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Applications of Fuzzy adaptive PID control in the thermal power plant denitration liquid ammonia evaporation

Jing Li[1], Guo Qing Zhang[2] , Huan Xin Cheng [3,a],Li Cheng[4,a]

[1,2,3]*College of Automation and Electrical Engineering.Qingdao University of Science and Technology.Qingdao 266042.china*
[4]*Xinjiang Technical Institute of Physics and Chemistry.CAS,Urumuqi,Xinjiang,830011,China*
[a]*Urumqi Xiaming Innovation Electronic Technology Co.,Ltd,Urumuqi,Xinjiang,830011,China*

Abstract. For the control of the liquid level of liquid ammonia in thermal power plant's ammonia vaporization room, traditional PID controller parameter tuning is difficult to adapt to complex control systems, the setting of the traditional PID controller parameters is difficult to adapt to the complex control system. For the disadvantage of bad parameter setting, poor performance and so on，the fuzzy adaptive PID control is proposed. Fuzzy adaptive PID control combines the advantages of traditional PID technology and fuzzy control. By using the fuzzy controller to intelligent control the object, the performance of the PID controller is further improved, and the control precision of the system is improved[1]. The simulation results show that the fuzzy adaptive PID controller not only has the advantages of high accuracy of PID controller, but also has the characteristics of fast and strong adaptability of fuzzy controller. It realizes the optimization of PID parameters which are in the optimal state, and the maximum increase production efficiency, so that are more suitable for nonlinear dynamic system.

1 Introduction

Coal is the main energy source of our country nowadays and the future. When coal is burned in the boiler, sulfur and nitrogen oxide waste gas can be generated. Nitrogen oxides are one of the key reasons for the regional air pollution. It is not only the cause of acid rain and fog, but also causes the other mixed chemical air pollution, which is harmful to human survival and destruction of the ecological environment[2]. At present, although the vast majority of the thermal power plant is equipped with low nitrogen combustion technology in our country, but the denitration efficiency is low. The SCR technology combined with low nitrogen combustion technology using, out of stock will greatly increase the efficiency. Thermal power plant SCR device includes: flue gas system, ammonia injection system, liquid ammonia storage evaporation system, blowing ash system, SCR catalyst, and safety auxiliary equipment.

Liquid ammonia gasification is an important part of the thermal power plant denitration process hat[3]. It is also the first condition of ensure the normal operation of denitration. The safe operation of the liquid ammonia gasification directly affects the safety of the whole thermal power plant. Therefore to study advanced the application of DCS to control the denitration liquid ammonia vapors, improve the stability of the system is running safety is even more necessary, at the same time there is a growing concern of atmospheric pollution control is of great significance. So we put fuzzy adaptive PID control in the process of liquid ammonia, improve the efficiency of liquid ammonia vaporization and to meet the requirements of safety and process constraints, making the key points of each control to achieve the optimization and for the denitration follow-up work well enough ammonia gas supply, ultimately achieve the denitration efficiency maximization.

2 The design of fuzzy adaptive PID controller

2.1 PID control

PID controller is a linear controller. As shown in figure 1,

$$u(t) = k_p e(t) + k_i \int_0^i e(\tau) d\tau + \frac{de(t)}{dt}$$

In the formula, k_p is the scale factor. T_i is the integral time constant. T_d is the differential time constant.

At present, the incremental PID control algorithm is widely used, and its output $\Delta u(k)$ is the increment of the control quantity. Its formula is as follows.

$$\Delta u(k) = k_p \Delta e(k) + k_i e(k) + k_d [e(k) - \Delta e(k-1)]$$

Corresponding author: 317842602@qq.com

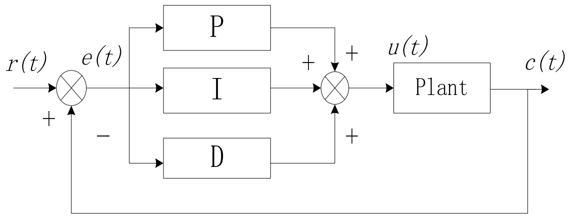

Figure 1. Block diagram of PID system

Among them, K_p is the proportion coefficient; $K_i = K_p T / T_i$ is the integral coefficient; $K_d = K_p T_d / T$ is the differential coefficient.

In the PID control process, first determine the mathematical model based on the controlled object PID, and then use the deviation e as input to calculate the amount of control and drive the appropriate enforcement agency to reduce the error until the controlled object stabilized within the allowable range.

