

Effective Factors and Improving Methods to Conversion Efficiency in Photovoltaic Power Generation System

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Abstract. Photovoltaic technology has been widely studied as one of the most promising new energy technologies around the world. The critical problem is, however, low conversion efficiency has hindered its development. This paper has analyzed effective factors to conversion efficiency in photovoltaic power system at first, and elaborated the way how these factors work simultaneously. Then, three typical methods including Constant Voltage (CV), Incremental Conductance (IC) and Perturbation & Observation (P&O) of maximum power point tracking (MPPT) have been summarized and concluded its characteristics application scope at the same time. Lastly, this paper has proposed a method by integrating Constant Voltage (CV) and Incremental Conductance (IC) to keep track of the maximum power point precisely and quickly.

Introduction

As a new energy and renewable resource, and with features of clean, green and endless, solar energy has been so prevalent in the world that would be exploited largely in the future. For the reason that variance among output power of photovoltaic component, ambient temperature and solar radiation intensity show a non-linear relevance. In order to improve the conversion efficiency that tracking the output power of photovoltaic cell all the time is necessary, which can ensure output power in the maximum power point, in other words, keep tracking the maximum power point when photovoltaic cell is working.

The vital problem now exists is the conversion efficiency so low that lead development of photovoltaic power technology to a situation of blocked. Photovoltaic array are the core component in photovoltaic generation power system mainly include crystalline silicon cells and thin film cells^[1], which the low conversion efficiency that makes it hard to improve efficiency of the system by increasing photoelectric conversion efficiency of photovoltaic cells. Hence, there is a need by choosing MPPT method for system efficiency promotion, which could make photovoltaic generation power system output the maximum power, saving energy and improving efficiency. Doing research about maximum power point tracking, therefore, make important realistic and far-reaching historical senses of taking full advantages of solar power, saving energy resources and advancing the development^[2].

Factors Influence Photovoltaic Power Generation Conversion Efficiency

Solar Radiation Quantity

The radiation reaching earth surface mainly affect by solar altitude, latitude, sunshine duration, atmosphere transparency, geography altitude and so on. The controllable factor is solar altitude equivalents to dip angle of photovoltaic array. Solar radiation intensity could be expressed by this formula: $I=I_0\sin(h)$

Here I_0 : solar radiation intensity at sea level and air mass is AM1;
 h : dip angle of photovoltaic array;

It should notice that solar altitude is relevant to latitude: the higher latitude is, the lower radiation intensity takes, and the weaker solar radiation quantity is; To the contrary, the lower latitude is, the stronger solar radiation quantity is.

And other uncontrollable factors including sunshine duration, atmosphere transparency and

geography altitude show a positive correlation to solar radiation quantity. The longer sunshine duration, higher atmosphere transparency and higher geography altitude is, the more solar radiation quantity is.

Photovoltaic Cell

Materials of photovoltaic (PV) cells profound influence photoelectric conversion efficiency, then determine the conversion efficiency of the whole system. These materials include: semiconductor, chemical compound, nanometer material, etc. So it can classify into four types as regard materials^[3]:

- (a): Crystalline silicon PV cell;
- (b): Multivariate compound film PV cell;
- (c): Organic material PV cell;
- (d): Nano crystalline silicon PV cell

Different PV cells have different conversion efficiency: crystalline silicon PV cell has a conversion efficiency at 24%-26% (mono crystalline silicon), 18%-20% (polycrystalline silicon), and 12%-14% (amorphous silicon); Multivariate compound film PV cell possesses the conversion efficiency with 24.2% (GaAs) and 14.7% (GaInP); Organic material PV cell presents conversion efficiency 9.5% under specific radiation; Conversion efficiency is 11.8% when nano crystalline silicon PV cell in air mass AM1^[4]. It fairly clearly shows that mono crystalline silicon PV cell has the highest conversion efficiency, while it is adverse with weaknesses of complicate extraction process, high cost and too heavy than others. Multivariate compound film PV cell has advantages of high conversion efficiency and light mass.

The Maximum Power Point

The output power of the PV array is a non-linear relevant function with radiation intensity and junction temperature of PV module^[5]. And it will still change with different system external load even though a stable ambient environment. Only when the system external load is matched with PV array impedance that the PV array will output the highest power, what it called maximum power point. Unfortunately, solar radiation intensity, atmosphere temperature are unstable in fact. So in order to acquire electricity as much as possible under the same radiation intensity and junction temperature of cell, it must adjust PV array into the maximum power point on the basis of system external load and ambient environment that keeping the whole PV power system in highest output and improving photoelectric conversion efficiency.

Typical Control Methods of MPPT

According to factors influence PV conversion efficiency. It could promote system conversion efficiency from PV tracker, improve conversion efficiency of PV cells and tracking the maximum power point. Here introduces the method of maximum power point tracking (MPPT).

