A Maximum Power Point Tracking Method Combined with Constant Voltage Tracking & Variable Step-Size Perturbation

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Abstract: According to the characteristics of photovoltaic cell output power curve, this paper analyzed and explained the principle of Maximum Power Point Tracking (MPPT) and both advantages and disadvantages of constant voltage tracking method & perturbation observation method. Further, in combination with the advantages of existing maximum power tracking methods, this paper comes up with an improved tracking method which is recognized as maximum power point tracking combined with constant voltage tracking method & variable step-size perturbation observation method. The Simulink simulation results have proven this enhanced tracking method has a better performance in System response and steady state characteristics.

Keywords: Photovoltaic, MPPT, Matlab, Perturbation observation, System simulation.

1. Introductions

The rapid development of modern economy leads to a serious energy crisis, therefore, it urges us to break up the current dependence on traditional energy resources and enforce the development and utilization of renewable and clean energy resources. Solar energy resource has characteristics of non-pollution and inexhaustibility, hence, solar energy has become an important breakthrough to the new energy resource issue.

Photovoltaic power generation will be the most important development trend of future energy utilization [1, 2]. Because of variety environmental conditions (light intensity, temperature, load characteristic and so on). The output characteristics of photovoltaic power generation turn out an obvious non-linear character. In a certain light intensity and environment temperature, the output power curve of photovoltaic cell is more likely to be a single-peak curve. Only when the photovoltaic cell works at the peak of the output power curve, will the output power reach the maximum power point [3]. However, the maximum power point may change with light intensity and temperature.

Therefore, the key to improve the overall efficiency of photovoltaic power generation is to always keep photovoltaic cells working nearby the maximum power point. This technology is recognized as Maximum Power Point Tracking (MPPT) [4, 5].

http://www.sensorsportal.com/HTML/DIGEST/P_2240.htm
2. Analysis of Characteristics of Photovoltaic Cells

2.1. Working Principle of Photovoltaic Cells

The very first problem to be solved is how photovoltaic cells convert solar energy into electrical energy. Photovoltaic cell is made out of semiconductor. By making use of photovoltaic effect of semiconductor, the working principle of photovoltaic cells is similar to the diode: when light project onto the photovoltaic cells array, valence electrons within semiconductor escape from the gravity of covalent binding to form electron-hole pairs and eventually generate voltage over the PN junction.

2.2. The Output Character of Photovoltaic Cells

Open-circuit voltage and short-circuit current of photovoltaic array is greatly affected by the light intensity and environment temperature. Therefore, the system working point is volatile and this surely reduces efficiency.

With the help of Matlab/Simulink simulation tool, we can draw the output characteristic curve of photovoltaic cells under different light intensity and different temperature (as in Fig. 1). Fig. 1(a) is the U-P character curves under different light intensity, the curve indicates that output power of photovoltaic cells is related to light intensity. Keeping the other conditions unchanged, with light intensity increasing, output power also increases. Fig. 1(b) is the U-I character curves under different light intensity, it indicates that the photovoltaic cell is neither a constant current source nor a constant voltage source. In the area left to the maximum power point the photovoltaic cell is equivalent to the constant voltage source. In the area right to the maximum power point the photovoltaic cell is equivalent to the constant current source. The left area is about 4 times larger than the right area. Fig. 1(a) is the U/P curve under different temperature, Fig. 1(b) is the U/I curve under different light intensity, as we expected, given the other conditions unchanged, the output power of photovoltaic cell decreased during the environment temperature increases.

![Fig. 1. Output characteristics under different light intensities and temperatures.](image-url)
According to the output characteristic curve of photovoltaic cells, the output power may change with light intensity and temperature. In other words, it can not always stay at the maximum power output point, there are great uncertainties. Therefore, some measures must be taken in order to keep the maximum output power against all environment changes.

3. Common Maximum Power Tracking Method

3.1. Constant Voltage Tracking Methods

When the solar radiation is extensive, the maximum output power of photovoltaic cells is approximately corresponding to a constant voltage value. That is to say, this method simply keeps the output voltage of the photovoltaic cells at the value of Vm. The advantage of this tracking method is easy and simple to realize without voltage convert oscillation. However, the constant voltage tracking method ignores the influence of temperature change on the maximum power point of photovoltaic cell array. Generally speaking, open circuit voltage of silicon photovoltaic cells are easily influenced by environment temperature. On average, when the environment temperature increases by 1 °C, the open circuit voltage is decreased by 0.35 %-0.45 % approximately. In other words, the maximum power point of the photovoltaic cell changes with environment temperature. The most important factors that influence on the temperature of solar cells are the environment temperature and sunlight intensity. Therefore, constant voltage tracking method is not so capable in the areas with conspicuous and constant temperature change.

