Maximum power point tracking control of photovoltaic power generation based on boost circuit

K Li1,2 and H X Cheng1
1School of Electrical and Electronic Engineering, Tianhe College of GPNU, Guangzhou 510540, Guangdong Province, China
E-mail: 823288626@qq.com

Abstract. In order to find an effective way of improving the power generation efficiency of photovoltaic solar panels, this paper discusses how to maximize the power point tracking control of photovoltaic panel power generation so that the panel is always output with the maximum power. This paper starts with an introduction of the working principle of maximum power point tracking (MPPT) and then compares several common methods of MPPT. After analyzing and comparing these methods, the most practicable and effective one is finally determined, which is the incremental conductance (INC) based on boost circuit. In this paper, modeling and simulations are carried out to prove the correctness and reliability of this method.

1. Introduction
With the increasing use of fossil energy, the global environmental problems such as the greenhouse effect and air pollution are getting worse as well. Under this circumstance, the new energy industry has received widespread attention from all over the world, and the photovoltaic power generation industry among which has become the main choice for humans' current and future new energy development. Photovoltaic cells are the core part of solar power generation, however, its power generation efficiency is still not that high due to the influence of primary materials and its specific features. Low efficiency and high cost result in a relatively high overall cost of photovoltaic power generation system, which directly restricts the development of the entire photovoltaic industry. Besides, external environmental factors, such as sunshine intensity, ambient temperature, condition of load, which also make an impact on the output power of photovoltaic cells, may result in even lower actual conversion efficiency. Therefore, applying the MPPT in photovoltaic power generation can improve the utilization ratio of solar energy conversion [1].

From the actual mathematical model of photovoltaic cells, we can understand that changes in the external environment have a great impact on the output power of photovoltaic cells [2]. There are several factors that cause obvious changes in the output characteristics of photovoltaic cells, the most important of which are changes in ambient light intensity and surface temperature of the cells. In order to improve the overall operating efficiency of the entire power generation system, on the one hand, it is possible to develop new materials with low price and high photoelectric conversion efficiency; but for now, the cost of photovoltaic cells is still high, accounting for about 50% - 60% of the cost of the entire photovoltaic power generation system. Another method is to adjust the photovoltaic output by checking the real-time change of external temperature and light intensity to control the photovoltaic output. Through artificial control, it always works at the maximum power point, that is, the system must changes based on the real-time external environment so as to make the output of the photovoltaic
cell at the maximum power point. Reasonable MPPT control technology can reduce the influence of seasons and other natural factors on the output power of photovoltaic power sources, thereby more effectively utilizing solar energy and improving photoelectric conversion efficiency. Maximizing the energy generated by photovoltaic cells is the most basic requirement of photovoltaic power generation system [3-5].

To solve the above problems, and to keep the output power of the photovoltaic array at a maximum value, it is necessary to apply the MPPT control of the distributed photovoltaic power generation, so that the photovoltaic battery can always output its maximum power in the current environment to improve the utilization rate of solar energy [6].

2. Principles and commonly-used methods of MPPT

From the simulation analysis of the photovoltaic cell in the previous section, it can be seen that the power output of the photovoltaic cell is greatly affected by the circumstance. With constant light intensity and the ambient temperature, only at the time the photovoltaic cell has a certain output voltage value that the output power of the PV array can reach its maximum value. This highest point is called the maximum power point (MPP). Therefore, in the photovoltaic power generation system, in order to improve the overall sales of the entire system, there is an important method that is to adjust the working point of the photovoltaic array according to the change of light intensity and temperature in real time, so that it always works at the maximum power point, and this process is called maximum power point tracking (MPPT) [6].

MPPT method detects the output power of the photovoltaic power source in real time. By changing the output current of the photovoltaic panel, the photovoltaic power supply output voltage can vary along its load curve. Therefore, an impedance transformer should be added between the photovoltaic power supply and the load to adjust the impedance change in real time to meet the changing operating point and always be near the MPP [7].

