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Management and Control for Optimal Performance of the Heating Substation

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Abstract: With the development of the scale of central heating, a higher managing level is needed for the heating substation. How to economize the more energy is the first factor that managers need to consider while ensuring the comfort of the heating consumer. The development of automation technology and the reduction in automation product prices and equipment supply, the technology guarantees reasonable heating of the heating substation. At the same time it brings a new problem—for ensuring the balance between investment and income, how to process central regulation at the heating substation? According to the three elements consisting of heat resource, heat consumer and heat-supply network, the article puts forward the basic principle of selecting the mode of central regulation, discusses the advantages and disadvantages of all kinds of regulation modes, and the essentials that designer should regard. In addition, the article especially studies the arithmetic of the controller, and discusses the possibility of replacing the normal PI or PID tune with fuzzy control by a case of quantitative regulation.

Key words: central heating; heating substation; central regulation; energy saving; fuzzy control

1. PREFACE

At the cold region, heat supply is related with people living close. Central heating is a progressive inevitable development trend of technique. It can economize the energy and reduce the pollution of the environment availably, can provide the high quality heat source for the resident. More and more heat consumers acquire indoor comfort by central heating. But the extension of the scale of central heating also brought the problem. That is how to lower the cost of heating branch while assuring the indoor thermal comfort. It is an effective way by using automatic equipments to regulate central hating system, and the development of automatic technique also provided the assurance for this kind of way.

2. REGULATION MODE FOR HEAT-SUPPLY SYSTEM

Heating substation is a necessary establishment that transferring the heat energy from primary water system to secondary water system. It main includes heating source, heating consumers and heat supply network. With the change of the outdoor temperature, the heating load of heating consumers is also variable; it must follow the following condition for ensuring the indoor temperature.[1]

Actual heat consumption
=actual heat dissipation capacity
=actual heating supply capacity

The equation above is fundamental for central regulation of heat-supply system; according it we can conclude the equations for central regulation.

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

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

In equation (1) and (2) above,

t_n - actual indoor temperature;

t_w - actual outdoor temperature;

t_g - actual temperature of supply water;

t_h - actual temperature of return water;

$t_n^{'}$ - indoor design temperature;

$t_w^{'}$ - outdoor design temperature for heating;

$t_g^{'}$ - design temperature of supply water;

$t_h^{'}$ - design temperature of return water;

B -heating radiator exponent;

$\overline{G}$ -ratio of actual flowrate to design flowrate.

Central operating regulation at heating substation is necessary to supply heat for consumer base on the actual heating load with the variety of the outdoor temperature. The regulation modes main include qualitative regulation, quantitative regulation, qualitative and quantitative regulation, qualitative regulation of phase-variable flowrate and quantitative regulation of phase-variable supply-water temperature etc.[2] But initial adjustment for heat supply network is essential for all regulation modes.

Qualitative regulation is a way that has variable water supply temperature and fixed circulation flowrate. It can ensure the heat comfort of consumer and stability hydraulic condition, but brings more energy consumption of circulating water pump. Quantitative regulation is a way that has variable circulation flowrate and fixed water supply temperature. It can lower energy consumption of circulating water pump, but less circulation flowrate may cause vertical misadjustment of thermal condition. Reducing the water supply temperature and lowering circulation flowrate simultaneous while outdoor temperature rise, this way is called qualitative and quantitative regulation. It can not only lower the energy consumption but also overcome the vertical misadjustment. Qualitative regulation of phase-variable flowrate and quantitative regulation of phase-variable supply-water temperature is similar with qualitative and quantitative regulation.

3. PRINCIPLE OF SELECTING REGULATION MODE

The designer must select a suitable regulation mode according to the characteristic of heat substation, heat consumer and heat supply network.

3.1 Type of Heating Load

For single design heating load, all regulation modes can be adopted. But quantitative regulation maybe is the better mode for multiple kinds of heating load, such as the total heating load include domestic hot-water load. In such instance designer may also consider local regulation.[3]

3.2 The Form of Heat Consumer System

The form of heat consumer system include traditional single pipe heating system, double-pipe heating system, single-double pipe combined heating system and household metering heating system etc. For traditional heating system, qualitative and quantitative regulation is the best mode. Because regulating valve installed for household metering heating system may cause the variable of flowrate so qualitative regulation is not suitable for this system.

3.3 The Type of Regulating Valve of Heat Supply Network

In order to acquire the design flowrate for all the branch of heat supply network, all kinds of regulating valves are installed on the branch pipe. They are necessary for initial adjustment according to pressure diagram. The regulation mode by using manual regulating valve or normal balance valve belongs to static regulation; additional belongs to dynamic regulation by using autoflow domination valve. Quantitative regulation is unsuitable for dynamic regulation, because it may cause serious horizontal misadjustment.

