Chapter 95
Improved MPPT Method Applied to PV System

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Abstract This paper considers the maximum power point tracking (MPPT) problem of the photovoltaic array, an improved method (the application of genetic algorithms to optimize the fuzzy controller) is presented based on fuzzy control. The simulation results are shown in different external environment conditions. It can be concluded that the proposed method can quickly track the maximum power point of photovoltaic arrays, and also reduce the maximum power point oscillation energy loss. Therefore, the energy conversion efficiency of photovoltaic power generation system is improved.

Keywords Maximum power point tracking (MPPT) · Photovoltaic · Fuzzy control · Genetic algorithm

95.1 Introduction

At present, as the growing energy crisis and environmental issues, it has become a global concern for effective and rational use of existing resources. The photovoltaic power generation is a broad prospect of green energy, and has become the

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hotspot of domestic and international academic and industrial research. The bottleneck problem of the photovoltaic cell research is the low efficiency of photoelectric conversion. In order to solve this problem, an effective measurement of maximum power point tracking Maximum Power Point Tracking (MPPT) is employed to improve the efficiency of the PV system [1–3]. This approach allows to maximize the power output of photovoltaic cells in load and environmental conditions.

Traditional MPPT control methods include the constant voltage method, perturbation and observation method and the incremental conductance method and so on [4]. But in practical application, there are various shortcomings for different methods. Recently, control based on smart technology becomes a common method [5]. In this paper, the fuzzy control technique is applied to the MPPT control, and genetic algorithms are used to optimize the fuzzy controller, which can further improve the performance of the MPPT controller. Simulation results show that this method can effectively improve the system's ability to respond with changes of the external environment and reduce the oscillations around the maximum power point.

95.2 Characteristics of Photovoltaic Cells

The relations between current and voltage of photovoltaic cell output is given by

$$I = I_S - I_0\left\{\exp\left[\frac{q}{AKT}V\right] - 1\right\} \tag{95.1}$$

where, I is photovoltaic cell output current, I_s is short circuit current, I_0 is the reverse saturation current, q is charge constant, A is p-n junction coefficient of semiconductor devices in Photovoltaic cells, K is Boltzman constant, T is absolute temperature, and V is the output voltage of Photovoltaic cell.

Photovoltaic cell is neither a constant voltage source, nor the constant current source, but a non-linear DC power supply. Its output current is approximately constant in the most range of the work. However, when it's up to the open circuit voltage, the current sharply declines. From Fig. 95.1a and b, maximum output power of the PV array varies with the sunlight intensity and temperature. Therefore, it is necessary to control maximum power point tracking of photovoltaic arrays so that the array can obtain maximum power output under any conditions [6].

95.3 Fuzzy Controller Design

The Fuzzy inference system [7] is shown in Fig. 95.2. Mamdani fuzzy inference method is used and the defuzzification is utilized as the method in the area center of gravity.

Fig. 95.1 PV curves with the external environment variation. **a** Curve of solar radiation intensity. **b** Curve of the temperature changes
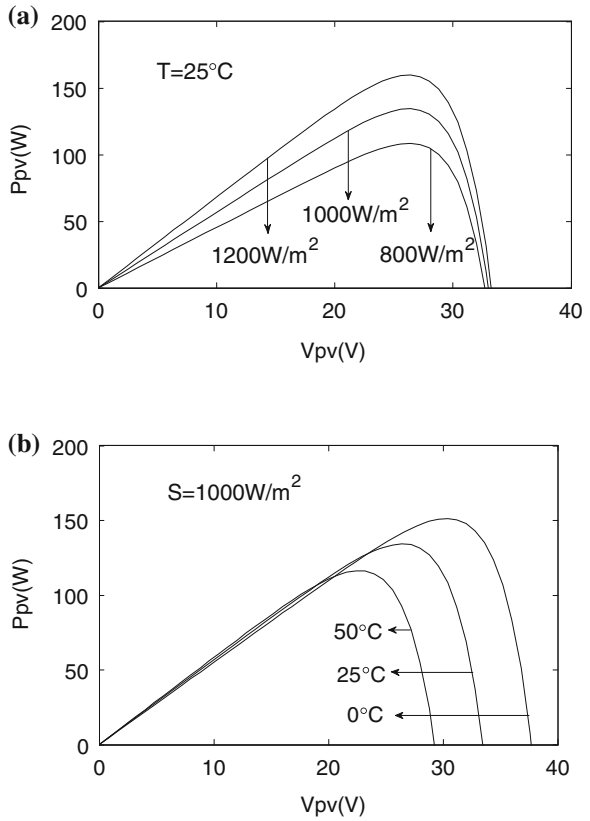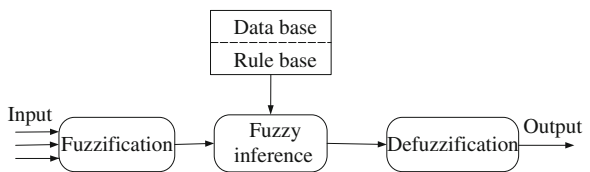
(a)

