Neurocontrol of Heating Systems

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Abstract: Data are given to the elements of heat supply systems of the Russian Federation (heat sources, heat networks), as well as their main energy characteristics. The main problems in the industry are indicated. It is concluded that it is necessary to optimize the operation of heat supply systems in all its parts on the basis of digitalization of processes and neurocontrol of the system. For optimal management of thermal power systems, the authors consider it advisable to create a digital information model of each element of the system at each stage of the life cycle, including: 3D engineering digital terrain model; Three-dimensional engineering digital model of heating networks, taking into account adjacent communications and facilities; Operational digital model of the heat supply system on the platform of Geoinformation software complex Zulu2021. The technology of data exchange in IFC format between software complexes is given. The need for verification of the operating model using in-situ measurement data on the physical model of the heat supply system is indicated. Creation of digital information 6D model of heat supply system allows to move to a higher level: intelligent dynamic control of complex energy system (neurocontrol). The SCADA software package collects online the necessary information (temperature, pressure, flow rate) from the sensors installed at the characteristic points of the system. All information is transmitted to the ZuluORS software package with built-in OPC technology support to obtain data from the SCADA system. The obtained data are fed into the ZuluGis software package, including the ZuluThermo module, with a loaded digital information model of the heat supply system. The module calculates the actual thermal and hydraulic modes of the system. Data on optimal and actual thermal-hydraulic modes are transmitted to the neurocontrol unit for comparison and management decision making. The decision made is sent to the appropriate controller to initiate actions to change a particular parameter. The technology for developing a digital information model for the elements of the heat supply system at all stages of its life cycle is proposed. Creation of a digital 6D information model of the heat supply system allows to move to a higher level: intelligent dynamic control of a complex energy system (neurocontrol). The use of intelligent control makes it possible to improve the quality of decisions made, significantly improve the energy efficiency of heat supply systems and the quality of services provided to the end consumer.

1 INTRODUCTION

The Russian heat supply system is the largest in the world, providing about 40% of the world's centralized heat production. According to the report of the Ministry of Energy of the Russian Federation “On the state of thermal power and district heating in the Russian Federation in 2020”, there are 572 thermal power plants with a capacity of 500 kW or more and 77.3 thousand heating boiler houses in the country. In 2020, heat sources in Russia produced 1,221.4 million Gcal of thermal energy. The length of heating networks in two-pipe count is 167.4 thousand km (Churashev, Markova, 2013).

The orientation of the Russian power industry towards district heating and district heating as the main way of satisfying the heating needs of the settlements and industrial centers has technically and economically justified itself. However, in the operation of district heating and district heating systems there are many flaws, unsuccessful technical solutions, unused reserves. By the end of 2020, the total length of heat networks in the Russian Federation that need to be replaced in accordance

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with their service life in two-pipe count was 51.5 thousand km, including the length of dilapidated networks (i.e. having more than 60% wear according to the technical inventory) of 38.8 thousand km.

Such a large number of worn-out heating networks leads to high accidents, excessive heat losses through the insulation and leakage of coolant (Serdyukov, 2011).

The prospective development of district heating, along with the evolution of traditional technologies for the production, transmission and consumption of thermal energy, provides for a transition to a qualitatively new level of their energy, environmental and economic efficiency. Optimization of heat supply systems in all its parts and at all stages of the life cycle is the primary task of the country's thermal power industry (Pasichko, Khaletskaya, Kolienko, 2002).

2 MATERIALS AND METHODS

District heating systems, including heat sources, heat networks-systems of pipelines and facilities on them, designed to transport the heat carrier, the final consumers of thermal energy, are complex engineering systems. For optimal management of these systems, the authors consider it advisable to create at each stage of the life cycle of the digital information model of each element - a set of interconnected engineering and engineering and technological data on the object of capital construction, presented in digital object-spatial form (Tikhomirov, Babushkin, 2010; Babushkin, 2021; Tikhomirov, Ananiev, 2020; Krasilnikova, Soloviev, 2016).

In accordance with the Code of Rules (CR) 333.1325800.2020 "Information Modeling in Construction. Rules for the formation of an information model of objects at different stages of the life cycle" the life cycle of a building or structure is a period during which engineering research, design, construction (including conservation), operation (including current repairs), reconstruction, overhaul, demolition of the building or structure are carried out.

The first stage of the life cycle is engineering surveys, including geodetic surveys. Surveys are carried out with electronic geodetic devices, as a result we get a three-dimensional engineering digital model of the terrain (Rafalskaya, Mansurov, Mansurova, 2019).