3.4 The Number of Circulating Water Pump

If the number of circulating water pump is more than ore, the suitable regulation mode is qualitative regulation of phase-variable flowrate. Especially, variable-frequency pump and normal-frequency pump work simultaneous are not allowed, although their type is same. For the instance, you should select variable-flowrate and invariable water-head pump. For better regulation, the designer should consider replacing more pumps with one pump, in addition it can reduce the total power of operating pump.

4. THE FACTOR CONSIDERED WHILE SELECTING REGULATION MODE

4.1 Selection of Controlled Variables and Manipulated Variables

Theoretically, controlled variable should be indoor temperature, but this variable is unpractical for lack of maneuverability. In fact designer usually select supply water temperature or return water temperature or pressure difference between supply and return water of worst loop. They are unreasonable. By equations (1) and (2), we can obtain:

$$t_p = \frac{1}{2}\left(t_g + t_h\right)$$

$$= t_n + \frac{1}{2}\left(t_g^{'} + t_h^{'} - 2t_n^{'}\right)\left(\frac{t_n - t_w}{t_n^{'} - t_w^{'}}\right)^{1/(1+B)} \quad (3)$$

By equation (3), indoor temperature only related with average temperature between supply water and return water. So selecting it as controlled variable is reasonable for all regulation modes. For the instance of selecting manipulated variable is simple, it depend on the regulation mode. For example, qualitative use flowrate of primary water system as manipulated variable, quantitative regulation use flowrate of secondary water system as manipulated variable.

4.2 The Fact that Heating Load Data for Load Estimation m and Radiator-surface L are Greater Than the Actual Need

By the fact that heating load data for load estimation m and radiator-surface L are greater than the actual need, normal exceed 10-20% of actual need, so much as more. It is especially obvious in old buildings. The basic equations of regulation must be corrected. [1]

4.3 Hysteresis of Regulating System[4]

Hysteresis is always existed for heating room and water supply network and heat exchanger. For a certain object, define hysteresis time as τ, define time constant as T, it usually cause the regulating system vibrating acutely when $\tau / T > 0.5$. This process should be regard as big hysteresis process, and adopt advanced control.

4.4 Arithmetic of Controller

For designer it is a complex work to select a suitable regulation mode. Normally, qualitative and quantitative regulation is a better choice for common heat-supply system. But heat-supply system is a non-linear and time-variable and hysteresis system, Arithmetic of controller should be regarded carefully. Routine PI or PID tune is just an ideal arithmetic, although it can solve some problem, but it isn't all-purpose. According to the complexity of heat-supply system, fuzzy control arithmetic maybe is another better choice for controller.

5. FUZZY CONTROL FOR QUANTITATIVE REGULATION OF HEAT-SUPPLY SYSTEM[5]

This case illustrates the design essential of fuzzy control for central quantitative regulation of heat-supply system. The control system samples outside temperature t_w and supply water temperature t_g and return temperature t_h of secondary water supply network. The average temperature t_p calculated by equation (3) is regarded as set value, and then calculate the difference e by comparing with actual average temperature. This fuzzy system has two input variables e and ec (the change of e between sample time), one output variable q (the frequency of transducer for pump).

5.1 Define Input/Output Variables and Corresponding Value Region

Using five language variables PB, PS, Z, NS, NB to illustrate fuzzy status of three variables, their region are:

$$X = \{-4,-3,-2,-1,0,+1,+2,+3,+4\}$$

Corresponding the value region of e (-10，+10)℃

$$Y = \{-3,-2,-1,0,+1,+2,+3\}$$

Corresponding the value region of ec (-5，+5)℃

$U = \{-4,-3,-2,-1,0,+1,+2,+3,+4\}$

Corresponding the value region of q (-10，+10)Hz

Output variable q may adopt absolute value or relative value according the value of e.The lower limit of q should be considered to avoid hydraulic unbalance.

5.2 The Design of Rules

Fuzzy control need design rules according to the designer's actual experience. See table 1 below of the rules of this case. The case has 25 rules.

Tab. 1 Fuzzy control rules

ec / q / e	NB	NS	Z	PS	PB
NB	PB	PB	PB	PS	Z
NS	PB	PS	PS	Z	NS
Z	PB	Z	Z	Z	NB
PS	PS	Z	NS	NS	NB
PB	Z	NS	NB	NB	NB

5.3 Design Membership Function

The case adopts triangular membership function for all three variables. Figure 1 below illustrates the membership function of e and figure 2 below illustrates the membership function of ec. The membership function of q is similar with e (ignored).

