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Comparison of P&O and INC Methods in Maximum Power Point Tracker for PV Systems

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Abstract. In the context of renewable energy, the maximum power point tracker (MPPT) is often used to increase the solar power efficiency, taking into account the randomness and volatility of solar energy due to changes in temperature and photovoltaic. In all MPPT techniques, perturb & observe and incremental conductance are widely used in MPPT controllers, because of their simplicity and ease of operation. According to the internal structure of the photovoltaic cell and the output volt-ampere characteristic, this paper established the circuit model and establishes the dynamic simulation model in Matlab/Simulink with the preparation of the s function. The perturb & observe MPPT method and the incremental conductance MPPT method were analyzed and compared by the theoretical analysis and digital simulation. The simulation results have shown that the system with INC MPPT method has better dynamic performance and improves the output power of photovoltaic power generation.

1. Introduction

Photovoltaic energy is the fastest growing new energy source, more and more people are beginning to pay attention to the development of photovoltaic power generation because of its universal, clean, renewable advantages [1]. But now there is a problem with photovoltaic power generation, its installation costs are high, and the conversion efficiency is low. In addition, the output characteristics of the photovoltaic are non-linear, greatly affected by the weather [2]. There is a point in the Photovoltaic output characteristic curve, in which the system's output power is the largest, so we call the system work in the maximum power point (MPP) [3]. The MPPT can make the system always work in MPP, so it plays an significant role in maximizing outputs of photovoltaic systems, thus maximizing the output efficiency of the array[4].

In recent years, several MPPT control technologies have been proposed. Among them, the P&O and INC MPPT technology is now the most widely used MPPT control technology, their procedures are simple [5, 6]. The principle of P&O MPPT technology is to disturb the duty cycle; The principle of INC MPPT technology is that the power-to-voltage slope is zero at MPP, and then to its disturbance, improve accuracy [7].

Although the study of P&O and INC MPPT method is now comprehensive, the comparative analysis of the two methods is rare. Based on the output model of the same photovoltaic cell, this paper used these two methods to realize MPPT of the system, and used the theoretical analysis and

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digital simulation to estimate and compare the performance of the photovoltaic cell, indicating that the incremental conductivity method has higher output efficiency.

2. Photovoltaic Model

According to the volt-ampere characteristics and internal structure of the PV module, and considering the factors such as the resistance characteristics and loss of the material, you can find the equivalent in Figure 1, it can be equivalent to one diode connected in parallel with a current source and then connected with a resistor in series, establishing of photovoltaic module equivalent model. The current I_{ph} is proportional to the radiance of the sun. Two most important parameters that characterize the PV module are the open circuit voltage and short circuit current provided by manufacturer. According to above model and Kirchhoff's law, we can get the mathematical model of PV modules (1) - (8), which is showing the volt-ampere characteristics of solar cells. The formula (1) can see that the current I_{pv} exists on both sides of the equation, and is the exponential function. It is very complicated to solve the problem by the voltage V_{pv}, so the approximate solution of the formula (1) is obtained by the Newton iteration method. The model starts to set $I = 0$, and we calculate the equation (9) by five cycles, so that we can use the 5th Newton iteration method to find the approximate solution of the equation (1), which has high accuracy. Using the s function to write these formulas, calling in Matlab, you can get the current at any voltage, light intensity, temperature and use it in the simulation of the photovoltaic system. The related mathematical formula is as follows:

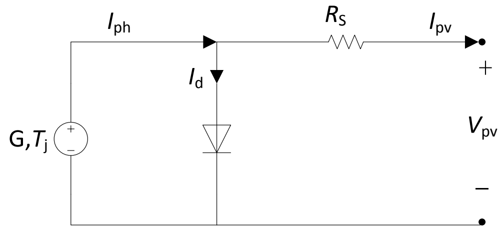

Fig.1. Photovoltaic module equivalent circuit

$$I_{pv} = I_{ph} - I_0 \left[e^{q\frac{V_{pv}+i_{pv}R_s}{AKT}} - 1 \right] \quad (1)$$

