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Research Article

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Study on tracking control of maximum power point for chemical photovoltaic power system

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ABSTRACT

In order to achieve the tracking control of maximum power point for chemical photovoltaic system, and improve the transferring efficiency of solar energy, the fuzzy PID controller is applied in it. Firstly, the working theory of photovoltaic cell is analyzed. Secondly, the fuzzy PID controller of maximum power point of chemical photovoltaic system is designed. Finally, the controlling simulation of tracking control of maximum power point is carried out, and the results show that the fuzzy PID controller can get good controlling effect.

Key words: Chemical Photovoltaic Power System; Maximum Power Point; Control

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With economic growth and social progress, seeking new sources of energy is an urgent task that mankind faces. The solar energy is an inexhaustible and endless source. Solar power with high efficiency and non-pollution has been concerned, which is unrestricted in region. Photovoltaic power is a main form of using solar power, which has vast prospect for development. The photovoltaic power has been applied in chemical industrial park widely. The rich chemical raw materials in chemical industrial park can offer sufficient resource support for photovoltaic industry, and reduce the production costs of chemical enterprise. There have always been some problems in photovoltaic power system. The output characteristics of photovoltaic cell are greatly affected by the external environment, such as environmental temperature and outer light intensity. In addition, the conversion efficiency of photovoltaic cell is low, and the price is high, then the initial input is big. Then it is necessary to find out an effective method to improve the conversion efficiency of photovoltaic cell. The maximum power point tracking circuit is collected between photovoltaic cell and load [1].

In recent years, a lot of algorithms of maximum power point tracking have been put forward, such as perturbation and observation method, incremental conductance method and constant voltage tracking method. The current algorithms are simple and easy to implement, however there are many disadvantages, for example, the convergence speed is low, and the steady state stability is poor. In order to avoid the defects, the traditional algorithm has been improved, the adaptive step is introduced, and the reliability and convergence speed can be obtained. But the working point can not be transferred to the maximum power point when the light strength changes suddenly. In order to reduce the stable error of system, the fuzzy PID controller is applied in it, the quick response ability of the photovoltaic power on outer environment can be improved, and stability near the maximum power point can be reduced, at the same time the PID controller can eliminate this oscillation [2].

Working theory of photovoltaic cell
T-V feature of the photovoltaic cell has something with light strength and environment temperature. In recent years, a lot of photovoltaic cell uses crystalline silicon as material. The equivalent circuit of the photovoltaic cell is shown in figure 1.

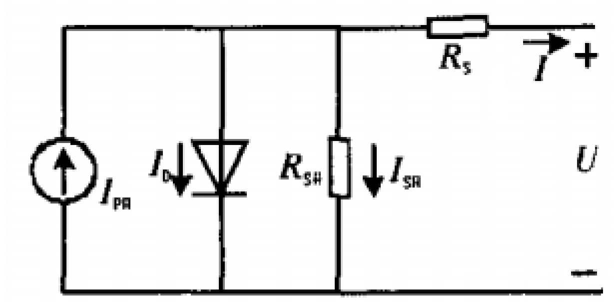

Figure 1 Equivalent circuit diagram of the photovoltaic cell

The output current and output voltage of the photovoltaic cell satisfies the following expression [3]:

$$I = I_{ph} - I_0[e^{\frac{q(V+R_s I)}{nKT}} - 1] - \frac{V + R_s I}{R_{sh}} \quad (1)$$

where, I denotes the output current of photovoltaic cell, A; I_{ph} denotes the photocurrent, A; I_0 denotes reverse saturation current A; q denotes quantity of electric charge, $q = 1.6\times10^{-19} C$; K denotes the Boltzmann constant, $K = 1.38\times10^{-23} J/K$; n denotes the ideal factor of photovoltaic cell plate, $n = 1-5$; T denotes the surface temperature of photovoltaic cell plate, K;

The saturation current without light can be calculated according to the following expression:

$$I_d = I_0[e^{\frac{q(V+R_s I)}{nKT}} - 1] \quad (2)$$

where I_d denotes the saturation current without light, A.

