Development of Temperature Process Control Method Using Smith Predictor

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Abstract. The analysis of a problem of development of control systems for objects with big time delay is carried out in this work. For such objects it is difficult to provide high-quality control, because the control is carried on the last status of object's output. The main setup methods of PID regulators have been examined. Based on this analysis the technique of complete synthesis of the regulator of higher level is given in order to regulate building's heating system. This work offers a new method of object's control with distributed delay. As the test bed for the offered structure of control the valve of hot water supply in a heat-node is used. Using the test bed the stability of the system with time delay have been studied, which is controlled by the PID-regulator assisted by Smith Predictor used to compensate the dead time.

1 Introduction

Energy saving in the field of building's heating is important task, considering both the criteria of market capacity and the aspect of status of engineering systems. In the European Union, buildings are responsible for 40% of total energy consumption including approximately 20% absorbed in heating which can be effectively used in the demand side management (DSM) strategy as a shift able load.

Energy saving in heating systems from control point of view is characterized by the need of stable maintenance of air temperature for building's premises at adjusted comfort level in the presence of external perturbations affecting the building. Today, considering the development of automation equipment and largescale implementation of individual thermal points, implementation of more effective heat controlling algorithms became possible [6]. Thermo-hydraulic processes in the building have big momentum; have nonlinear or variable linear dynamic behaviour and distributed nature, subjected to vast number of the influencing factors, which direct measurements are extremely difficult in practice.

The main task is analysis of heating units operating conditions and energy efficiency. Known necessary parameters of air supply flow and calculated physical energy with the program allows choosing the correct configuration of the heating units operating parameters. Coincidences from parameter settings of the airflow supply on the heating units configuration and control system should be investigated further. Necessary supply airflow can be adjusted in area to insure comfortable conditions. Regulation according to comfort zone requires higher-level control system comparing to temperature regulation with deadbands, but gives possibility to calculate optimal air supply parameters, which requires minimum energy consumption.

The management with prediction models in microclimate control algorithm allows increasing the effectiveness of HVAC system in buildings.

There is a problem of the correct setup of the heating equipment as excessive increase in temperature on the heating element leads to overheating of rooms, which results in excessive consumption of thermal resource and decreased comfort level. At the same time it is necessary to consider that the greatest saving of thermal energy in heating systems of buildings is reached by using intellectual automation. It is explained by the fact that automatic control allows to save heat due to accounting of those factors, which can't be considered by calculation methods, such as:

- influence of solar radiation;

- accounting of fluctuations in outside air temperature;

- heat release from people and equipment;

- chaotic operating time of ventilation.

Thus, the development of intellectual management systems for heating systems is a relevant task. The adjustment method based on prediction is offered in this work.

Predictive control is not a single strategy, but a set of control methods with predictive model of the process expressed in specific order to obtain a control signal by minimizing objective's function subjection to some constraints. In building's control, one would aim to optimize delivered energy subjecting to constraints. One

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2 Related works

Basnayake in his work offers to replace PLC controllers of building's automatics with new controllers designed based on artificial intelligence. These controllers use intellectual identification of users [1].

Amit Badlani's work describes smart home systems that decrease energy consumption by studying human behaviour pattern [2].

Roengruen proposed in paper simulation methods for the temperature control systems. Work results shown success usability of test model to use this regulation method in PLC controller for temperature control in buildings [3].

Wolfgang book author describes regulation principles of process control and regulation methods in variable processes in building heating systems. This book discusses different approaches for regulation loops. It also shows the applying of Smith Predictor model in process control [4].

Srinivas mentions the disadvantages of the applying the classical PID controller regulation and tuning. The paper shows examples how to improve system regulation with Smith Predictor. This control method allows avoids decreasing of regulator gain factor as result the system regulation performance increases [5].

Despite the large number of valuable research work describing different types of management, there is no management system, which could increase the effectiveness in existing buildings by using predictions. Control algorithms are developed for such research, described below, based on Smith's predictor, which are designed and used in building management system.

3 Formulation of the problem

In automation of heating, ventilation and air conditioning (HVAC) systems the PID regulators are used everywhere. They allow regulating motorized air dampers and hydraulic valves, frequency converters of pumps, fans and compressors are regulated. The problem of controlling inlet air temperature by direct-flow air handling unit (AHU) with water heater is considered in this publication. In cases when such AHU is equipped with simple ON/Off ventilator without frequency converter or EC-regulator fan, the maintenance of stable set inlet air temperature is carried out by motorized valve

through PID regulator [6]. Described AHU are found on outdated HVAC systems and also in specialized systems of production, professional kitchens, etc.

