MPPT research based on fuzzy adaptive PID control

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Abstract: In order to improve the efficiency and precision of maximum power point tracking (MPPT) control, a new method is proposed. Based on original MPPT technology of photovoltaic cells, the fuzzy adaptive proportion-integral-differential (PID) control has less fluctuation and higher stability. The simulation circuit using Simulink is established, and output power curves under constant temperature or constant sunlight are obtained. The superiority of the fuzzy PID control method has been proved by means of the simulation results, and it makes the solar system approach maximum power point quickly and smoothly.

Key words: photovoltaic cells; fuzzy proportion-integral-differential(PID); maximum power point tracking(MPPT); simulink

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As a kind of renewable energy, solar energy has got more and more attention in recent years. For the utilization of solar energy, energy efficiency is a particularly important factor. The proposal of maximum power point tracking (MPPT) method has greatly improved the energy efficiency. The traditional MPPT methods include fixed voltage method, perturbation and observation method, etc., among which perturbation and observation method is the most commonly used method. However, the traditional methods have low precision and much fluctuation, which bring risks to the operation of the load. In this paper, a proportion-integral-differential (PID) control method based on fuzzy adaptive control tuning is proposed. Contrasted with the traditional PID control methods, this method greatly improves the robustness and anti-jamming capability of the system.

1 Characteristics of photovoltaic cells

1.1 Mathematical model of photovoltaic cells

Photovoltaic cells are semiconductor devices which turn solar energy into electrical energy. A photovoltaic cell is composed of a current source, a diode and a resistor[1-4]. The equivalent circuit of the cell is shown in Fig. 1, where I and U are the output voltage and output current of the photovoltaic cell group, respectively. And as a non-linear power, its parameters are influenced by the external environments and loads.

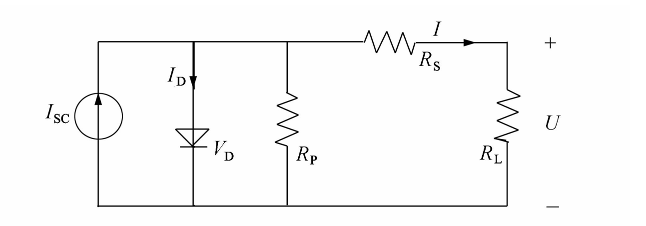

Fig. 1 Equivalent circuit of photovoltaic cell

According to the equivalent circuit, the following equations can be listed.

$$I = I_{SC} - I_D - \frac{V_D}{R_P},$$

$$I_D = I_0(e^{V_D/V_P} - 1),$$

$$U = V_D - R_S I, \tag{1}$$

$$I = I_{SC} - (I_o(\exp(\frac{q(U + IR_S)}{AKT}) - 1) - \frac{U + IR_S}{R_P}, \tag{2}$$

$$I_o = I_{or}(\frac{T}{T_r})^3 \exp(\frac{qE_G}{AK}(\frac{1}{T_r} - \frac{1}{T})), \tag{3}$$

$$I_{SC} = (I_{SCR} + K_i(T - 298))\frac{S}{1\,000}, \tag{4}$$

where I_{SC} represents photocurrent; I_{SCR} is short-circuit current of the cell under standard test condition

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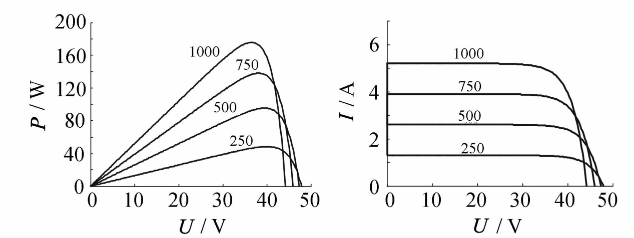
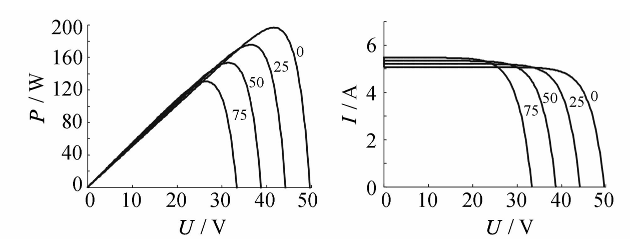
with temperature 298 K and sunlight 1 000 W/m^2; I_o is saturation current; K represents Boltzmann constant, $K=1.38\times10^{-23}$ J/K; T is the temperature of the battery; T_r is the reference temperature; E_G is the band width of Silicon; K_i is temperature coefficient; S is light intensity. According to the mathematical model, the output characteristic curves of the photovoltaic cells can be simulated.