The engineering model of photovoltaic cell uses the short-circuit current I_{sc}, the short-circuit voltage V_{oc}, output current I_m at maximum power point, output voltage V_m at maximum power point offered by manufacturer, other electrical parameters of photovoltaic cell under different light strength and cell temperature can be obtained according to the following expressions [4]:

$$I_{sc}^{'} = I_{sc}\frac{S}{S_{ref}}(1 + A\Delta T) \quad (3)$$

$$V_{oc}^{'} = V_{oc}(1 - C\Delta T)\ln(e + B\Delta S) \quad (4)$$

$$I_m^{'} = I_m\frac{S}{S_{ref}}(1 + A\Delta T) \quad (5)$$

$$V_m^{'} = V_m\frac{S}{S_{ref}}(1 - C\Delta T)\ln(e + B\Delta S) \quad (6)$$

where $T = T_{air} + KS$, T_{air} denotes the environmental temperature, ℃, $\Delta T = T - T_{ref}$, $\Delta S = \frac{S}{S_{ref}} - 1$, $A = 2.5\times10^{-3}$ / ℃, $B = 6\times10^{-1}$ / ℃, $C = 3\times10^{-3}$ / ℃, S_{ref} denotes the reference light strength, $S_{ref} = 1\times10^3 W/m^2$,

Under a certain light strength and temperature, the photovoltaic power system can achieve the steady status of maximum power point. Near the maximum power point, the output power of photovoltaic power system can be expressed as follows:

$$P(t) = \frac{u_{PV}^2(t)}{R_{MPP}} \tag{7}$$

where $P(t)$ denotes output power, R_{MPP} denotes the resistance of the maximum power point. When output load of photovoltaic power system is equal to R_{MPP}, and the system can export maximum power.

The photovoltaic cell group is made up of many photovoltaic cells with a small unit in series or in parallel. The photovoltaic cell series combination can improve the maximum output direct current of chemical solar energy power system, and the photovoltaic cell parallelling combination can also improve it. Therefore the series or paralleling combination of photovoltaic cells can obtain the expected direct current or voltage, the output characteristics of the photovoltaic cells group is expressed as follows:

$$I = n_p I_{LG} - n_p L_{os}[e^{\frac{q(V+iR_s)}{n_s AkT}} - 1] \tag{8}$$

where n_p denotes the number of photovoltaic cells in series, n_s denotes photovoltaic cells in paralleling. I_{LG} denotes the light current, L_{os} denotes the dark saturation current.

Design of Fuzzy PID controller of maximum power point

The traditional PID controller has some disadvantages, for example, the structure is simple, and the performance is steady. However, it has some disadvantages, it can be affected by the disturbance, and the reliability is poor. The fuzzy control belongs to an intelligent controlling technology, has a good self adaptive characteristics, but the static error can not be eliminated during the procession of controlling the maximum power point of chemical photovoltaic power system. Therefore the fuzzy controlling technology and PID controller can be combined considering the above factors, the relating parameters of PID controller can be regulated according to the fuzzy controlling principle, the real time control of maximum power point of the of chemical photovoltaic power system can be achieved [5].

In order to control the maximum power point of photovoltaic power system, the fuzzy PID controller is applied in it. The conventional fuzzy PID has small exceeding regulation and slow response speed comparing with the traditional PID controller, however the fuzzy PID controller exists a lot of disadvantages, for example, and the fuzzy controller can be amended when it is designed, and the self-adaptivity of it is poor. If the input and output of fuzzy controller have big changes, only a part of principles can be applied. When the range of the discourse domain is small, the input and output of the fuzzy controller is out of range of the discourse domain, the fuzzy controller can not work effectively. When the range of discourse domain is big, the number of principles of the fuzzy controller is small, then the controlling precision can reduce, the function of fuzzy PID controller can not be developed.

