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Application of Intelligent Three-state Pang-Pang Control to Heat Exchange Station

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Abstract

The heat exchange station of central heating system has been increasingly widely used as the intermediate hub connecting the heat source and heat users. If the specific temperature control requirements are not satisfied effectively and specifically, the security and stability of the primary network and quality of the secondary network will be affected directly. A temperature control scheme of the heat exchange station is presented based on intelligent three-states Pang-Pang. On the basis of mechanism analysis, we choose the average of supply and return water temperatures of secondary network as the controlled variable in presented temperature control scheme, which is equivalent to inducing the supply water temperature as the feedforward signal. The advantages of the intelligent three-state Pang-Pang control algorithm lie in improving the stability of the primary network, reducing the overshoot and accelerating the response of the secondary network. The application of the presented control scheme to the practical engineering shows that it not only implements the automatic control of the temperature of heat exchange station hence improves its control performance but also enhances and improves the controllability of the system effectively and especially has the referential and extending significance for heat exchange station transforming open-loop to closed-loop control.

Keywords: *heating quality, average temperature, intelligent three-state Pang-Pang, controllability*

1. Introduction

With the development of global urbanization, the application of central heating has been becoming more and more widely used. And also the heat exchange station is increasingly prominent because of the important role in the heat distribution and transformation. However,most of the heat exchange stations are generally controlled by manual operation and in open-loop control mode. The automation degree is low [1]. Even if along with the advancement of information technology, in recent years, the station realizes the telemetry and remote control to a certain extent, it is still difficult to meet the dynamic changes heating demand in real-time. Meanwhile,due to the whole society attaches great importance to energy conservation, the terminal heat users who actively participate in the heat measurement and regulation, which have become the inevitable trend. Therefore, pressing needs are put forward for practical algorithm of the closed-loop control either from the perspective of the security and economy of heat exchange station or meeting the feasibility of process requirements.

In the traditional control mode, it usually changed the regulating valve of the primary network to satisfy the returnwater temperature to heating index requirements according to the outdoor environment temperature. Because of the characteristics of heat storage and the essence of large inertia link, the station not only meets the demand of the secondary network temperature, but also ensures the stability of pressure fluctuations in primary network according to the technological requirements and constraints. Thus the regulating valve should not act frequently, so such as PID control algorithm is difficult to adapt to the heating system control requirements [2]. The simple Pang-Pang control algorithm which has been successfully applied in practice regulates the regulating valve by limiting the valve amplitude to ensure the impact to primary network pressure fluctuations in the technology license range. At the same time, taking the characteristic of heat storage and large lag into account to meet heat demand of the secondary network, the system puts forward the idea that replaces precise control with satisfactory control. Pang-Pang control algorithm reflects its strong practicability in the practical

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heating control engineering. But Pang-Pang control is really simple to stabilize the secondary network controlled temperature into a satisfactory range. The upper and lower limits of the valve opening of Pang-Pang control are constrained by water and heat balance of primary network. Whether can we adopt the more simple and convenient improvement to enhance the stability, accuracy and speed of the heating control system comprehensively to produce the following intelligent three-state Pang-Pang control.

2. Control Process

The process flow diagram of control system is shown in Figure 1. Heat exchange station control system mainly includes heating temperature control, circulating pump transferring heat control, make-up water control and pressure relief control.