1.2 Output characteristic curves of the photovoltaic cells

According to the mathematical model, a sub module of the photovoltaic cell is established by Simulink of Matlab. Through the simulation of the features of the cell under different temperatures and sunlights, the output characteristics under constant sunlight and constant temperature are obtained.



(a) *P-U*, *I-U* curves under constant temperature (25 ℃) and diverse sunlights (W/m^2)



(b) *P-U*, *I-U* curves under constant sunlight (1 000 W/m^2) and diverse temperatures (℃)

Fig. 2 Characteristic curves of the photovoltaic cells under different external environments

The characteristic curves show there are always only one maximum power point (MPP) under fixed temperature and sunlight[5-7]. If the cell can keep working at MPP, the efficiency of solar energy can reach the maximum.

2 MPPT based on fuzzy tuning adaptive PID control method

PID control has advantages of simple structure, high stability and high reliability[8]. This method is suitable for control system which has mathematical models. By introducing PID control into MPPT, the system can obtain more accurate MPP. PID control needs to tune the parameters. Fuzzy control has weak dependence on the mathematical model, so there is no need to establish accurate models. According to the basic theories and methods of fuzzy mathematics, the conditions and operations of the rules can be expressed by fuzzy sets. Adding the fuzzy rules as well as other information like evaluation and the initial PID parameters to computer, then according to the response of the computer, and using fuzzy inference, the best adjustment of the PID parameters can be automatically got.

2.1 Structure of fuzzy adaptive controller

Fuzzy adaptive ID controller has two inputs and three outputs. Two-dimensional fuzzy controllers usually input given deviation and the variation of the given deviation[9-11]. These controllers have better response to the dynamic performance of the controlled object taking shorter computation time. So fuzzy controllers choose error signal

$$e(k)=\Delta P(k)=P(k)-P(k-1), \quad (5)$$

and error variation

$$ec(k)=\frac{\Delta P(k)}{\Delta U(k)}=\frac{P(k)-P(k-1)}{U(k)-U(k-1)}, \quad (6)$$

as inputs, choose Δk_p, Δk_i and Δk_d as outputs. The system schematic is shown in Fig. 3.