For convenience of explanation, see figure 1: the current-voltage output characteristic curves (I-U Curve) of the photovoltaic cell under different light intensities are shown as Curves 1 and 2, and Point A and B are their corresponding MPPs respectively. Assuming that the temperature and light intensity are at a certain value, the photovoltaic system operates at Point A of the MPP. When the light intensity changes, the output characteristic Curve (I-U Curve) of the photovoltaic cell rises from Curve 1 into Curve 2. If Load 1 remains unchanged at that time, it can be seen from the load curve in figure 1 that the system will rise from Point A on Curve 1 to Point a on Curve 2, thus deviating from the actual MPP. In order to track the MPP under current environmental conditions, the load characteristics of the system should be changed from Load 1 to Load 2 in the figure to ensure that the photovoltaic system operates at a new maximum power point B after abrupt temperature and light intensity changes [8].

![Figure 1. Diagrammatic Illustration of MPPT.](image_url)
At present, many countries in the world including China have launched mature research on MPPT control technology of photovoltaic arrays. Commonly-used methods mainly include the followings: Constant Voltage Tracking method (CVT), Perturbation and Observation method (P & O) and Incremental Conductance method (INC) [4]. These methods will be analyzed and compared in the following part.

- **CVT**

  Constant Voltage Tracking method (CVT), also called Constant Voltage method, is a simplified method of the MPPT control method, and is actually a fixed voltage control method. The output voltage of the photovoltaic cell array is controlled to be a fixed value, and the general value is taken as 0.8 times of the open circuit voltage. CVT method does not take into account the influence of the temperature (T) on the output voltage of the photovoltaic cell array: When T changes, the maximum power point of the photovoltaic cell output will shift; if continuing give a certain fixed voltage value, it will cause a loss of photovoltaic cell power. Therefore, CVT method is not MPPT in the true sense. In addition, CVT method is surely not applicable to the certain area with large seasonal or daily temperature difference. With the development of digital signal processing technology, CVT method has been substituted by other MPPT methods.

- **P & O**

  The basic principle of Perturbation and Observation (P & O) is to measure the current and voltage values of the photovoltaic panel output under the current environmental conditions and calculate the power in the current situation. After a certain period of time, with the change of the conditions, it measures the current and voltage values of the photovoltaic panel output, then calculate the power level in the current state, compare it with the power calculated at the previous time, and then apply a change amount to the voltage according to the change of power. This change amount is called the disturbance amount. After that, observe the power change trend of the given disturbance and determine the next control signal according to the specific situation of the power change.

  The P & O method has the advantages of plain controlling structure and easily-accessed hardware. Therefore, it is a suitable MPPT control method in some cases where accuracy requirements are not high. However, shortcomings exist in this method, i.e. its relatively slow dynamic response speed. In the case of a fixed step-size, there would be a small oscillation in the steady state. Since the variation of voltage before and after a certain time is usually small, in the case of slow changes in external conditions, the control effect of the P & O method can generally meet the demand, but its dynamic response cannot keep up with the abrupt changes of light intensity in the environment. In addition, when the steady state is reached, the output power of the photovoltaic cell will swing up and down around the maximum power value due to the constant disturbance amount. The swing amplitude is related to the selection of the disturbance amount: the larger the step size, the larger the vibration amplitude, and vice versa. Hence, on the basis of the fixed step-size, a variable step control method has been developed, that is, step-size is determined according to the speed of the external environmental conditions and whether the current work is close to the MPP. If the external environmental conditions has abrupt and fast change or the current output power value is much smaller than the maximum output power value, the appropriate step-size can be given larger, so that the photovoltaic cell can quickly reach the MPP, and vice versa [9-11].

- **INC**

  As an MPPT method, Conductance Increment (INC) method determines and adjusts the output voltage direction of the photovoltaic cell by comparing the dynamic .To put it simply, the INC method adjusts the voltage of the photovoltaic cell operating point according to environmental changes, so that it is close to the voltage of the MPP to achieve the tracking of the MPP. The INC method has no drawback of P & O, and it can judge the relationship between the operating point voltage of the photovoltaic cell and the voltage of MPP under the current conditions [11].

