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Research on a Photovoltaic MPPT Based on Fuzzy Control Algorithm

Dexiao Han^{1,*}, Yanping Wang¹, Zhisen Wang¹ and Li Liu¹

¹School of Information Science and Engineering, Dalian Polytechnic University, Dalian ,China

*Corresponding author e-mail: hdx2619@163.com

Abstract. In photovoltaic power generation systems, the output power of photovoltaic panels is greatly affected by the environment. Experiments show that each point formed by temperature and light intensity corresponds to a power output curve of a photovoltaic panel. Under conditions with certain external conditions, guarantees Photovoltaic panel output maximum power becomes a difficult problem for PV development and utilization. In the traditional MPPT algorithm, disturbance observation method is widely used. Although the method has fast response and simple structure, the accuracy is not high, and it fluctuates at the maximum power point. More severe, causing a waste of power to a certain extent. For this problem, an improved algorithm based on fuzzy control is proposed to optimize the disturbance observation method to further increase the tracking speed of the maximum power and to eliminate the static error to some extent. The output power of the photovoltaic panel is kept at its maximum.

1. Introduction

With the development of society, mankind's demand for energy is also increasing. Fossil energy, as the main energy source in existence, also has a sharp decline in the amount of earth's storage. After the use of fossil fuels, the resulting pollution problem is also becoming increasingly serious. Therefore, mankind is eager to find a clean energy instead of traditional energy, in order to solve the existing energy shortage and pollution problems [1]. Because of its reproducibility, cleanliness, inexhaustibility, and inexhaustibility, solar energy is being developed into an important part of the world's energy composition. In recent years, the domestic government has issued a series of related major policies to develop solar energy and encourage the application of solar energy equipment throughout the country. In China's northwest and Inner Mongolia, large-scale solar power plants have been gradually built and put into use [2]. However, at present, the efficiency of solar energy is still



very low. Its intermittency and volatility are significant. In the process of photovoltaic power generation, the solar light intensity, working temperature, and load characteristics greatly affect the output characteristics of photovoltaics. Nonlinearity. However, at a certain temperature and light intensity, photovoltaic has the maximum output capability. Therefore, in order to increase the working efficiency and make the photovoltaic cell always work near the maximum power point(MPP), the maximum power point needs to be tracked, that is, maximum power point tracking (MPPT).

At present, the traditional MPPT methods include Per-turb and Observe Algorithms, Incremental Conductance, and Hill-Climbing. The disturbance observation method is more commonly used [3]. The method does not need to know the characteristics of the photovoltaic cell, the structure is simple, the tracking speed is fast, and it is easy to implement. However, the rapidity of perturbation observations comes at the expense of accuracy. Therefore, in practical applications, it is often necessary to compromise the two. In addition, the traditional perturbation observation method will produce oscillation near the MPP when the system is in a steady state, which will cause energy loss to a certain extent [4]. Therefore, an MPPT method based on fuzzy control algorithm is proposed to optimize the perturbation observation method and to improve the power generation efficiency of photovoltaic cells to some extent.

The MPPT method based on fuzzy control algorithm is a new type of photovoltaic MPPT method combined with perturbation observation method. The fuzzy logic control method has obvious intelligence, and is more suitable for strong nonlinear systems such as photovoltaic cell output power, and the fuzzy algorithm can further improve the tracking speed, eliminate static errors, make up for the insufficiency of disturbance observation method, and the overall performance is good. The dynamic performance [5]. In this paper, the photovoltaic cell model and Boost circuit are built under the Simulink environment. Two methods are used to control the simulation. The power tracking speed is compared with the fluctuation of the power when the system is stable, thus verifying the fuzzy control algorithm of the photovoltaic MPPT method. Effectiveness.

2. Modeling of photovoltaic cells

Photovoltaic cell modeling is divided into many types, including ideal model, dual diode model, power model, etc. This paper uses an ideal model containing loss to build the photovoltaic cell MPPT system. The photovoltaic cell model with loss is generated by multiple Photocurrent diodes are connected in series and in parallel, and increase with the increase of light intensity, but have a negative correlation with temperature [6]. When ambient light and temperature are constant, photovoltaic cells can be regarded as constant current sources and their equivalence. The circuit diagram is shown in Fig.1.

Among them, I_{ph} represents the excitation current of the photon in the photovoltaic cell, I_d is the total diffusion current of the internal PN junction of the solar cell, R_s is the series resistance, R_{sh} is the parallel resistance, the load-circuit current is I_L , and the load voltage is U_L .