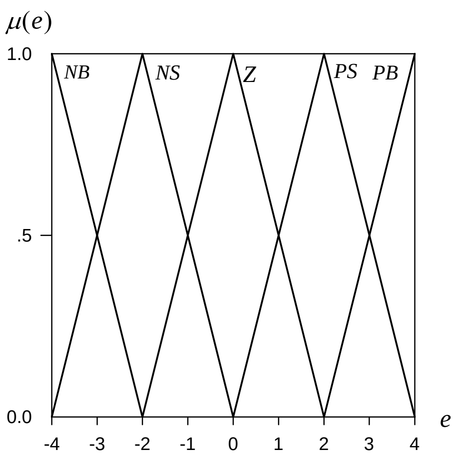

Fig. 1 Membership function of e

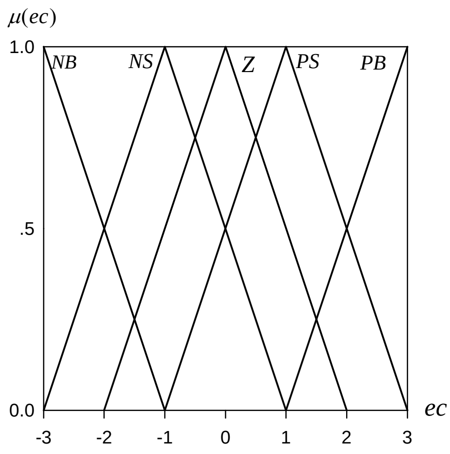

Fig. 2 Membership function of ec

5.4 Fuzzy Decision-making[6]

The value of output can be calculated by fuzzy operating with fuzzy matrix. The process is very complex; it need recur to program in computer. But it turns to easy by using FUZZY LOGIC TOOLBOX of MATLAB software. Figure 3 is the mamdani model of this case. Figure 4 is the result of output variable calculated by MATLAB.

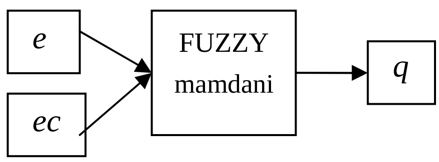

Fig. 3 Mamdani model of fuzzy

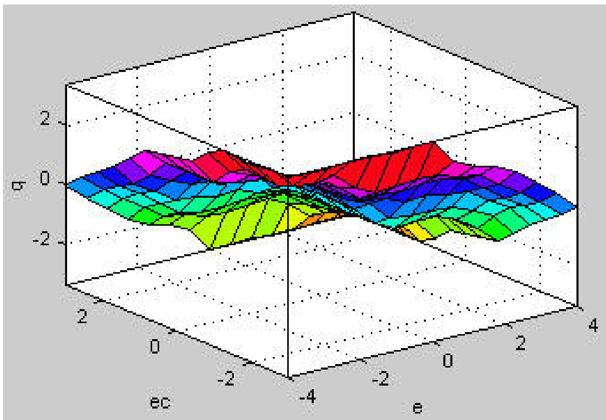

Fig. 4 Result of q

Table 2 is the table of control decision-making according figure 4. The data of the table has been rounded to integer.

Tab. 2 Fuzzy control decision-making

ec / *q* / *e*	-3	-2	-1	0	1	2	3
-4	4	3	3	2	2	1	0
-3	3	2	2	1	1	0	-1
-2	3	2	2	1	1	-1	-2
-1	3	1	1	1	1	-1	-2
0	3	1	0	0	0	-1	-4
1	2	1	-1	-1	-1	-1	-3
2	2	1	-1	-1	-2	-2	-3
3	1	0	-1	0	-2	-2	-3
4	0	-1	-2	-2	-3	-3	-3

6. CONCLUSION

The selection of central regulation mode of heat substation is a complex and important work for designers. The designers should adequately hold the characteristic of all elements of heat-supply system, and then choice a suitable regulation mode. For the arithmetic of controller, designer should consider the possibility that replacing normal PI or PID tune with fuzzy control. The effect of fuzzy control only lies on the designer’s actual experience. It maybe a better choice because the mathematic model of fuzzy control is more close to reality.

The fuzzy control may bring more economical benefits for heating substation. The article discusses how to select input/output variables and how to decide the control rules, membership function by using the experience of designers and manager while using fuzzy control for heating substation. And the article also gives the sample of fuzzy control decision making by using MATLAB. It may be helpful for designers and managers involved in heating supply.

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