

Adaptive control of housing and utilities infrastructure objects

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Annotation. Transition to digital technologies in management of state, industrial facilities, energy, utilities, agriculture, etc., will significantly simplify various procedures, but if the possibility of unauthorized access to management processes and confidential information is not excluded, this might incur a number of negative consequences.

1 Introduction

The existing mathematical models [1–4] give possibility to estimate the discounted payback period of investments for reducing energy consumption of housing and utilities infrastructure objects. This estimation may include different approaches for improving an energy performance of buildings as geothermal heat pump [5] and energy performance of domestic hot water systems [6]. Housing and utilities infrastructure objects include building of kindergarten [7], residential buildings [8,9], district heating [10,11] and other objects. The thermal behavior of buildings changes from quasi-stationary [12] to dynamic [13,14]. Switch to a decentralized distributed adaptive system of production facilities control might become a complementary tool of housing and utilities infrastructure objects control systems upgrade. Upon that, with the objects are poorly formalized. [15–18]. The scope of this research is a method for adaptive control of poorly formalized housing and utilities infrastructure objects.

2 Methods

Generally, adaptive management is applied in relation to controlled objects with developed numerically simulated model, which gives an opportunity to anticipate the object's behavior under different external influences. There are quite a number of production facilities, which do not have any clear model, with reasonable accuracy describing behavior of alike objects under different influences. Development of technology, switch to digital economy makes it possible to apply different adaptive control techniques.

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3 Results and Discussion

It is understood that this causes an increase of requirements to the field control means (controllers) being (as a rule) proximately at the object and performing this object full scale control, conveying information concerning the process progress and the controlled object status to the upper level. At that, inappropriate commands, coming from the automated control system upper level, should be rejected.

As the controllers' hardware and software abilities grow, there are increasingly used techniques of production facilities adaptive control and techniques of intelligent diagnostics in different branches of economy and housing and utilities infrastructure, including gas and heat supply systems equipment control.

Adaptive control provides optimal objects control in all its operating modes, which ensures energy efficiency increase of all these production facilities

Beyond that, adaptive control permits to dramatically reduce the controlled objects setup costs. For example, using this technique for boiler control will provide an opportunity to practically eliminate such a labor-consuming and costly procedure as thermotechnical setup.

There are different adaptive control techniques, some way or another stipulating identification of PID control law indices, which could be adjusted in the course of the object operation.

For several controlled objects, for example, in atomized district heating, heat supply and space-heating systems, "appliance of traditional PID controllers in digital control systems is inconvenient, as improvement upon quality criterion does not provide stability, because of which it is necessary to apply improvement with stability conditions concerned constraints" [1].

Classical approaches to control, for example, [2], [3], are based on the speculation that it is possible to get, though a complicated one, but a precise analytically set form of functional relationship of the control system input and output signals with the following adjustment of the values of the indices included into it.

While using of the alike techniques, apart from relative complexity of their mathematical description and, respectively - programming, there is a probability of the controlled object characteristics admissible values limits violation because of absence of the constraints necessary to provide stability.

These techniques are as well not applicable in cases of absence of the numerically simulated model of the controlled object, i.e. in relation to poorly formalized objects.

In [4] one can find a way of adaptive control according to precedents, in compliance with which there are composed state classes of the controlled objects with the known reaction of every class object. Pursuing the objective after a finite number of controlling actions is reached by means of use of information about similar controlled objects behavior.

Such a technique claims an extensive precedents library, as well there are plenty of similar controlled objects, which characteristics and response to external influence differ from each other.

For example, characteristics of boilers, manufactured according to the same drawings, differ. Such objects as well include different buildings, constructed according to the same project and bearing different characteristics.

The following techniques of adaptive control are put forward for adaptive control of poorly formalized objects, possessing a substantial response rate, i.e. the rate of the output parameter change, following the controlling action, surpasses by far the controller input signals process (measurement) time and the time of the controlling action formation.

The first proposed technique [21] provides adaptive control of heat consumption of a building.

The following data is entered into the heat introduction control system:

q_{OT}^{TP} - specific characteristic of thermal energy input to provide heat and ventilation of a building – thermal energy consumption per 1 m³ of the heated volume in unit time under differential temperature of 1 °C), W/(m³•°C) – specific heat consumption for the set building type (multicompartment building, school, child welfare institution, hospital etc.), determined by health and safety regulations in power, for example, in the Russian Federation specific heat consumption regulations are specified in Construction Rules 50.13330.2012 “Buildings Heat Insulation” (Tables 13 and 14);

t_{BH}^{TP} – in-building air temperature °C, required according to sanitary standards or set by the user;

V_h – building volume, (m³).

Measured values:

- outdoor temperature - t^{TP} , °C;

- in-building temperature - t_{BH} , °C.

The amount of thermal energy consumed per hour to provide heating in the set building with the heated volume V_h (m³) according to the formula (1) under real differential temperature is defined:

$$Q_{OT}^{TP} = V_h \times (t_{BH}^{TP} - t_{HP}) \times q_{OT}^{TP} \times 0.86 \times 10^{-6}, \text{ Gcal/h.} \quad (1)$$

The control device performs input of the received thermal energy amount into the heat supply system of the building. Upon that there is measured the in-building air temperature t_{BH} really formed upon the thermal energy Q_{OT}^{TP} input. If $t_{BH}^{TP} = t_{BH}$, the control device does not change the amount of thermal energy fed into the building before a change either of the outdoor temperature or of the set in-building temperature.