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In a commonly used shunt group scheme circulation pump (4) is operating constantly, ensuring freeze protection and a steady water temperature regulation with control valve (3), see in Figure 1. Where:

1 - Shut off valve; 2 – Strainer; 3 - Three-way valve with actuator; 4 - Circulation Pump; 5,6 - Check valves; 7 – Thermometer; 8 – Manometer; 9 - Water/Air Heat exchanger; 10,13 - Balancing valves.

By launching such system, in order not to overcool inlet air, the triple running valve is usually completely opened, providing the maximum flow of heat carrier g and respectively the heat power Q.

The problem is that inlet air temperature undergoes strong fluctuations while the PID regulator finds the necessary valve position for heating the air from outside temperature to the one that is set. It negatively reflects on thermal comfort of people indoors and also it can influence technological processes.



Fig. 1. A typical AHU shunt group hydraulic scheme.

Heating energy trnsfered to the airflow by heating coil can be calculated using formula:

$$Q = g \cdot p \cdot c_{cw} (T_{in} - T_{out}) \tag{1}$$

Where:

- Q heating output, kW,
- g heating fluid flow, m3/s,
- ρ heating fluid density, kg/m3,
- c_{cw} heating fluid specifies heat, kJ/(kg*°C),
- T_{in} , T_{out} supply and return flow temperatures, °C.

In three-position regulators the actuator can hold three positions: completely open, normal (average) or completely closed [7.8]



Fig. 2. Characteristics of three-position regulator.

The value of hysteresis H affects the accuracy temperature adjustment. Reduction the value of hysteresis zone not only increases the accuracy of adjustment, but also the frequency of opening the valve that leads to a fast wear of commutation elements.

4 Enhanced Smith predictor for heating control

Buildings' modern heat-nodes regulating heat consuming by the use of valves and pumps which regulate heat supply to the building in compliance with a desirable temperature for locations. According to the temperature diagram and weather conditions further regulation of the consumed thermal energy takes place, thus, providing comfortable conditions taking into account the temperature of outside air. Microprocessor controller serves as a central device, which controls operation of valves and pumps. It allows regulating heat carrier's temperature according to temperature of outside air; to automatically reduce temperature and to control circulation pumps [9]. Heat carrier's temperature control is carried out by means of the PID regulator. Using PID control for Building Management System (BMS) is not effective method to control the heating system. Thus, a considerable change in set point occurs. Integral terms cause an overshooting error during the rise.

Since heat-node's temperature regulation is carried out by means of PID regulator according to temperature of outside air (especially in case of sharp temperature drop), systems form the delay of automatic control. As each link of the heat-node has its own response time bringing the negative phase displacement, it is capable to result in loss of stability in regulatory system [10,11]. It is necessary to apply the ratio between delay value and the object's time constant, described by the following ratio:

$$\frac{\tau}{\tau + T} > (0, 2...0, 5)$$
 (2)

T - object's time constant.

Where τ - heating valve delays, depend on weather and thermo hydraulic processes in the building.

Time of transport delay is calculated by formula:

$$\tau = \varepsilon \left(\frac{L}{\nu}\right) \tag{3}$$

L - the distance from the sensor to the executing mechanism, M;

U - movement speed of the substance M/c;

To determine dynamic characteristic \mathcal{E} of c the control object it is necessary to reveal the regularity in practice as it was done in this work, see Figure 3



Fig. 3. Dynamic characteristics of time delay of outside temperature.

The dynamic characteristics \mathcal{E} was determined experimentally. The best coefficient was defined at the temperature of 8 in point A and -23 in point B. A linear dependence was obtained after this. The linear dependence for each heating system is separate and it needs to be defined experimentally. The controller parameters could not the results had been achieved by just tuning (applies a correction based on proportional, integral, and derivative terms) them without adding the Smith predictor because τ is dynamics parameters which depending on outdoor temperature.

The purpose of Smith's predictor – to foretell the signal strength at the object exit before it actually

appears there. Due to this prediction the delay factor is excluded from the model, which allows predicting the behaviour of an object before the moment when signal appears at the exit.

Further, to make a prediction, it is necessary to use the model of object's control that consists of fractional rational part M_0 and delay $e^{-s\tau}$. Here, the R – common PID regulator, $P_0e^{-s\tau}$ - additional characteristic of the control objects (see Figure 3).



Fig. 4. Control system with Smith's predictor.

