Modeling and Simulation of a Fuzzy PID Controller for Heat Exchanger Systems in District Heating

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Abstract. Heating exchange in district heating network is a complex process with great inertia and longtime delay, it is hard to control the temperature of secondary supplying water effectively with traditional PID controllers. This paper studies the fuzzy PID method and models the heat exchanger system through combining the fuzzy control algorithm with the traditional PID method. Meanwhile, simulation experiments of the fuzzy controller, which is based on the MATLAB/SIMULINK platform, is performed in detail .The results of the simulation show that this control strategy has characters of faster response and strong robustness. It is appropriate for controlling the temperature in district heating network.

Introduction

District heating systems are common in northern China, which provide higher efficiencies and better pollution control than localized boilers. In such a system, however, substations are indispensable for heat transfer from the district heating pipes into a building. Basically, a district heating substation is a heat exchanger system that connects the main network (the primary network) to a building's own heating system (the secondary network) for the end-users to get heat on demand. The water temperature on the secondary side usually needs to be precisely controlled, which is the basis for quality heating. At present, the control of the water temperature relies heavily on proportional–integral–derivative (PID) controllers, which are simple in structure and easy to be implemented. However, conventional PID controllers cannot satisfy both the static and dynamic properties of the heating system because that the temperature control of such a system is very complex, which has the characters of great inertia, long time delay, large time-variance and no precise mathematical model[1].

Meanwhile, the literature shows that the fuzzy control strategy is suitable for analogous process control, such as the air-conditioning, medical, and chemical processes[3]. The combination of fuzzy logic and PID controller leads to pronounced characters of adaptation, robustness and no need for precise mathematical model. Furthermore, the fuzzy PID method increases the efficiency of energy use[2]. So this paper models a fuzzy PID controller for a heat exchanger system through combining the fuzzy control algorithm with the traditional PID method, and simulates its performance using the MATLAB/SIMULINK platform.

Control Strategy

In general, the temperature of the return water of the secondary network depends on the heating load. So the secondary supply temperature is the main measure of the heating quality. For climate compensation, the temperature of the secondary supply water is varying with the outdoor temperature. According to the theoretical analysis, the correlation of the temperature of the secondary supply water with the outdoor temperature is described by the following equation[4]:

$$t_g = t'_n + \Delta t'_s \overline{Q'_2}^{\frac{1}{1+b}} + 0.5 \Delta t'_j \overline{Q'_2} \tag{1}$$

Where t'_n is indoor design temperature, t'_g is design temperature of secondary supplying water, t'_h is design temperature of return supplying water , t'_w is design outdoor temperature, mean temperature difference of users' heating radiators $\Delta t'_s = 0.5(t'_g + t'_h - 2t_n)$, temperature difference between design supplying and return water $\Delta t'_j = t'_g - t'_h$,relative thermal load $Q'_2 = \frac{t_n - t_w}{t_n - t'_w}$.

The secondary supply temperature is regulated by adjusting the electric valve for supply flow of on the primary side. While the actual temperature value of the secondary supplying water is smaller than the set point, the valve is turned up. On the contrary, if it is bigger than the set point, the valve is turned down. Thus the control variable of the heat exchanger system is the opening of the electric valve of the primary network. Figure 1 shows the control process of the heat exchanger system [4].

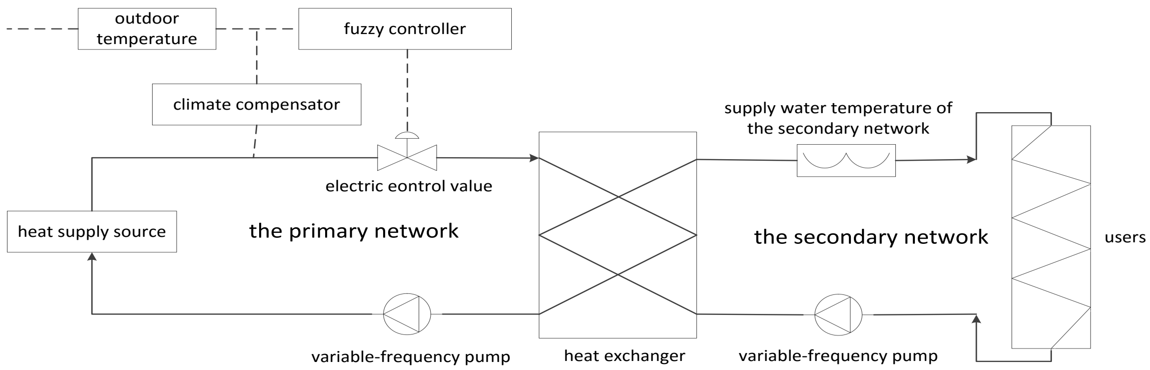


Figure 1. Structure diagram of the heat exchanger system

Model

The model of the heat exchanger system has to be built, which is using to simulate the control of the secondary supplying water of the distributed heating substation [5].The mathematical model of the heat exchanger system is usually described by a pure time delay element with a second-order system which can be replaced by a first-order model approximately after the system identification. It is shown as follows[6]:

$$G(s) = \frac{K}{TS+1} e^{-\tau S} \tag{2}$$

Where K, T, τ are constant parameters, which can be determined through system identification. In this case, K=1, T=35s ,τ=19s.