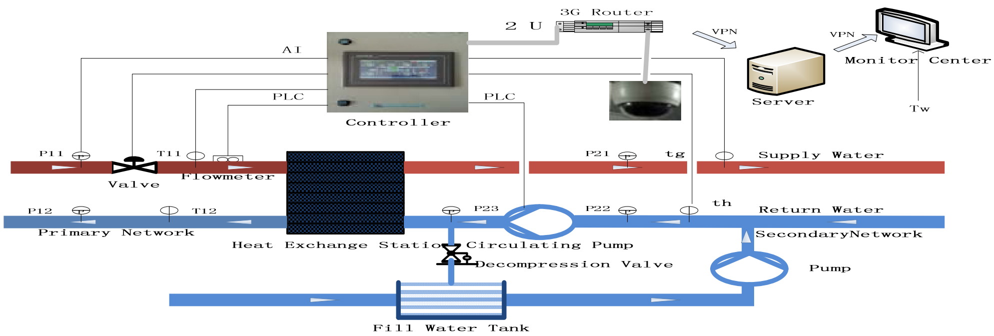

Figure 1. Process Flow Diagram of Control System

The heating temperature control mainly regulates the primary network valve based on the heat demand of the secondary network. Circulating pump transferring heat control transfers the heat circulating pump to terminal heat users safely and reliably by frequency control. Make-up water pump control keeps the network full of water to avoid empty and air resistance also to prevent air corrosion by make-up pump; Pressure relief control utilizes pressure relief valve to ensure that there are no overpressure and burst pipes in secondary network system in order to the safe operation of heating network. The research focuses on the heating temperature control of the heat exchange station. Firstly, make a simple summary analysis for the other three control components.

2.1. Circulating Pump Transferring Heat Control, Make-up Water Control and Pressure Relief Control

Circulating pump transferring heat control includes constant pressure control and differential pressure control. Constant pressure control selects the circulation pump outlet pressure as set value while differential pressure control selects pressure difference between the supply water pipe network and the return water pipe network of secondary network. The working principle of both is adjusting the speed of the circulation pump by altering the circulating pump operating frequency based on the set value changing to ensure that the secondary network heat is sent to the users in time orderly. The control structure block diagram of frequency control speed is shown in Figure 3. When the measured pressure value is higher than the set value, PLC emits signal to reduce the frequency to reduce the second network flow to maintain the set value constant according to control algorithm. When the measured pressure value is lower than the set value to increase the frequency to keep the set value constant.

In the heat exchange station operation of central heating system, if the secondary network water is not enough, it will cause the pipe network pressure reduced and lead to the phenomenon of empty and air resistance of the pipe network also it can corrode pipe network and affect the life of equipment. What's worse, it can result that the heat load can't be transported to the heat users in time which affects heat quality directly. The principle of make-up water control is that when the measured pressure is below the set value to fill water to the system, when reaches the requirement to stop. In the intermittent heating, due to the expansion and contraction of water in pipe network, the system also needs to make-up water and pressure relief dynamically.

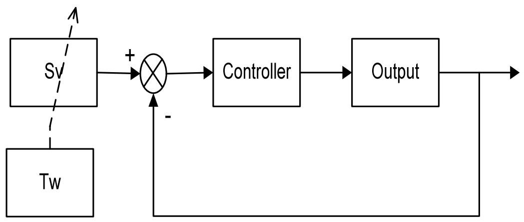

Figure 2. Block Diagram of Average Temperature Control

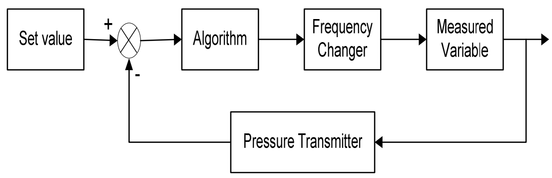

Figure 3. Principle Diagram of Frequency Control

When more than one users close the regulating valve at the same time, the secondary network pressure of heat exchange station will increase sharply which will cause the accident of bursting the pipe network of the users. In order to prevent excessive pressure, it is necessary to ensure that the maximum pressure value of heat exchange station must not exceed the set value or the minimum pressure value must not exceed the set value. When the measured value is higher than the set value to relieve the pressure to guarantee the safe operation of heating network. However, in the course of the pressure relief, the system vents out the hot water, fills the cold water when the system needs to make up water. Therefore, under the premise of safety, the system should perform as little as possible relief action to avoid the phenomenon of side of making up water while pressure relief

2.2. Principle of Heating Temperature Control

The scheme of heating temperature control selects the average of supply and return water temperatures of secondary network as the controlled parameters. The controlled object is the regulating valve on primary network of heat exchange station. Under the condition of climate compensation, select average temperature set value of the secondary network as the given value, the valve opening (frequency) as the output, so that the average of the supply and return water temperatures of secondary network maintains at the set value, the block diagram is shown in Figure 2.

