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A Survey on Maximum Power Point Tracking Methods in Photovoltaic Power Systems

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Abstract

One of the most important issues associated with photovoltaic systems is receiving maximum power and tracking maximum power point. Hence, researchers have proposed numerous methods in recent years. The first step toward selecting a useful method is recognizing algorithms, methodology and advantages of each method. In this study MPPT methods are deeply investigated. For this purpose, first off, equations governing photovoltaic systems are explicated. Then, nonlinear behavior of photovoltaic cells is demonstrated by simulation. Finally, different methods of MPPT and their advantages are mentioned.

Keywords*: photovoltaic- tracking - maximum power- MPPT*

1. Introduction

One of the approaches to extracting solar energy is direct conversion of its light to electricity which is called photovoltaic. In this method where light beams are directly converted to electricity, electrons and holes follow in a semiconductor [1, 2, 3].

Different factors affect increase or decrease of generated voltage and current. As it is important to understand effective factors, various studies have been conducted on this field.

I-V characteristic of a photovoltaic cell is nonlinear as a result of nonlinear curve of semiconductor materials [4]. It means that a photovoltaic cell may locate on each point of its P-V curve. Operating point of photovoltaic cell definitely has a direct relationship with incident level and panel temperature. Since the diode characteristic is nonlinear some adjustments must be done to maintain operating point of the system on P_{mp}(maximum power).

On the other hand, due to various limitations such as cost and short efficiency time of systems finding an algorithm which constantly provides maximum power for consumers is essential. In this study methods introduced for finding and tracking P_{mp} point are investigated.

2. Investigating Photovoltaic Cells Models and Curves

Recently, researchers have proposed various models for simulation and modeling of photovoltaic systems. It is valuable effort as it may lead us to real model. In this study, single diode model is employed as it is simpler and close to actual model. Figure 1 depicts single diode model of a photovoltaic cell.

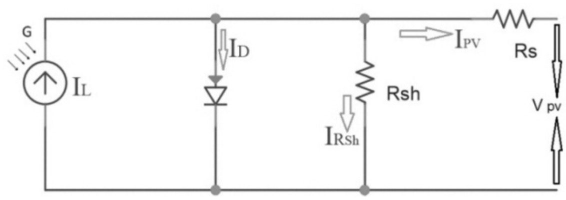

Figure 1. Circuit model of a photovoltaic cell [4]

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In this model $I_l$is the current generated by the cell and R_{sh}models current loss in the cell. I_{Pv}And V_{pv}model output current and voltage of the cell, respectively. Equations 1-5 might be utilized to simulate a photovoltaic cell [5, 6, 7, 8].

$$I_l = \frac{G}{G_n}(I_{scn} + K_i(T - T_n) \quad (1)$$

$$I_{Rsh} = \frac{V_{pv}+R_S I_{Pv}}{R_{sh}} \quad (2)$$

$$I_D = I_s\left(e^{\frac{V_{pv}+R_S \times I_{pv}}{nKT/q}} - 1\right) \quad (3)$$

$$I_{pv} = I_l - I_D - I_{Rsh} \quad (4)$$

$$I_o = \frac{I_{scn}+K_i(T-T_n)}{exp((V_{ocn}+K_v(T-T_n)/nV_t)-1)} \quad (5)$$

The parameters exploited in equations 1-5 are presented in table 1.

Table I. Variables used in equations 1-5

Variable	definition
I_{PV}	system output current
R_{sh}	shunt resistance modeling current loss
R_s	series resistance
V_{PV}	output voltage of the system
G	solar incident
G_n	reference incident level
K_i	thermal coefficient of short circuit current
K_v	thermal coefficient of open circuit voltage
n	ideality factor
I_{scn}	short-circuit current in T_n and G_n condition
V_{ocn}	open circuit voltage in T_n and G_n condition
I_o	reverse situation current
V_t	thermal voltage of the junction
T	current temperature of the cell
T_n	reference temperature of the cell
I_L	current generated by light

Simulating equations 1-5 in SIMULINK- MATLAB results in diagrams shown in figures 2 and 3. Figure 3 illustrates that increase in incident increases P_{mp}. Furthermore, figures 2 and 3 demonstrate nonlinear behavior of photovoltaic cells. This nonlinearity threatens utilization and constant use of maximum power as well as system performance in different weather conditions.