According to Figure 1, the equivalent mathematical model of a photovoltaic cell can be obtained:

$$I = I_{ph} - I_d \left\{ \exp\left[\frac{q(U_{oc} + I_{sc}R_s)}{AKT}\right] - 1 \right\} - \frac{U_{oc} + I_{sc}R_s}{R_{sh}} \quad (1)$$

In the formula: q is the amount of charge; I_{sc} is the short-circuit current; U_{oc} is the open circuit voltage; A is the diode factor parameter; K is the Boltzmann constant ; T is the absolute temperature of

the photovoltaic panel battery [7].

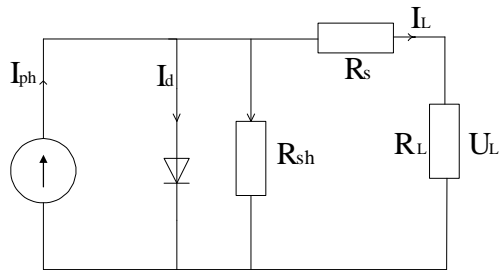


Figure 1. Photovoltaic cell equivalent model

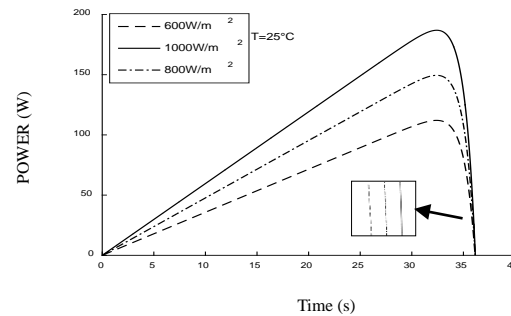


Figure 2. Photovoltaic panel output characteristic curve under different lighting conditions

3. The Principle of Maximum Power Tracking

Through this mathematical model, the physical model of the photovoltaic cell is set up in the Simulink environment, and the characteristics of the photovoltaic cell under different lighting conditions are simulated, as shown in Fig. 2.

As can be seen from Fig. 2 when the light intensity is different, the output power of the photovoltaic panel battery is not the same, and the voltage is also the same, and the output power and the voltage both show a positive correlation with the light intensity. According to the mathematics relationship, under the same conditions, the maximum power output of the photovoltaic panel is exactly when the slope is zero, that is:

$$\frac{dp}{du} = 0 \quad (2)$$

The disturbance observation method is the most representative of many self-optimizing MPPT control methods. The essence of this method is to use the formula (2) as a criterion to change the magnitude of the voltage so as to achieve power tracking. From the circuit theory analysis, according to the principle and the maximum power theorem, we can see that when the load impedance and the circuit Thevenin equivalent impedance match, then the load to obtain the maximum power.

In a typical photovoltaic power generation system, and referring to Fig.2, the movement of the MPP is not due to a change in the load, but because the photovoltaic panel battery itself constantly changes the internal equivalent impedance as the external conditions change. Therefore, in order to make the photovoltaic panel maintain the maximum power operation mode, the load impedance needs to be changed accordingly, so as to achieve the purpose of impedance matching. Therefore, in the system circuit, the power conversion circuit is often added between the photovoltaic panel battery and the load. Boost circuit is used in this paper. The system circuit is shown in Fig.3[8].

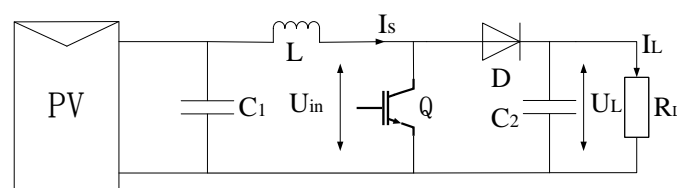


Figure 3. System circuit diagram

In the working process of the Boost circuit, the relationship between the input impedance and the output impedance can be obtained according to the power conservation and the working principle of the Boost circuit, that is:

$$R_{in} = (1 - \alpha)^2 R_L \quad (3)$$

In the formula, R_{in} is the input impedance, R_L is the load, and α is the duty cycle.

From equation (3), we can see that changing the duty cycle can adjust the output impedance. Therefore, the adjustment voltage is usually converted into the adjustment of the duty cycle. which is:

$$\frac{dP}{d\alpha} = 0 \quad (4)$$

4. Fuzzy theory control algorithm

Fuzzy control is an intelligent algorithm based on human fuzzy concepts. It has strong nonlinearity, robustness, adaptability and fault tolerance. It provides powerful tools for dealing with nonlinear systems that are nonlinear, time-varying, and difficult to build mathematical models [9]. Due to the randomness and instability of the illumination, the quality of the power generated by the photovoltaic cells is also poor and affects the maximum power output of the photovoltaic cells. Therefore, the fuzzy control technology can be applied to the control of the MPPT of the photovoltaic system.