Algorithm of the PID Control

The algorithm equation of the PID controller in the continuous time domain is described bellow:

$$u(t) = k_p \left[e(t) + \frac{1}{T_i} \int_0^t e(t)dt + T_d \frac{d(t)}{dt} \right] \tag{3}$$

The discrete equation of the PID control algorithm is described bellow [7]:

$$u(k) = k_p e(k) + k_i \sum_{j=0}^{k} e(j)T + k_d \frac{e(k) - e(k-1)}{T} \tag{4}$$

Where: k_p , k_i and k_d are the coefficients for the proportional, integral and derivative items respectively. $k_i = {k_p}/{T_i}$; $k_d = k_p T_d$.

The key to PID controller is the parameters tuning. A heuristic method of tuning a PID controller is formally known as the Ziegler-Nichols tuning method to compute the k_p, T_i, T_d [8] . According to the transfer function and Ziegler-Nichols tuning method, where: $k_p = 1.2\frac{T}{K*\tau} = 2.211$, $T_i = 2.2\tau = 41.8$, $T_d = 0.5\tau = 9.5$.

So, $k_p = 2.211$, $k_i = 0.053$, $k_d = 21.013$

Structure of Fuzzy Controller

The lingual variables of the input (e, ec) and output $(\Delta k_p, \Delta k_i, \Delta k_d)$ are E, EC, KP, KI, KD. Fuzzy theory domain of each of the variables is set to $[-6,6]$, and seven fuzzy subsets $\{NB, NM, NS, ZO, PS, PM, PB\}$ are selected for each variable. To improve the robustness of the system, the Gaussian curve is adopted for the membership function in the initial phase and the triangle curve is selected as the membership function at the little error domain. The membership function is shown in figure 2.

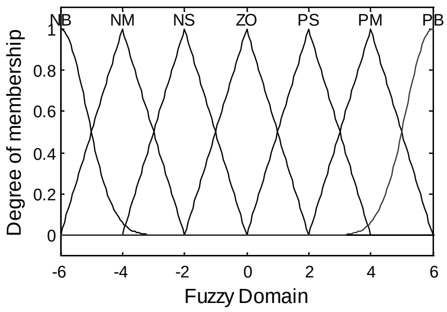
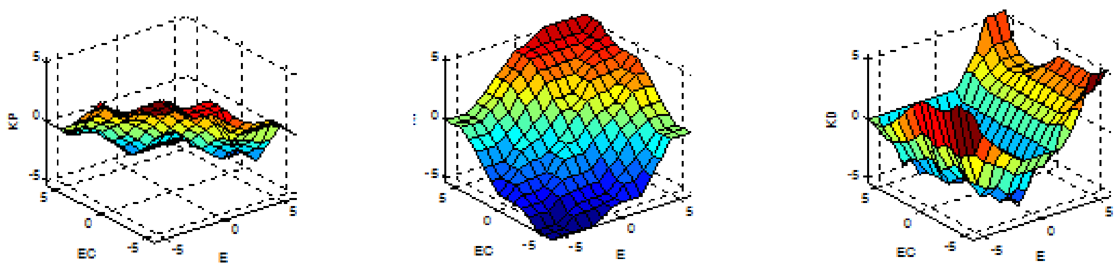


Figure 2. Membership function of input and output

Actually, the fuzzy control rules are usually based on the experiences of the experts .The bivariate continuous equations between the absolute value of deviation $|E|$ and its variety $|EC|$ as well as the k_p, k_i, k_d are shown as the following equations (5)[9], where f_1, f_2 and f_3 are the control rules, which are adopted from references[4].

$$\begin{cases} k_p = f_1(|E|,|EC|) \\ k_i = f_2(|E|,|EC|) \\ k_d = f_3(|E|,|EC|) \end{cases} \quad (5)$$

The control surfaces of the fuzzy controller are shown as figure 3.



(a) k_p (b) k_i (c) k_d

Figure 3. Control surface of the fuzzy controller

Simulation Model of the Heat Exchanger System

According to the above, the structure of the fuzzy PID controller and the simulation model are shown as figure 4 and figure 5.