$$I_{ph(Ta)} = I_{SC(Tb)} * Sun \quad (2)$$

$$a = \left(I_{SC(Tb)} - I_{SC(Ta)}\right) / I_{SC(Ta)}\left(Tb - Ta\right) \quad (3)$$

$$I_{ph} = I_{ph(Ta)}\left(1 + a\left(T - Ta\right)\right) \quad (4)$$

$$I_{0(Ta)} = I_{SC(Ta)} / \left(e^{qV_{OC(Ta)}/nkTa} - 1\right) \quad (5)$$

$$I_0 = I_{0(Ta)} * \left(T / Ta\right)^{3/n} * e^{-qV_g/nk*(1/T - 1/Ta)} \quad (6)$$

$$X_V = I_{0(Ta)} * q / nkTa * e^{qV_{OC(Ta)}/nkTa} \quad (7)$$

$$R_S = -dV / dI_{V_{OC}} - 1 / X_V \quad (8)$$

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$$I = I - \frac{I_{ph} - I_0\left(e^{q(V+IR_S)/nkT} - 1\right) - I}{-1 - I_0 e^{q(V+IR_S)/nkT} R_S / nkT} \tag{9}$$

The parameters of solar array (MSX60 at 25℃ and 1000W/m^2) used are given in Table 1.

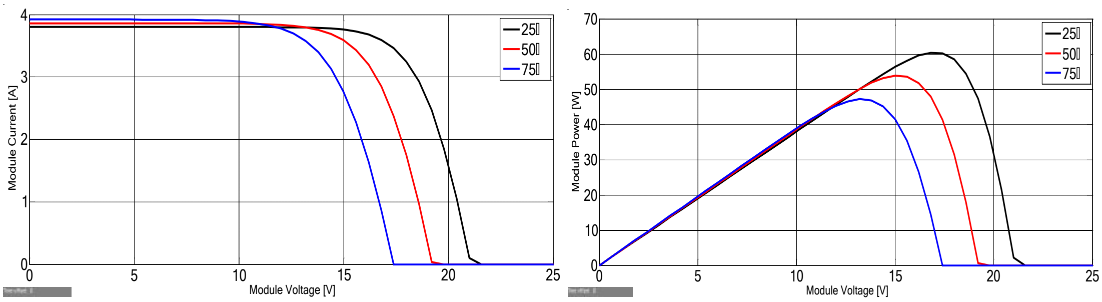
Table 1. MSX60 PV module parameter information

PV Parameter	Variable	Value
Maximum voltage	V_M	17.1[V]
Maximum power	P_M	59.9[W]
Current at MP	I_M	3.5[A]
Short circuit current	I_{SC}	3.8[A]
Open circuit voltage	V_{OC}	21.06[V]
Total cells in parallel	N_P	1
Total cells in series	N_S	36

Nomenclature

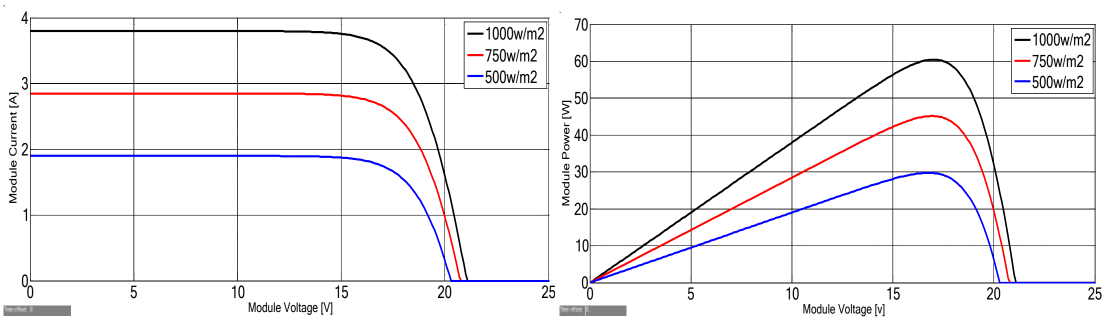
V_{pv}	PV module output voltage [V].
I_{pv}	PV module output current [A]
N_s	Total cells in series.
I_{ph}	PV module light current [A].
I_0	PV module saturation current [A].
R_s	Series resistance on the PV module [Ω].
A	Ideal factor
K	Boltzman constant number
T	Cell temperature
q	Electronic charge
I_{sc}	Photovoltaic module short circuit current at 25℃ and 1000w/m^2
Sun	PV cell illumination
Vg	Band gap silicon