(b)

Fig. 95.2 Fuzzy inference system

95.3.1 Input and Output of Fuzzy Controller

The two inputs of the fuzzy controller are the error E and error change CE. The error E and error change CE have been defined in formula (95.2) and (95.3), and the output is duty cycle change of switching device in the MPPT circuit.

$$E(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{v_{pv}(k) - v_{pv}(k-1)} \tag{95.2}$$

$$CE(k) = E(k) - E(k-1) \tag{95.3}$$

where, P_{pv} is PV output power and v_{pv} is PV output voltage.

95.3.2 Membership Function

Membership function includes normal type, triangular, rectangular, Gaussian and other forms [8]. In this paper the triangle membership function is used. Traditional triangular membership functions are shown in Fig. 95.3a.

In order to improve the performance of the fuzzy controller, the genetic algorithm is used to find the optimal membership function. Specific steps are as follows:

(1) Establishment of the initial population

Two inputs $E(k)$, $CE(k)$ and an output dD are used in fuzzy controller design. Each variable are described by five membership functions. The group includes a certain number of individuals, and each individual is composed of three chromosomes: $E(k)$, $CE(k)$ and dD, which is described as follows:

(a) the gene of chromosome $E(k)$: A_1, A_2, A_3, A_4 are changing in the interval (0, 1).
(b) the gene of chromosome $CE(k)$: B_1, B_2, B_3, B_4 are changing in the interval (0, 1).
(c) the gene of chromosome dD: C_1, C_2, C_3, C_4 are changing in the interval (0, 1).

The respective relationships between each gene and x_i, y_i, z_i are denoted by

$$\begin{cases} x_1 = (A_4 + A_3) \times (-20) \\ x_2 = A_3 \times (-20) \\ x_3 = A_1 \times 20 \\ x_4 = (A_1 + A_2) \times 20 \end{cases} \quad \begin{cases} y_1 = (B_4 + B_3) \times (-20) \\ y_2 = B_3 \times (-20) \\ y_3 = B_1 \times 20 \\ y_4 = (B_1 + B_2) \times 20 \end{cases}$$

$$\begin{cases} z_1 = (C_4 + C_3) \times (-6) \\ z_2 = C_3 \times (-6) \\ z_3 = C_1 \times 6 \\ z_4 = (C_1 + C_2) \times 6 \end{cases}$$

The schematic of the individual is shown in Fig. 95.4. In this paper, the groups containing 100 individuals are used to obtain the optimal solution.

(2) Applying the following fitness function to select:

$$J = \int_0^{t_f} (P_{\max} - P)^2 dt$$

where, P is the ideal power and $P_{\max}$ is the maximum output power of the module under standard conditions. The ways to produce the next generations are as follows:
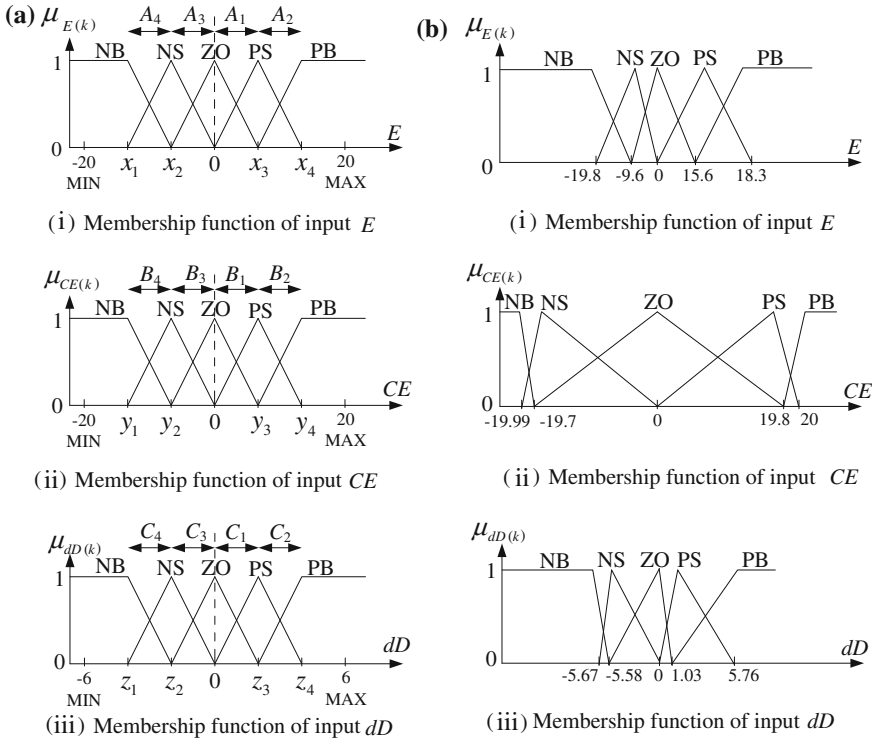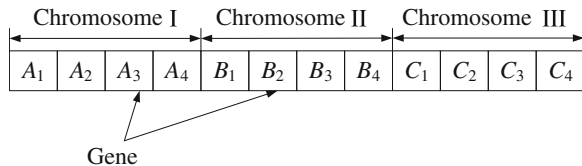
Fig. 95.3 The membership functions of fuzzy input and output variables. **a** Traditional membership function. **b** Optimized membership function

Fig. 95.4 Description of an individual

(1) The crossover operator: the continuous variables of a crossover probability are equal to 1 and the distribution of index $n = 5$.
(2) Variation: the use of continuous variables, the probability $P_m = 1/N_g = 1/12$, and distribution of index $n = 5$.
(3) Implementation of the restructuring: the optimal strategy. Parent population and offspring population are put together, selecting the best N individuals into new populations.
(4) Termination conditions: Computation is terminated when the largest genetic generation is up to 60, then the fitness function achieves the minimum.

(3) Optimization of membership function

The above process enables the system gradually achieve the optimal solution. In the last generation, the best individual of the population represents the optimal solution. The individual is given based on the parameter requirements. The optimal solution is obtained given the shape of the membership function, as shown in Fig. 95.3b.

95.3.3 Fuzzy Decision

The fuzzy rules, which are the core of the fuzzy controller, can be established according to whether the power output of photovoltaic cells is able to quickly reach a given scope of the request or not. The fuzzy rule IF A AND B then C is used [9], and the final fuzzy rules are shown in Table 95.1.

95.4 Simulation and Results Analysis

Figure 95.5 shows the simulation system block diagram. The system consists of photovoltaic modules, DC/DC converter, and the fuzzy logic controller. Simulations are employed by Matlab/Simulink [10], and under the standard state that the temperature T = 25 °C, light intensity R = 1000 W/m^2, the photovoltaic cell output power waveform is shown in Fig. 95.6.

Further test of the system performance are shown in the following steps

(1) R = 1000 W/m^2 is constant and temperature slowly roses from 25 to 30 °C at the time of 0.05–0.15 s.
(2) T = 25 °C is constant and light intensity slowly rise from 1000 to 1200 W/m^2 at the time of 0.05–0.15 s.

With the external environment variation, the waveform of the output power of the photovoltaic cells is shown in Fig. 95.7.

The simulation results show that the optimized fuzzy MPPT controller possesses excellent performance. As can be seen in Fig. 95.6, the output power of photovoltaic cells can be stabilized at maximum power point in the 5 ms. Meanwhile, the steady-state tracking accuracy is up to 99.9 % and steady state accuracy is close to 100 % under standard conditions. It can be seen from Fig. 95.7 that the photovoltaic cells can quickly and accurately track the alternation as the external environment varies. The law is compliance with the output characteristics of photovoltaic cells and the new maximum power point can be obtained with very high tracking accuracy.