There are many method for MPPT in fact, including Open-loop control methods, close-loop control methods and intelligent control methods. Open-loop control methods contains short-circuit current control and open-circuit voltage control; Close-loop control includes perturbation and observation method (P&O), incremental conductance (IC), etc. Intelligent control method has fuzzy control method, neural network and so on. Classical methods are constant voltage tracking method, incremental conductance and perturbation and observation method^[6].

Constant Voltage

There is the solar photovoltaic cell output I-V characteristic curve in different solar radiation intensity and in a temperature of 25 ° C as Figure 1 shows^[8]. Here R represents the actual load characteristic. The curve intersection A, B, C, D of R and I-V characteristic represent the PV array in solar radiation intensity of operating point as 0.4 kw/m², 0.6 kw/m², 0.8 kw/m², 1 kw/m²^[7]. As can be seen from the curve, the voltage equal to a constant value (U_m) at the maximum power points A', B', C', D' under different radiation intensities in PV array respectively, what U_m calls the maximum power point. If accesses the system external load directly, it commits a low output power. So in order to improve conversion efficiency as possible, it should adjust A (working point) to A' (maximum power point), which a impedance converter is necessary for matching system external load and impedance of PV array. The constant voltage method which connects a impedance converter between the PV array and the system external load can compensate power loss which dues to impedance mismatch and make the operating voltage near U_m^[8]. It can extract the maximum

output power and improve the conversion efficiency of the PV generation system by this method.

Constant voltage tracking method has the advantages of simple control, good stability, high reliability, easy achievement, etc. The photovoltaic power generation system with CV tracking method will obtain more than 25% of the electric energy compared with no CV tracking method. However, the only drawback of this method is that the effect of temperature variation on the open circuit voltage is neglected. In generally, the expression $U_m=(0.75\sim 0.8)U_{oc}$ is satisfied, when the temperature changes, the open circuit voltage U_{oc} changes along with the temperature and the maximum power point voltage U_m changes. Therefore the constant voltage tracking method cannot track the MPP of the PV array completely in all temperature environments and have a poor adaptive ability.

Incremental Conductance

Incremental conductance is a commonly used control method in MPPT which detects and make a comparison of instantaneous conductance value and incremental conductance value. The maximum power point tracking is achieved by comparing the results [9]. There is a photovoltaic cell output P-V characteristic curve in solar radiation intensity of 1 kw/m^2 and in a temperature of 25° C as Figure 2 shows [10]. Which is a single peak curve and the slope of P-V curve is zero at the MPP. From this curve, there are following criteria:

$$dP/dU = dUI/dU = I + U \cdot dI/dU . \tag{1}$$

$$I + U \cdot dI/dU < 0 \Leftrightarrow I/U + dI/dU < 0. \text{ right of the MPPT} \tag{2}$$

$$I + U \cdot dI/dU = 0 \Leftrightarrow I/U + dI/dU = 0. \text{ At the MPPT} \tag{3}$$

$$I + U \cdot dI/dU > 0 \Leftrightarrow I/U + dI/dU > 0. \text{ left of the MPPT} \tag{4}$$

Therefore, the MPPT can be achieved by judging the symbol of $I/U+dI/dU$. If the symbol is greater than zero, it indicates the operating point at the left of MPP and it need to increase the output voltage of the solar photovoltaic cell; if it is zero symbol, it indicates at the maximum power point, and the output voltage maintain the current constant; if the symbol is less than zero, indicating the working point at the right of MPP and it need to reduce the output voltage. Output voltage regulation by PWM technology can adjust the duty cycle of the output voltage to achieve maximum power point tracking.

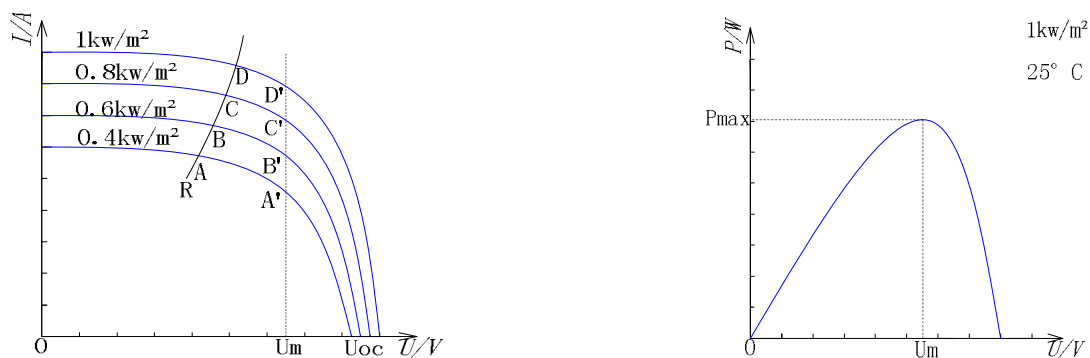


Figure 1: PV cell output I-V characteristic curve Figure 2: PV cell output P-V characteristic curve