According to the above model, we can see that the system voltage and current output and temperature and light are related. So we use the model to get the system at different temperatures and different light intensity of the output model shown in Figure 2, 3. Figure 2 shows the Photovoltaic module's output voltage is influenced by the temperature, while the current is almost unchanged. The maximum power decreases as the temperature increases. Figure 3 shows that the Photovoltaic module's output voltage is influenced by light and the output current remains constant. The maximum power increases as the light increases.



(a) I-V characteristic curve (b) P-V characteristic curve

Fig.2. Photovoltaic modules at different temperatures I-V and P-V characteristics



(a) I-V characteristic curve (b) P-V characteristic curve

Fig.3. I-V and P-V characteristics of photovoltaic modules under different solar irradiance

3. DC-DC Boost Converter

The DC-DC converter circuit used in this paper is a boost chopper circuit with the advantage that the boost circuit is more efficient than the buck circuit and its energy efficiency can vary with the duty cycle. When the converter runs stably, mean of the induced voltage in one switching cycle is zero. So the output voltage can be obtained:

$$V_{out} = \frac{V_{in}}{1-D} \tag{10}$$

The relationship between the input and output voltage of a PV module depends on the duty cycle [8]. If the efficiency of the PV module converter is 100% and the circuit output load is purely resistive, to maximum the system output power, there is the equivalent resistance:

$$R^{'} = R_L * (1-D)^2 \tag{11}$$

According to the impedance transformation relationship of the boost circuit, the paper uses Matlab function module in Matlab / simulink, and the boost circuit is written into the simulation model in the form of function.

4. MPPT Algorithms

Perturb & observe is the most widely used MPPT algorithm, which adds a small perturbation to the system, using interference to affect the maximum power point. The main process shown in Figure 4, through the converter to impose the disturbance: interfering the photovoltaic operating point through the PV module output voltage, the control algorithm will be compared before and after the interference of the photovoltaic power output value after each interference. If the PV output power is higher after interference, this means the point tends to the MPP, and then the applied voltage disturbance direction will be the same as the original. If the output of the PV module is reduced after voltage disturbances, this means that the running point has been away from the MPP and then the applied voltage perturbation direction will be opposite to the original [9].

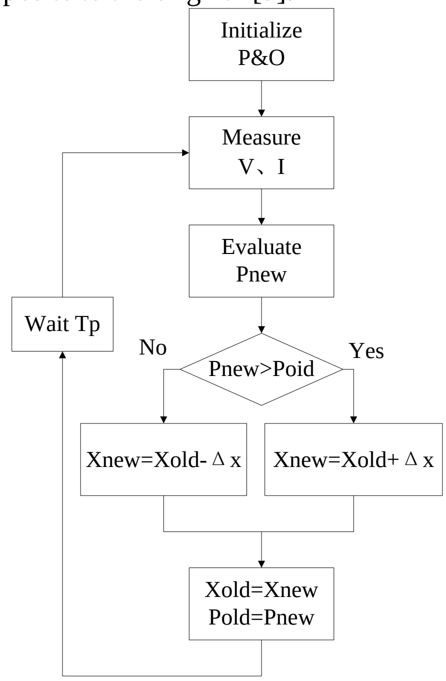


Fig.4. P&O MPPT method flow chart

INC is one of the most commonly used MPPT methods, which is achieved by comparing the instantaneous conductance and conductance changes of photovoltaic cells to achieve maximum power tracking [10]. From the P-V curve of the photovoltaic cell, the MPP is at the vertex of the curve. This is available:

$$\frac{dP}{dU} = \frac{d(UI)}{dU} = I + U\frac{dI}{dU} = 0 \tag{12}$$

$$\frac{I}{U} + \frac{dI}{dU} = G + dG = 0 \tag{13}$$

The following relationship can be obtained:

(a) If the PV array is running on the left side of the MPP, $\frac{dI}{dU} > -\frac{I}{U}$, in order for the system to operate at the MPP, the reference voltage should change in the direction of the voltage increase.