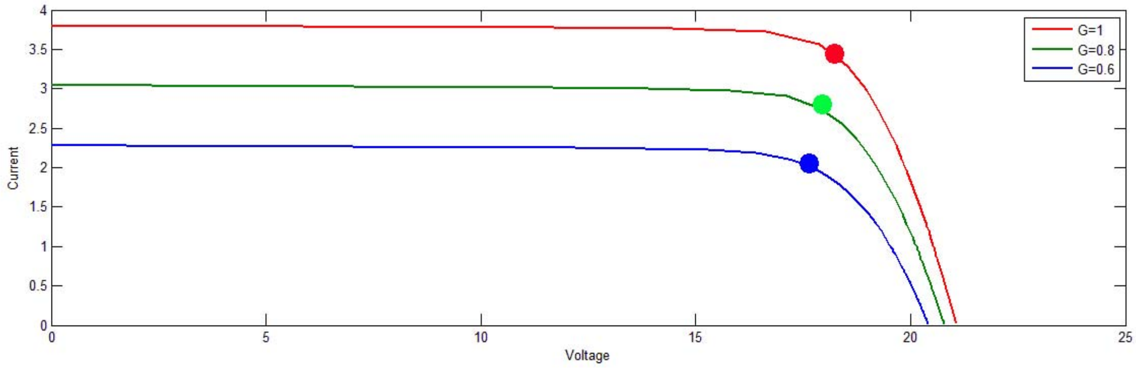

Figure 2. I-V characteristic constant temperature, 25 Celsius degrees and variable incident

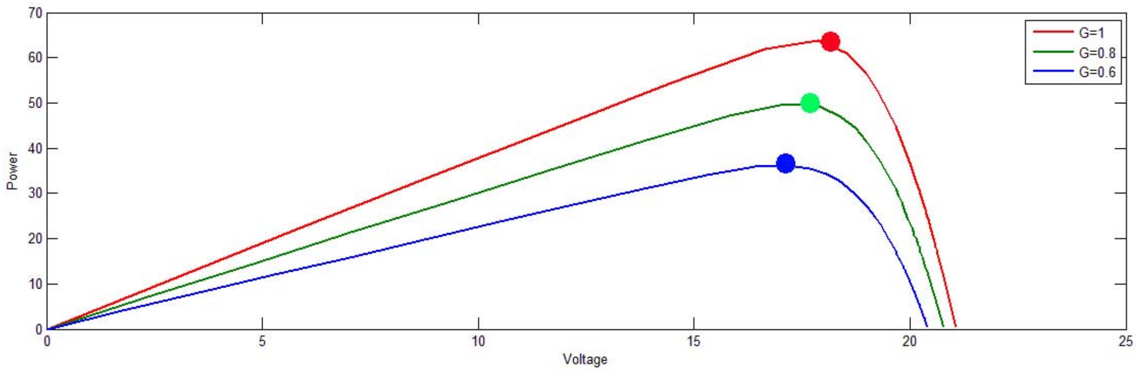

Figure 3. P-V characteristic in constant temperature, 25 Celsius and variable incident

Figure 3 demonstrates wide change in power curve for incident variations. Optimum maximum power condition in the above diagrams is the peak of the diagram; thus, an algorithm must be designed so that operating point is maintained on the peak power point while incident and, in turn, characteristic are changing.

3. Methods for Maximum Power Point Tracking

According to figures 2 and 3 it might be seen that maximum power point considerably changes when incident level changes. During the day time many factors may affect incident. As mentioned before it is really crucial and adversely affects efficiency and performance of the system. In the following different MPPT methods are explicated.