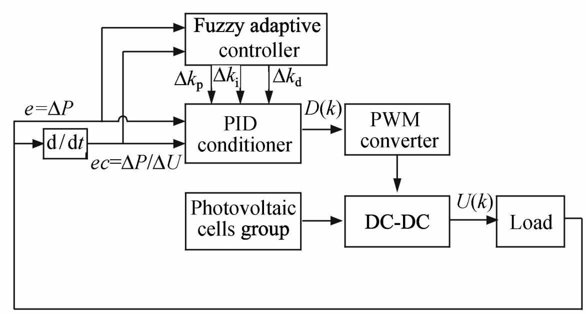


Fig. 3 System schematic

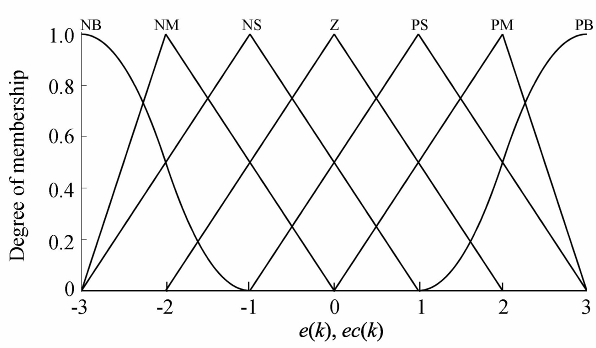


Fig. 4 Membership curves of $e(k)$, $ec(k)$

2.2 Definition of input and output fuzzy sets and membership functions

Divide error $e(k)$ and error variation $ec(k)$ into seven fuzzy sets: negative big (NB), negative middle (NM), negative small (NS), zero (Z), positive small (PS), positive middle (PM), positive big (PB). The membership curves of $e(k)$ and $ec(k)$ are shown in Fig. 4. Similarly, the PID parameters can be divided into seven fuzzy sets too.

2.3 Establish fuzzy control rule

Establish fuzzy control rule table of k_p, k_i, k_d. Find out the PID correction value from the fuzzy control rule table, obtain amended PID parameters through the following formulas

$$k_p = k_p' + \Delta k_p = k_p' + \{e_i, ec_i\}_p, \quad (7)$$

$$k_i = k_i' + \Delta k_i = k_i' + \{e_i, ec_i\}_i, \quad (8)$$

$$k_d = k_d' + \Delta k_d = k_d' + \{e_i, ec_i\}_d. \quad (9)$$

Table 1 Fuzzy control rule table

$e(k), ec(k)$	NB	NM	NS	ZO	PS	PM	PB
NB	PB/NB/PS	PB/NB/NS	PM/NM/NB	PM/NM/NB	PS/NS/NB	ZO/ZO/NM	ZO/ZO/PS
NM	PB/NB/PS	PB/NB/NS	PM/NM/NB	PS/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/ZO/ZO
NS	PM/NB/ZO	PM/NM/NS	PM/NS/NM	PS/NS/NM	ZO/ZO/NS	NS/PS/NS	NS/PS/ZO
ZO	PM/NM/ZO	PM/NM/NS	PS/NS/NS	ZO/ZO/NS	NS/PS/NS	NM/PM/NS	NM/PM/ZO
PS	PS/NM/ZO	PS/NS/ZO	ZO/ZO/ZO	NS/PS/ZO	NS/PS/ZO	NM/PM/ZO	NM/PB/ZO
PM	PS/ZO/PB	ZO/ZO/NS	NS/PS/PS	NM/PS/PS	NM/PM/PS	NM/PB/PS	NB/PB/PB
PB	ZO/ZO/PB	ZO/ZO/PM	NM/PS/PM	NM/PM/PM	NM/PM/PS	NB/PB/PS	NB/PB/PB

3 Simulation and result analysis

Main circuit is established in Simulink. Boost circuit is selected as DC-DC circuit. IGBT is chosen as power switch, and gravity is used for defuzzification. Fuzzy-PID sub-module is established. The values of the initial PID parameters are $k_p = 0.25$, $k_i = 1$, $k_d = 0.05$. Sampling time is 0.01 s. The fuzzy PID controller sub-module is shown in Fig. 5, which is the core of the arithmetic.