According to the analysis of the maximum tracking principle, the power and duty ratio at the MPP have the same relationship as the voltage. So this paper directly takes the duty cycle as the output of fuzzy control. The direct control of the duty cycle is utilized to increase the tracking speed of the system to the maximum power and to reduce the oscillation degree of the system near the MPP.

Fuzzy control is mainly divided into four modules: fuzzy input signal, fuzzy rule base, fuzzy reasoning and de-fuzzification. The difference between the input signal and the rate of change of the difference is collected by the sensor, quantified and passed to the fuzzification module, and the specific quantity is converted into a fuzzy quantity. Then fuzzy reasoning is performed according to the fuzzy rule library to obtain a fuzzy form of control quantity, and finally control is performed. The signal deblurring gives a specific amount to the controlled unit, which in turn implements fuzzy control [10].

In this paper, the power difference e at the two moments before and after and the rate of change ce of the power difference are taken as the input, and the duty cycle of the Boost circuit is used as the controlled variable, that is:

$$\begin{cases} e = P(k+1) - P(k) \\ ce = \frac{P(k+1) - P(k)}{U(k+1) - U(k)} \end{cases} \quad (5)$$

In the formula, $P(k)$ and $U(k)$ represent the k -th sampled value. When ce is zero, the system has stabilized at the MPP. The inputs and outputs designed in this paper have 7 fuzzy subsets, namely $\{NB, NM, NS, ZE, PS, PM, PB\}$, and they have the same domain as $\{-3, -2, -1, 0, 1, 2, 3\}$. According to the characteristics and requirements of the system, the input and output are triangles as membership functions. In addition, fuzzy control rules are the core of the entire controller and directly determine the success or failure of the maximum power point. Therefore, according to a large number of

experiments and theoretical analysis, the following fuzzy physical rules are obtained:

(1) If $e > 0$ and $ce > 0$, then the operating point is tracked from left to right to find the MPP. At this time, it is necessary to ensure that the state of the duty cycle is the same as the original state, so as to continue to find the MPP of the system.

(2) If $e > 0$ and $ce < 0$, then the operating point is on the right side of the MPP and is approaching it. Therefore, the original duty cycle state should be maintained and the operating point should be maintained. Return to MPP.

(3) If $e < 0$ and $ce < 0$; then the operating point is to the right of the MPP and continues to move away from it. At this time, the duty cycle status should be quickly adjusted to be opposite to the original status.

(4) If $e < 0$ and $ce > 0$, the operating point is to the left of the MPP and continues away from it. Therefore, it is urgent to adjust the duty cycle state to make it the opposite and restore the tracking of the MPP.

The above four rules are all general reasoning about the duty cycle. When the external conditions change, the power fluctuates, and the degree of the specific adjustment state also depends on the distance of the working point from the MPP. Therefore, it is necessary to carry out many experiments and eventually summarize the rule base and fuzzy reasoning applicable to photovoltaic power generation systems.

Table 1. Fuzzy Controller Rules Table

| $\Delta\alpha$ \ ce | | e | | | | | | |
|-----------------------|----|-----|----|----|----|----|----|----|
| | | NB | NM | NS | ZE | PS | PM | PB |
| e | NB | PB | PB | PM | PS | NM | NB | NB |
| | NM | PB | PM | PM | PS | NM | NM | NB |
| | NS | PB | PM | PS | ZE | NS | NM | NB |
| | ZE | PM | PS | PS | ZE | NS | NS | NM |
| | PS | PS | PS | ZE | ZE | ZE | NS | NS |
| | PM | PS | PS | ZE | ZE | ZE | NS | NS |
| | PB | PS | ZE | ZE | ZE | ZE | ZE | NS |

According to the above principle, the fuzzy inference table shown in Table 1 can be obtained by applying the fuzzy rules of IF A AND B and THEN C.

According to Table 1, there are 49 fuzzy rules, each representing a fuzzy reasoning. For example, e is NB, indicating that the current operating point is far away from the MPP, ce is NB, indicating that the current operating point is on the right side of the MPP and is far from the MPP. The result of the inference is PB, the perturbation amount of the duty cycle should be increased, and the output of the photovoltaic panel voltage is reduced in a short time, that is, the operating point is moved to the left. Its complete inference expression can be expressed as: If e is NB AND ce is NB, then $\Delta\alpha$ is PB.

