Study and Application of Fuzzy PID Intelligent Control

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Abstract. In the boiler automatic control system, there are some characteristics of time-varying, large lag and many disturbances in the process of boiler superheated steam temperature control. The traditional PID control cannot achieve the desired control effect, so an intelligent control algorithm called fuzzy PID control is proposed. Fuzzy PID control is based on the PID algorithm, with the error and error rate as input, using fuzzy rules for fuzzy control. By comparing the PID control algorithm with the fuzzy PID control algorithm in MATLAB simulation, the superiority and feasibility of the fuzzy PID control algorithm are verified.

Introduction

Boiler is an indispensable power equipment in power, metallurgy, petrochemical and other industrial sectors, and the product is steam. The saturated steam from the boiler drum in a power plant is continuously heated by the superheater, which is called superheated steam. The temperature of superheated steam is an important parameter in the production process of thermal power plants. The temperature control of superheated steam is an important condition to ensure the normal operation of steam turbine units. Each type of boiler and steam turbine has a specified operating temperature, at which the efficiency of the unit is the highest. If the temperature of superheated steam is too high, the service life of steam turbine will be greatly shortened; if the temperature is too low, when the superheated steam drives the steam turbine to work, it will make part of the superheated steam into small droplets, which will impact the turbine blades and cause production accidents. Therefore, the temperature of superheated steam must be controlled[1].

The traditional PID control algorithm is usually used in the superheated steam temperature control of boilers, but the application of the traditional PID control algorithm has its limitations. It is difficult to establish an accurate model, and the PID control cannot meet the process requirements. Because the superheated steam temperature of boiler is a non-linear control system with many disturbances, long time lag and uncertain object model, the quality of system control can be improved by using fuzzy PID control[2].

PID Control System

In practical engineering applications, most of the regulators in closed-loop control systems adopt PID control, i.e. proportional, differential and integral control. The PID controller is a linear controller. According to the system error, the control quantity is calculated by proportion, integral and differential.
The structure diagram of the PID control system shown in Figure 1 is composed of the PID controller and the controlled object. According to the fixed value $r(t)$ and the actual output value $y(t)$, the PID controller constitutes the control deviation, i.e. $e(t) = r(t) - y(t)$. Then the deviation is controlled by linear combination of proportion, integral and differential, and the controlled object is controlled. Thus, the ideal algorithm of the PID controller of the equation (1) is obtained.

$$u(t) = K_p e(t) + \frac{1}{T_i} \int e(t) dt + T_d \frac{de(t)}{dt}$$  \hspace{1cm} (1)

$K_p$, $T_i$ and $T_d$ are respectively proportional gain, integral time constant and differential time constant of the PID controller. For the production process with complex dynamic characteristics, large disturbances or disturbances and high quality control requirements, the PID control system is difficult to meet the control requirements. Therefore, on the basis of the PID control system, the fuzzy-PID intelligent control system is needed to meet the complex process requirements.

**Fuzzy PID Control**

Fuzzy-PID control is based on the PID algorithm, taking error $e$ and error rate of change $ec$ as input, using fuzzy control rules for fuzzy reasoning, automatically realizing the optimal adjustment of PID parameters. Fuzzy rules are used to adjust the parameters of PID on-line to form the fuzzy PID controller shown in Figure 2.
parameters kp, ki and kd of PID controller as output. Taking the error E and error rate EC of superheated steam temperature and the three parameters kp, ki and kd of the PID controller as quantization domains are {-3, -2, -1, 0, +1, +2, +3}, the fuzzy subsets are {NB, NM, NS, ZO, PS, PM, PB}, and the linguistic variables are {negative, negative, negative, zero, positive, positive, and large}, all of which adopt the Gauss membership function.

Fuzzy control rules\(^3\) are language control rules based on the description of fuzzy conditional statements. Fuzzy control rules play an important role in the fuzzy-PID control system. The tables of kp, ki and kd fuzzy control rules are shown in Table 1, 2 and 3, respectively. Fuzzy rules are used to adjust the parameters of PID on-line to meet the requirement of self-tuning of the parameters of PID in different time deviation and deviation change rate, so that the controlled object has good dynamic characteristics.

| kp  | E    |
|-----|------|
| NB  | NB   |
| NM  | NM   |
| NS  | NS   |
| ZO  | ZO   |
| PS  | PS   |
| PM  | PM   |
| PB  | PB   |

| ki  | E    |
|-----|------|
| NB  | NB   |
| NM  | NM   |
| NS  | NS   |
| ZO  | ZO   |
| PS  | PS   |
| PM  | PM   |
| PB  | PB   |

| kd  | E    |
|-----|------|
| NB  | NB   |
| NM  | NM   |
| NS  | NS   |
| ZO  | ZO   |
| PS  | PS   |
| PM  | PM   |
| PB  | PB   |

**MATLAB Simulation**

Using step response curve method, the superheated steam temperature of boiler is controlled by PID and fuzzy PID respectively. When the system is at a stable operating point, the step signal is selected as the input of the system's excitation signal, the output of the system is recorded, and the input and output data are obtained. Figure 3 shows the simulation curve of PID control\(^4\), and Figure 4 shows the simulation curve of fuzzy PID control\(^5\).
Summary
The excessive process of PID control for boiler superheated steam temperature takes a long time and has a large overshoot. The transition time of the fuzzy control is small, and the overshoot is well controlled. The steady-state error of the two kinds of control is controlled in a very small range. So it can be concluded from the simulation results that the fuzzy control can replace the PID control to control the superheated steam temperature of the boiler. Fuzzy control system has better stability and robustness than PID control system.

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