  Figure 2 is the PV-power-voltage (P-U) characteristic curve. It can be seen from the curve that there is a relationship between the power-to-voltage derivative and zero at the MPP of the photovoltaic cell output, i.e. dP/dU=0.
\[ P = UI \]  

\[ \frac{dP}{dU} = I + U \frac{dI}{dU} \]  

At the maximum power point, \( \frac{dP}{dU} = 0 \), substituting into equation (2) and comes equation (3).

\[ \frac{dI}{dU} = -\frac{I}{U} \]  

Equation (3) is the condition that the photovoltaic power reaches the MPP, that is, the derivative of power to voltage is equal to zero, and at this time the output power of the photovoltaic cell is maximum. When \( \frac{dI}{dU} > -\frac{I}{U} \), i.e. \( \frac{dP}{dU} > 0 \), it can be seen from the P-U curve that the operating point of the photovoltaic cell is located to the left of the MPP in the current environment, and the maximum power point is not reached, so the reference voltage needs to be continuously increased; when \( \frac{dI}{dU} < -\frac{I}{U} \), i.e. \( \frac{dP}{dU} < 0 \), the operating point of the photovoltaic cell is located to the right of the MPP in the current environment, and the maximum power point has been exceeded, so the reference voltage needs to be reduced to close to the MPP; when \( \frac{dI}{dU} = -\frac{I}{U} \), i.e. \( \frac{dP}{dU} = 0 \), the working point of the photovoltaic cell is at the MPP at this moment, and the reference voltage needs to maintain constant, so that the photovoltaic cell always works at the MPP [4].

Compared with the P & O method that the adjustment of the voltage is aimless and is easy to swing up and down at the MPP, INC method can theoretically avoid the swing at the MPP, and it also can adapt to the rapid changes in the environment with high control accuracy. However, the INC method requires higher hardware cost and higher precision sensor to collect the current and voltage value of the photovoltaic output, and it also needs the processor to perform power calculation based on the collected current voltage value. In addition, the entire system is more complex due to its uncertain step-size selection [12-14]. Through the above comprehensive comparison, considering accuracy requirements, the MPPT control method selected in this paper is the INC method.

3. Theoretical analysis of MPPT of photovoltaic generation based on boost circuit

The above sections discuss several commonly-used methods of MPPT control. In this section, the MPPT control based on the boost circuit will be analyzed. Usually, the DC power generated by photovoltaic power generation is converted by DC/DC circuit and used for DC Load or inverted into AC power to supply AC Load use and inverter grid connection. If it is connected to the grid, the voltage measurement level of the power grid is generally high. The DC power generated by the photovoltaic power generation needs to be boosted by the boost circuit, and then connected to the grid [15].
The following figure is a schematic diagram of the MPPT control of photovoltaic power generation based on boost circuit. A DC/DC boost converter is added between the photovoltaic and the load to achieve maximum power tracking of photovoltaic power generation by controlling DC/DC conversion. The current output of the panel is non-linear, and the DC/DC circuit is also a non-linear circuit, but if the time is extremely short, both can be analyzed as linear. Therefore, as long as the switching conductance of the DC/DC converter circuit is adjusted, that is, by changing the duty ratio of the PWM wave that has been turned off by the control DC/DC circuit, when the equivalent resistance of the DC/DC circuit is equal to that of the photovoltaic cell, the photovoltaic cell can obtain its MPPT.

![Schematic diagram of MPPT control of photovoltaic power generation based on boost circuit.](image)

**Figure 3.** MPPT schematic diagram based on boost circuit curve.

**Figure 4.** Boost circuit.

Figure 4 below shows the boost circuit. The boost circuit shown in the figure is a non-isolated DC boost chopper circuit with input voltage less than the output voltage. The circuit is mainly composed of Filter Inductor L, Diode VD, Filter Capacitor C and Switching Tube VT. The working process is as follows: when VT is turned on, the power supply starts to charge the inductor, and C starts to supply power to Load R; when VT is turned off, the power source and L jointly supply power to R, and simultaneously charge C [16]. In the photovoltaic power generation system, the output voltage $U_{pv}$ of the photovoltaic array is the power supply of the boost circuit, and the output voltage of the boost circuit is $U_o$. When the circuit is stable in working, the average voltage value of the output is:

$$U_o = \frac{t_{on} + t_{off}}{t_{off}} U_{pv} = \frac{T}{t_{off}} U_{pv} = \frac{1}{1-D} U_{pv}$$

(4)

In this equation, $t_{on}$ refers to turned-on time of VT; $t_{off}$ refers to turned-off time of VT; $T$ refers to the switching cycle of VT; $D$ refers to ducting on-duty ratio of VT; $U_{pv}$ is supply voltage, and $U_o$ is output voltage of the boost circuit.

