A Rapid MPPT Algorithm Based on the Research of Solar Cell’s Diode Factor and Reverse Saturation Current

Liu Li-qun  
Department of Electrical Engineering, 
Shanghai Jiaotong University,  
Shanghai, 200240, China; 
Department of electronic and information, 
Taiyuan University of Science & Technology, 
Taiyuan 030024, Shanxi Province, China  
Email: llqd2004@163.com

Wang Zhi-xin  
Department of Electrical Engineering, 
Shanghai Jiaotong University,  
Shanghai, 200240, China; 
wangzxin@sjtu.edu.cn

Abstract: - An efficient Maximum Power Point Tracking (MPPT) algorithm is important to increase the output efficiency of a photovoltaic (PV) generate system. The conventional method have some problems in that it is impossible to quickly acquire the generation power at the maximum power (MP) point, i.e., the efficiency of electric power generation is very low, and the amount of electric power generated by solar cell is always changing with weather conditions. Normally, the different solar cells have different diode factor (n) and reverse saturation current (Io). Theoretical and simulative results show that the approximately linear relationship exists between the optimal output current and the short-circuit current, and if the weather conditions are sameness, a piece of solar cell have same photocurrent under different diode factor n and reverse saturation current Io conditions. A new combined perturb and observe (PO) method is described in order to acquire the actual diode factor and reverse saturation current. This paper describes a rapid maximum power point tracking method which is based on the actual n and Io. An expiatory program is applied to acquire the actual maximum power point. The correctness and validity of expiatory coefficients is verified through simulation. The simulation results verified the correctness and validity of MPPT algorithm.

Key-Words: - Maximum Power Point Tracking (MPPT), Renewable energy, Photovoltaic (PV) system, Diode factor, Reverse saturation current, Photocurrent

1 Introduction

Renewable energy sources, such as solar, wind, biomass, etc., are desirable for electrical power generate due to their unlimited existence and environmental friendly nature [1]. PV technology has been developed rapidly over the last two decades from a small-scale, specialist industry supplying the U.S. space program to a broadly based global activity [2]. Studies on PV generate systems are actively being promoted in order to mitigate environmental issues such as the green house effect and air pollution [3-4]. In developing nations, the PV generate system is expected to play an important role in total electrical energy demand, and solar photovoltaic energy has gained a lot of attention because it is renewable, friendly to the environment, and flexible for installation. And more and more specialist of China realized the fundamentality of PV generate systems. A photovoltaic generate system consists of a number of solar cells depending on the required power, voltage and current ratings, and the solar cell price is decreasing. But a photovoltaic generate system still requires expensive initial investments. In order to extract as much energy as possible from a PV system, it is important to have an efficient Maximum Power Point Tracking algorithm.

