Application of Fuzzy Strategy in the Superheated Steam Temperature Control System of Boiler

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Abstract. By testing the superheated steam temperature and its variation trend, the traditional superheated steam temperature control system of boiler regulates desuperheating water flow so as to control the superheated steam temperature within permitted range. Under the influence of disturbance in desuperheating water flow, the delay of superheated steam temperature is bigger, which makes superheated steam temperature control lagged and dynamicity is strong, the effect of control is not ideal. This paper interpreted a kind of cascade PID control system with good adaptability to load variation and a design scheme of PID parameter self-adapting controller based on fuzzy control principle is put forward, simulation study is made with the tool boxes of SIMULINK and FUZZY inside MATLAB, comparisons show a better control result of fuzzy control system with self-adapting parameter than with fixed parameter system.

Keywords: superheated steam, fuzzy control, PID controller, SIMULINK.

1. Introduction

The superheated steam temperature is one of the important parameters for thermal power plant boiler equipment. Because of the influence of working conditions, the superheated steam temperature become a time-varying, nonlinear, big lag, large inertia of complex thermal control object, it is difficult to control, a variety of different control method have been produced. Due to simple algorithm, the conventional PID controller, good stability, high reliability, advantages, has been widely used. But its limitation for complex controlled object application is one of the important factors that restrict its development. As the development of intelligent control, the generation of cascade control system and fuzzy control technology brings new vitality for the development of PID control. Cascade control system can not only overcome disturbance of vice loop early, but also improve the dynamic characteristics of the process, and it has good adaptability to load changes. Fuzzy control need not informed of the exact mathematical model of objectives, however, it based on human's thinking and experience of production, describing control process with language rules and according to the rules to adjust the control algorithm or control parameters. To mix fuzzy control and PID control together can complement their shortages: On the one hand, fuzzy control can make up the shortages of PID control to the delay and nonlinearity complex object; On the other hand, combining PID control with fuzzy control can largely improve control quality and steady precision of fuzzy control [1][2].

2. Principle of Cascade PID Control System

Wherever Cascade control system has two sets of testing transmitter and regulator. Prior regulator named mainly regulator, the variables detected and controlled by it called principal variable (the principal controlled parameters); Latter regulator named vice regulator, the variables detected and controlled by it called vice
variable (the vice controlled parameters), it is auxiliary variable to maintain stability of principal variable. The system includes main loop and vice loop. Vice loop is constituted of vice variable detection transmitter, vice regulator, dampers and vice process; main loop is constituted of main variable detection transmitter, vice regulator, main regulator, dampers, vice process and main process. In the cascade control system, the roles of main and vice regulator are different. The main regulator is fixed value control, while the vice regulator is servo control. The main loop of general requirement makes no difference to the control law, and the main regulator select PID control laws. Vice loop request rapidity of control, generally selecting P control laws without introducing I or D control. If introducing I control, it will extend control process, weaken the rapidity of vice loop. There is no necessary to introduce D control either, because vice loops adopt P control that has played a rapid control function[3]. The structure of cascade control system shows in Figure 1.

3. Design of Fuzzy PID Controller

The superheated steam temperature is one of the important parameters for thermal power plant boiler, which has a great influence to the safety of equipment operation and economy. When power plant boiler is running, to maintain a stable temperature of the superheated steam is an important guarantee for economic operation and unit safety. For the drum boiler, the superheated steam temperature control generally require 70 to 100% load, the deviation of actual temperature and settings require between the ± 5 ℃. While as for the DC boiler is concerned, the temperature control should be the scope of this deviation in the range of 35 to 100% load. Because of the inertia and delay characteristics of superheated steam temperature, it is very difficult to Regulate the steam temperature, especially when load is changing, the characteristics of main steam temperature changes obviously, cascade PID control is hard to obtain satisfactory control effect. Fuzzy PID controller uses error E and error rate EC as input variables based on PID algorithm[4], which can effectively solve the problem of the large inertia, pure delay, dynamicity of the boiler superheated steam temperature control system. Usually different error E and error rate have different requirements to the setting of Kp Ki, Kd, which can be summed up a simple rule:

1. When |E| is bigger, in order to accelerate the response speed of system, value of Kp is larger; In order to avoid the differential supersaturated and control effect beyonding the Permitted scope due to the beginning of error |E| Getting too big instantaneously, value of Kd is smaller; In order to prevent the system response appearing larger overshoot and producing the integral saturation, Ki = 0.

2. When the error |E| is medium, in order to make the system response having small overshoot, value of Kp is smaller, value of Ki should be appropriate, at this time value of Kd has a great impact on the system, it shoud be taken right size to guarantee the response speed of system.

