Research on Control Strategy of Main Steam Temperature System of Thermal Power Plant Boilers

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Abstract: This paper analyses the cascade PID control system used in the boiler on the main steam temperature system based on the introduction of the importance and control principle of the main steam system of the boiler, and propose a fuzzy PID control system for improving the cascade control system. As a consequence, the MATLAB simulation outcomes show that the system has better control effect and reaction speed, and the hysteresis of the main steam control system in the boiler is improved.

1. Introduction

Along with the economy developing faster and faster, the people's requirement for electricity is getting bigger and bigger, which requires the safe operation of the thermal power generation unit, and its active power can keep up with the changes in the grid load [1].

The normal operation of thermal power plants is inseparable from the performance of basic equipment boilers. The main steam in the boiler is the steam discharged from the superheater outlet. In the operation of the power plant, its temperature is very significant, which directly affects the safety and economy of power production.

In the boiler, the problem and difficulty of the main steam temperature control system is that the system has a large inertia, which causes a large delay in the temperature control effect. To solve this problem, domestic and foreign scholars have done a lot of research.

In view of the main steam control problem, Jingtong Chen proposed a fuzzy neural network cascade control to simulate and control the temperature of the boiler's main steam system, and used MATLAB for simulation analysis [2]. Huishan Feng applied the Smith predictor to the main steam cascade PID control system, which proved the superiority of the control with Smith predictor compared to the traditional PID control [3].

Osama I. Hassanein used genetic algorithms to determine PID control parameters on fire tube boilers to achieve optimal steam control [4]. Kaveh used the predictive PID control model (MPC) to adjust the PID parameters to adjust the main steam system to cope with the parameters changing over time in the main steam system [5].
2. main steam temperature control principle

2.1. PID controller principle

PID control system is the most widely used and the most effective basic control method in the application of modern control theory in engineering. Figure 1 below shows the basic feature of the PID controller. PID control belongs to negative feedback control. It is a linear controller with three adjustment functions: proportional (P), differential (D) and integral (I). And the system error \( e(t) \) is formed by the actual output value \( y_{out}(t) \) of the system and the set value \( r_{in}(t) \), as shown in equation (1).

\[
e(t) = r_{in}(t) - y_{out}(t)
\]  

(1)

The PID controller control law is:

\[
u(t) = K_p e(t) + \frac{1}{T_i} \int_0^t e(t) dt + T_D \frac{de(t)}{dt}
\]  

(2)

Or write it as a transfer function form:

\[
G(s) = \frac{U(s)}{E(s)} = K_p \left(1 + \frac{1}{T_i s} + T_D s\right)
\]  

(3)

Where \( K_p, T_i \text{ and } T_D \) are the proportionality factor, the integral time constant, and the differential time constant. \( K_p, T_i, T_D \) are three important parameters of PID regulation. Whether they are suitable or not directly relates to the disadvantages and advantages of the whole control result.

2.2. Fuzzy Adaptive PID Controller

In general, fuzzy control is based on fuzzy logic reasoning and fuzzy language control and fuzzy set theory.

The basic theory diagram of fuzzy control is shown in Figure 2 below. The core part is the fuzzy controller, which mainly includes: calculation of control variables, fuzzy quantization processing, fuzzy control rule formulation, fuzzy decision-making, non-fuzzification processing (solution Fuzzy processing).

The fuzzy controller is composed of a fuzzy knowledge interface, an inference engine, a defuzzification interface, a database and a rule base.
3. control system of main steam temperature in the boiler

In the boiler control system, the PID control mode is adopted for the main steam temperature control, but the single-loop PID system will cause the hysteresis and inertia of the control system to increase, so the requirements for safe operation cannot be met in production.

In view of the above situation, a cascaded dual-loop PID control system has been proposed to reduce the inertia of the control system. The main steam control system separates from two main control circuits, the secondary circuit is the inner ring, the main circuit is the outer ring, and the output of the inner circuit is the input of the outer circuit, which is shown in figure 3 below.