Many MPPT algorithms and control schemes of PV generate system have been proposed in the literature [1-10], i.e., a cost-effective single-stage control scheme is proposed in the literature[1], it proposes a cost-effective single-stage inverter with maximum power point tracking (MPPT) in combination with one-cycle control (OCC) for photovoltaic power generation. A comparative study of the maximum power point trackers using a switching-frequency modulation scheme (SFMS) for photovoltaic panels is presented [2]. Method of locating the maximum power point (MPP) is based on injecting a small-signal sinusoidal perturbation.
into the switching frequency of the converter and comparing the ac component and the average value of the panel’s terminal voltage. The linearity method is a novel method in order to track the maximum power point [3-4], the proportionality coefficient of the prediction line is automatically corrected using the hill-climbing method when the panel temperature of the solar arrays is changed. The incremental conductance (IC) method is proposed in the literature [5], which is based on the Incremental Conductance method but does not require any current sensing devices. The perturbation and observation (PO) method is well known as the hill-climbing method, it has been widely used because of its simple feedback structure and fewer measured parameters. A digital hill-climbing control strategy combined with a bidirectional current mode power cell is presented which allows getting a regulated bus voltage topology [6]. A simple method which combines a discrete time control and a PI compensator is proposed [7], the object of this paper is to investigate the maximum power tracking algorithms which were often used to compare the tracking efficiencies for the system operating under different controls. The constant voltage (CV) and perturbation and observation (PO) method are very common, a cost-effective two-method MPPT control scheme is proposed in this paper to track the maximum power point (MPP) at both low and high irradiation, by combining a Constant Voltage (CV) method and a modified PO algorithm [8]. The fuzzy methods are described in the literature [9-12] that focus on the nonlinear characteristics of solar cell. A power management system is presented [13], which allows for maximum exploitation of the solar energy. Although, various methods of MPPT control have been proposed in existing literature, but the power generate efficiency is relative low, and the amount of electric power generated by solar arrays is always changing with weather conditions. Different solar panel have different diode factor (n) and reverse saturation current (Io). So they are impossible to quickly acquire the generate power at the maximum power point (MPP). The essential reason is the unknown values of n and Io. The theoretical and simulative results show that not only the optimal output current and short-circuit current have an approximate linear relationship at a constant temperature. But also if the weather conditions are sameness, a piece of solar cell have same photocurrent under different diode factor n and reverse saturation current Io conditions. The conclusion is very important to acquire the actual diode factor and reverse saturation current.

In this paper, first, theoretical and simulative results show that a piece of solar cell have same photocurrent under different diode factor n and reverse saturation current Io conditions, and a novel combined perturb and observe (PO) method is described in order to acquire the actual n and Io. Next, the approximately linear relationship exists between the optimal output current and the short-circuit current is described. Finally, an expiatory program is applied to acquire the actual maximum power point, and a rapid maximum power point tracking method is described which is based on the actual n and Io. The simulative results verified the correctness and validity of MPPT algorithm.

2 Principle analyzing and modeling of solar cell

2.1 Solar cell modeling

Various modelling of solar cell have been proposed in the literature [3-10]. The output current I and output voltage V of solar cell is given by (1) and (2) using the symbols in Fig. 1, i.e.,

\[
I = I_{ph} - I_d - V_d / R_{sh} \tag{1}
\]

\[
V = V_d - R_s I \tag{2}
\]

\[
I_d = I_0 \exp \left( \frac{q V_d}{n k T} \right) - 1 \tag{3}
\]

here \( I_{ph} \) is the photocurrent (in amperes), \( I_0 \) is the reverse saturation current (in amperes), \( I_d \) is the average current through diode (in amperes), \( n \) is the diode factor, \( q \) is the electron charge (in coulombs), \( k = 1.6 \times 10^{-19} \text{C} \), \( k \) is Boltzmann’s constant (in joules per Kelvin), \( k = 1.38 \times 10^{-23} \text{J/K} \), and T is the solar arrays panel temperature (in Kelvin). \( R_s \) is the intrinsic series resistance of the solar cell. Normally, the value of \( R_s \) is very small (in milliohm). \( R_{sh} \) is the equivalent shunt resistance of the solar array, and the value is very large (in kilo-ohm). In general, the output current of solar cell is expressed by
(11) is expressed by (9) and are the instantaneous output power.

Here and are the maximum output power and optimal output voltage at the time, respectively.

(15) is the maximum output current is expressed by (12) as a function of the optimal output voltage Voc.

Various parameters affect the output power, i.e., two intrinsic resistances, the temperature, the irradiation, the diode factor and the reverse saturation current. Firstly, Rs is very small (mΩ), and Rsh is very large (in kilo-ohm). The effect of two intrinsic resistances is ignored under ideal condition. The values of two intrinsic resistances are the unknown constants. Secondly, the important factors are temperature and irradiation. The short-circuit current Isc and the open-circuit voltage Voc of solar cell are always changing with the temperature and irradiation. If the temperature is changeable, the changing coefficient Kt of Voc is (-0.37 - 0.4%) C at solar panel temperature 25°C, the changing coefficient Kt of Isc is (+0.09 + 0.1%) C at solar panel temperature 25°C, where, Tt are 25°C (in Kelvin). If the irradiation is changeable, the short-circuit current Isc is expressed by using (11) at a temperature 25°C. Here Isc(25°C,1KW/m²) is the short-circuit current at solar panel temperature 25°C, and the irradiation is 1KW/m². The relationship exists between short-circuit current Isc and output cell Voc by using (8).

