy is a promising energy source as it is abundant, pollution free and noise free. The efficiency of commercially available solar cell is in the around 38-43% and solar system is around 25-29% [1].Hence it becomes necessary to use effective techniques in order to maximise energy conversion efficiency and thereby reduce the cost. A PV system converts solar energy into electrical energy by using PV effect. In a particular environment, there is only a maximum power point (MPP) due to the non-linear currentvoltage characteristics of PV systems. The MPP keeps changing accordingly with the solar irradiation levels and cell temperature. Moreover, the impedance mismatch between solar panel and the load may reduce the output power. In order to solve this, a DC-DC converter is used between solar panel and the battery. A maximum power tracking technique will be required to solve the impedance mismatch. This is done by ensuring that PV array operates at a single operating point where the current and voltage of the cell provides maximum power output, regardless of the variations in solar radiation levels and temperature. The paper is organized as follows: Maximum Power Point tracking is discussed in section II. A literature review about MPPT is presented in Section III. Section III discusses modelling of PV panel. Section IV illustrates MPPT techniques along with simulation results. Finally, the work is concluded in Section V.

2. MAXIMUM POWER POINT TRACKING (MPPT) CONTROLLER

The role of the MPPT is to match panel output power with load requirements. MPPT controller ensures that a PV module's operating point is maintained at the reference voltage that will produce maximum power for varying atmospheric conditions. The mechanism is based on the principle of impedance matching between source and load, for maximum power transfer between load and PV array at different operating points. The MPPT controller varies the ratio between voltage and current to match impedance of a solar array until the operating point provides maximum power for a given set of conditions. It also ensures a proper charging condition for the batteries and avoids any overcharging and discharging to improve the battery life.

3. REVIEW ON MPPT TECHNIQUES

A significant amount of research has been conducted to improve the efficiency of solar tracking systems. It is important to choose the most suitable MPPT based on factors like accuracy in predicting the true MPP, cost, convergence speed and sensitivity. This paper reviewed conventional techniques, stochastic-based algorithm and artificial intelligence techniques for partial shading conditions[4] .Due to the simple implementation and also fewer sensor requirements, Perturb and Observe (P&O) is most widely used[6]. The efficiency of Incremental conductance(InCond) is about the same as the P&O method but under partial shading condition, it is not able to track the global MPP[4-7].Other MPPT techniques such as Fractional Short Circuit Current(ISC), Fractional Open Circuit Voltage VOC), Current Sweep, Ripple Correlation Control (RCC), also discussed in[8-10].SimulateAnnealing(SA), Genetic Algorithm(GA), Fuzzy Logic controllers(FLC), Neural Network and Artificial Neural networks(ANN) are stochastic based and artificial intelligence methods developed to perform tracking at minimal oscillation around MPP[9-11]. FLCs have can work with imprecise inputs, without having accurate mathematical model. Based on literature review ANN can provide an accurate MPPT at a faster convergence speed [4-5].A comparative analysis is given in Table.1.

TABLE I. REVIEW OF MPPT TECHNIQUES

MPPT Techniques	Array dependent	Analog/Digital	Periodic Tuning	Sensed Parameter	Initial parameter requirement	Convergence speed	Complexity	Sensitivity	Ability to track true maxima
PO	No	Both	No	V	No	Varies	Low	Moderate	Yes
Inc	Yes	Digital	No	V,I	Yes	Varies	Medium	Moderate	Yes
VOC	Yes	Both	Yes	V	Yes	Medium	Low	low	No
ISC	Yes	Both	Yes	I	Yes	Medium	Medium	low	No
RCC	No	Analog	Yes	V,I	No	Fast	Low	Moderate	Yes
PSO	No	digital	no	V,I	Yes	Fast	low	High	Yes
FLC	No	Digital	Yes	V,I	Yes	Moderate/ Low	High	High	Yes
GA	No	Digital	No	V,I	Yes	Fast	High	High	Yes
Neural Network	No	Digital	Yes	Varies	Yes	Fast	High	Moderate	Yes
ANN	No	Digital	Yes	Varies	Yes	Fast	High	Moderate	Yes

4. MATHEMATICAL MODELLING OF PV ARRAY

As shown in Fig.1.,Array voltage and current is required by the Maximum power point tracker to track the MPP. A PV array needs to be modelled in order to estimate the PV array characteristics at different atmospheric conditions.

