MPPT Control Strategy of Photovoltaic Cells Based on Duty Cycle Disturbance

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Abstract. Photovoltaic cell is a key part of solar power generation system, and whether its photoelectric conversion is sufficient is also called the maximum power point tracking problem, that is, photovoltaic cell MPPT. Different from the traditional MPPT control algorithm, this paper models and analyzes the output characteristics of solar cell. on this basis, proposes a fuzzy control algorithm based on duty cycle disturbance, and simulates it with MATLAB. The result shows the algorithm can well take into account the tracking speed and control accuracy when the external environment change.

Keywords: Photovoltaic Cells, Duty Cycle Disturbance, Fuzzy Control.

1. Introduction
The technical difficulty of solar power generation system is to maximize the photoelectric conversion efficiency, and the most effective method currently implemented is the maximum power tracking algorithm [1,2,3]. Compared with this, some traditional methods have more shortcomings. The constant voltage method is easy to implement and has excellent performance, but the voltage tends to change with the environment [4]; The disturbance observation mode has less measured parameters, concise control system structure and easy control algorithm, but its control objective is relatively blind. Due to constant perturbation, the working point is prone to deviation, resulting in a certain power loss [5]; The conductance increment method has accurate control accuracy. The voltage can follow the change in a stable manner, but it has higher hardware requirements for the control system, especially for the sensitivity of sensors and the response speed of various parts of the system [6]. Because the specific mathematical model of photovoltaic cells is not clear, the response of the tracking system has a high degree of Fuzziness with the change of the external environment. Therefore, this paper proposes a fuzzy control algorithm based on duty cycle disturbance, and carries out the simulation experiment in Simulink to the effectiveness of the algorithm.
2. Output Characteristic of Solar Cell

2.1. Circuit Model of Solar Cell
According to electrical theory, the equivalent circuit model of solar cell can be expressed as shown in Figure 1 [7].

![Circuit model](image)

**Figure 1.** Circuit model

Refer to the above equivalent circuit model, the output voltage is set as \( V \), the output current is set as \( I \), so:

\[
I = I_{sc} \left( 1 - C_1 \left[ \exp \left( \frac{V}{C_2 V_{oc}} \right) - 1 \right] \right)
\]  

(1)

At the maximum power point, the voltage is \( V_m \), the current is \( I_m \), so:

\[
I_m = I_{sc} \left( 1 - C_1 \left[ \exp \left( \frac{V_m}{C_2 V_{oc}} \right) - 1 \right] \right)
\]  

(2)

Under standard reference conditions\( (S_{ref}=1000\text{W/m}^2, \ T_{ref}=25^\circ \text{C}) \), \( \exp \left( \frac{V_m}{C_2 V_{oc}} \right) \gg 1 \), so \( C_1 \) :

\[
C_1 = (1 - \frac{I_m}{I_{sc}}) \exp \left( \frac{V_m}{C_2 V_{oc}} \right)
\]  

(3)

When the circuit is open, \( V=V_{oc}, I=0 \), substitute equation (3) into equation (1), in the same way, \( \exp \left( \frac{V}{C_2 V_{oc}} \right) \gg 1 \), so \( C_2 \) :

\[
C_2 = \frac{\left( \frac{V_m}{V_{oc}} - 1 \right)}{\ln(1 - \frac{I_m}{I_{sc}})}
\]  

(4)

\( C_1 \) and \( C_2 \) can be calculated by the four parameters \( V_m, I_m, V_{oc}, I_{sc} \) provided by the manufacturer. When the external conditions are inconsistent with the standard reference conditions, the output characteristics will be offset. Set the output voltage at this time as \( V' \), and the output current is as \( I' \), then:

\[
dT = T - T_{ref}
\]  

(5)
\[
dI = \alpha \frac{S}{S_{ref}} \,dT + \left( \frac{S}{S_{ref}} - 1 \right) \,I_{sc}
\]

\[
dV = \beta \,dT + R_s \,dI
\]

\[
I' = I + dI
\]

\[
V' = V + dV
\]

Where, T is the environment temperature; T_{ref} is the standard reference temperature (25°C); S is the actual light intensity, W/m²; S_{ref} is the standard reference light intensity (1000 W/m²); \( \alpha \) and \( \beta \) are current temperature and voltage temperature coefficient respectively, A/°C and V/°C; R_s is the equivalent series resistance, Ω; V_{oc} is the open-circuit voltage; I_{sc} is the short-circuit current.