(14) is the irradiation changing coefficient Co of Voc at solar panel temperature 25°C, where, Co is the optical constant. Although different solar cells have different n and Io, a piece of solar cell’s n and Io are the unknown constant. Normally, n exists between 40 and 110, and the Io exists between 0.2 μA and 500 μA.

If the value of n and Io are known, the method is easy to acquire a piece of solar cell’s maximum output power. The effect of n and Io are analysed in this paper. The irradiation S is expressed by (14) as a function of Iph. The optimal maximum output power is given by (15) as a function of the optimal output voltage Vmpp using circuit parameters q, n, k, T.

2.2 Relationship of n, Io and Iph
For example, the open-circuit voltage $V_{oc}$ and short-circuit current $I_{sc}$, which were measured at irradiation $1\text{KW/m}^2$ and temperature $25^\circ C$, are $22\text{V}$ and $3.8\text{A}$, respectively. The changing coefficient $K_i$ of $I_{sc}$ and the changing coefficient $K_{v}$ of $V_{oc}$ were measured, are $0.001$ and $-0.004$, respectively. Fig. 2 shows $P$–$I$ characteristics and $P_{\text{max}}$ curve of solar cell, the data are calculated by using above values under the same $n$ and different $I_0$ conditions. Fig. 2 (a) shows the maximum power curve at same irradiation and different temperature, Fig. 2 (b) shows the maximum power curve at same temperature and different irradiation.

If the irradiation is $800\text{W/m}^2$, and the temperature is changing from $50^\circ C$ to $75^\circ C$, under same diode factor $n$ and different reverse saturation current $I_0$ conditions, Fig. 2 (a) shows that the photocurrent $I_{ph}$ is same under same temperature conditions, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$. If the temperature is $25^\circ C$, and the irradiation is changing from $100\text{W/m}^2$ to $1\text{KW/m}^2$, under same diode factor $n$ and different reverse saturation current $I_0$ conditions, Fig. 2 (b) shows that the photocurrent $I_{ph}$ is same under same irradiation conditions, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$.

If the irradiation is $800\text{W/m}^2$, and the temperature is changing from $50^\circ C$ to $75^\circ C$, Fig. 2 shows the photocurrent $I_{ph}$ is same under different temperature conditions, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$. If the temperature is $25^\circ C$, and the irradiation is changing from $100\text{W/m}^2$ to $1\text{KW/m}^2$, under same diode factor $n$ and different reverse saturation current $I_0$ conditions, Fig. 2 (b) shows that the photocurrent $I_{ph}$ is same at same irradiation, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$.

If the irradiation is $800\text{W/m}^2$, and the temperature is changing from $50^\circ C$ to $75^\circ C$, Fig. 2 shows the photocurrent $I_{ph}$ is same under different temperature conditions, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$. If the temperature is $25^\circ C$, and the irradiation is changing from $100\text{W/m}^2$ to $1\text{KW/m}^2$, under same diode factor $n$ and different reverse saturation current $I_0$ conditions, Fig. 2 (b) shows that the photocurrent $I_{ph}$ is same at same irradiation, and the output power is increasing with the $I_0$ decreasing from $500\ \mu\text{A}$ to $0.2\ \mu\text{A}$.
Fig. 3 Calculated P-I characteristics and $P_{\text{max}}$ curve under the different n and same Io conditions. (a) The irradiation $S$ is $600 W/m^2$, and the temperature is changing from $-50^\circ C$ to $75^\circ C$. (b) The irradiation is changing from $100 W/m^2$ to $1KW/m^2$ at temperature $35^\circ C$.