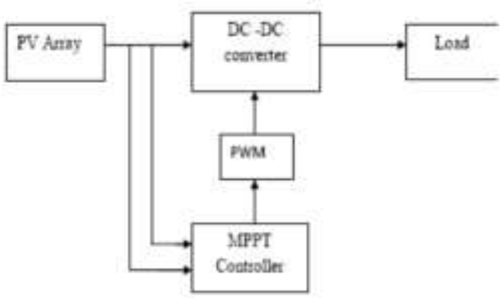

Fig.1.PV System

Modelling PV cell involves developing circuit behavior in terms of mathematical expressions using basic circuit equations. As shown in Fig.2,Practical Single Diode Model (SDM) takes into consideration the series resistance Rs, represents the internal losses due to the current flow and shunt resistance Rsh, in parallel with the diode. It accounts for the leakage current to the ground when diode is in reverse bias [2-3], and it can be neglected. The shunt resistance is too large compared with series resistance. In an ideal solar cell Rs =Rsh = 0, which is a common assumption. The output current from PV-module IPV is given as:

$$I_{pv} = I_{ph} - I_D \qquad (1)$$

Diode current I_D

$$I_D = I_o\left(e^{\frac{V}{n_s V_T}} - 1\right) \qquad (2)$$

$$V_T = \frac{nKT}{q} \qquad (3)$$

where Io is the module reverse saturation current, ns is number of cells in series, V is the panel voltage, VT is the thermal voltage equivalent to the diode factor (1 ≤ n ≤ 2), K is Boltzmann constant (1.3805 × 10-23 J/K), T is the module operating temperature in Kelvin and q is the electron charge(1.6 × 10-19 C).

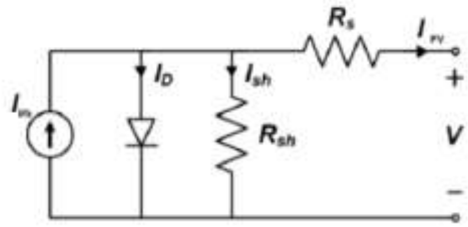

Fig.2.Single Diode Model (SDM) with R_s and R_{sh}

The analytical expression for the current in a PV cell according to the model is as follows:

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

Where I_{PV} is the current output of PV-Panel, R_S is series resistance and R_{sh} is shunt resistance. Panel photo-current I_{ph} is modelled as follows:

$$I_{ph} = \frac{[Iscr + Ki\ (T - T_r)]}{1000} \qquad (5)$$

Where Iscr is the module short-circuit current (1.1 A), Ki is the current temperature co-efficient (0.0017A / C) and T is the module operating temperature. Hence the panel saturation current Io is calculated as under:

$$I_o = I_{rs} \times \left(\frac{T}{T_r}\right)^{\frac{3}{n}} e^{\frac{qE_{g0}}{nKT}\left(\frac{1}{T} - \frac{1}{T_r}\right)} \qquad (6)$$

Where Ego is the silicon gap energy of semiconductor (1.1eV). The panel reverse saturation current Irs is as under:

$$I_{rs} = \frac{I_{scr}}{e^{\left(\frac{qV_{oc}}{nKT_r n_s}\right)} - 1} \qquad (7)$$

Where Voc is the open-circuit voltage and the value of series resistance can be estimated as under:

$$R_S = -\frac{dV}{dV_{oc}} - \frac{1}{X_V} \qquad (8)$$

Where $X_V = I_{rs}\frac{q}{nKT_r}e^{\left(\frac{qV_{oc}}{nKT_r}\right)}$ (9)

Short circuit I_{sc} is calculated as:

$$I_{sc} = I_{ph} - I_{rs}\left(e^{\frac{I_{sc}R_s}{n_s V_T}} - 1\right) - \frac{I_{sc}R_s}{R_{sh}} \qquad (10)$$

Current at maximum power point I_{mp} is shown in equation 11.

$$I_{mp} = I_{ph} - I_o\left(e^{\frac{V_{mp}+I_{mp}R_s}{n_s V_T}} - 1\right) - \frac{V_{mp}+I_{mp}R_s}{R_{sh}} \qquad (11)$$

Where Imp is maximum panel current, Vmp is the maximum panel voltage. A 60W PV panel is simulated for the specifications given in Table 2.

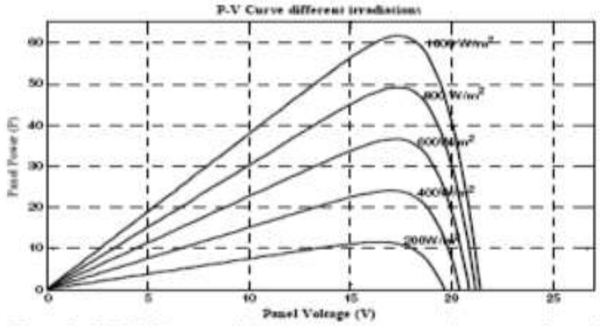

Fig .5. P-V Curve different solar irradiation levels

Table.2.PV panel specifications

Maximum Power P_m	60W
Voltage V_m	17.1V
Current I_m	3.5A
Short circuit current Isc	3.8A
Open-circuit voltage Voc	21.1V

A. Simulation results

The single diode model was used to simulate the 60W PV array using MATLAB Environment. Fig. 3& 4 shows that PV array output current and voltage increases with solar irradiation levels from 200 to 1000W/m2 and Fig. 5& 6 shows that an increase in ambient temperature causes a linear decrease of panel voltage and current.