The incremental conductance method has high control precision, fast response, high tracking accuracy, and still has good tracking performance in the case of rapidly changing ambient environment, which is suitable for the situation of external conditions rapidly changing. But, the

algorithm is more complicated and the hardware system is required to have a great performance especially the sensor and every part of the system need to have a fast response speed. Therefore there is the relatively high cost of the system. It is applicable to the changes rapidly working environment in the different temperature.

Perturbation & Observation

Perturbation & Observation (P&O) is a method which tracks the maximum power point by disturbing the operating point voltage of the solar photovoltaic power generation system continually [11]. P&O is one the simplest MPPT methods. The principle of the P&O method is to increase or decrease the output voltage of the PV array at a certain time, and then observe the variation of the output power to decide the next controlling procedure. In figure 3, solar photovoltaic cell output P-V characteristic curve at the irradiance $1\text{kw}/\text{m}^2$ and temperature 25°C is presented. We can apply positive disturbance voltage ΔV and observe how the output power changed [12]. If the output power increased, then continue to put forward disturbance voltage value so that the output power is increased further; else if the output power decreased, applying reverse perturbation voltage $-\Delta V$, so as to increase the output power. By this way, we can stabilize the output power at the maximum power point, which is P_{max} , to achieve maximum power point tracking.

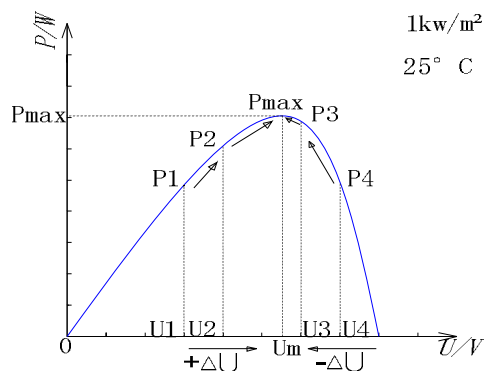


Figure 3: PV cell output P-V characteristic curve

Perturbation & Observation (P&O) has the advantages of easy implementation in low cost system, simple algorithm, and simple system, which is usually used in the illumination changed slowly. However, in the steady state, disturbance observation method will lead to the actual operating point shock in the vicinity of the maximum power point, leads to energy loss. On the other hand, the algorithm accuracy of P&O method is low to lead the wrong judgment of tracking direction under the illumination intensity changed rapidly [13].

Combination Method of Constant Voltage and Incremental Conductance

This paper proposed anew method which combined the Constant Voltage with the Incremental Conductance to track the maximum power point more efficiently. The principle is that use the Constant Voltage method to adjust the operating point voltage of the photovoltaic cell to the maximum power point's voltage quickly. It could ensure the speed of tracking the maximum power point by this way. And then use the Incremental Conductance method to track accurately. We can increase or decrease the output voltage of the photovoltaic array by judging the plus or minus of the expression $I/U+dI/dU$. If the $I/U+dI/dU$ is positive, increase the output voltage; else if the $I/U+dI/dU$ is negative, decrease the output voltage. We should choose step size ΔV as possible as small to reduce shock phenomenon of PV array output power at the maximum power point [14]. The erroneous judgment is avoided and the accuracy of MPPT system is ensured.

The Constant Voltage method has fast tracking performance, but it does not apply to the fast changing environment factors, including irradiance and temperature. On the other hand the Incremental Conductance method with tracking accuracy is high, and still to have the good tracking performance in the case of the fast changing environment factors, but the tracking speed is slow. The two methods combined can offset disadvantages and improve advantages of each other. This method will have a good performance of tracking MPP more rapid and accurate so that improve the efficiency of solar photovoltaic power generation system.

Conclusion and Prospect

The key factor of solar photovoltaic generation technology is how to improve the conversion efficiency of solar photovoltaic generation system. We should do the following works to improve solar photovoltaic power generation system conversion efficiency in the future in order to make photovoltaic power generation industry further development:(1)Continue to develop new solar cell materials to improve the photoelectric conversion efficiency of photovoltaic cells;(2)Study on solar tracker further on in order to realize the optimization of controlling and tracking;(3)Realize optimization of MPPT controlling algorithm and combine classical MPPT methods to recombine new tracking method;(4)Optimize the combination of solar PV array and realize the optimal combination to improve the photoelectric conversion efficiency.

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