If the weather conditions are same, Fig. 4 shows that the output photocurrent $I_{ph}$ is same under different diode factor n and different reverse saturation current Io conditions. If the irradiation is $600 W/m^2$, and the temperature is increasing from $-50^\circ C$ to $75^\circ C$, Fig. 4 (a) shows that the photocurrent $I_{ph}$ is same under different diode factor n and different reverse saturation current Io conditions. If the temperature is $45^\circ C$, and the irradiation is increasing from $100 W/m^2$ to $1KW/m^2$, Fig. 4 (b) shows that the photocurrent $I_{ph}$ is same under different diode factor n and different reverse saturation current Io conditions.

A conclusion is gained in this paper. If the weather conditions are same, a piece of solar cell’s output photocurrent $I_{ph}$ is same under different diode factor n and different reverse saturation current Io conditions. The conclusion is very important to acquire the maximum power point of PV system. Based on the conclusion, a novel method was presented to acquire the actual diode factor and reverse saturation current.

2.3 Acquire the actual n and Io

In this case, firstly, the diode factor n and reverse saturation current Io were supposed, are 40 and $500 \mu A$, respectively. The output voltage $V$, the output current $I$ and temperature $T$ of the solar panel, which were detected by using sensors, are the voltage sensor, current sensor and temperature sensor, respectively. The photocurrent $I_{ph}$ is given by using (5), and the assumptive maximum power point was acquired. Fig. 5 shows the assumptive maximum power point A of solar cell by using the assumptive n and Io under steady weather conditions. Secondly, Fig. 5 shows the actual maximum power point B by using Perturb and Observe method under same weather conditions. The actual optimal output current $I_{mppt}$ and optimal output voltage $V_{mppt}$ is gained by using sensors. As shown in Fig. 5, the photocurrent $I_{ph}$ is
same under same weather conditions. Finally, the diode factor n is supposed minimum and the reverse saturation current Io is supposed maximum. The actual maximum power is more than the assumptive maximum power. Based on above conclusion, the diode factor n should increase and the reverse saturation current Io should decrease in order to acquire the actual n and Io. Based on the increasing diode factor n and the decreasing reverse saturation current Io, the photocurrent Ip and actual optimal output voltage Vmppt is used to calculate the assumptive optimal output current Imppt using (5). Then, the difference between the actual optimal output current and assumptive optimal output current is \( \Delta I = I_{mppt} - I_{ptt} \). If the \( \Delta I = 0 \), the diode factor n and reverse saturation current Io are actual value. Thus, the actual value of n and Io was saved, and PO method is stopped.

![Graph showing calculated values](image)

**Fig. 5** Calculated the actual diode factor n and reverse saturation current Io by using the combined perturb and observe (PO) method.

Next, the process cited above is concretely explained by examples with number obtained based on Fig.5. First, the output voltage and output current were measured at time n1, are 7.0573V and 2.1812A, respectively. In this case, the generated power \( P(n1) \) is 15.3934W. The temperature T of solar penal is 25°C at time n1. Then, the diode factor n and reverse saturation current Io were supposed, are 40 and 500μA, respectively. The photocurrent Ip = 2.66A is gained by using (5). The irradiation S is 700W/m² by using (14). The temperature and irradiation are steady at enough long time. The calculated optimal output current and optimal output voltage were gained, are 2.3089A and 6.7400V, respectively. The calculated optimal output power \( P_{max}(n1) \) is 15.562W. Second, the PO method is utilized to acquire the actual maximum power point under same weather conditions. The actual optimal output current \( I_{mppt}(n1) \) and optimal output voltage \( V_{mppt}(n1) \) were measured, are 2.396A and 11.24V, respectively. Thus, the maximum output power \( P_{max}(n1) \) is 26.9310W, and \( (P_{max}(n1) > P_{max}(n1)) \). Based on above conclusion, in order to acquire the actual n and Io of a piece of solar cell it is obligatory to increase the diode factor n and decrease the reverse saturation current Io. In this case, the actual output optimal voltage \( V_{mppt}(n1) \) and photocurrent Ip were used to calculate the assumptive optimal output current Imppt by using (5). Then, the difference \( \Delta I \) between the actual optimal output current and assumptive optimal output current is calculated. If \( \Delta I = 0 \), the actual value of the diode factor n and reverse saturation current Io is gained, are 48.2 and 30.3e-6, respectively. The values of actual n and Io were saved.