2.2 The control principle of Fuzzy adaptive PID controller

The control principle of fuzzy adaptive PID control is to identify the fuzzy relationship with PID three parameters K_p, K_i, K_d between e and e_c, through continuous testing e and e_c in the operation, based on fuzzy control theory to online modification of the three parameters in order to satisfy different e and e_c for different requirements of the control parameters and leave the controlled object has a good dynamic and static performance[4]. The whole structure of fuzzy adaptive PID controller is as shown in figure 2.

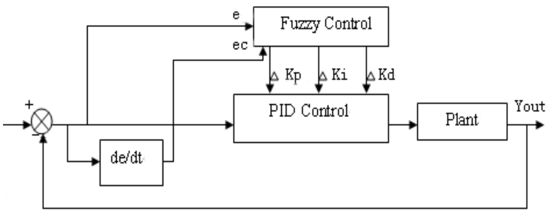

Figure 2. Block diagram of Fuzzy adaptive PID controller

2.3 The design of fuzzy adaptive PID controller

2.3.1 The determination of membership function of linguistic variables

We put the deviation e and the change rate deviation e_c as the input fuzzy controller and the three parameters of PID controller Δk_p , Δk_i , Δk_d as the output. According to the project of the actual situation, fuzzy subset of the input variables e and e_c are {negative big, negative middle, negative small, zero, positive small, positive middle, positive big}, denoted as {NB, NM, NS, ZO, PS, PM, PB}. The deviation e and deviation change rate e_c were quantified into the region of (-3, 3). Meanwhile, the fuzzy subset of the output variable KP, KI, KD are {negative big, negative middle, the negative small, zero, positive small, positive middle, positive big} denoted as {NB, NM, NS, ZO, PS, PM, PB}, respectively, to be quantified into the region of (-3, 3) (0.06, 0.06) (0, 3). These membership function curves are shown in figure 3, figure 4.

According to the membership assignment table of each fuzzy subset and the fuzzy control model of each parameter, using fuzzy synthesis reasoning design the fuzzy matrix table of PID parameters to realize online correction PID parameters. Computation formula is as follows:

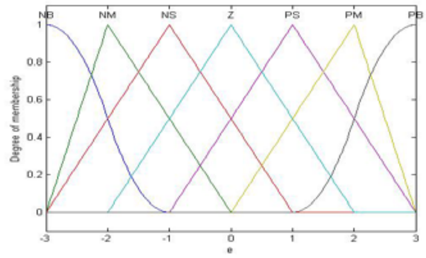

Figure 3. The membership function of input variable e e_c curve

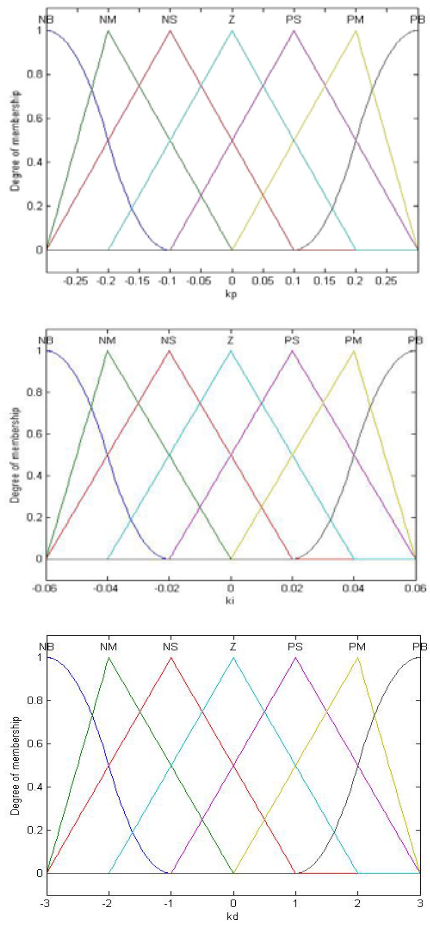

Figure 4. The membership function of output variable Δk_p Δk_i Δk_d

$$k_p = k_p' + \Delta k_p$$
$$k_i = k_i' + \Delta k_i$$
$$k_d = k_d' + \Delta k_d$$

In the above formula $k_p^{'}, k_i^{'}, k_d^{'}$ is original PID parameter that have been setted .

2.3.2 Control rule table of fuzzy controller

Here's to establish the fuzzy rules with fuzzy adaptive PID control. First we need to judge the knowledge library based on expert knowledge and determine the three parameters in PID and fuzzy relationship between the deviation e and deviation change rate e_c.And then through continuous detection of the operation of e and e_c, according to the fuzzy control rules to determine the three parameters to online adaptive in order to meet the different requirements of the two parameters of different e and e_c, leaving the controlled object has good dynamic and static performance.

