Research on Control Method of Valve-controlled Heating System

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Abstract. The valve-controlled heating system mainly controls the hot water flow to achieve the automatic adjustment of the room temperature. However, the common flow control algorithms have some disadvantages, such as large overshoot and slow response, which cannot meet the requirements of fine control of the system. On the basis of optimizing the fuzzy control algorithm, a model reference predictive fuzzy adaptive control method is adopted in this paper. The system simulation test showed that this control method had good dynamic performance and anti-jamming performance, which could achieve the relative accurate control of room temperature, and achieve control objectives.

1. Introduction

Affected by climatic conditions, heating has become a basic living demand for residents of northern China during the winter. At present, the central heating mode of direct coal-fired and cogeneration is still used in most areas of northern China, resulting in a large amount of energy waste. With the development of new energy and new technology, heating mode is gradually developing in a diversified direction. The emergence of independent household heating methods has provided an effective way for energy conservation and environmental protection.

The household heating mode adopts room temperature automatic control system, which has the characteristics of user self-adjusting temperature, heat can be measured independently, and room comfort is higher. The room temperature automatic control system mainly uses the automatic control technology and communication technology to realize the opening and closing, shifting, and controlling the hot water flow of the user heating valve, thereby achieving the purpose of automatically adjusting the room temperature. Therefore, the use of advanced control technology to effectively control hot water flow is the key to room temperature regulation.

Flow rate is one of the important control parameters in process control. Because of the non-linearity of valve, the impact of water flow on pipeline, liquid turbulence, pipeline characteristics and other factors, flow tracking control system is a typical non-linear system, and it is difficult to achieve accurate flow tracking [1]. At present, the common research methods include self-tuning PID algorithm, fuzzy PID algorithm, fuzzy control, Smith predictive compensation control and so on [2-5]. Most of these control methods have the disadvantages of large overshoot and slow response, which cannot meet the fine control requirements of the room temperature automatic control system. In view of this, on the basis of optimizing the fuzzy control algorithm, this paper adopts a model reference predictive fuzzy adaptive control method. This control method has good dynamic performance and anti-interference performance, and has strong practical significance for room temperature control in valve-controlled heating system.
2. Overall structure of valve-controlled heating system

At present, the most widely used heating system in public buildings and residential buildings is the hot water central heating system. It is a heating control mode that uses hot water as the medium to change the room temperature by regulating the flow of hot water flowing through radiators. On the basis of this, the household heating form can be formed by adding the household temperature control device. The indoor part at the end of the heating system mainly includes regulating valve, radiation equipment, inlet pipe and outlet pipe, etc. During the operation of the system, the controller can use the control algorithm to adjust the hot water flow by changing the opening degree of the flow valve according to the change of the room temperature. The change of the hot water flow in the pipeline further causes the heat of the radiator to change, thereby achieving the purpose of adjusting the room temperature. The overall structure of the valve-controlled heating system was shown in figure 1.

![Figure 1. The overall structure of the valve-controlled heating system.](image)

3. Control algorithm of valve-controlled heating system

The temperature control of the valve-controlled heating system mainly depends on the regulating valve. The controller uses the control algorithm to realize the opening and closing, shifting of the user heating valve, and controlling the hot water flow, so as to achieve the purpose of automatic regulation of room temperature. At present, the commonly used temperature control algorithms are PID control, fuzzy control and Smith predictive control. These control methods were applied to the valve-controlled heating system for room temperature control. It was found that the PID control response time was long and the overshoot was large. The fuzzy control was greatly affected by the fuzzy rules. Smith predictive control was better than the PID control in reaction time and stability, but there was also a problem of long rise time. These control algorithms could basically achieve the heating control objectives, but the dynamic characteristics and anti-jamming ability of the system still need to be improved. Through the analysis of different control system principles and solving methods, combined with the situation of valve-controlled heating system, this paper combines fuzzy control and Smith predictive control to obtain a model reference predictive fuzzy adaptive control method, so as to achieve effective control of room temperature.

The model reference prediction fuzzy controller is a new type of controller based on fuzzy controller which was optimized by adding predictive feedback link. It is mainly composed of a fuzzy controller, a comprehensive error comparison part, an output feedback link and a predictive feedback link [5]. The optimized control model designed for the valve controlled heating system using this...
controller was shown in figure 2.