We will assume that the model is absolutely exact. Then the difference between signals on model's outputs and the object will be equal to zero ($\varepsilon = 0$) [12]. But in that case, directly from the diagram of Figure 4, it is possible to obtain:

$$y = P_0 e^{-s\tau} \left(\frac{R}{1 + RM_0} \right) r = \left(\frac{P_0 R}{1 + RP_0} e^{-s\tau} \right) r$$
(4)

In this expression the member $\left(\frac{P_0 R}{1 + RP_0}\right)$ represents a

transfer function of a system without delay. And it means that the link with the time delay is not included in the circuit of feedback and doesn't affect the stability and high-speed performance of the system, which means that there is adjustment in the circuit with the model without delay, and the transport delay is added to receive result [13]. Due to this prediction the delay value is excluded from the model, which allows predicting of object's behavior until the signal appears at the outlet.

Smith's predictor imitates a difference between the process model with no sensitivity zone and a real object. This adjusting signal is added to the measured output signal to foretell what signal would be at the exit if there were no delay [14,15].

The transfer function in (4) models the way a change in the voltage (0-10 Volt) driving the water valve opening affects the heater temperature.

5 Practical implementation of the enhanced Smith Predictor for heating control

Simulations of the regulator in simulators based on Smith Predictor is labor-consuming, as the dynamic characteristics of \mathcal{E} is stochastic and separate for each building's heater and it is also hardly predictable.

Simulation and laboratory conditions can differ highly, therefore, we have to try this adjustment method in practice and a real object was used for this, PLC controller is shown in Figure 5.

The predicted value τ goes to Q(c), controller, which adjusts the controlling influence of AO.



Fig. 5. PLC Controller for AHU heater.

This heater of the ventilation system is controlled with ALERTON controller in which software is written to control the valve of water heater [16]. The controller by means of BACnet protocol is connected to the server where archiving of data and monitoring of the system is carried out. The water heater valve is a one analog output system [17].



Fig. 6. Experimental results for valve heating control from PID with outdoor temperature -2° C.



Fig. 7. Experimental results for valve heating control with enhanced Smith Predictor for outdoor temperature -2° .

Figure 6 shows that by using standard PID regulator the precise adjustment of the heating valve is not reached and based on this a new method of adjustment system with great delay was studied.

The Figure 7 shows the result with enhanced Smith Predictor.

The Figure 8 shows the experimental (with outdoor temperature from 8°C to -25°C) result, received with Smith's predictor The structure of this predictor is also given in this Figure 4.



Water supply temperature in AHU heater

Fig. 7. Average results for valve heating control with outdoor temperature -8°C from PID regulator and PID with Smith's predictor.

It is important that comparing to the PID, the curve of adjustment is approximately by 25% less. The time of adjustments also decreased. Such effect was obtained by using Smith Predictor.

	Characteristics			
Model	Max. Peak (%)	Rise time(s)	Peak time(s)	Settling time(s)
PID	25	420	480	840
PID Smith's predictor	2	118	32	360

Table 1. Comparison of responses

From Table 1 it can be said that PID with Smith Predictor gives better transient response characteristics than PID controller for process with constant time delay.

6 Conclusion

The article shows that for objects with a big value of transport delay it is suggested to use Smith Predictor. When compared to the usual PID, the Smith Predictor more improves the system's response to set-point changes.

Finally the experimental result of the heating control with both traditional PID regulator and PID with Smith

predictor are built in PLC Alerton microcontroller. By comparison with traditional PID regulator, the experimental results demonstrate the effectiveness of the proposed methods towards the heating valve delays and system uncertainties integrated in the building heating control system. A consistency of Smith predictor control signals of all possible time delays can be generated in advance and the actual delays will be compensated. This control method is mathematically simple implemented in PLC Alerton microcontroller with reduce resources.

The temperature control system based on the Smith Predictor controller can precisely control the temperature inside the instrument. Therefore, it is able to provide the best temperature for enzymatic detection to ensure the accuracy of results.

7 Future works

In future work is planned to address all above-mentioned problems within the framework of research by providing following solutions:

Matlab machine learning toolbox could solve the problem of optimizing the Building Management System algorithm by analyzing weather forecast for the next day and sing Finite Difference Method in self-learning model. The automation of the home or the building has a great potential in reducing the cost and energy consumption using, machine learning for intelligent control.

It is necessary to study new class of regulators, which are based on indistinct logic, genetic algorithms and neural networks.

Next research of our control model will include a human occupancy in the building. New control methods using machine learning and buildings new data will upgrade our model results.

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