### 3 The proposed MPPT algorithms

For instance, in the case of solar cell, \( V_{oc}, Isc, Rs, Rsh, K_i, K_v, n, \) and \( Io \) at irradiation 1K/m² and temperature 25°C, are 22V, 3.8A, 8mΩ, 10KΩ, 0.001, -0.004, 60 and 10×10⁻⁶A, respectively. Fig. 6 shows \( V-I \) characteristics and \( P_{max} \) curve of solar cell are calculated using above values. Fig. 6 (a) shows the maximum power curve at different temperature and same irradiation 600W/m², Fig. 6 (b) shows the maximum power curve at same temperature 25°C and different irradiation. It is confirmed through calculating results shown in Fig. 6 that a proportional relationship between the short-circuit current and the optimal output current have been proposed in the literature [3], [4]. The proportionality coefficient using \( K_x \), \( K_x \) is \( I_{mppt(n1)}/Iscc(n1) \), which is the coefficient of the optimum output current and the short-circuit current at the time. Normally, it exists between 0.9 and 0.95. The simulative and calculated results verified that an error exists between the maximum power curve and the power curve at \( K_x = 0.9 \sim 0.95 \). Based on the simulative conclusion, if the irradiation \( S \) is more than 150W/m², the coefficient \( K_x \) exists between 0.87 and 0.95 under different n and different Io. The irradiation \( S \) is less than 150W/m², the coefficient bound is different. Normally, it exists between 0.8 and 0.87 under different n and different Io.
For instance, the diode factor $n$ and the reverse saturation current $I_0$ were supposed, are 40 and 500 $\mu A$, respectively. Other factors are same. Fig. 7 (a) shows the $P-I$ characteristics, and draws a comparison between the $P_{max}$ curve and the $P_{max'}$ curve at $K_x=0.9$ and $K_x=0.95$ under same irradiation $1KW/m^2$ and various temperatures. Fig. 7 (b) shows the $P-I$ characteristics, and draws a comparison between the $P_{max}$ curve and the $P_{max'}$ curve at $K_x=0.9$ and $K_x=0.95$ under same temperature $25^\circ C$ and various irradiation conditions. As shown in Fig. 7, the bound of coefficient $K_x$ is not very accurate in the literature [3], [4].

Base on above conclusion, a proposed MPPT algorithm is described. If the diode factor $n$ and the reverse saturation current $I_0$ are known quantities by using the combined perturb and observe (PO) method. The effect of the temperature, the irradiation, the diode factor and the reverse saturation current must be considered in order to acquire the maximum power point.

Fig.6 Calculated V-I characteristics and $P_{max}$ curve. (a) If the irradiation is $600W/m^2$, and the temperature is changed from $-25^\circ C$ to $75^\circ C$. (b) If the irradiation is changed from $50W/m^2$ to $1KW/m^2$ at temperature $25^\circ C$.

Fig.7 Draw a comparison between $P_{max}$ curve and $P_{max'}$ curve at $K_x=0.9$ and $K_x=0.95$. (a) If the irradiation is $1000W/m^2$, the temperature is changing from $-50^\circ C$ to $75^\circ C$. (b) If the irradiation is changing from $50W/m^2$ to $1KW/m^2$ at temperature $25^\circ C$.