The system consists of two parts: fuzzy control and predictive feedback link $G_y(s)$. The predictive feedback link $G_y(s)$ is a first-order inertia plus lag form. The estimated model was shown as in equation (1).

$$G_y(s) = \frac{0.4}{16s + 1}$$

Compared with conventional control system, the optimal control mode of valve-controlled heating system adds not only the estimated link, but also the comprehensive error link. The comprehensive error part $E_z(s)$ was composed of the difference between the system feedback and the predictive feedback and the reference value. Its concrete expression was shown as in equation (2).

$$E_z(s) = aE(s) + (1 - a)\hat{E}(s)$$

where $E_z(s)$—The comprehensive error of the system, which is input to the fuzzy controller; $E(s)$—The actual error of the system, which is equal to the given value (set temperature) minus the feedback value (output temperature); $\hat{E}(s)$—The estimated error of the system, which is equal to the given value minus the estimated value (estimated link output value); $a$—The error weight coefficient, whose value range is $[0, 1]$. 

The design of the fuzzy controller for the optimal control mode of the valve-controlled heating system adopted the traditional form of two inputs and one output, and the fuzzy set domain was $[-3, 3]$, which adopted the triangle membership function. Considering the system error $E$, error rate $EC$ (namely $de/dt$) and the output variable $U$ were selected in seven levels. The universe was set as $\{-3, -2, -1, 0, 1, 2, 3\}$. The two input system error and error rate represent the amount of change in the temperature of the measuring point and the amount of change in speed. According to the control idea and the structure of the fuzzy controller, the fuzzy control rules were set up as shown in Table 1.

| Output variable (U) | Error rate of input variable (EC) |
|---------------------|----------------------------------|
| NL                  | NL NL NL NL NL NM NS ZO          |
| NM                  | NM NL NL NM NM NS ZO ZO          |
| NS                  | NS NL NM NM ZO ZO PS             |
| ZO                  | ZO NM NS NS ZO PS PM            |
| PS                  | PS ZO ZO PS PM PM PL            |
| PM                  | PM ZO ZO PS PM PL PL PL         |
| PL                  | PL ZO PS PM PL PL PL PL         |

4. System testing and analysis

In order to verify the effect of model reference predictive fuzzy adaptive control in valve-controlled heating system, simulation test was needed for the system. Combining with the structure of the
above-mentioned valve-controlled heating system and its optimal control mode, a simulation control model was built by using MATLAB/Simulink. At the same time, fuzzy control was selected as a comparison to better observe the dynamic characteristics of different control algorithms. At the beginning of the test, the reference signal was applied at 20°C, and step interference was added to the two control processes at t=1200s. The simulation waveforms of control effect comparison were shown in figure 3.

![Figure 3. The simulation waveforms of control effect comparison.](image)

From figure 3, it could be seen that the fuzzy control system had a rise time of 230s, an adjustment time of 660s, and an overshoot of 23.4%. The model reference prediction fuzzy adaptive control system had a rise time of 340s, an adjustment time of 380s, and an overshoot of 0.8%. The response time of the fuzzy control system was short, but the adjustment time and overshoot were large. The response time of model reference predictive fuzzy adaptive control system was slightly longer, but the adjustment time was short and the overshoot was small. When the step interference was added and the reference signal changed, the response time and overshoot of the model reference predictive fuzzy adaptive control system were better than the fuzzy control. Therefore, in terms of system dynamic performance and anti-jamming, the optimized model reference predictive fuzzy adaptive control algorithm had better control effect than the fuzzy control algorithm in the valve-controlled heating system.

5. Conclusions
Aiming at the temperature control problem of valve-controlled heating system, a model reference predictive fuzzy adaptive control method was adopted on the basis of optimizing the fuzzy control algorithm. This paper mainly discussed the structure and control algorithm of the system, and the simulation control model was built by MATLAB/Simulink for system testing and analysis. The test results show that the optimized model reference predictive fuzzy adaptive control algorithm had better control effect than the fuzzy control algorithm of the valve-controlled heating system in terms of system dynamic performance and anti-jamming.

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