Table 95.1 Fuzzy control rule table

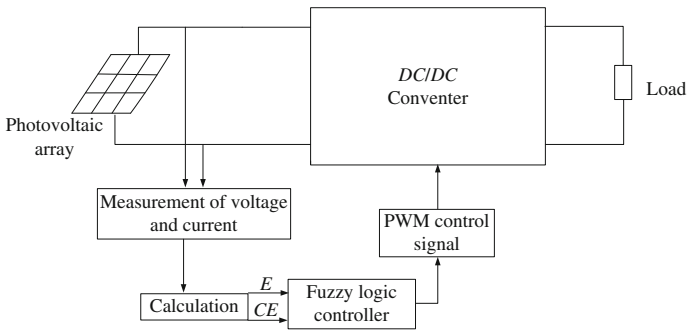| E	CE				
	NB	NS	ZO	PS	PB
NB	ZO	ZO	PB	PB	PB
NS	ZO	ZO	PS	PS	PS
ZO	PS	ZO	ZO	ZO	NS
PS	NS	NS	NS	ZO	ZO
PB	NB	NB	NB	ZO	ZO

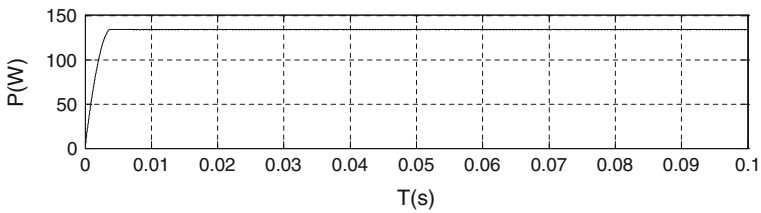**Fig. 95.5** Basic block diagram of the system

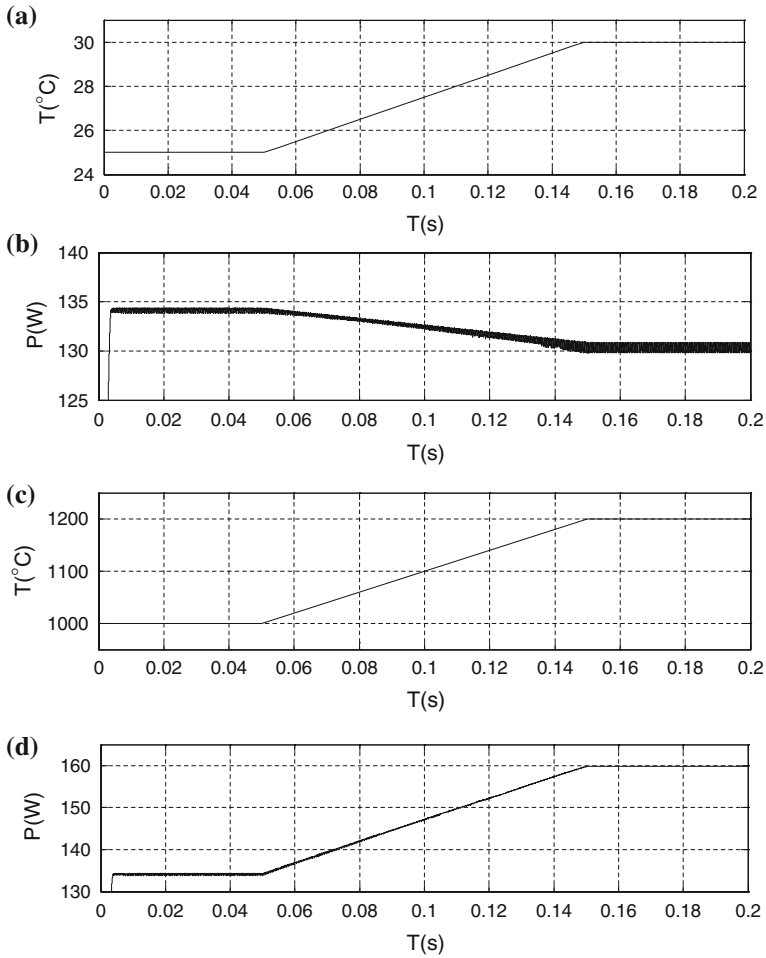**Fig. 95.6** Output power waveform in the standard state

Fig. 95.7 Output power waveform with external environment change. **a** Temperature curve. **b** Temperature curve. **c** Light intensity curve. **d** The battery output power waveform with light intensity change

95.5 Conclusions

In order to improve the conversion efficiency of PV systems under different temperatures and light intensities, the fuzzy control is applied in the MPPT of photovoltaic cells. Firstly, the MPPT controller based on fuzzy logic control technology is designed. In order to improve the performance of the controller, the genetic algorithm is used to obtain the optimal membership function. Then, we test the optimized fuzzy MPPT controller under different conditions of temperatures and light intensities. Optimized controller shows the expected tracking performance, and has a high control accuracy and stability.

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