3.1. Perturb and Observation Method

It is one of the simplest and most popular MPPT methods. In this method firstly, current value of cell operating voltage is read in the form of its equivalent power from the diagram. Afterwards, voltage is perturbed (voltage is slightly changed by the algorithm) and power is read again. Now if ΔP is positive, operator moves the voltage toward the maximum point using step value (c); whereas, if ΔP is negative the operation is reversed till the maximum power point is obtained [9, 10, 11, 12, 13, 14, 15]. The flow chart of this algorithm is depicted in figure 4.

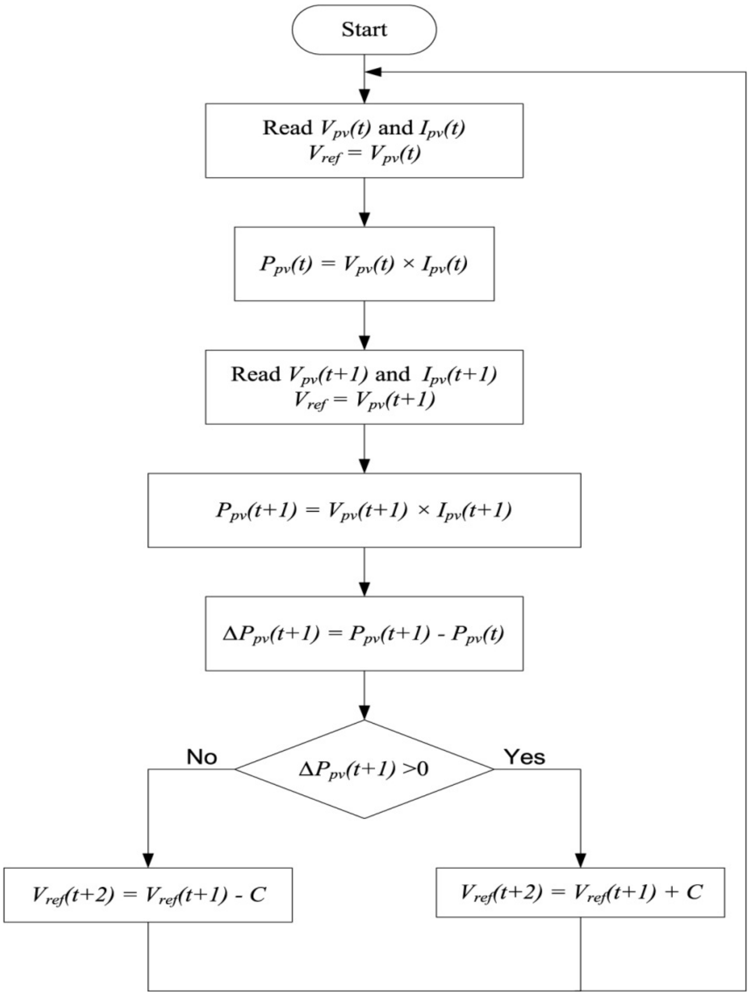

Figure 4. The algorithm of perturb and observe method

3.2. Incremental Conductance Method

Incremental conductance method is another approach to MPPT. It is mainly used in space industry and conditions where high precision is needed. In this method the sign of $\frac{dP}{dV}$is exploited for tracking maximum power point [16-17-18]. Equations 6, 7 and 8 might be concluded.

$$dP/dV = 0 \text{atmpp} \tag{6}$$

$$dP/dV > 0 \text{left of mpp} \tag{7}$$

$$dP/dV < 0 \quad \text{Right of mpp} \tag{8}$$

Moreover form I-V and P-V characteristics we have:

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong V\frac{\Delta I}{\Delta V} \tag{9}$$

Therefore, the following equations might be interpreted using I-V characteristic:

$$\left(\frac{\Delta I}{\Delta V}\right) = -I/V \;\; at\; mpp \tag{10}$$

$$\left(\frac{\Delta I}{\Delta V}\right) > -I/V \ left\ of\ mpp \quad (11)$$

$$\left(\frac{\Delta I}{\Delta V}\right) < -I/V \ Right\ of\ mpp \quad (12)$$

Figure 5, illustrates incremental conductance method. Its complexity and sensitivity to noise might be mentioned as its problems; however, it is more precise than perturb and observe method. It is also an expensive method.