The fuzzy inference uses MAX-MIN's reasoning method to obtain the size and direction of disturbance by fuzzy inference on e and ec . However, the quantity at this time belongs to the fuzzy quantity and the weight is added. Therefore, the fuzzy control is required to apply the control signal.

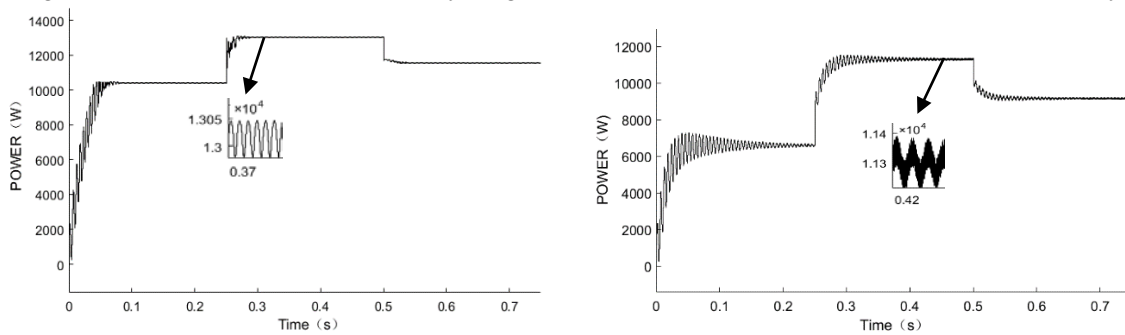
To the controlled unit. There are many ways to solve the problem of blurring. Generally, the maximum degree of membership method and the area-based method are used. This article uses the area center of gravity method, and its formula is shown in formula (6).

$$\Delta\alpha_0 = df = \frac{\sum_{i=1}^n \mu(\Delta\alpha_i) \Delta\alpha_i}{\sum_{i=1}^n \mu(\Delta\alpha_i)} \quad (6)$$

In the formula, the precise value output by the fuzzy controller is the corresponding weight value. The membership function determines the linguistic variables corresponding to e and ec . The weights are calculated by the fuzzy inference algorithm.

5. Simulation analysis

The system model was built in the Simulink environment, and the MPPT control model was built using the relevant modules of the Fuzzy-Logic-Toolbox in the environment for simulation analysis.



(a) Fuzzy Control Simulation Waveform (b) Perturbation observing simulation waveforms

Figure 4. System Simulation Waveform

Because the temperature has little effect on the experimental results, the temperature is not described in detail in this paper. Only the change of the light intensity is analyzed and discussed. The temperature was set 25°C, and the light intensity was changed from 800W/m² to 1000W/m² and then to 900W/m². The system simulation time is 0.75s. The simulation uses ode45 algorithm. In order to verify the effectiveness of the fuzzy adaptive algorithm, this paper will build a disturbance observation system under the same conditions and conduct comparative analysis. The simulation diagram is shown in Fig.4.

By comparing and analyzing (a) and (b) in Fig.4, it is not difficult to conclude that the fuzzy control algorithm is better than the perturbation observation method both in terms of power tracking speed and tracking accuracy. The results obtained from the fuzzy control algorithm show that the MPP has been traced in less than 0.1 s, while the latter is relatively stable at about 0.2 s. In addition, when the MPP is tracked, the static error obtained by the MPPT method using the fuzzy control algorithm is small, only about 0.4%, and the result obtained by the perturbation observation method is 3 times that of the fuzzy control.

In the case of sudden changes in light intensity, the fuzzy control also shows a strong advantage, tracking the maximum point of system power in a short period of time and restoring the stability of the system, while the disturbance observation method can trace the MPP here, but it takes longer.

In summary, from the analysis of steady-state error and dynamic performance, the MPPT constructed by the fuzzy control algorithm presented in this paper all performs better, especially in

tracking speed and accuracy. Once again, the superiority of fuzzy control over disturbance observation method is proved.

6. Conclusion

This paper mainly elaborates the detailed process of constructing MPPT by fuzzy control algorithm, and briefly introduces the basic principle of traditional disturbance observation method. By setting up the system physical model in the Simulink environment for simulation analysis, it is concluded that the fuzzy control algorithm is superior to the perturbation observation method in static error and dynamic response, taking into account the accuracy and speed, and making up for the insufficiency of the perturbation observation method. The feasibility of the new method.

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