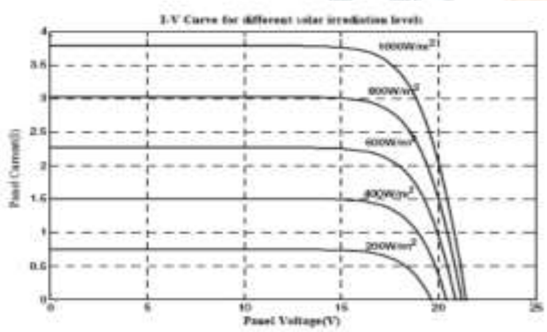

Fig .3. I-V Curve different solar irradiation levels

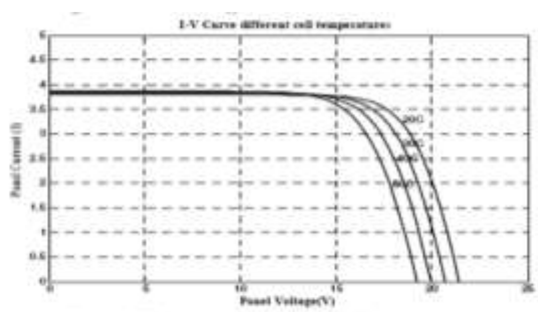

Fig.4. I-V Curve for different cell temperatures

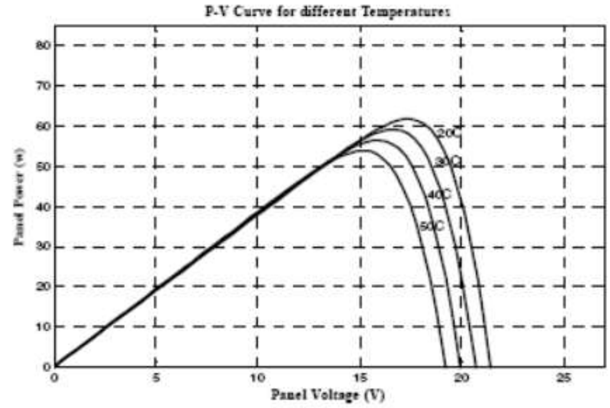

Fig .6. P-V Curve different cell temperatures

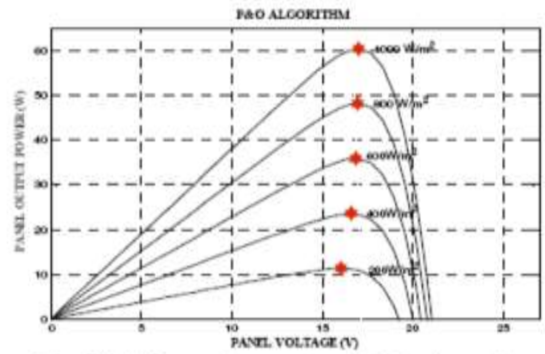

Fig.7 MPP tracking using P&O algorithm

5. MPPT TECHNIQUES

A. Perturb and Observe (P&O) method

Perturb and Observe is widely used MPPT algorithm because of its simplicity and low-cost in implementation. P&O perturb the operating voltage and power at one point and then it compares with previous value. It keeps on increasing or decreasing the voltage until it reaches the maximum output power where dP/dV = 0 as discussed in [6].

B. Incremental Conductance (InCond) Method

The incremental conductance algorithm is based on the slope of the P-V curve. The slope will become zero at MPP, increases on the left side of Maximum power point(MPP) curve and decreases on the right side of the MPP as discussed in [7]. The basic equations of this method are as follows.

$$\frac{dI}{dV} = -I\,V \quad \text{At MPP}$$

$$\frac{dI}{dV} > -I\,V \quad \text{Left of MPP}$$

$$\frac{dI}{dV} < -I\,V \quad \text{Right of MPP}$$

C. Results and discussions

The simulation results illustrated in Figs. 7& 8 shows the performance and effectiveness of P &O and InCond algorithms in tracking the maximum power point. The tracking efficiency of P&O is obtained as 96.9% and InCond is 100%. Cell temperature was chosen 250C and irradiation levels were varied from 200 to 1000W/m2 with a variable step size of 0.1 for InCond algorithm.

6. CONCLUSION

There are number of research groups actively involved in developing techniques to optimize energy conversion efficiency of PV systems. Based on the literature review, it can be concluded that the conventional MPPT algorithms will provide maximum power output under uniform solar irradiance. But during rapidly changing atmospheric conditions these algorithms will fail to provide MPP.This can be resolved by using stochastic and artificial intelligence based MPPT techniques. This paper also presents simulation based comparative study between perturb and observe (P&O) and incremental conductance (InCond). Results show that InCond algorithm with varying step size can track MPP accurately in terms of tracking efficiency. Future work will involve optimizing the energy conversion efficiency of PV system using GA and SA optimized Artificial Neural Networks.

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