3.2. The Variable Step-size Perturbation Observation Method

Due to the advantages of less measurement parameters, simple structure and hardware realization, the perturbation observation method becomes the most commonly used tracking method. However, fixed step-size makes it much vulnerable to oscillation, especially when the working point is near to the maximum power point. The oscillation reduces the efficiency of power generation greatly. By truncating step-size can suppress oscillation near the maximum power point, but the system will become insensitive to the external environment change. Therefore, selecting an appropriate step-size is the key to the success of perturbation observation method.

Variable step-size perturbation observation method tracks the maximum power point in accordance with the duty ratio (D) of voltage regulator. In order to reduce the design difficulty of the voltage regulator, it needs only one control cycle. The relationship between output power of photovoltaic cells (P) and duty ratio (D) is as in Fig. 2. The basic idea of variable step-size perturbation observation method is: when the current working point is far away from the maximum power point, it takes long step-size to rapidly get closed to the maximum power point; in the vicinity of the maximum power point, it takes a shorter step-size to reduce or even prevent the system oscillation. The P-D curves of photovoltaic cells indicated that, the absolute value of the derivative of dP/dD tend to stable when getting close to the maximum power point.

![Fig. 2. The relationship between P and D.](image)

The diagram of this method Firstly, to detect the output current and output voltage of photovoltaic cells and calculate the instant output power (refers to P (K)), and then we can get \( \Delta P = P(K)-P(K-1) \). When \( \Delta P = 0 \), it indicates that the system is working in the maximum power region, so it does not require the adjustment of duty-ratio (D); when \( \Delta P \) does not equal to 0, it indicates that the current operating point is not the maximum output power point, hence, it requires to recalculate the step-size to adjust the output power of photovoltaic cells. Next, to examine whether the direction of \( \Delta P \) is positive or negative. If negative, to apply a positive direction perturbation, and vice versa, until \( P(K) = P(K-1) \), this tracking method stops. The other disadvantages of perturbation observation method are misjudgment-prone; especially when the light intensity changes drastically, which may eventually leads to tracking failure.

3.3. Constant Voltage & Variable Step-Size Perturbation Method

Each kind of maximum power point tracking algorithm has its own advantages and disadvantages, therefore, engineers must take the difficulties and cost into their consideration. Algorithms which
combine with other algorithms’ advantages can usually have a better performance.

The constant voltage tracking method indeed has a fast tracking speed, however, the linear fitting values of changing weather is not always the same as the real situation. But if the ratio constants can be updated periodically, the performance of constant voltage observation method can be much more excellent. By using variable step perturbation method, we must first solve the tracking failure problem when light intensity changes suddenly. As the output current of photovoltaic cells is almost linearly proportional to the intensity of illumination. This tracking system measures the intensity of illumination by detecting the strength of output current. The constant voltage method is used when the change of light intensity is too drastically, when the change of light intensity tend to be stable, then the perturbation observation method can be used.

Fig. 3 shows the Software flow chart, after system initialization, the first step is to detect the open circuit voltage. According to the characteristics of photovoltaic cells, the value of maximum power point is approximately 78% of the open circuit voltage, and this open circuit voltage act as the benchmark voltage (Vbase). The period of MTTP is 0.015 and the duty-ratio of perturbation step-size is 1%.

The output of current and voltage of the photovoltaic cell is measured at a fix time interval and calculates the instant output power. After that, the tracking system halts for 10 ms and repeats former steps, meanwhile, the tracking system also analyses the change trend of output current. In low light intensity situations, the maximum power point is set to 0.78 Uo. Once the detected current is higher than the pre-set value (0.78 Uo), the perturbation observation method is activated for optimization, meanwhile, the system detect the change of output current. As it is put in the context, dramatic change of light intensity will bring working point away from the maximum power point. Due to the output current of photovoltaic cells is almost linearly proportional to the intensity of illumination; therefore, it only needs to calculate the value of $\Delta I$. When $\Delta I > 50$ mA, it indicates that the light intensity changes drastically. The system will run a constant voltage observation mode.