It can be known from the above equation (5) that the relationship between the input voltage and the output voltage of the boost circuit is

$$U_o = \frac{1}{1-D} U_{pv}$$

(5)

Assume that the conversion efficiency of the boost circuit is 100%, and the internal impedance is ignored. The power capability is unchanged before and after the conversion, thus

$$I_L = \frac{1}{1-D} I_0$$

(6)
And the equivalent resistance of the circuit $R_{eq}$ is

$$R_{eq} = \frac{U_{pv}}{I_L} = \frac{U_o(I-D)^2}{I_o} = R(1-D)^2$$  \hspace{1cm} (7)

It can be seen from the above equations that by adjusting the on-duty of the switching transistor of the boost circuit, when the condition shown in equation (7) is satisfied, the photovoltaic output power reaches the maximum.

4. Simulations

In the previous section, the principle of MPPT based on boost circuit and INC method are discussed. The MPPT model of photovoltaic cell based on boost circuit is built in Matlab/Simulink, and the model is mainly composed of two parts: MPPT algorithm and PWM drive. The system simulation diagram is shown in figure 5.

![Simulation diagram of MPPT system based on boost circuit](image)

**Figure 5.** Simulation diagram of MPPT system based on boost circuit

The temperature is set to a constant state of 25°C and the change of light intensity is set; step-function signal is applied to simulate the change of light intensity. The current and voltage acquisition module is used to collect the current and voltage of the photovoltaic cell PV output. The specific parameters of the photovoltaic panel are shown in table 1.
Table 1. Simulation parameters.

| Parameter | Numeric (Unit) |
|-----------|----------------|
| $I_{sc}$  | 12.92 A        |
| $U_{oc}$  | 107.5 V        |
| $I_{m}$   | 11.42 A        |
| $U_{m}$   | 87.5 V         |
| $T_{ref}$ | 25°C           |
| $S_{ref}$ | $1000 W/m^2$   |
| $L$       | $3.675e-3H$    |
| $R$       | 50Ω            |
| $C_1$     | $500e-5F$      |
| $C_2$     | $2.825e-4F$    |

The system is simulated in the following two conditions as shown in figures 6 and 7: (1) light intensity $S=800 W/m^2$, temperature $T=25°C$; (2) light intensity $S=1000 W/m^2$, temperature $T=25°C$. In both conditions, the simulation time is set as 1s. The simulation of the abrupt change of light intensity from 800 W/m$^2$ to 1000 W/m$^2$ at 0.5 s is shown in figure 8.

Figure 6. Photovoltaic output power curve, $S=800 W/m^2$, $T=25°C$.

Figure 7. Photovoltaic output power curve, $S=1000 W/m^2$, $T=25°C$.

Figure 8. Photovoltaic output power curve, abrupt light intensity change from 800 W/m$^2$ to 1000 W/m$^2$ at 0.5 s.

Figure 9. Photovoltaic output power curve, $S=800 W/m^2$, $T=15°C$.

It can be seen from the simulation results shown in figures 6 and 7 that the system can quickly
reach the maximum power operation after starting the operation and is stable at the MPP. In figure 8, MPPT control can also quickly track the maximum power of the photovoltaic output and remain stable when there is an abrupt change of light intensity.

The next simulation is set in a condition where the light intensity is stable, i.e. $S = 1000 \text{ W/m}^2$, but temperature changes. The system is simulated in the following two conditions as shown in figures 9 and 10: (1) light intensity $S=1000 \text{ W/m}^2$, temperature $T=15^\circ \text{C}$; (2) light intensity $S=1000 \text{ W/m}^2$, temperature $T=50^\circ \text{C}$. In both conditions, the simulation time is set as 1s. The simulation of the abrupt change of temperature from $15^\circ \text{C}$ to $50^\circ \text{C}$ at 0.5 s is shown in figure 11.