When the average temperature is less than the set value, the controller adopts reasonable algorithm to adapt the regulating valve automatically to increase the heat load when the average temperature is more than t set value, the controller adapts the regulating valve to reduce the heat load

3. The Theoretical Design Value of Average of Supply and Return Water Temperatures of Secondary Network

The heating quality automatic control of heat exchange station is that it ensures that user indoor temperature is reasonable and meeting the heat demand of users when the outside temperature is changing. So the indoor temperature is undoubtedly the most intuitive controlled parameters, but in the most of the users, it's difficult to find a broadly representative point. In the heating system the heat supplied by system equals the heat dissipating capacity and of the indoor temperature maintained by users. System adjustment formula [3] shows:

$$\begin{cases} t_g = t_n + \frac{1}{2}(t_g' + t_h' - 2t_n)\left(\frac{t_n - t_w}{t_n - t_w'}\right)^{\frac{1}{1+B}} + \frac{1}{2\overline{G}}(t_g' - t_h')\left(\frac{t_n - t_w}{t_n - t_w'}\right) \\ t_h = t_n + \frac{1}{2}(t_g' + t_h' - 2t_n)\left(\frac{t_n - t_w}{t_n - t_w'}\right)^{\frac{1}{1+B}} - \frac{1}{2\overline{G}}(t_g' - t_h')\left(\frac{t_n - t_w}{t_n - t_w'}\right) \\ t_p = (t_g + t_h)/2 = t_n + \frac{1}{2}(t_g' + t_h' - 2t_n)\left(\frac{t_n - t_w}{t_n - t_w'}\right)^{\frac{1}{1+B}} \end{cases} \quad (1)$$

Where *tn* is indoor temperature calculated in winter heating, *tw* represents outdoor temperature calculated in winter heating, *tg* and *th* delegate the supply and return water temperature under heating system design conditions, *B* represents radiator heating transfer index which equals to 03, *G* is the relative flow rate of circulating water.

The fundamental Equation (1) of operating regulation in heating system shows that under the condition of the indoor temperature unchanged, the average temperature *tp* in secondary network is just a uniform function of outside temperature *tw*; *tp* can accurately response to user's heat load change.

3.1. The Dynamic Set Value of Average Temperature of Secondary Network

The relationship between set value and the outdoor temperature can be defined as a linear equation shown in Equation (2). Figure 4. describes the relationship between set value and the outdoor temperature clearly.

$$SV=A*X+B. \quad (2)$$

Where *SV* is the set value of the average of supply and return water temperatures of secondary network, *X* is the outdoor temperature, *A* and *B* are the parameters to define the linear relationship whose value and symbol can be set according to actual needs. *A* and *B* can be obtained as follows. For example, when the outdoor temperature is -15℃, we make *SV* is 60℃; when the outdoor temperature is equal to 5℃, *SV* is 40℃.

It is easy to obtain *A*=-1, *B*=45 then substitute them into Equation (2). After that, we can get the linear equation about the set value of the average temperature of secondary network and the outdoor temperature that is shown in Equation (3). The relationship between set value and outdoor temperature is shown in Figure 5.