In order to avoid the disadvantages, variable discourse domain is applied in it. The basic ideas of it are to reduce or improve the range and input value of discourse domain of fuzzy set simultaneously. The decrease and expansion of discourse domain can improve the fuzzy controlling number that affects it significantly, and then the controlling precision can be improved.

The main problem of the variable discourse domain is to confirm the optimal extension and contraction mechanism, then the optimal controlling effect can obtained. The input variable of the discourse domain X_i is defined as x_i, the output variable of the discourse domain Y is defined as y, the variable discourse domain refers that X_i and Y can regulate with changes of x_i and y.

The changed discourse domain can be expressed as follows [6]:

$$X_i^{'} = [-\alpha_i(x_i)E_i, \alpha_i(x_i)E_i] \tag{9}$$

$$Y' = [-\beta(y)U, \beta U(y)] \tag{10}$$

where, $\alpha_i(x_i)$ and $\beta(y)$ denote contraction-expansion factor of the discourse domains X_i and Y, the output of the variable discourse domain controller is expressed as follows:

$$u_{VFC}(x\beta) = \beta \sum_{k=1}^{m} \prod_{i=1}^{n} A_{ik} \frac{x_i}{\alpha(x_i)} y_k^0 \tag{11}$$

The contraction-expansion factors of the discourse domains are expressed as follows:

$$\alpha(x) = \left[\frac{|x_i|}{X_i}\right]^{\varepsilon_1}, \quad 0 < \varepsilon_1 < 1 \tag{12}$$

$$\beta(x) = \left[\frac{|y|}{Y}\right]^{\varepsilon_2}, \quad 0 < \varepsilon_2 < 1 \tag{13}$$

where ε_1 and ε_2 are the value factor of the minimum discourse domains, which has big effect on the controlling precision of the system, the value of ε_1 and ε_2 can be regulated according to the simulation analysis, and the final results are listed as follows: $\varepsilon_1 = 0.59, \varepsilon_2 = 0.35$.

The fuzzy theory and traditional PID controlling technology can be combined to construct the adaptive PID controller, the deviance $|e|$ and changing rate of deviance $|ec|$ are the function of proportion coefficient k_p, integrated coefficient k_i and differential coefficient k_d, the following the expression can be obtained [7]:

$$k_p = h_1(|e|,|ec|) \tag{14}$$

$$k_i = h_1(|e|,|ec|) \tag{15}$$

$$k_d = h_1(|e|,|ec|) \tag{16}$$

The adaptive PID controlling system of maximum power point of the photovoltaic power system is shown in figure 1.