![Figure 10. Photovoltaic output power curve, $S=800 \text{ W/m}^2$, $T=50^\circ \text{C}$.

Figure 11. Photovoltaic output power curve, temperature changes from $15^\circ \text{C}$ to $50^\circ \text{C}$ at 0.5 s.

It can be seen from the simulation results shown in figures 10 and 11 that the system can quickly reach the MPP after starting the operation and is stable at the MPP. It can be seen from figure 11 that the MPPT control can also quickly track the maximum power of the photovoltaic output and remain stable when there is an abrupt change in temperature.

Therefore, by comparing the simulation results shown in figures 8 and 11, a fact can be seen that the effect of temperature change on the maximum output power of the photovoltaic cell is much less than the effect of light intensity change on the maximum output power of the cell.

5. Conclusion
The change of the light intensity of the photovoltaic cell at a certain temperature causes the increase of the output power of the photovoltaic cells, and vice versa, the output power of the photovoltaic cell decreases, and it has a positive characteristic. Under a certain light intensity, the increase of temperature makes the output power of the photovoltaic cell decrease. Conversely, the output power of the photovoltaic cell will increase correspondingly with negative temperature characteristics. On this basis, the output characteristics of photovoltaic cells can be further understood when it is simulated under the Matlab/Simulink circumstance. Through the INC method, simulations of MPPT control of photovoltaic power generation based on boost circuit have been modeled under the conditions of (1) constant temperature with capricious light intensities, and (2) constant light intensity with capricious temperature to check the validity of the MPPT model. The simulations result show that the built-up MPPT model can track the maximum power output of the photovoltaic cell with the change of the environment.

Acknowledgments
This research was financially supported by the Key Disciplines of Guangdong Province, Electrical Engineering, Document No. 1 of Guangdong Education and Research (2017).

References
[1] Ma J H 2015 The research on inverter techniques under non-linear load condition of
photovoltaic power generation system Power Electronics 49 94-6
[2] Yang Y et al 2014 An adaptive and variable step MPPT method based on current predictive controllers P. CSEE 34 855-62
[3] Zhou D B et al 2015 Maximum power point tracking strategy based on modified variable step-Size incremental conductance algorithm Power Syst. Technol. 39 91-8
[4] Loghman S et al 2019 Model predictive control method to achieve maximum power point tracking without additional sensors in stand-alone renewable energy systems Optic 185 1189-204
[5] Zhang X H et al 2015 Research on AC/DC hybrid low voltage distribution system suitable for distributed photovoltaic power access J. Guizhou Univ. (Natural Sciences) 5 56-9
[6] Wu Z 2018 MPPT method based on non-singular fast terminal sliding model control Renew. Energ. 36 1022-6
[7] Xiong Y S et al 2009 MPPT control of photovoltaic generation system combining constant voltage method with perturb-observe method Electr. Power Autom. Eq. 29 85-8
[8] Li P et al 2015 Study on optimization of output characteristicsof solar power system based on novel incremental conductance method Renew. Energ. 33 27-31
[9] Wang W D 2010 Research on converter and control for photovoltaic power generation system (Sichuan, China: Southwest Jiaotong University)
[10] Yang B et al 2019 Modified salp swarm algorithm based maximum power point tracking of photovoltaic system under partial shading condition Control Theory & Applications 36 339-52
[11] Meng C et al 2019 The optimal control and simulation of MPPT for photovoltaic generation system Computer Simulation 36 128-32
[12] Chen Z G 2012 Design and simulation implementation for maximum power point tracking in photovoltaic system (Shenyang, China: Northeastern University)
[13] Mohammad J K et al 2019 Comparative study of maximum power point tracking techniques for hybrid renewable energy system International J. Electronics 106 1216-28
[14] Faiza B et al 2019 Comprehensive review on global maximum power point tracking techniques for PV systems subjected to partial shading conditions Sol. Energ. 183 476-500
[15] Wang F et al 2011 Stability analysis of photovoltaic generation system under rapid change of light intensity Power Syst. Technol. 35 60-5
[16] Seyed M H 2019 A new model-based technique for fast and accurate tracking of global maximum power point in photovoltaic arrays under partial shading conditions Renew. Energ 139 1061-76