For monocrystalline silicon solar cells, the actual measurement \( \alpha = 0.0012 \, I_{sc}, \beta = 0.005 \, V_{oc} \). The technical parameters of the panels adopted are shown in Table 1.

| P_m | V_m | I_m | V_{oc} | I_{sc} | \( \alpha \) | \( \beta \) | R_s |
|-----|-----|-----|--------|-------|----------|----------|-----|
| 175W | 35.2V | 5.2A | 44.2A | 5.2A | 6.24mA/°C | 0.221V/°C | 0.5 Ω |

2.2. Output Characteristics of Photovoltaic Cell

Establish a photovoltaic cell simulation model in Matlab/Simulink. The powerful packaging function of Matlab was used to encapsulate the above models into subsystems, the simulation model of output characteristics established is shown in Figure 2.

![Figure 2. Simulation model of output characteristics](image)

The simulation time was set to 60S, and the ode45 algorithm was adopted to carry out four groups of simulation experiments with different external conditions. The final results are shown in Figure 3.
Figure 3. Output characteristics under different conditions

(a) I-V curves of different light intensity at the same temperature (T=25°C)

(b) I-V curves of the same light intensity and different temperatures (S=1000 W/m²)

(c) P-U curves of different light intensity at the same temperature (T=25°C)

(d) P-U curves of the same light intensity and different temperatures (S=1000 W/m²)
In Figure 3 (a) and (b), the trend of change is similar. In the right area with high voltage, the photovoltaic cells can be equivalent to a series of voltage sources of different grades with obvious low internal resistance, while in the left area with low voltage, the solar cell can be seen as a series of current sources of different grades with obvious high resistance. Figures 3(c) and 4(d) also show that no matter what the circumstances, solar cell has always a specific maximum power point that can be clearly visible.

3. MPPT Control Algorithm and the Design of Fuzzy Controller

3.1. MPPT Control Algorithm
Traditional control theory such as constant voltage, disturbance observation and incremental conductance can not give consideration to tracking speed and control accuracy, and will cause certain power loss [8]. The control method proposed in this paper changes the disturbance direction of the duty cycle step length according to the direction of power change after adjustment. It changes the load impedance by changing the duty cycle D of the boost circuit PWM. Value to make it completely match the output impedance, \( R = R_L * (1 - D)^2 \). The schematic diagram is shown in Figure 4.

3.2. Design of Fuzzy Controller
The controller structure is shown in Figure 5. The output power difference value \( e(n) \) and the duty cycle step \( A(n-1) \) are the input variables, and the duty cycle step value \( a(n) \) is the output variable [9].

4. Simulation Analysis

4.1. Simulation Model
Establish a simulation model as shown in Figure 6.
4.2. Simulation Results

Set the load $R_L = 32\, \Omega$, Transport Delay module Delay time is 0.05s, after repeated experiments, the value of quantization factor $K_e$ is 0.1, the value of proportional factor $K_a$ is $1/70^{[10]}$. Two step signals are used to represent the illumination and temperature variation under standard reference conditions, the simulation results are shown in Figure 7.

As seen in Figure 7, the output power of solar cell reaches the maximum again for about 0.1s when the conditions change. When the temperature changes, the output power reaches the new steady state almost immediately, and the output power almost does not oscillate after reaching the new steady state.

5. Conclusion

Designed to improve the photovoltaic conversion rate, this paper modeled and analyzed the output characteristics of solar cell, and proposed a fuzzy control algorithm based on duty cycle disturbance, take duty cycle step as the only control quantity. The simulation experiment verifies the good control effect of this method in the MPPT control of solar power generation system.

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