The diode factor $n$, the reverse saturation current $I_0$ and the coefficient $K_x$ were supposed, are 60, $0.25\mu A$ and 0.87, respectively. The $P_{max}$ curve, $P-I$ characteristic, and calculating $P_{max'}$curve at irradiation $800W/m^2$ and different temperature show in Fig. 8 (a). The error between $P_{max}$ and $P_{max'}$'s is big as Fig.8 (a) shows. Fig. 8 (b) shows that $P-I$ characteristics, $P_{max}$ curve and the calculatingly $P_{max'}$ curve at the temperature $25^\circ C$ and different irradiation. The error between $P_{max}$ and $P_{max'}$ is big as Fig.8 (b) shows. Theoretical and simulation results show that the effect of temperature and irradiation must be considered. The reverse saturation current $I_0$ has an important effect in order to acquire the actual $K_x$. The effect of diode factor $n$ is very small. In order to
acquire the actual $K_x$, the expiatory of the temperature, irradiation and reverse saturation current $I_o$ are necessary.

Fig.8 Draw a comparison between $P_{max}$ curve and $P_{max'}$ curve. (a) Under same irradiation conditions, the temperature is changing from $25^\circ C$ to $75^\circ C$. (b) Under same temperature conditions, the irradiation changing from $50 W/m^2$ to $1KW/m^2$.

Using (14), the irradiation can be gained at time $m$. Theoretical and simulation results show that the expiatory coefficient $\Delta K_x$ of irradiation is expressed (16) as a function of the irradiation $S$. The expiatory coefficient is 0.3 when the irradiation $S$ is less than $100 W/m^2$. The expiatory coefficient is -0.00073$m^2/W$ from 0.1 with the irradiation increasing from $100 W/m^2$ to $200 W/m^2$. The expiatory coefficient is -0.00009$m^2/W$ from 0.041 with the irradiation increasing from $200 W/m^2$ to $400 W/m^2$. The expiatory coefficient is -0.00004$m^2/W$ from 0.023 with the irradiation increasing from $400 W/m^2$ to $700 W/m^2$. Or else, the expiatory coefficient is 0.00002$m^2/W$ from 0.0176 with the irradiation increasing.

Theoretical and simulation results show that the expiatory coefficient $\Delta K_t$ of temperature is expressed (17) as a function of the temperature $T$. The expiatory coefficient is a constant from temperature $-50^\circ C$ to $-25^\circ C$. The expiatory coefficient is -0.00004 $^\circ C/m$ from 0.001 with the temperature increasing from $-25^\circ C$ to $5^\circ C$. The expiatory coefficient is zero from temperature $5^\circ C$ to $35^\circ C$. Or else, the expiatory coefficient is -0.00002$^\circ C/m$. Here, $T_{ref}$ is the actual solar panel temperature.
The expiatory coefficient $\Delta K_I$ of reverse saturation current $I_0$ is expressed (18) as a function of $I_0$. The expiatory coefficient is $5.35e-5/\mu A$ from 0.005 with the reverse saturation current $I_0$ increasing when the value of $I_0$ is more than $10 \mu A$. Or else, the expiatory coefficient is $5.35e-5/\mu A$ from 0.02 with the reverse saturation current $I_0$ increasing.

\[
\begin{align*}
\Delta K_I &= \begin{cases} 
0.001 & T_r < -25^\circ C \\
0.001-0.00004(T_{r1}+25) & T_r < 5^\circ C \\
0 & T_{r1} < 35^\circ C \\
-0.00002(T_{r1}-35) & T_{r1} > 75^\circ C 
\end{cases} \\
0.005e^{(5.35e-5-4)I_0} & \times 500 \text{ for } I_0 > 10e-6 \\
0.02e^{(5.35e-5-4)I_0} & \times 500 \text{ for } I_0 < 10e-6 
\end{align*}
\]

\[K_{xp} = 0.87 - \Delta K_s + \Delta K_t + \Delta K_{Io}\] (19)