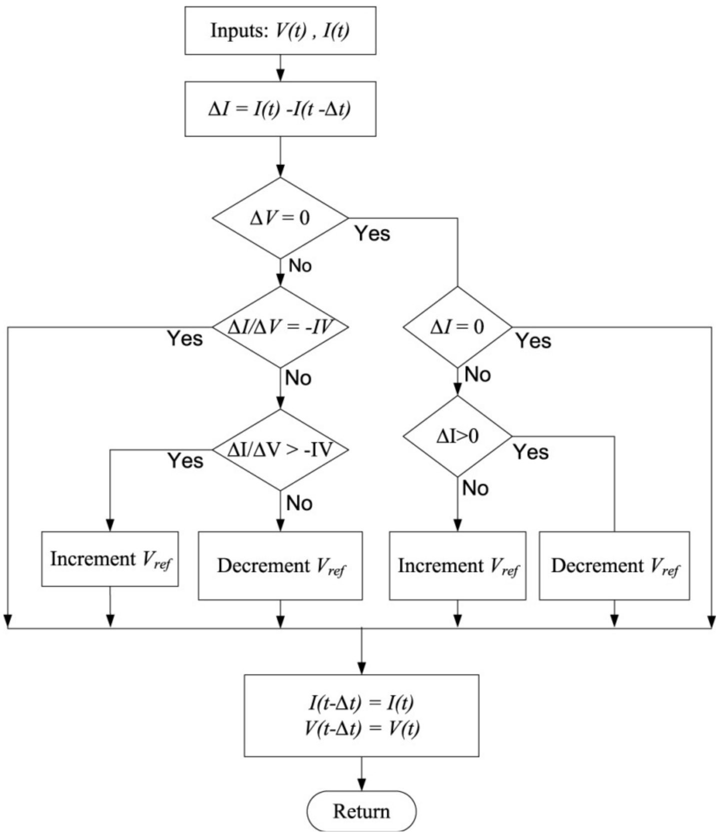

Figure 5. Incremental conductance algorithm

3.3. Current Sweep Method

In this method current fluctuations are utilized to track maximum power point. In the I-V diagram P_{mp} is in the knee point which has the maximum variation in current. In this algorithm the point where current has maximum variation is considered. Considering current fluctuations around P_{mp} in I-V.

3.4. Open Circuit Voltage and Short-Circuit Current Method

A simple method for tracking maximum power point is using open circuit voltage and short-circuit current method [19, 20, 21, 22]. It is usually used in the islanded systems. In this method an approximately linear relation is found between open-circuit voltage and short-circuit current in the maximum power point.

$$V_{mp} \approx KV_{oc} \quad (13)$$

Where K is a number between 0.7 and 0.8. It is determined according to characteristics of materials constituting photovoltaic panel. Furthermore, the relationship between short-circuit current and maximum power current (I_{mp}) might be derived.

$$I_{mp} \approx KI_{sc} \quad (14)$$

Where K is a number between 0.8 and 0.9 Current linearization method is more accurate than voltage linearization; however, it imposes more implementation cost. Using linearization by the aforementioned methods optimization might be done and maximum power point could be tracked. Although it is a simple method, its less precise comparing to other methods.

4. Conclusion

Considering global attention toward solar energy, its problems must be overcome to obtain maximum efficiency in solar systems. In this study, firstly a model of photovoltaic cells was presented. Then, the governing equations were explained. The nonlinearity of I-V and P-V characteristics was shown by simulating equations in SIMULINK. The nonlinearity necessitates positioning of operating point onP_{mp}. Then, a few methods for maximum power point tracking were investigated. An appropriate method must be selected according to required precision. Each method has pros and cons and one of them cannot be introduced as a generic solution for all circumstances. The designer must select the best solution considering the required precision and allowable cost. This paper might be a good resource for researchers which are dealing with MPPT methods. As future work, the optimization of mentioned methods might be investigated.

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