When the change of light intensity tends to stable, the system will run a perturbation observation mode and forecast the direction of the next perturbation, according to output power. The area left to the maximum power point is 3 to 6 times larger than the area right to the maximum power point; hence, here we set the leftward step-size as $4\Delta D$ and the rightward step-size as $\Delta D$. When each disturbance first reaches the maximum power point, software of this tracking system will mark a variable named Flag_MPP.

If the direction of perturbation is positive, the step-size will remain as $\Delta D$. If the direction of perturbation is negative, the step-size will be set as $4\Delta D$ and unmark Flag_MPP at the same time. After a RTC interruption (which will generate every a minute), the program will shift MPPT subroutine to daytime subroutine.

4. Simulation Test

4.1. Test Model

In order to ensure the effectiveness of the tracking algorithm above, we carry out a simulation with Matlab. Light intensity can be set to different values in order to simulate different working conditions. First of all, it needs to build a model for photovoltaic cell, According to the working parameters of the
photovoltaic cell \( (I_{SC}, V_{OC}, I_{M}, V_{M}) \), here we establish an engineering model via Simulink. Given that \( I_{SC} = I_{ph} \), the V-I equation can be simplified as:

\[
I = I_{SC} - C_1 I_{SC} \frac{\exp[(V - DV)/C_2 V_{OC} - 1]}{1/C_2 V_{OC} - 1} + DI,
\]

where \( C_1, C_2, DI, DV \) is:

\[
C_1 = (1 - I_{M}/I_{SC}) \exp(-V_{M}/C_2 V_{OC}),
\]

\[
C_2 = (V_{M}/V_{OC}) - 1/C_2 (1 - I_{M}/I_{SC}),
\]

\[
DI = \alpha I_r DT + (I_r / I_r - 1) I_{SC},
\]

\[
DV = -\beta DT + R_s + DI,
\]

\[
DT = T - T_r,
\]

where \( \alpha \) refers to the temperature coefficient of current change, \( \beta \) refers to the temperature coefficient of voltage change, \( R_s \) refers to the series resistance of photovoltaic cells array, \( I_r \) refers to reference pyranometer, \( T_r \) refers to temperature; \( I_r \) refers to actual pyranometer, \( T \) refers to actual temperature.

4.2. Simulation Principle of Simulink

The output voltage of photovoltaic cell can be interpreted as \( U = I \times R \). Where \( R \) refers to the equivalent load resistance. To track the maximum power point by adjusting the duty ratio \( D \). It is equivalent to adjust the load resistance \( R \) to match the system load to realize the maximum power track. The relationship among the duty ratio \( D \), the output voltage and load resistance can be interpreted as:

\[
R = R_1 / D,
\]

\[
U = I \times R = I \times R_1 / D,
\]

where \( R_1 \) refers to the load resistance.

4.3. Simulation Results

Fig. 4 shows the simulation results of variable step-size perturbation observation under stable light intensity. Fig. 4(a) and Fig. 4(b) are curve diagrams of voltage change and current change respectively, Fig. 4(c) is a MPPT tracking curve diagram. The result shows that the tracking system can quickly and stably reach the maximum power point.

Fig. 5 shows a duty-cycle change under different weather conditions. According to the data of light intensity, the light becomes strong rapidly, at the beginning the disturbance step is four times. The duty cycle gradually decreases and default step-size appears misjudgment. However, the tracking system
soon runs under a constant voltage tracking mode, the duty cycle is rapidly adjusted to 0.78 approximately.

![Fig. 5. Duty-cycle change under different weather conditions.](image)

5. Conclusions

According to the output characteristics of photovoltaic cell and the traditional maximum power point tracking algorithm, this enhanced tracking method which is recognized as maximum power point tracking based on constant voltage method & variable step-size perturbation observation method. According to the mathematical model of photovoltaic module using Matlab/Simulink as a tool to build the simulation model, the method can rapidly achieve the maximum power point and through the simulation model of photovoltaic cell this tracking method can prevent misjudgments under different light intensity and temperature conditions. Simulink simulation also proves the reliability and stability of this enhanced tracking method.

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