(b) If the PV array is operating on the right, $\frac{dI}{dU} < -\frac{I}{U}$, in order for the system to run at the MPP, the reference voltage should change in the direction of the voltage decrease.

(c) If the PV array is just working at the MPP, $\frac{dI}{dU} = -\frac{I}{U}$, reference voltage unchanged [11].

The flow chart of the INC MPPT method is shown in Figure 5:

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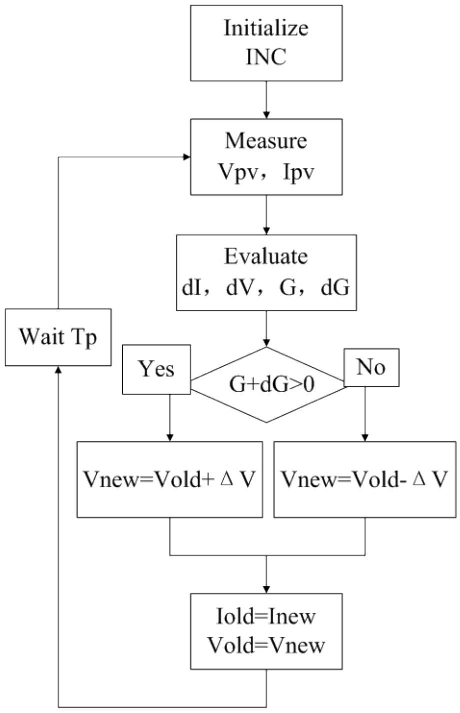
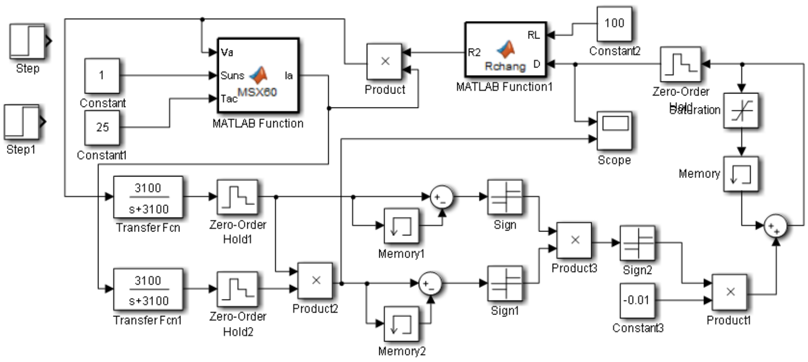
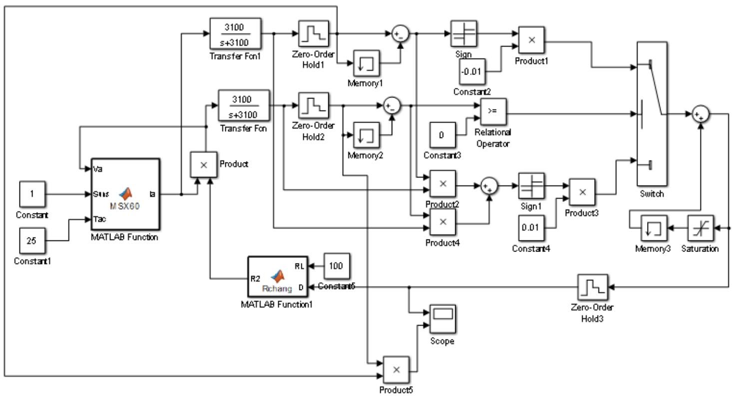


Fig.5. INC MPPT method flow chart

The flow chart of two MPPT algorithms shows that the algorithm is written on Matlab/Simulink as shown in Figure 6. Fig.6 (a) is a model of the P&O MPPT techniques, Fig. 6 (b) is a simulation model of the INC MPPT method. Their PV modules and DC-DC modules are same, are written with the s function, respectively, with different control algorithms to achieve MPPT.



(a) P&O

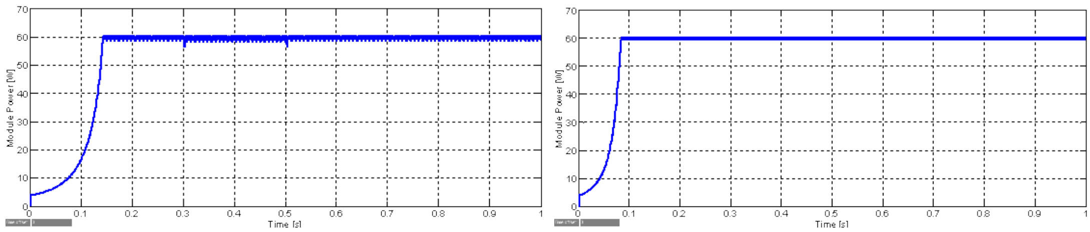


(b) INC

Fig.6. Configurations of MPPT algorithms in Simulink

5. Simulation Results and Discussion

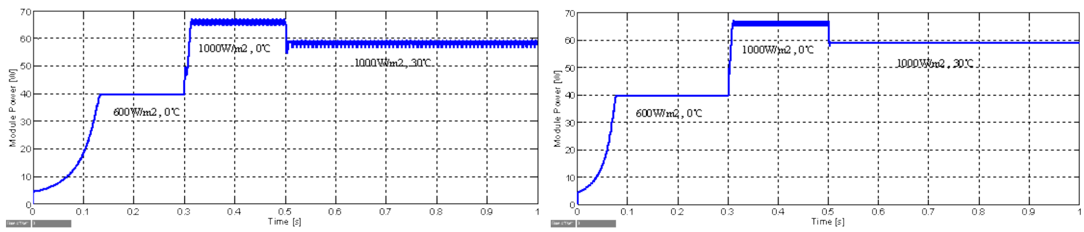
According to the above simulation model, in Matlab/Simulink simulation, there are perturb & observe and incremental conductance techniques of the photovoltaic output curve shown in Figure 7.The performances of them have been investigated and compared at 1000[W/m^2] and 25[℃], which show that the incremental conductivity method finds the maximum power point faster, the shock is smaller and the accuracy is higher.



(a) P&O (b) NC

Fig.7. Photovoltaic power curves generated by two different MPPT control algorithms

To further verify the effectiveness of the two control technical algorithms, the performance of the system is tested by changing the external conditions such as illumination and temperature. The light intensity is changed from 600[W/m^2] to 1000[W/m^2] at 0.3s and the temperature from 0℃ to 30℃ at 0.5s. The simulated power curve is shown in the following figure:



(a) P&O (b) INC

Fig.8. The output power curves of two MPPT algorithms when illumination and temperature change.

As can be seen from Figure 8, both the P&O and INC methods can achieve maximum power point tracking. However, contrasted with the P&O MPPT techniques, the simulation outcomes of the INC MPPT techniques can achieve the maximum power point tracking more quickly, less oscillation and more precise to track.

Conclusion

This paper introduced the P-V and I-V characteristic curve of the MSX60 PV Module, on this basis, designs the P&O MPPT and the INC MPPT techniques, and compared the performance of the two methods. The process is mainly that regardless of solar sunshine and temperature conditions, the algorithm can control the system to change the converter duty cycle, to obtain maximum power of the system. Through simulation, it can be concluded that the perturb & observe MPPT method and the INC MPPT method can realize the MPPT of the PV panel. In contrast, the performance of the INC MPPT method is much better than the P&O MPPT method, it can be faster to maximum power point with its high precision and small shock. In the case of cost permits, it is more suitable for improving the MSX60 battery output efficiency.

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