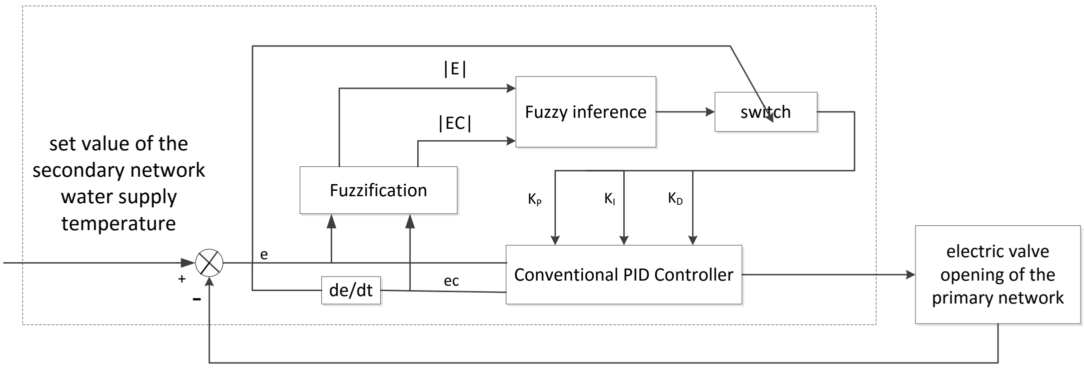


Figure 4. Structure of fuzzy PID controller

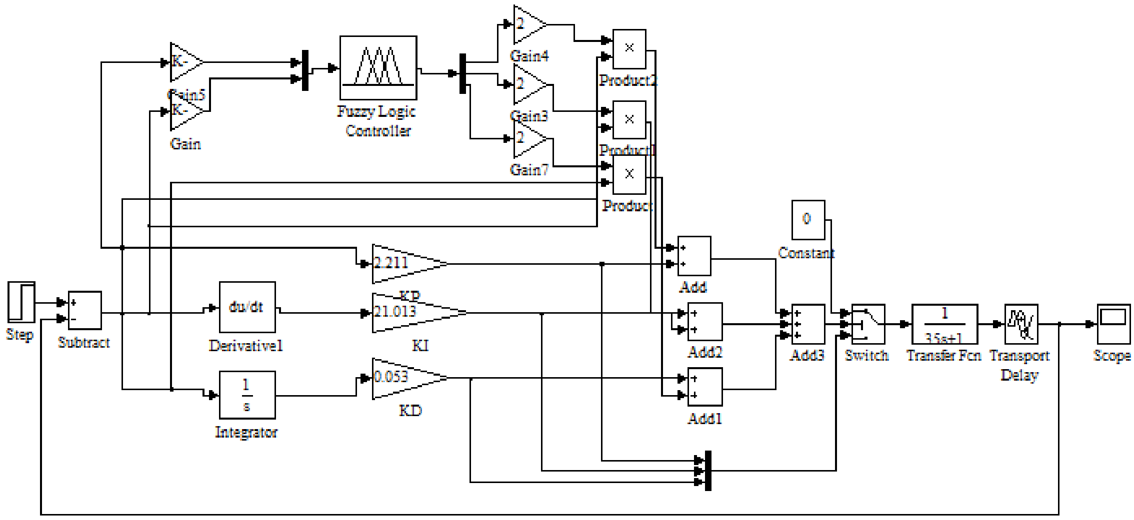
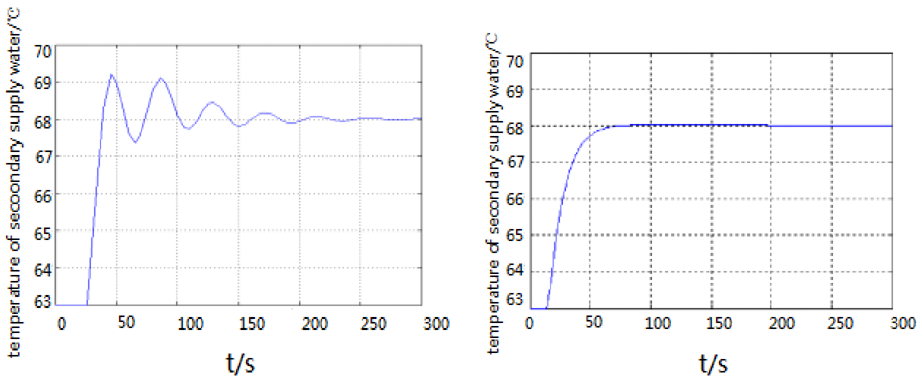


Figure 5: simulation model of the heat exchanger system

Effect of Simulation

The simulation model of the heat exchanger system is constituted based on MATLAB/SIMULINK platform. In view of a specific heat exchanger system, the $t'_n = 18$ ℃, $t'_g = 80$ ℃, $t'_h = 60$ ℃, $t'_w = -7$ ℃, When outdoor temperature t_w varies from 0 ℃ to -2 ℃, the temperature of secondary supply water changes from 63 ℃ to 68 ℃. As we can see from figure 6, the overshoot is over 20%, and it takes nearly 260 seconds to stabilize with the conventional PID control, while the overshoot is zero and the stabilization time is only 70 seconds with the fuzzy PID control. Compared with the conventional PID controller, it's obvious that the fuzzy PID controller is more suitable for temperature control in a heat exchanger system.



(a) conventional PID control (b) fuzzy PID control

Figure 6. Step response curve

Conclusion

The heat exchanger system is a system with great inertia, long time delay and large time-varying. According to this system ,this paper designed a fuzzy PID controller by combining the fuzzy algorithm and the conventional PID method .The simulation results show that compared with the conventional control method ,the fuzzy PID controller has characters of faster response, nearly no overshoot, and the control precision is significantly improved. So the fuzzy PID control strategy is suitable for the temperature control of the heat exchanger system.

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