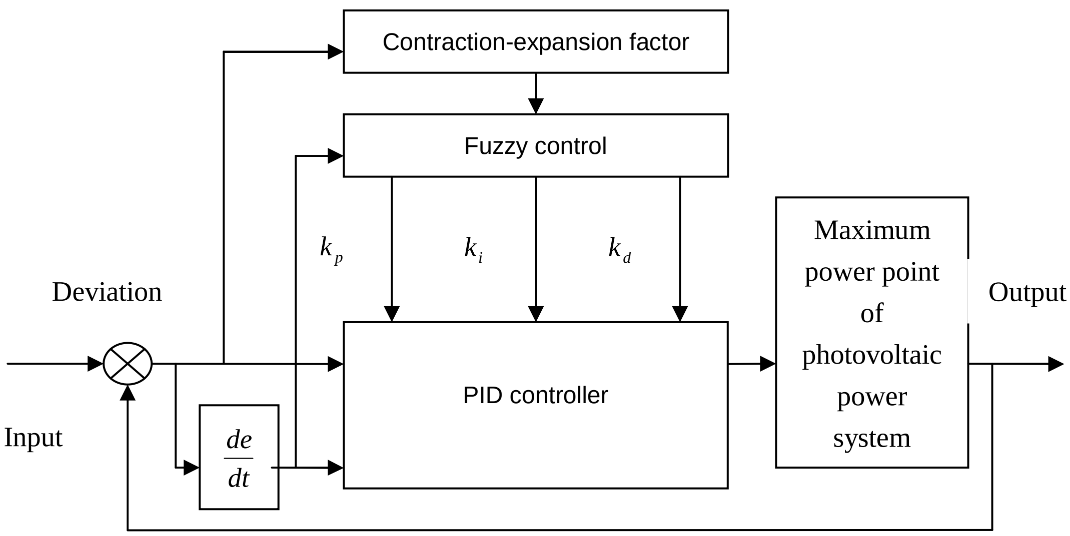

Figure 1 Adaptive PID controlling system of maximum power point

The fuzzy self adaptive PID controller can be applied in controlling the maximum power point of the photovoltaic power system. According to the deviances, changing rate of the desistance and fuzzy theory, the fuzzy controlling principles of the proportion coefficient change Δk_p, integrated coefficient change Δk_i, and differential coefficient change Δk_d can be established, the fuzzy discourse domain is set as [-3，3], which is divided into seven grades and is denoted as {PL，PM，PS，ZE，NS，NM，NL}，where PL denotes positive large, PM denotes positive medium, PS denotes the positive small, ZE denotes the zero, NS denotes negative small, NM denotes the negative medium, NL denotes negative large.

The corresponding controlling principles are shown in table 1, table 2 and table 3 respectively.

Table 1 Controlling principle of Δk_p

ec	*e*						
	NL	NM	NS	ZE	PS	PM	PL
NL	NS	ZE	ZE	NS	NM	NL	NL
NM	PS	PS	ZE	NS	NS	NM	NM
NS	PL	PL	PM	ZE	ZE	NS	NS
ZE	PL	PM	PS	PS	ZE	ZE	NS
PS	PM	PM	PM	PM	PS	ZE	ZE
PM	PL	PM	PM	ZE	NS	ZE	ZE
PL	PL	PL	PL	PM	PM	PS	ZE

Table 2 Controlling principle of Δk_i

ec	*e*						
	NL	NM	NS	ZE	PS	PM	PL
NL	ZE	NS	NS	NM	NM	NL	NL
NM	PM	PM	PS	PS	ZE	ZE	NS
NS	PS	ZE	ZE	NS	NS	NM	NM
ZE	PS	PS	ZE	ZE	ZE	NS	NS
PS	PM	PM	PS	PS	ZE	ZE	NS
PM	PL	PM	PM	PS	PS	ZE	ZE
PL	PL	PL	PL	PM	PM	ZE	ZE

Table 3 Controlling principle of Δk_d

ec	*e*						
	NL	NM	NS	ZE	PS	PM	PL
NL	PS	ZE	NS	NS	NM	NM	NL
NM	PM	PS	ZE	ZE	NS	NM	NM
NS	PL	PS	PS	ZE	ZE	NS	NS
ZE	PS	PS	ZE	ZE	NL	NS	NS
PS	PL	PL	ZE	NS	NS	NS	NM
PM	PL	PL	PM	PM	ZE	NS	NS
PL	PL	PM	PM	PS	PS	ZE	NS

According to the actual requirement of controlling maximum power point of chemical photovoltaic power system, the corresponding controlling principles are set as follows:

$IF \quad e = NS$ AND $ec = PL \quad THEN \quad u = NL$
$IF \quad e = PM$ AND $ec = NM \quad THEN \quad u = NS$
…
According to the fuzzy above controlling principle, the fuzzy logical operation table of fuzzy control can be obtained.

The output value of fuzzy parameter self regulation PID controller can be calculated according to the weighted average method, the corresponding procedure is listed as follows:

Step 1: Calculate the core elements of all elements in fuzzy reasoning conclusion.

Step 2: Obtain the corresponding precision value after the core elements are fuzzed, the corresponding calculating expression is listed as follows:

$$u^* = \sum_{i=1}^{n} u_i \cdot \frac{\phi(i)}{\sum_{i=1}^{n} \phi(i)} \quad (17)$$

Where, u^* denotes the exact solution, $\phi(i)$ denotes the membership degree function of Δk_p, Δk_i and Δk_d, n denotes the number of output elements.