The integrated expiatory coefficient $K_{xp}$ is expressed (19). Fig.9 shows the simulation results under different $n$ and different $I_0$ conditions. As shown in Fig.9 (a), the expiatory coefficient is reasonable under the $I_0$ is more than $10 \mu A$ conditions. Fig.9 (b) shows that the expiatory coefficient is reasonable under the $I_0$ is less than $10 \mu A$ conditions. As shown in Fig.9 (c), the expiatory coefficient is reasonable under the $I_0$ is more than $10 \mu A$ conditions at low irradiation. As shown in Fig.9 (d), the expiatory coefficient is reasonable under the $I_0$ is less than $10 \mu A$ conditions at low irradiation. Fig.9 (e) shows that the expiation coefficient is reasonable under the $I_0$ is less than $10 \mu A$ and different $n$ and different $T$ conditions. Fig.9 (f) shows that the expiatory coefficient is reasonable under the $I_0$ is more than $10 \mu A$ and different $n$ and different $T$ conditions.

Based on the results of Fig. 9, no matter how the solar radiation and solar panel temperature change, the maximum power point is gained by using the integrated expiatory coefficient $K_{xp}$. The maximum power point is gained by using the integrated expiation coefficient $K_{xp}$ no matter how the values of the diode factor $n$ and the reverse saturation current $I_0$ vary with various solar cell. Based on the simulative results, the output efficiency of proposed MPPT algorithm is more than 99% under different $n$ and different $I_0$ and most weather conditions.
For instance, in the case of solar cell, the diode factor \( n \), the reverse saturation current \( I_{0} \), and the temperature \( T \), are 50, 0.6 \( \mu \)A, and 75\(^\circ\)C, respectively. The proportionality coefficient using \( K_I \), \( K_I \) is \( I_{mppt}/I_{mpt} \). It is the coefficient of the calculated optimum output current and the actual optimum output current. The proportionality coefficient using \( K_V \), \( K_V \) is \( V_{mppt}/V_{mpt} \). It is the coefficient of the calculated optimum output voltage and the actual optimum output voltage under various irradiation conditions. The proportionality coefficient using \( K_P \), \( K_P \) is \( P_{mppt}/P_{mpt} \). It is the coefficient of the calculated maximum output power and the actual maximum output power under different irradiation conditions. As shown in Table 1, if the irradiation is more than 100 \( W/m^2 \), the output efficiency of proposed MPPT algorithm is more than 99% under different \( n \) and different \( I_{0} \) and various weather conditions.

Table 1: Simulative results of high irradiation.

<table>
<thead>
<tr>
<th>( S )</th>
<th>( K_I )</th>
<th>( K_V )</th>
<th>( K_P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>100 ( W/m^2 )</td>
<td>0.9928</td>
<td>1.0091</td>
<td>0.9994</td>
</tr>
<tr>
<td>200 ( W/m^2 )</td>
<td>0.9730</td>
<td>1.0242</td>
<td>0.9957</td>
</tr>
<tr>
<td>300 ( W/m^2 )</td>
<td>0.9807</td>
<td>1.0178</td>
<td>0.9976</td>
</tr>
<tr>
<td>400 ( W/m^2 )</td>
<td>0.9887</td>
<td>1.0109</td>
<td>0.9991</td>
</tr>
<tr>
<td>500 ( W/m^2 )</td>
<td>0.9917</td>
<td>1.0080</td>
<td>0.9995</td>
</tr>
<tr>
<td>600 ( W/m^2 )</td>
<td>0.9948</td>
<td>1.0053</td>
<td>0.9998</td>
</tr>
<tr>
<td>700 ( W/m^2 )</td>
<td>0.9914</td>
<td>1.0084</td>
<td>0.9995</td>
</tr>
<tr>
<td>800 ( W/m^2 )</td>
<td>0.9931</td>
<td>1.0067</td>
<td>0.9996</td>
</tr>
<tr>
<td>900 ( W/m^2 )</td>
<td>0.9946</td>
<td>1.0051</td>
<td>0.9998</td>
</tr>
<tr>
<td>1000 ( W/m^2 )</td>
<td>0.9964</td>
<td>1.0036</td>
<td>0.9999</td>
</tr>
</tbody>
</table>

For instance, the diode factor \( n \), the reverse saturation current \( I_{0} \), and the temperature \( T \), are 60, 7.3 \( \mu \)A, and 35\(^\circ\)C, respectively. The irradiation is less than 100 \( W/m^2 \). As shown in Table 2, the output efficiency of solar cell is more than 98%. A conclusion is gained in this paper. Not matter the irradiation and the temperature are varying with the weather, the proposed MPPT algorithm is high efficiency to track the maximum output power of solar cell, and large numbers of calculation is not essential.

