Optimization and Comparison of Photovoltaic MPPT

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Abstract. Maximum Power Point Tracking (MPPT), as the control core of the output power of photovoltaic power generation system, is extremely crucial to the entire photovoltaic power generation system. In this paper, a number of common MPPT control methods are analyzed in comparison, and the traditional conductance increment method is improved as well. By means of comparative analysis in the simulation software MATLAB/Simulink, it turns out that the improved conductance increment method excels the traditional method with regards to optimization speed and stability.

Keywords: MPPT; Conductance Increment Method; MATLAB/Simulink.

1. Introduction
The inheritance and continuation of human civilization and the advancement and progress of society can't be achieved without energy and power, and energy development has pushed forward the progress of society and science and technology [1]. Witnessing the ecological deterioration and the arising energy crisis, governments and enterprises on a global scale have begun to work out energy strategies and research programs laying emphasis on clean energy. Generally, photovoltaic power generation is definitely the most flexible and feasible one among the currently known renewable energy sources. However, as photovoltaic power generation is easily vulnerable to the external environment, with a view to boost the efficiency of photoelectric conversion and render it to output energy to the maximum extent, it is essential to trace its maximum power point [2]. There are varieties of common MPPT algorithms, such as perturbation and observation method, constant voltage tracking method, conductance increment method, etc. There exist defects and limitations to varying degrees in the traditional MPPT algorithm, such as long optimization time, poor stability accuracy and serious power loss. Thus, this paper, premised on the traditional conductance increment method, makes further improvements and simultaneously verifies the correctness and superiority of the improved conductance increment method in the simulation environment of Matlab/Simulink.

2. Modelling of Photovoltaic Cells(PV) and Output Characteristics

2.1. Model of PV Cells
Photovoltaic cell is the most basic unit in photovoltaic power generation system, and its physical mechanism is extremely similar to P-N junction diode [3].
Under the condition that the temperature and the amount of solar radiation are known, the relation formula of the output power of the photovoltaic cell is as below:

\[ P = IV = \left( I_{ph} - I_A - I_{sh} \right)V = \left( I_{ph} - I_0 \left( \frac{(V+IR_s)}{A} \right) \right)V = \left( I_{ph} - I_0 e^{\frac{V+IR_s}{A}} - I_0 - \frac{(V+IR_s)}{R_{sh}} \right)V \]  \hspace{1cm} (1)

Wherein, \( I \) for the output current of the cell; \( I_A \) for the current of diode in equivalent circuit; \( I_{ph} \) for the photo-generated current of the photovoltaic cell in the equivalent circuit; \( I_{sh} \) for the magnitude of current flowing through parallel resistances in the equivalent circuit; \( V \) for the terminal voltage at both ends of the load; \( R_{sh} \) for the parallel resistance in the equivalent circuit; \( A \) for the ideal factor of P-N junction; \( R_s \) for the series resistance in the equivalent circuit. Due to infinite \( R_{sh} \) and infinitesimal \( R_s \) (omissible), the formula can be reduced to [3]:

\[ P = IV = \left( I_{ph} - I_0 e^{\frac{V+IR_s}{A}} \right)V \] \hspace{1cm} (2)

2.2. Output Characteristics of Photovoltaic Cells

Affected by external conditions, there is only one maximum power output point of photovoltaic cell, which is called maximum power point (MP) [4]. The curve shown in Figure 2 is a typical characteristic curve of photovoltaic cells I-U and P-U when the external temperature is 25°C.

3. Comparison of MPPT Algorithms for Photovoltaic Systems

3.1. Perturbation and Observation Method

Currently, perturbation and observation method is one of the most traditional MPPT algorithms and the most extensively used one, whose working principle is to change the output voltage or current of photovoltaic power generation system by using a fixed step size in each optimization period. If the power increases after the change, it suggests that the direction of the perturbation is correct and the perturbation will continue; if the power decreases after the change, it reveals that the direction of the perturbation is incorrect. The perturbation is repeated in the opposite direction, and the maximum power point is searched without stop. Figure 3 demonstrates the working process of perturbation and observation method.
Sampling open circuit voltage $U(t)$, $I(t)$

Calculate $P(t) = U(t) \times I(t)$

If $P(t) > P(t-1)$?

Updated in real time $U(t-1)$, $I(t-1)$

Calculate $U(t) = U(t-1)$, $I(t) = I(t-1)$

$U(t) < U(t-1)$

$U(t) > U(t-1)$

$U_r = U_r + \Delta U$

$U_r = U_r - \Delta U$

Figure 3. Flow Chart of Control Principle of Perturbation and Observation Method.

Actually, perturbation and observation method is a relatively simple control method, which is relatively easy to implement in practical application. However, as this method is under different starting conditions, the optimization process of the system will not stop, and eventually it will repeatedly perturb and oscillate around the maximum power point. This will not merely waste external energy and some power, but lower the power generation efficiency of the system. When the external environment changes slowly, it will even misjudge the external situation, rendering it impossible to emit wrong perturbation signals, increase the optimization time and lose energy.

3.2. Constant Voltage Tracking Method

The constant voltage tracking method is that the process is principally tracked by controlling the rise and fall of voltage. Figure 4 displays the working process of the constant voltage tracking method. In the first place, using the constant voltage tracking method, assuming that the outside temperature does not change, the maximum power point must fluctuate around a specific voltage value under different intensities of solar radiation. When the illumination intensity changes, whether the system is still working at the maximum power point can be judged by the instantaneous voltage value.