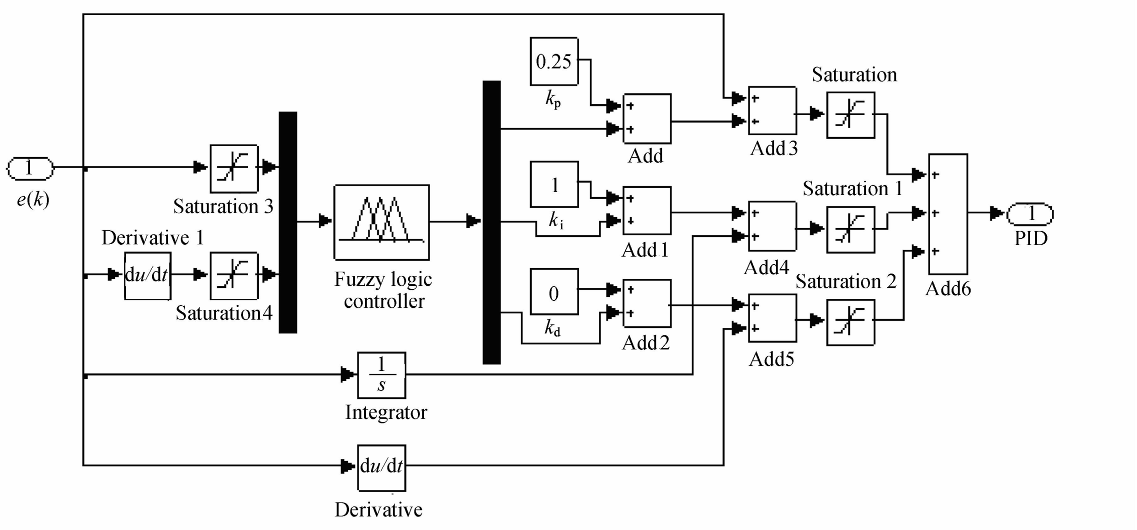


Fig. 5 Fuzzy PID controller sub-module

Two power curves are obtained from the simulation. One is simulated where constant temperature but changing sunlight, which is shown in Fig. 6. The other is in the constant sunlight but changing temperature, which is shown in Fig. 7.

The curves illustrate that when parameters of environment change, although the power curves have oscillation, they converge steadily and quickly. The output power reaches the maximum point quickly, which reflects the good performance of the system.

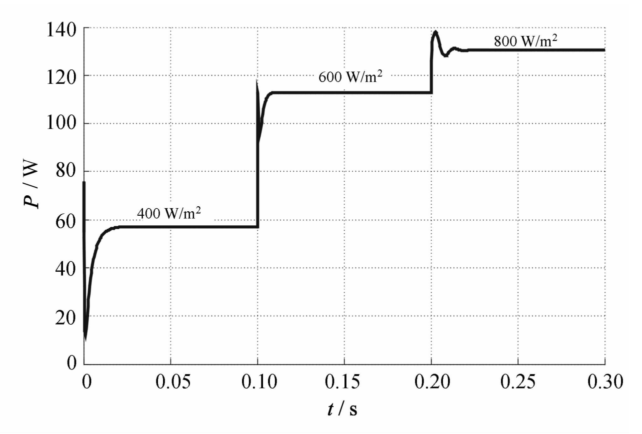


Fig. 6 Power curve while temperature maintaining 25 ℃

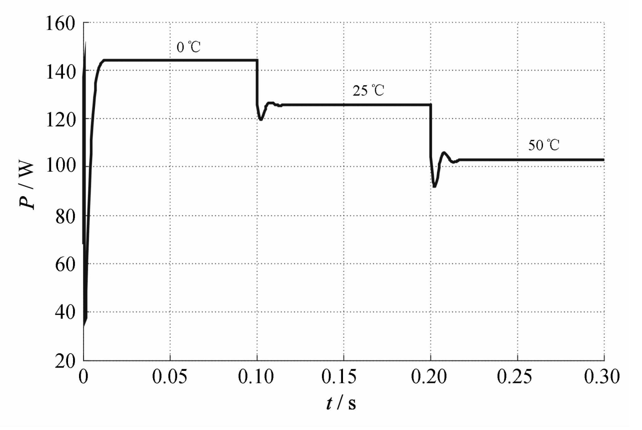


Fig. 7 Power curve while sunlight maintaining 700 **W/m**^{2}

4 Conclusion

Through the results from the simulation of fuzzy PID control method, the stability and quickness of the system can be proved. When external environment changes, the system takes less than 0. 02 s to adjust to the new surroundings and find the exact MPPs. As a result, the utilization of solar energy as well as the safety of the circuit loads are guaranteed.

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