According to the parameters $K_p, K_{,i} K_d$ affect the output characteristics of the system, we can summarize the self-tuning principles of the system in the controlled process for different deviation e and deviation change rate e_c and parameters $K_p, K_{,i} K_d$ as follows:

1) When the deviation e is larger, in order to speed up the response speed of system and prevent deviation e at the beginning of the instant greatens may cause differential supersaturated and make the control action is beyond the scope of, we should take the larger KP and smaller KD, usually take $K_i = 0$.

2) When the deviation e and deviation change rate e_c are at medium size, in order to make the overshoot of system respond to reduce and guarantee a certain response speed, K_p should take smaller. In this case, the value of K_d has a great influence on the system, so we should also take a small number. The value of K_i should be appropriate.

3) When the deviation e is smaller, in order to make the system have better steady-state performance, we should increase the value of K_p KP and K_i. At the same time in order to avoid output response's oscillation around the set value, and to consider anti-jamming capability of system, K_d should be properly selected. Its principle is: when the deviation rate e_c is smaller, the value of K_d is larger, When the deviation rate e_c is larger, K_d take smaller values; Usually K_d for medium size.

Control rules table of output variable Δk_p 、 Δk_i 、 Δk_d as shown in table 1, 2, 3.

Table 1. The fuzzy rule table of Δk_p

Δk_p (e \ e_c)	NB	NM	NS	ZO	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZO	ZO
NM	PB	PB	PM	PS	PS	ZO	NS
NS	PM	PM	PM	PS	ZO	NS	NS
ZO	PM	PM	PS	ZO	NS	NM	NM
PS	PS	PS	ZO	NS	NS	NM	NM
PM	PS	ZO	NS	NM	NM	NM	NB
PB	ZO	ZO	NM	NM	NM	NB	NB

Table 2. The fuzzy rule table of Δk_i

Δk_i (e \ e_c)	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NM	NM	NS	ZO	ZO
NM	NB	NB	NM	NS	NS	ZO	ZO
NS	NB	NM	NS	NS	ZO	PS	PS
ZO	NM	NM	NS	ZO	PS	PM	PM
PS	NM	NS	ZO	PS	PS	PM	PB
PM	ZO	ZO	PS	PS	PM	PB	PB
PB	ZO	ZO	PS	PM	PM	PB	PB

Table 3. The fuzzy rule table of Δk_d

Δk_d (e \ e_c)	NB	NM	NS	ZO	PS	PM	PB
NB	PS	NS	NB	NB	NB	NM	PS
NM	PS	NS	NB	NM	NM	NS	ZO
NS	ZO	NS	NM	NM	NS	NS	ZO
ZO	ZO	NS	NS	NS	NS	NS	ZO
PS	ZO	ZO	ZO	ZO	ZO	ZO	ZO
PM	PB	NS	PS	PS	PS	PS	PB
PB	PB	PM	PM	PM	PS	PS	PB

2.3.3 Control rule table of fuzzy controller

Mamdani inference method is a common method used in fuzzy control. Using a fuzzy relation by X to Y to represent a fuzzy conditional statement: if A then B，When the input is A*, B* can be obtained from the output.

$$B^* = A^* \circ R_{a \to b}$$

It represents the synthesis operation of fuzzy relations.

Mamdani fuzzy relationship definition of R_a→ ε based on

$$u_{R_{A \to B}}(x, y) = [u_A(x) \wedge u_B(y)]$$

Therefore, according to the membership function of controller's output B * is

$$\mu_{B^*}(y) = \sup_{x \in X} \{\mu_{A^*}(x) \wedge [\mu_A(x) \wedge \mu_B(y)]\}$$

2.3.4 Defuzzification

The process of converting the fuzzy quantity into the precise quantity is called as the clarity, also known as the fuzzy, or called the fuzzy judgment. In order to obtain the accurate controlled variable, the fuzzy method is required to be able to output the accurate calculation results of the membership function. In this paper, we use the fuzzy method widely used in industrial control, weighted average method, is taking a weighted average of the membership degree of output value clearly. Assuming that the output fuzzy sets can be represented as $U = \sum u_U(x_i)/(x_i)$, according to the following formula, we can clear quantity as follows:

$$u_c = \frac{\int_U x u_U(x)dx}{\int_U u_U(x)dx}$$

3 System simulation using Simulink

The fuzzy adaptive PID controller is used for liquid ammonia buffer tank level control. Simulink program of Fuzzy PID liquid ammonia buffer tank liquid level adaptive control is as shown below. Pay attention to the deviation e and its change size when the controlled object is in the actual passing ammonia. After the fuzzification we need check out the $\Delta k_p, \Delta k_i, \Delta k_d$ on the above should be in line, and then multiplied by the formula according to the respective ratio coefficient. Then use the formula to calculate the dynamic online PID parameters.