The integrated value of Δk_p, Δk_i and Δk_d can be calculated through regulating the precision value. And the input parameter of fuzzy parameter self regulation PID controller can be obtained by the following expression:

$$\begin{cases} k_p = k_{p0} + \Delta k_p \\ k_i = k_{i0} + \Delta k_i \\ k_d = k_{d0} + \Delta k_d \end{cases} \quad (18)$$

where, k_{p0}, k_{i0} and k_{d0} denote original value of k_p, k_i and k_d.

RESULTS AND DISCUSSION

According to the basic theory of fuzzy PID controller, the controlling simulation programmer is compiled by MATLAB software, at the same time the traditional PID controller is applied in controlling the same system. A chemical photovoltaic power system is used as researching object, the corresponding parameters are listed as follows: short-circuit current I_{sc} is equal to 4.88A, the open circuit voltage V_{oc} is equal to 20.6V, the current of maximum power point I_m is equal to 4.18A , the voltage of maximum power point V_m is equal to 16.8V.

The environmental temperature T =30℃, and the light strength changes from 750W/m^2 to 1250W/m^2 in 1s. The corresponding simulation curve is shown in figure 2.

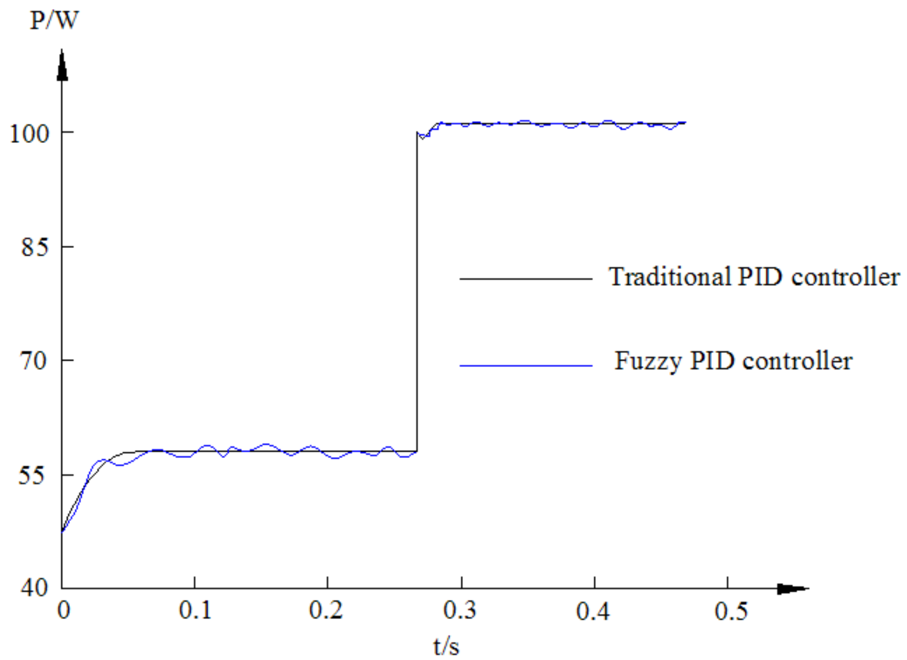

Figure 2 Controlling simulation curves of maximum power point of chemical photovoltaic power system

As seen from figure 2, the controlling simulation curves based on traditional PID controller has a small oscillation, while the controlling simulation curves based on fuzzy PID controller can get the output power curves with smooth changes. Therefore controlling effect of the fuzzy PID controller is better than that of traditional PID controller.

Then the transferring efficiency of solar energy of chemical photovoltaic power system can be improved effectively.

CONCLUSION

The fuzzy PID controller is applied in controlling the maximum power point of the chemical photovoltaic power system and the amended factor is introduced in regulating the parameters of fuzzy PID controller, and the correctness and stability of the chemical photovoltaic power system can be improved, controlling simulation results show that the fuzzy PID controller can achieve the tracking and controlling of the maximum power point, the feasibility of fuzzy PID controller on the chemical photovoltaic power system is verified.

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