$$SV=(-1)*X+45. \quad (3)$$

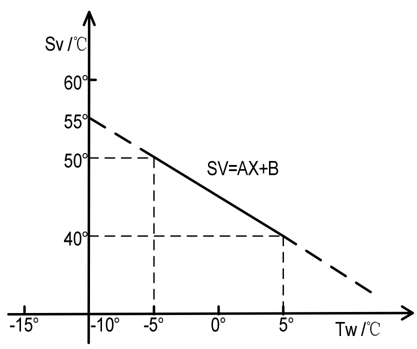

Figure 4. Relationship between Set Value and Outdoor Temperature

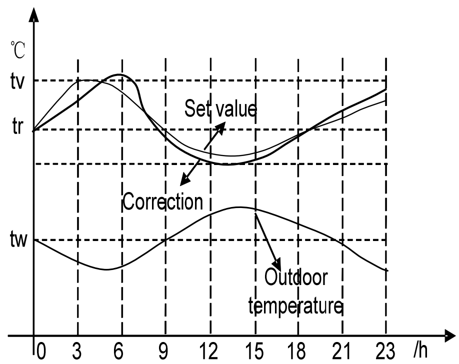

Figure 5. Time Correction Curve of Secondary Network Temperature

Human-machine dialogs of the highest outdoor temperature, the lowest outdoor temperature and the corresponding minimum average water temperature, maximum average temperature are given in this system. After users input the two sets of values according to local conditions or personal habits, the system can calculate the set value of average temperature automatically [4]. So when the outdoor temperature is higher, the set value of average temperature is smaller; when the outdoor temperature is lower, the set value is larger. And the minimum average temperature and the maximum average temperature restrict the range of average temperature to avoid the temperature too large or too small. By this means, the system can adjust the average temperature in a suitable value. So it can save a lot of energy on the basis of ensuring human comfort.

3.2. The Calculation of Set value Correction

To meet the heat requirements of indoor thermal comfort is not simply depending on the outdoor temperature, it is also closely related to factors such as solar radiation, wind direction, wind speed. When the system can't obtain comprehensive meteorological parameters, for further energy saving and raising heat quality, multi-period correction function of average temperature set value can be added in accordance with the statistic demands on the basis of normal climate compensation. That is to say based on different characteristics in different regions or different user demands to do further refinement correction. Correction method is shown in Equation (4), where *SVc* represents the correction value and k0 ~ k23 correspond to the day from 0:00 to twenty three in 24 hours shown in Table 1. The correction curve is shown in Figure 5. By adding or subtracting the value to fine tuning for further correction.

$$SVc = SV + \Delta t \tag{4}$$

During the sleeping period of "0:00 - 6:00" and "11:00 ~ 15:00" at noon, correction value has a certain degree of reduction based on the set value in the original setting while in the time living of "18:00 ~ 21:00 ", the correction value is increasing to a certain degree.

Table 1. Correction Coefficient

Time [h]	0	1	2	……	k21	k22	k23
Δt [□]	-2	-3	-2		4	2	2

3.3. The Smart Pang-Pang Control

Equation (1) indicates that the return (supply water temperature) water temperature of the secondary network and outdoor temperature correspond to each other. When we adopt the classical control, the return (supply water temperature) water temperature is continuously tracking the outdoor temperature, so that the regulating valve moves frequently and cause pressure fluctuations of primary network strongly which may induce industrial accident. On the other hand it can lead the life of the regulator to shorter to damage the equipment easily. Although Pang-Pang control accuracy is not high, it can achieve the control standard, meet the heat demand and solve the problem above, so Pang-Pang control is feasible in central heating system with characteristics of big delay and large lag [5].

The basic principle of Pang-Pang control is shown in Figure 6. Pang-Pang control has two positions—the upper limit and the lower limit.When the measured temperature value is higher than the upper limit temperature of Pang-Pang, the primary network regulating valve runs in the lower limit position automatically to decrease the water flow of primary network to reduce heat load; When the measured temperature value is lower than Pang-Pang lower limit value, the primary network regulating valve operates in the upper limit position to increase the water flow to improve the heat load. The calculation equation of the upper and limit temperature of Pang-Pang is shown as Equation (5). The regulating valve setting of dynamic upper and lower limit value and the amplitude value depend on the process actual demands which includs the area of taken warm and the pressure influence caused by all the heat exchange station opening or closing in the permitted range [6]. σ1% and σ2% represent the overshoots of the average temperature of secongdary network. Because the amplitude value between the two positions is relatively far distance so that it can easily lead to pressure fluctuation of the primary network and the overshoot will be relatively large.

$$\begin{cases} Tu = SVc + 1.5 \\ Tl = SVc - 1.5 \end{cases} \tag{5}$$

Where *SVc* is the correction value of *SV*, *Tu* is the Pang-Pang temperature upper limit, while *Tl* is Pang-Pang temperature lower limit.

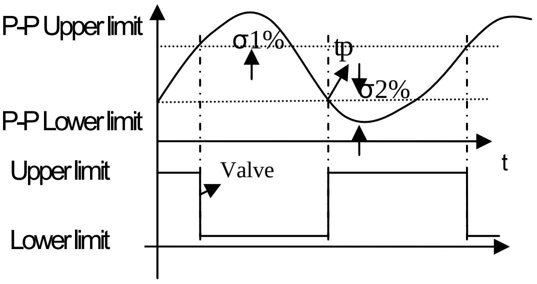

Figure 6. Principle Diagram of P-P Control

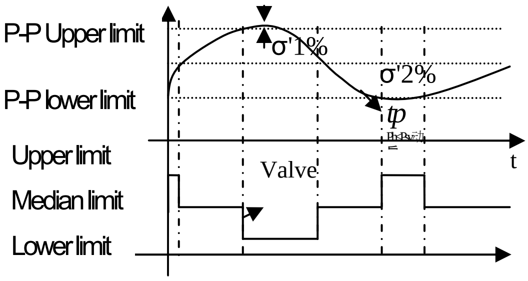

Figure 7. Principle Diagram of Three-state Control

3.4. The Three-state Pang-Pang Control

In order to reduce the pressure fluctuation of the primary network and reduce the overshoot to promotes the control accuracy to enhance the heat quality of the secondary network. On the basis of Pang-Pang control two-position limit, the system introduces the third limit—the median limit (the median limit is equal to average of the upper and lower limit) so that the amplitude value of valve relatively shrinks to relieve the pipe network pressure fluctuations caused by valve action. The principle of the three-state Pang-Pang control is shown in Figure 7. When the average temperature measured is higher than the temperature upper limit value of Pang-Pang, the primary network regulating valve runs to the lower limit position automatically to decrease the average temperature, when the average temperature is less than upper limit of $|Pv\text{-}Sv| \leq 0.5$, the valve switches to valve median limit position to ease the average temperature decreasing speed of secondary network. When the average temperature measured is lower than the temperature lower limit of Pang-Pang ,the valve runs to upper limit position to increase the heat load; when the average temperature is more than the lower limit of $|Pv\text{-}Sv| \leq 0.5$,the valve switches to median position to alleviate the average temperature to continue to rise. In the ideal case, when the outdoor temperature is relatively low, the regulating valve stays in upper limit position to increase the heat load. When the measured temperature *Pv* is going to reach the set value *Sv*, the valve runs to the median position then *Pv* tends to *Sv* gently to stay in a reasonable temperature range; Similarly, when the temperature is relatively high, because of the median limit of the regulating valve, *Pv* will reach to *Sv* gently and stay in a reasonable temperature range to get the control effect [4]. The intelligent three-state Pang-Pang control reduces the pressure fluctuation of the primary network,alleviates the fluctuation range of the average of supply and return water temperatures in secondary network and reduces the overshoot compared to simple Pang –Pang control which means σ'1% <&1%,σ'2%≈ 0.

3.5. Process Indicators

The research focuses on a heat exchange station of a university student apartments in Dalian which taken warm covers an area of 39000 m2 currently and the heat users are mainly for student hostels. The scheme that selects the average of the supply and return temperatures of the secondary network as the controlled parameters meanwhile Pang-Pang control algorithm and three-state control algorithm are applied to the actual temperature control systems. Corresponding parameters in the controller are set shown in Table 2.

Table 2. Parameter Setting of the Controller

Parameter setting	Upper limit value	Median limit value	Lower limit value
Pang-Pang valve opening	40		20
Three-state control valve opening	40	30	20
Outdoor temperature	5°		-15°
Average temperature	40°		60°

4. Experiment Result and Analysis

Making a comprehensive comparison Pang-Pang control effect with three-state Pang-Pang control effect from Figure 8 and Figure 9, we can see that the amplitude value of valve limit is relatively large due to the two-position of the Pang-Pang control so that the measured value usually deviates from the set value of the temperature which results in a relatively large overshoot. Also, the valve acts relatively frequently. If adopting the three-state Pang-Pang control which is equivalent to two sets Pang-Pang control because of the median limit.Thereby it enables the average temperature value measured remains in the area of | *Pv* - *Sv* |≤0.5. When the outdoor temperature is low, the regulating valve is in the upper limit to increase the primary network water flow and the secondary network average temperature rises. As the average temperature raises to conform the median limit operation condition, the valve moves to the median limit to ease the increasing slope of the average temperature, which is better for *Pv* stabilizes near the set value *Sv*; Similarly, when the outdoor temperature is high, the median limit also plays a role in reducing the overshoot. So that, regardless of the outdoor temperature raises or falls, the median limited acts two times in the transition process. So that the valve will remain in the median limit position a relatively long time which reduces the overshoot and improves the control accuracy (heating quality). Some evaluation indexes can be obtained from the historical data: Pang-Pang control algorithm, the average overshoot σ% = 7.9%, while the use of three-state control Pang-Pang average overshoot σ%= 3.1%,which reduces 86.1%.

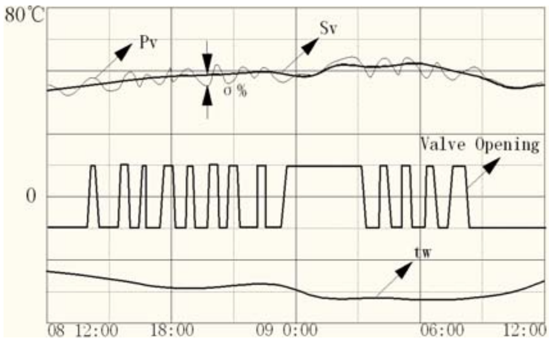

Figure 8. The Curve of P-P Control

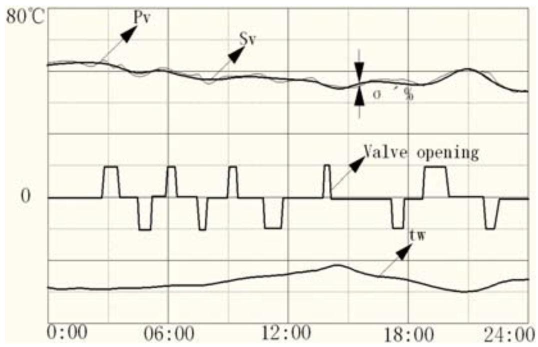

Figure 9. The Curve of Three-state Control

The three-state Pang-Pang control algorithm reduces the overshoot and improves the control accuracy effectively compared to Pang-Pang control algorithm. The average of the supply and return temperatures as the controlled parameter and the intelligent three-state Pang-Pang control algorithm improves the control performance and heating quality and has the benefit for the primary network pressure stability.

5. Conclusion

The average of supply and return water temperatures of secondary network as the controlled parmeter is similar to inducing the supply water temperature as the feedforward signal which played a role in lead control. It's very important for central heating control systems with a large time constant and large delay.

The Pang-Pang control with reasonable setting boundaries conforms process requirements especially the intelligent three-state Pang-Pang control algorithm is simple and effective to accelerate the speed of response of the controller.

The intelligent three-state Pang-Pang control not only improves the stability of the primary network and reduces the overshoot of the secondary network but also improves the controllability of the system, solves uncontrollability that the simple PID algorithm doesn't do ,breaks the "bottleneck" that the process heat of the heat exchange station transfers from open-loop into a closed loop and improves the quality of heating which has referential and promotional value on the growing popularity of the heat exchange station

Further research and improvements includes on the basis of statistical analysis introduce the dynamic three-state Pang-Pang control which means to regulate the dynamical boundaries of Pang-Pang according to the time proportion of the upper limit or the lower limit everyday.Meanwhile,make sure that the primary network disturbance is in the process permitted range according to the process actual demand and the average temperature stays at median limit value in more time as far as possible.

Acknowledgements

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