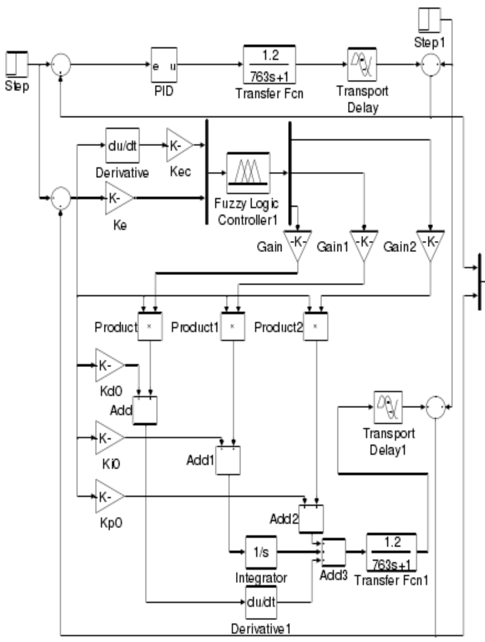

Figure 5. Fuzzy Adaptive PID Liquid Ammonia Buffer Tank Liquid Level Control System Simulation

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At the beginning of setting parameters we use the experience of the actual project, assuming that the initial level is 1. When the simulation time is 5000 seconds, the step disturbance that value is 0.2 was added. The total simulation time is 10,000 seconds. Simulation type selects ode5 fixed step size and step length value is 1. In the fuzzy adaptive liquid ammonia buffer tank liquid level control system, deviation value K_e is 0.1, deviation change values K_{ec} is 20, object Online proportional gain quantization factor is 4.5, integral gain quantization factor is 0.0045, the initial values of proportional, integral, differential are 0.8,0.0012,50[5]. According to the formula, it can be concluded that the values of actual control ratio coefficient, the integral time and the differential time. The step response curve of fuzzy adaptive PID liquid ammonia buffer tank control system is obtained according to the simulation program. As shown in the figure below[6].

The transfer function of the liquid ammonia buffer tank level control is as follow.

$$G_{(S)} = \frac{7.3118}{500s+1}$$

Step response curve of fuzzy PID ammonia buffer tank level control system is shown below.

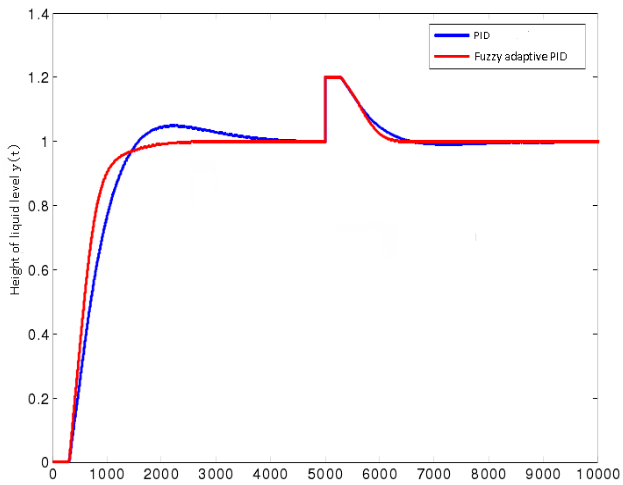

Figure 6. Traditional PID and Fuzzy Adaptive PID Algorithm Level Control Simulation Curve

Through the simulation, we can see that the fuzzy adaptive PID can reach the preset liquid level more quickly. That is to say, compared to the traditional PID, it has faster rising speed, shorter time. And the traditional PID control has overshoot, fuzzy control PID without overshoot, so that it can be very effective to reduce the impact of hysteresis[7]. In the 5000s, we give controlled object step disturbance of value is 0.2. Because in the actual engineering projects the collected signal is often affected by human being unable to control the interference signal, so when adding disturbance we observed will be more in line with the real situation. We can also see that the fuzzy control PID has better robustness and anti- disturbance ability compared with the traditional PID control[8]. This is because the control algorithm can adjust the PID parameters according to the deviation and deviation change rate and make the proportional, integral and differential parameters in algorithm were within reasonable range. As seen in the simulation, the response can more quickly return to the set value, so that the fuzzy adaptive PID control has better effect[9].

4 Conclusions

In this paper, through the establishment of fuzzy adaptive PID controller to control the liquid ammonia system, and simulation was carried out using Simulink[10]. The simulation results show that the fuzzy adaptive PID control compared with the traditional PID control has great superiority. It possesses the advantages of both PID control and fuzzy control, which shortened the time stability and reduce the overshoot. Fuzzy adaptive PID control has strong robustness and adaptive ability. When there is an outside interference, its control effect is satisfactory.

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