It should be noted that the proportional link 2 can consider the value of the secondary loop and the primary loop to be equal to link 1 when it is negligible, so that the cascade PID control system can be predigested into the PID control system with a single loop, however, the control functions of the equivalent loop are quite different and the selection of their PID control parameters is also quite different.
3.1. Control system design

This paper will take the main steam system of a super-critical boiler in a power plant as an example. The main steam temperature is jointly controlled by two-stage desuperheating water. According to the measured data of the boiler operation, and referring to the boiler design manual, the calculation program of the desuperheating water flow is written in the MATLAB. The program can obtain the relationship between the main steam temperature and the desuperheated water, so the amount of desuperheated water based on the assumed main steam temperature can be determined. Through these data, the transfer function and the control parameters can be provided for the control system.

As shown in Table 1 below, according to the MATLAB program, the relationship between the primary and secondary desuperheating waters of the main steam system and its temperature can be obtained.

**Table 1** Correspondence table between the relationship between desuperheated water and main steam temperature

| The flow of first level desuperheating water /t/h | The flow of second level desuperheating water /t/h | Main steam temperature/℃ |
|-----------------------------------------------|-----------------------------------------------|--------------------------|
| 29.35                                         | 7.65                                         | 530                      |
| 29.37                                         | 7.59                                         | 530.5                    |
| 29.39                                         | 7.50                                         | 531                      |
| 29.41                                         | 7.42                                         | 531.5                    |
| 29.43                                         | 7.36                                         | 532                      |
| 29.45                                         | 7.28                                         | 532.5                    |
| 29.49                                         | 7.14                                         | 533                      |
| 29.51                                         | 7.06                                         | 533.5                    |
| 29.51                                         | 7.07                                         | 534                      |
| 29.56                                         | 6.91                                         | 534.5                    |
| 29.58                                         | 6.84                                         | 535                      |
| 29.60                                         | 6.76                                         | 535.5                    |
| 29.62                                         | 6.69                                         | 536                      |
| 29.67                                         | 6.52                                         | 536.5                    |
| 29.69                                         | 6.45                                         | 537                      |
| 29.71                                         | 6.38                                         | 537.5                    |
| 29.75                                         | 6.22                                         | 538                      |
| 29.76                                         | 6.21                                         | 538.5                    |
| 29.76                                         | 6.18                                         | 539                      |
| 29.81                                         | 6.01                                         | 539.5                    |
| 29.84                                         | 5.93                                         | 540                      |

Using the CFTOOL toolbox in MATLAB, the data above is fitted into a function, and finally transformed into a control system transfer function \( G(s) \) by Laplace transform:

\[
G(s) = \frac{1.17}{67.66s^2 + 36.66s + 1}
\]  

According to the fuzzy control principle, and using the fuzzy toolbox in MATLAB, the system takes the first and second stage desuperheating water as input, and the PID control parameters \( K_p, K_i, K_d \) as the fuzzy output to establish the fuzzy controller.
3.2. Analysis of simulation results

After establishing the fuzzy controller, we combine the fuzzy controller with the equivalent PID control system. Simultaneously, we also use the transfer function obtained by the MATLAB desuperheating water calculation program, use the simulink to build the simulation module.

![Simulation diagram](image)

**Figure 5.** The system of boiler main steam temperature fuzzy PID control

As we can see in Figure 5, the system takes the step as the control change signal, and uses the first and second desuperheating water as the fuzzy controller’s input, and uses the fuzzy controller output as the PID control parameter, and feedbacks the entire loop to ensure the integrity of the system. As a simulation result of the above system, Figure 6 is the simulation response of the step signal.

![Simulation response](image)

**Figure 6.** Simulation effect of the fuzzy control system on temperature

As shown in the figure 6, the ordinate is High-temperature superheater outlet steam temperature of the boiler. According to the operation of the supercritical boiler, the temperature should be limited at 530 °C in order to make the boiler operate normally. In Figure 6, we can see that after the step signal is given, its temperature rises and tends to be stable at about 15 seconds, and its final stable temperature is about 530.95 °C. The adjustment error is less than 5%, which proves that the fuzzy control system has a faster reaction speed and better stability when the main steam temperature changes.

4. Summary

Through the analysis of the boiler main steam control system and the construction of the fuzzy control system, the following conclusions can be drawn:

1. The cascade PID control system has better control effect in the control of the boiler’s main steam temperature, which compares to the traditional single-loop PID control system,

2. To improve the main steam cascade PID control system, using the fuzzy control principle can make the control system response adjustment speed faster and the adjustment effect is better.

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