Table 2: Simulative results of low irradiation.

<table>
<thead>
<tr>
<th>( S )</th>
<th>( P_{mppt} )</th>
<th>( P_{mpt} )</th>
<th>( K_P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ( W/m^2 )</td>
<td>0.3280W</td>
<td>0.3336W</td>
<td>0.9833</td>
</tr>
<tr>
<td>20 ( W/m^2 )</td>
<td>0.7267W</td>
<td>0.7381W</td>
<td>0.9846</td>
</tr>
<tr>
<td>30 ( W/m^2 )</td>
<td>1.1510W</td>
<td>1.1700W</td>
<td>0.9837</td>
</tr>
<tr>
<td>40 ( W/m^2 )</td>
<td>1.5928W</td>
<td>1.6198W</td>
<td>0.9834</td>
</tr>
<tr>
<td>50 ( W/m^2 )</td>
<td>2.0459W</td>
<td>2.0828W</td>
<td>0.9822</td>
</tr>
<tr>
<td>60 ( W/m^2 )</td>
<td>2.5007W</td>
<td>2.5587W</td>
<td>0.9817</td>
</tr>
<tr>
<td>70 ( W/m^2 )</td>
<td>2.9815W</td>
<td>3.0391W</td>
<td>0.9810</td>
</tr>
<tr>
<td>80 ( W/m^2 )</td>
<td>3.4600W</td>
<td>3.5293W</td>
<td>0.9804</td>
</tr>
<tr>
<td>90 ( W/m^2 )</td>
<td>3.9459W</td>
<td>4.0261W</td>
<td>0.9801</td>
</tr>
<tr>
<td>100 ( W/m^2 )</td>
<td>4.5274W</td>
<td>4.5289W</td>
<td>0.9997</td>
</tr>
</tbody>
</table>

4 Flowchart of the proposed MPPT algorithm

The control procedure cited above is summarized in the flow chart shown in Fig.10. First, \( m \) is defined zero, and the open-circuit voltage \( V_{oc} \) and the short-circuit current \( I_{sc} \), which were measured at solar panel temperature 25\(^\circ\)C and high irradiation 1\( KW/m^2 \). The changing coefficient \( K_I \) of \( I_{sc} \) and the changing coefficient \( K_V \) of \( V_{oc} \) were measured. Second, The diode factor \( n \) and the reverse saturation current \( I_{0} \) are supposed. Third, the output current \( I \) and the output voltage \( V \) were detected by using sensors at time \( n_1 \). Next, based on the supposed \( n \) and \( I_{0} \), the photocurrent \( I_{ph} \) and the irradiation \( S \) were calculated. Then, the expiatory program is applied in order to acquire the supposed maximum power \( P_{max} \). Draw a comparison between the value of \( m \) and 10. If the value of \( m \) is less than 10, the value of \( m \) adds one. The actual maximum power point is gained by using the PO method under same weather conditions. The actual values of \( n \) and \( I_{0} \) are gained, and the values are saved, and the average values is calculated. Or else, the actual values of \( n \) and \( I_{0} \) were applied to acquire the maximum power \( P_{max} \) at the time, and the PO method is stopped. The proposed MPPT algorithm is high efficiency to track the maximum output power.
power of solar cell, and large numbers of calculation is not essential.

![Flowchart of the proposed MPPT algorithm](image)

### ACKNOWLEDGMENT

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### References:


