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Photovoltaic Cell MPPT Simulation System Based on Hybrid Algorithm

Miaomiao Wang[a,*], Hui Li[a], Shuangyou Wang[b]

[a]School of Information Engineering, Handan University, Handan 056001, China
[b]Software School, Handan University, Handan 056001, China
w.mm840217@163.com

Subject to the energy shortage and environmental pollution and based on the traditional photovoltaic cell mathematical model, a simple and accurate photovoltaic cell model was established in Matlab/Simulink environment. It can be seen from the input/output curve that this model can perfectly reflect the input/output characteristics of photovoltaic cells. The disturbance algorithm and the fuzzy algorithm are combined into the model to establish the MPPT simulation system of the photovoltaic cell. The simulation results show that the system can track the Maximum Power Point (MPP) in the current environment.

1. Introduction

With the increasingly serious global energy problems, vigorous R&D of new clean energy and renewable energy has become a hot spot in energy research today, and also the only way for energy development (Wu et al., 2017). As a clean and pollution-free renewable energy source, solar energy is extremely rich and inexhaustible, so solar photovoltaic power generation technology has become a research hotspot (Zhang et al., 2017). As a key part of photovoltaic power generation system, photovoltaic cells are the focus of research. However, the expensive cost and precise characteristics make photovoltaic cells have many limitations in research and engineering applications. The establishment of practical photovoltaic cell simulation models is very important (Yan et al., 2015). The simulation model of photovoltaic cell was established in Matlab/Simulink environment, and the input/output characteristic curve is obtained. The disturbance algorithm and fuzzy algorithm were combined to establish a Maximum Power Point (MPP) simulation system for photovoltaic cells based on hybrid algorithm.

2. Simulation model of photovoltaic cell

Photovoltaic cells use photovoltaics to convert solar energy directly into electrical energy, and their conversion efficiency is affected by light intensity and ambient temperature.

2.1 Equivalent circuit model of photovoltaic cells

The equivalent circuit of the photovoltaic cell is shown in Figure 1.

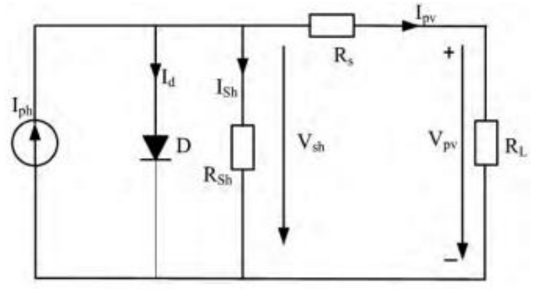

Figure 1: Equivalent circuit of the photovoltaic cell model

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In the figure, I_{ph} is the photo-generated current, which is related to the size of the photovoltaic cell and the irradiance of the solar light.
I_d is the dark current.
R_{sh} is equivalent bypass resistance, usually several thousand ohms; R_s is equivalent series resistance, generally less than 1 ohm. Both are inherent internal resistance of photovoltaic cells, which can be ignored in the calculation of ideal photovoltaic cell parameters.
According to KCL,

$$I_{pv} = I_{ph} - I_d - I_{sh} \tag{1}$$

Where

$$I_d = I_0[\exp(\frac{qV_{sh}}{nkT}) - 1] \tag{2}$$

(I_O is the reverse saturation current of the photovoltaic cell; q is the electron charge; T is the thermodynamic temperature in K; k is the Boltzmann constant; n is the diode parameter)

$$I_{sh} = \frac{V_{sh}}{R_{sh}} \tag{3}$$

$$V_{sh} = V_{pv} + I_{pv}R_s \tag{4}$$

Take (2), (3) and (4) into (1), obtain the output current of photovoltaic cell

$$I_{pv} = I_{ph} - I_o\{\exp[\frac{q(V_{pv} + I_{pv}R_s)}{nkT}] - 1\} - \frac{(V_{pv} + I_{pv}R_s)}{R_{sh}} \tag{5}$$

If allowed for the engineering, for the equivalent bypass resistance R_{sh} is large, the item $\frac{(V_{pv} + I_{pv}R_s)}{R_{sh}}$ is ignored;
Assume I_{ph}=I_{SC} (I_{SC} is the short circuit current in the photovoltaic cell equivalent model). In the open state U_{oc}=U_{pv} (U_{oc} is the open circuit voltage in the photovoltaic cell equivalent model) I_{pv}=0, obtaining a practical and simplified mathematical model:

$$I_{pv} = I_{sc}\{1 - C_1[\exp(\frac{V_{pv}}{C_2U_{oc}}) - 1]\} \tag{6}$$

Where

$$C_1 = (1 - \frac{I_m}{I_{sc}})\exp[-\frac{U_m}{C_2U_{oc}}] \tag{7}$$

$$C_2 = (\frac{U_m}{U_{oc}} - 1)[\ln(1 - \frac{I_m}{I_{sc}})]^{-1} \tag{8}$$

(I_m=I_{pv}, U_m=V_{pv} at the Maximum Power Point (MPP) of photovoltaic cells).
Under standard test conditions (light intensity of 1000W/m^2, 25℃), the parameter I_m, U_m, I_{sc} and U_{oc} are given by the PV cell manufacturer. According to (6), (7) and (8), the output characteristics of the photovoltaic cell can be obtained.

2.2 Modeling and simulation of photovoltaic cells

In the Matlab/Simulink environment, the simulation model for photovoltaic cells is shown in Figure 2 (Rafael et al., 2014), where S is the light intensity and T is the ambient temperature.
Set the temperature to 25℃, the curve of output power as a function of voltage under different illumination intensity S is obtained (Figure 3).

Set the light intensity to 1000W/m^2, obtain the curve of output power as a function of voltage at different temperature T (Figure 4).

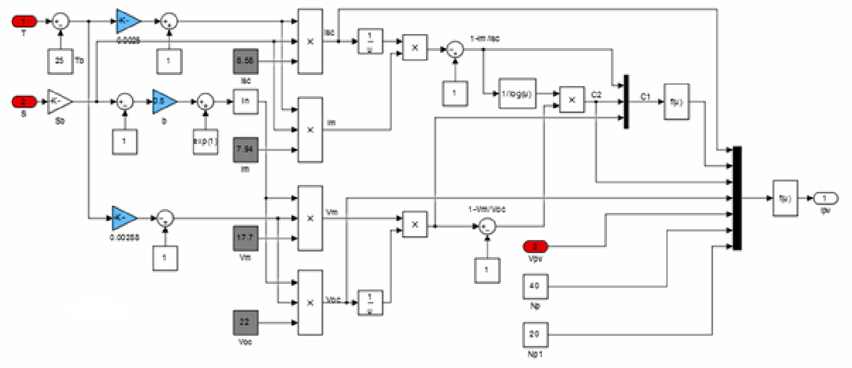

Figure 2: Photovoltaic cell simulation model

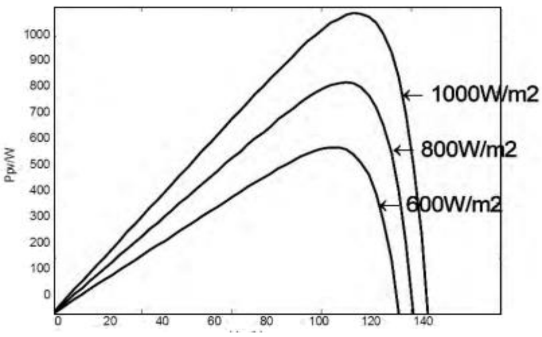

Figure 3: P-V curve when S changes

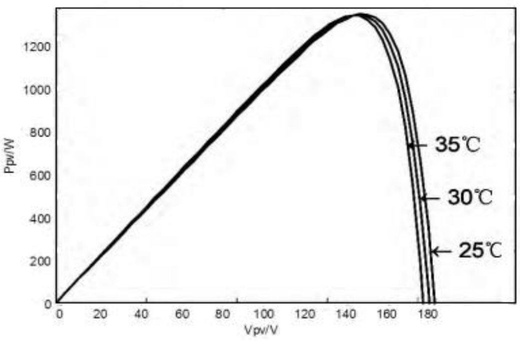

Figure 4: P-V curve when T changes

As can be seen from Figure 3 and Figure 4, the output power of the photovoltaic cell increases with the increase of the illumination intensity, decreases with the increase of the temperature, and is accompanied by the movement of the Maximum Power Point (MPP) when the illumination intensity or temperature changes.

3. Maximum power principle of photovoltaic cells

According to the equivalent circuit principle, when the output impedance of the photovoltaic cell is equal to the load impedance, the output power of the photovoltaic cell reaches the maximum, and the process of obtaining the Maximum Power Point (MPP) of the photovoltaic cell is the process of matching the output impedance with the load impedance, generally achieved via adjusting the duty cycle of the optical device.

Under certain ambient temperature and light intensity, when the output voltage takes different values, the output power differs greatly. Only when the output voltage is at a certain value, the output power reaches the maximum value in the environment. At this time, the photovoltaic cell works at the Maximum Power Point

(MPP). In actual engineering, the ambient temperature and the light intensity are always changing. When the temperature or the light intensity changes, the Maximum Power Point (MPP) also changes. To fully improve the utilization of photovoltaic power generation, it is necessary to change the output voltage of the photovoltaic cell in real time according to environmental changes, so that it is always equal to the voltage corresponding to the Maximum Power Point (MPP) in the current environment. This real-time adjustment process is the Maximum Power Point Tracking (MPPT) of photovoltaic cells.

4. Maximum Power Point Tracking (MPPT) of photovoltaic cells

MPPT is essentially a self-optimizing process (Ma et al., 2017). The more common methods are disturbance observation method, incremental conductance method, constant voltage tracking method, power detection feedback method, etc. These methods have their own advantages and disadvantages. Among them, the most common disturbance observation method is relatively simple and has less measurement parameters. But after the Maximum Power Point (MPP) is reached, a disturbance signal is continuously added to the system to make it unstable (Zhu, 2018).

In view of the disadvantage of the disturbance observation method, the fuzzy algorithm and the disturbance observation method are combined with the Maximum Power Point (MPP) of the real-time tracking system. The fuzzy rule is used to intelligently change the input duty cycle of the voltage conversion circuit, and the voltage value is changed in real time to find the Maximum Power Point (MPP) of the system.

4.1 MPPT fuzzy algorithm

The fuzzy control method is an expert control method based on empirical knowledge, suitable for complex nonlinear systems with unknown mathematical model. It is difficult to describe the working conditions of photovoltaic cells in actual engineering with accurate mathematical models, therefore it is proper to use the fuzzy control method to realize the Maximum Power Point Tracking (MPPT) of the system.

The fuzzy control process includes three steps of fuzzification, fuzzy reasoning and anti-fuzzification (Yue and Xu, 2017). The fuzzy controller works by fuzzifying the input digital signal into a fuzzy quantity, then input it to the fuzzy inference module to obtain a fuzzy set, and then converting it into a clear digital quantity through the anti-fuzzification module to control the controlled object (Kang et al., 2016).

The fuzzy controller takes the control error e and the error change rate *ec* as inputs.

$$e = \frac{P(k) - P(k-1)}{U(k) - U(k-1)} \tag{9}$$

$$ec = e(k) - e(k-1) \tag{10}$$

Where *P(k)* and *U(k)* are the power and voltage obtained by sampling the photovoltaic cell at point *k*.

The output of the fuzzy controller is u (the duty cycle increment at point k).

The fuzzy control strategy defines *e*, *ec*, and *u* as 7 subsets:

$$e = [NB, NM, NS, ZO, PS, PM, PB]$$

$$ec = [NB, NM, NS, ZO, PS, PM, PB]$$

$$u = [NB, NM, NS, ZO, PS, PM, PB]$$

According to the characteristics of the photovoltaic cell, the triangle function is selected as the membership function, and the fuzzy rule inference table is shown in Table 1.

Table 1: Fuzzy control rule reasoning table

u		ec						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	NB	NB	NB	NB	NS	NS	ZO
	NM	NB	NB	NB	NS	NS	ZO	PS
	NS	NB	NB	NS	NS	ZO	PS	PS
	ZO	NB	NS	ZO	ZO	PS	PS	PB
	PS	NS	NS	PS	PS	PS	PB	PB
	PM	NS	ZO	PS	PS	PB	PB	PB
	PB	ZO	PS	PS	PB	PB	PB	PB

The simulation model of fuzzy control strategy based on fuzzy control algorithm is shown in Figure 5.

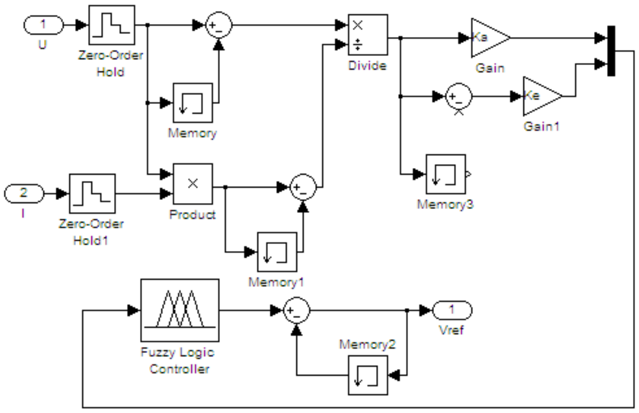

Figure 5: Simulation model of fuzzy control strategy

4.2 MPPT system simulation model

The system simulation model combined with fuzzy control and disturbance observation method is shown in Figure 6 (Liao et al., 2014).

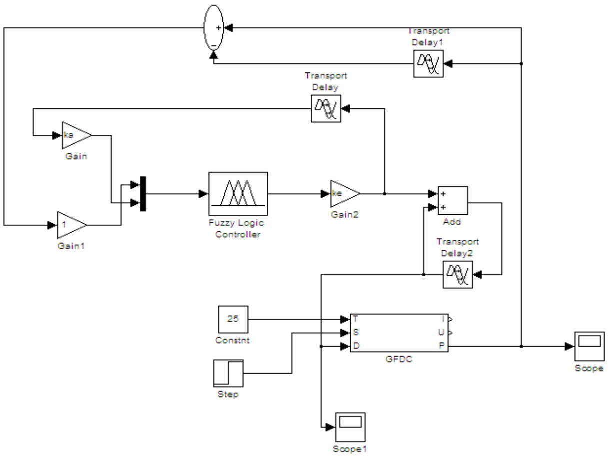

Figure 6: MPPT system simulation model in Matlab/Simulink environment

Set the ambient temperature to 25℃, and the illumination intensity increases from 600W/m^2 to 800W/m^2 and 1000W/m^2, and then decreases from 1000W/m^2 to 600W/m^2 and 400W/m^2 (simulate by step signal). Set the simulation time to 12s, and the transformation occurs at 6s. The simulated wave diagram is shown in Figure 6 and Figure 7.

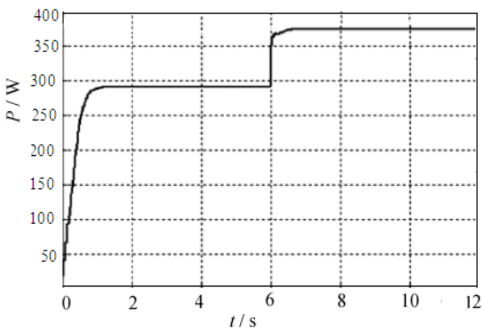

Figure 7: Conversion waveform of output power when the light intensity increases

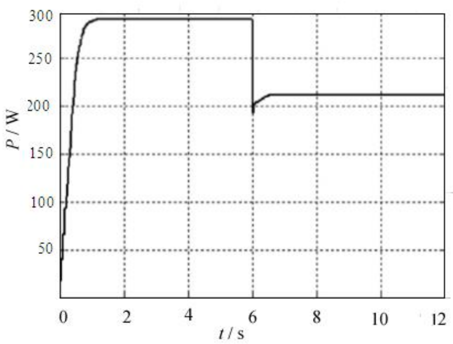

Figure 8: Conversion waveform of output power when the light intensity decreases

It can be seen from Figure 7 and Figure 8 that, when the illumination intensity changes, the combination of fuzzy control and disturbance can make the photovoltaic cell quickly track to the Maximum Power Point (MPP), and there is almost no oscillation at the output power, and good results are obtained.

5. Conclusion

The equivalent mathematical model of photovoltaic cells is derived from its equivalent circuit diagram and simplified and improved. The simulation model of the photovoltaic cell is established, and the relationship between the output voltage and power of the photovoltaic cell under different temperature and illumination conditions is given. This model is used to construct a photovoltaic cell MPPT system based on the combination of fuzzy control algorithm and disturbance observation method, which can quickly capture the Maximum Power Point (MPP) of the photovoltaic cell and has no fluctuation at the Maximum Power Point (MPP), featuring good control effect.

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