If $t_{BH}^{TP} \neq t_{BH1}$, then Q_{OT1}^{TP} is defined, i.e. the amount of the thermal energy necessary to provide t_{BH}^{TP} according to the formula (2):

$$Q_{OT1}^{TP} = Q_{OT}^{TP} \frac{(t_{BH}^{TP} - t_{HB})}{(t_{BH1} - t_{HB})}. \quad (2)$$

The control device performs input of the thermal energy Q_{OT1}^{TP} into the heat supply system, the temperature t_{BH2} is measured and compared with t_{BH}^{TP} .

If $t_{BH}^{TP} \neq t_{BH2}$, the procedure is repeated.

Let us assume that under Q_{OTn}^{TP} the condition $t_{BH}^{TP}=t_{BH(n+1)}$ is fulfilled, then the correction index $k = Q_{OTn}^{TP}/Q_{OT}^{TP}$ can be defined

In this case, in future the amount of thermal energy, necessary to set the required temperature, is defined according to the formula (3):

$$Q_{OT}^{TP} = V_h \times (t_{BH}^{TP} - t_{HP}) \times q_{OT}^{TP} \times 0.86 \times k \times 10^{-6}, \text{ Gcal/h.} \quad (3)$$

In order to save energy and to improve energy efficiency, there were specified buildings energy efficiency classes, and there is expected introduction of heat consumption social norms. Upon that there is a probability of receiving certain bonuses when meeting the indicated requirements. Accordingly the proposed heat consumption control technique provides additional adjusting indices:

$k_1 < 1$, which value is defined depending on the building energy efficiency class

k_2 – limiting thermal energy consumption within the social norms limits, set for a certain building type.

In that case (3) will be written as (4):

$$Q_{OT}^{TP} = V_h \times (t_{BH}^{TP} - t_{HP}) \times q_{OT}^{TP} \times k \times k_1 \times k_2 \times 0.86 \times 10^{-6}, \text{ Gcal/h.} \quad (4)$$

In order to perform adaptive control of poorly formalized objects, when dependence of the controlled parameter from the controlling action differs from the linear one, there is provided the technique [5].

In case of absence of the opportunity to define the controlling parameter initial value, and if the dependence of the controlled parameter from the controlling action is admittedly not linear, the provided technique stipulates preliminary test startups of the controlled object under different controlling actions and permanent external action, at that, there should be stipulated limitations excluding exceedance of known in advance threshold limit values and loss of stability of the controlled object.

Upon that, during the test startups there is performed registration of the controlling actions values and of the received values of the controlled parameter after the parameter reaches the set value and the dependence (5) is estimated:

$$y = f(x, 1/z), \quad (5)$$

where

- y – controlled parameter,
- x – controlling parameter,
- z – external action

There should be performed two test startups of the controlled object, when $z = \text{const}$ and the controlling parameter value x_i, x_{i+1} , upon that the controlled parameter takes values y_i and y_{i+1} correspondingly (see. Figure 1).

Now, it is time to specify the controlled parameter setting $y = y_{in}$.

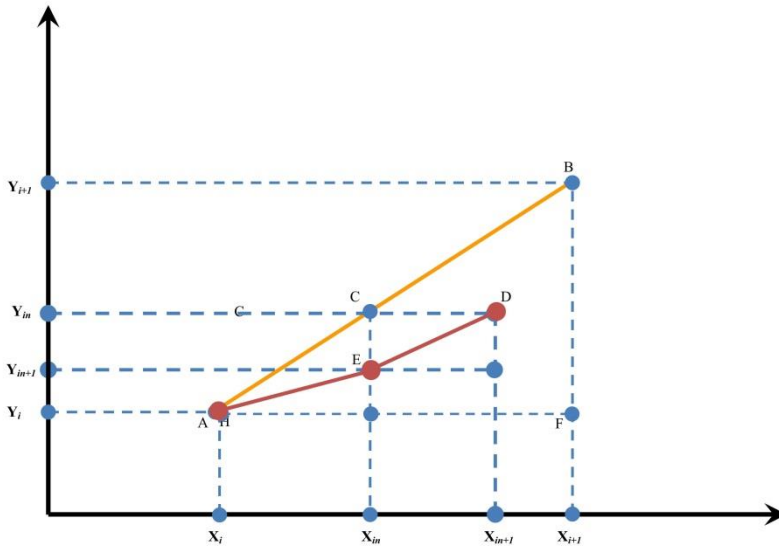


Fig. 1

The value of the controlling parameter x_{in} , giving the opportunity to reach the required value y_{in} in case the dependence (5) is linear, will be identified according to the formula (6).

$$X_{in} = X_i + (Y_{in} - Y_i) \times \frac{Y_{i+1} - Y_i}{X_{i+1} - X_i}. \quad (6)$$

Let us set $x = x_{in}$, upon that the controlled parameter value comes up to $y = y_{in1} \neq y_{in}$ and, if $(y_{in1} - y_{in}) > (\pm \delta)$, where δ – the controller dead band, set in the control device database, and identify the new value of the controlling parameter $x = x_{in+1}$ according to the formula (7).

$$X_{in+1} = X_{in} + (Y_{in} - Y_i) \times \frac{Y_{in1} - Y_i}{X_{in} - X_i}. \quad (7)$$

The like procedures are repeated up to the moment the condition $(y_{in1} - y_{in}) \leq (\pm \delta)$ is fulfilled. The received data are saved. Thus the table of correspondence of the controlled parameter with the controlling parameter value is made. Similar procedures repeat at $z \neq \text{const}$.

The memory space needed to save the necessary amount of the dependence of the controlled parameter from the controlling parameter and from the controlling action is relatively small and is supplied by current specialized industrial controllers [19].

The described method is patented [20].

5 Conclusion

As can be seen from the above, the proposed adaptive control techniques enable optimal control of different housing and utilities infrastructure objects etc.

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