3. When the error |E| is lesser, in order to make the system having good steady characteristics, the value of Kp and Ki increases. In order to avoid volatile, the anti-disturbance performance of system should be enhanced, when |EC| is lesser, value of Kd can be larger; When |EC| is bigger, value of Kd is smaller.

According to the above rules, using fuzzy inference to design fuzzy self-adaptive PID controller, Figure 2 shows the structure of fuzzy adaptive PID control system.
Language variables of Fuzzy Controller refer to input variables and output variables. They are based on natural language form, but not numerical form. Because the rules of fuzzy control is concluded according to the operator's manual control experience, and the operator only commonly observe the output variables and their rate, so we select error E and error rate EC as input variables. Output variable is Kp, Ki, Kd, the results of fuzzy inference are not directly the system output, but using the results to set PID parameters online, and then based on PID algorithm, it determine the system output. This structure reflects characteristics of nonlinear control law of Fuzzy Controller.

Considering the plus or minus characteristics of variables, for error E and error rate EC, five language variables are chosen, \{ positive middle (pm), positive small (ps), 0 (0), negative small (ns), negative middle (nm) \}; The domain of error E is [-2,2], the domain of error rate EC is [-0.1, 0.1]. For Kp, Ki, Kd, 7 language variables are chosen, \{ positive big (pb), positive middle (pm), positive small (ps), 0 (0), negative small (ns), negative middle (nm), negative big (nb) \}. The domain of Kp is [-1,1], the domain of Ki is [-0.001, 0.001]. The domain of Kd is [-0.5, 0.5], membership functions of input and output variables are created as gaussian curve. According to the above rules, fuzzy control table of Kp, Ki, Kd is written (as shown in Table 1).

<table>
<thead>
<tr>
<th>Kp, Ki, Kd</th>
<th>E</th>
<th>Nm</th>
<th>Ns</th>
<th>0</th>
<th>Ps</th>
<th>Pm</th>
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4. Simulation Based on the MATLAB

4.1. Simulation of cascade PID control

To compare the effects of two control methods, using FUZZY and SIMULINK toolbox create the model of boiler superheated steam temperature control system in MATLAB, mathematical model for a boiler superheated steam temperature control system is shown below:

Vice object:

\[ G_1(s) = \frac{-0.815}{(18s + 1)} \]  

(1)

Main object:

\[ G_2(s) = \frac{1.276}{(18s + 1)^3} \]  

(2)

Simulation model of Cascade Control System is created by SIMULINK in MATLAB shown in Figure 3. Final value of step signal is set as superheated steam temperature steadystate value 535°C, simulation time is set as 1000s.
4.2. Simulation of fuzzy PID Control

Simulation model of Fuzzy Adaptive PID Control System is created by SIMULINK in MATLAB shown in Figure 4, final value of step signal is set as superheated steam temperature steady-state value 535°C, simulation time is set as 1000s. PID control subsystem is shown in Figure 5, fuzzy module is shown in Figure 6.

Usually the temperature of superheated pipe of the boiler in normal operation had been close to that superheated pipe materials allowed. If the superheated steam temperature is exorbitant, superheater will be damaged easily, the inside device of turbine will be excessively expanded, which seriously impact the safety of operation; If the superheated steam temperature is too low, equipment efficiency will decreases, which cause turbine blade wear; therefore superheated steam temperature should be controlled in allowing range. However in the superheated steam temperature control system, because of controlled object with nonlinear, time-varying, hysteretic nature and the temperature control is susceptible to controlled object and environment factors, it is difficult to establish precise mathematical model, also it is hard to choose controller parameters. It is difficult to obtain satisfactory dynamic response characteristics with the traditional PID control, therefore this paper established the fuzzy self-adaptive PID controller, which improved the control effect obviously.
4.3. Comparison of simulation results

Figure 7 and Figure 8 show results of simulation. Figure 7 shows the overshoot of Cascade Control System is 21.5%, regulating time of Cascade Control System is 295s; Figure 8 shows the overshoot of Fuzzy Control System is 8.4%, regulating time of Fuzzy Control System is 205s; comparisons show a better control result of fuzzy control system with self-adapting parameter than with fixed parameter system.

4.4. Conclusion

This paper makes a comparison study of Cascade PID Control System and Fuzzy PID Control System, which prove Fuzzy PID Control System can overcome the limitations of the traditional PID control system, and it also makes overshoot small, speed of regulation fast. Due to Fuzzy Control System makes a nonlinear processing for complex system, which make it have adaptive adjustment capabilities, thereby improving the intelligent of system and control effects.

5. References