Figure 4. Flow Chart of Control Principle of Constant Voltage Tracking Method.

Constant voltage tracking method is simple in process, technologically reliable and relatively stable, and it is quite easy to put it into use owing to its low cost and simple control. However, the constant
voltage tracking method does not take into account the influence of the external temperature, which makes it less adaptable, constantly fluctuates in search, and is easy to cause energy loss. In actual use, it is often used as the initial power tracking.

3.3. Conductance Increment Method

In the conductance increment method, the maximum power point is tracked by analyzing the nonlinear ratio changes of voltage and current. Specifically, in this method, based on some small variation values, the position of working areas of the real-time system is estimated, and the maximum power point is not tracked by the fluctuation before and after the maximum power point, so that the photovoltaic array can work in the neighborhood of stable MPP. The working process of the conductance increment method is exhibited in Figure 5.

![Flow Chart of Control Principle of Conductance Increment Method.](image)

**Figure 5.** Flow Chart of Control Principle of Conductance Increment Method. The conductance increment method is characterized by excellent control effect and strong stability, and it is a real MPPT algorithm, which can deal with sudden changes in the external environment quickly. However, in actual application, the entire control algorithm is more complex than other control algorithms, and the variability in the selection of its threshold ε also renders it easy to make the system to lose power because it cannot reach the maximum power point.

3.4. Circuit Simulation

Figure 6 is a system block diagram of maximum power tracking of photovoltaic power generation system. Thus, the output voltage of the photovoltaic array is supplied to the loading after passing through the DC/DC conversion circuit, and the working voltage of the photovoltaic array can be changed by controlling the DC/DC switching devices through PWM. \( I_{DC} \) and \( U_{DC} \) the sampling current and sampling voltage of photovoltaic array respectively. The control system, namely MPPT control, judges whether the system works at the maximum power point at this time based on the sampling values \( I_{DC} \) and \( U_{DC} \) and the method described above. If not, the voltage value is indirectly changed by changing the duty ratio of the PWM signal. At this time, based on MPPT algorithm, the system will determine the direction of voltage change, keep the output power around the maximum power point.
until it reaches a steady state, and feed it back to photovoltaic array by DC/DC converter. The control system, i.e. MPPT algorithm, lies in the focus of the entire tracking system.

![System Block Diagram](image)

**Figure 6.** System Block Diagram for Maximum Power Tracking of Photovoltaic Power Generation System.

4. Simulink Simulation of Maximum Power Tracking System and Waveform Analysis

4.1. Simulation Analysis of Conductance Increment Method

The external structure is exhibited in Figure 7. By changing the illumination and temperature conditions, observe the waveform of output power to see whether it can be in line with the requirements of maximum power tracking. Firstly, set the constant temperature at 25°C and change the illumination intensity from 1,000 W/m² to 600 W/m² for 0.8 seconds, and then from 600 W/m² to 800 W/m² for 1.2 seconds. After that, set the illumination intensity to 1,000 W/m² constant, and the temperature rises from 15°C to 35°C in 0.8 seconds now, and then the temperature is reduced from 35°C to 25°C in 1.2 seconds. Two sets of simulation waveforms are displayed in (a) and (b) of Figure 8 respectively.

![Simulation Model](image)

**Figure 7.** Simulation Model of Conductance Increment Method.

(a) Simulation Waveform When the Temperature Remains Unchanged and the Illumination Intensity is Changed; (b) Simulation Waveform when the Illumination Intensity Remains Unchanged and the Temperature is Changed

![Simulation Waveform](image)

**Figure 8.** Simulation Waveform of Conductance Increment Method.

4.2. Simulation Analysis of Improved Conductance Increment Method

The external structure is demonstrated in Figure 9 and the internal structure is demonstrated in Figure 11.
Unlike the traditional conductance increment method, as DivideService exists in this study, a trigger module is added here to trigger the MPPT module separately, and the trigger pulse period is 10 times slower than the external sampling period. If this method is not used, as the sampling period is rather short, the values of sampling twice are quite close even after passing through the delay module and approximately equal to 0 after doing difference, so the denominator of division is always 0, which cannot be operated in Simulink. The traditional conductance increment method for simulating external simulation conditions is the same, and the simulation waveforms are shown in Figure 11(a) and Figure 11 (b).

(a) When the Temperature Remains Unchanged and the Illumination Intensity is Changed
(b) When the Illumination Intensity Remains Unchanged and the Temperature is Changed

By comparing with the simulation waveforms of the traditional conductance increment method, it is able to be observed that the improved conductance increment method has been tremendously enhanced in respect of dynamic response speed, while the steady-state performance has not been obviously affected. Besides, with regards to simulation speed, the time required for simulation by the original conductance increment method is 1 minute and 16 seconds, while it only takes 22 seconds by the improved conductance increment method, which suggests that the number of operations has been substantially decreased and the
requirements on hardware have been lowered further. The above analysis indicates that the improved method is effective.

5. Conclusion
In this paper, the maximum power tracking algorithm for photovoltaic power generation is studied in detail and improved further, and the researcher makes improvements on the basis of the traditional conductance increment method and comes up with an improved conductance increment method. The simulation software of Matlab/Simulink is employed to simulate and verify the traditional conductance increment method and the improved conductance increment method respectively under different illumination intensities. It turns out that the improved conductance increment method boasts faster steady state and higher accuracy, and the photovoltaic power generation system using its control algorithm is also more stable as well.

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