The second stage is the design. Three-dimensional design of heating networks includes consideration of adjacent utilities and structures. Design is carried out in CAD programs, while the topographic substrate is an engineering digital terrain model. For the design of linear infrastructure facilities, which include heating networks, widely used Civil 3D program, Autodesk on the platform Autocad. In connection with the departure of the company from the Russian market, the authors recommend the program Geoni CS, a Russian developer CS Development, working on a platform of nanoCAD22 (Solovjev, 2019).

The third stage is the construction of system objects, using digital working documentation. During construction, in agreement with the design organization, changes may be made to the design documentation. It is the as-built documentation that is the basis for creating a digital operational model.

It should be noted, each type of digital information model at each stage of the life cycle corresponds to a certain level of elaboration - the minimum amount of geometric, spatial, quantitative, as well as any attribute data required to solve the problems of information modeling at a particular stage of the life cycle of the object (Yakimchuk, Martemyanov, Averyaskin, Soloviev, 2014; Kislov, Ryabenko, Rafalskaya, 2018).

The fourth stage is the creation of an operational model (6D model) in accordance with the classification of CR 331.1325800.2017 "Information modeling in construction. Rules for the exchange between information models of objects and models used in software systems» (Shishkin, 2022).

The authors propose to transfer geometric information on heating network objects using the block diagram shown in Figure 2.

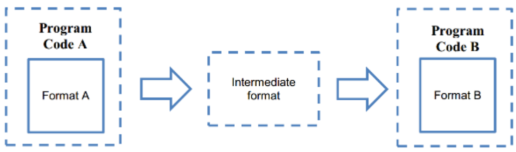

Figure 1: Block diagram of data transmission using the intermediate exchange format.

Data transfer should be in IFC format, a format of industry base data classes with an open specification for sharing them in construction and facility management with the fulfillment of interoperability requirements. As Software Package B, it is proposed to use the Zulu2021 software package with the ZuluThermo module developed by the domestic company Polyterm. The complex Zulu2021 will create topological connections of heat supply system objects (using graph theory) on the basis of 3D graphical model of heat network. The subsequent creation of semantic databases for all elements of the system will lead to the creation of a full-fledged operational 6D model. An important moment of creating an operational model is its verification for compliance with the physical analogue. Verification is performed using the data of measurements of the main parameters at characteristic points of the physical heat supply system (Zheng, Sun, Wang, Zheng, Gao, You, Zhang, Shi, 2021; Zheng, Zhou, Zhao, Wang, 2017; Falay, Schweiger, O'Donovan, Leusbrock, 2020; Barone, Buonomano, Forzano, Palombo, 2020; Larsen, Palsson, B0hm, Ravn, 2002; Zheng, Zhou, Zhao, Wang, 2017; Hussein, Klein, 2021; Badami, Fonti, Carpignano, Grosso, 2018; Schweiger, Larsson, Magnusson, Lauenburg, Velut, 2017).

3 RESULTS

Creation of digital information 6D model of heat supply system allows to move to a higher level: intelligent dynamic control of complex energy system (neurocontrol).

The operation of the heat supply system involves maintaining the optimal parameters of thermal and hydraulic modes. The optimal thermal regime is understood as the maintenance of normative microclimatic parameters in heated (ventilated) rooms, regardless of changes in external climatic influences. Ensuring normative parameters is achieved by regulating the heat load of heating and ventilation systems by centralized, local and individual methods.

The main contribution to the regulation system comes from the central regulation at the heat source. Currently, in our country is the most widespread qualitative method of central regulation - change of the coolant temperature in the supply pipeline, depending on the temperature of the outside air, without changing its flow. This regulation is carried out in accordance with the temperature schedule calculated for the climatic conditions of a particular area. The principle of the temperature schedule is shown in Figure 2.

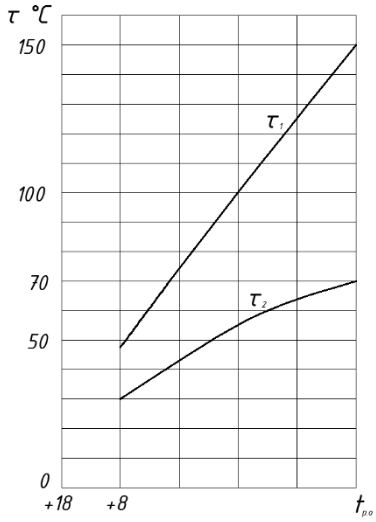

Figure 2: Temperature graph. τ-temperature of the coolant, t-current temperature of the outside air.

Central regulation by the quantitative method involves changing the flow rate of the coolant, depending on climatic influences, without changing its temperature. Mixed, qualitative-quantitative regulation is more flexible.

To ensure quality heat supply it is required to maintain the required available head and flow rate of heat carrier at all subscribers of the system, regardless of hydraulic changes in the network.

Graphically, the hydraulic mode is depicted by the piezometric diagram, the general view of which is shown in Figure 3.

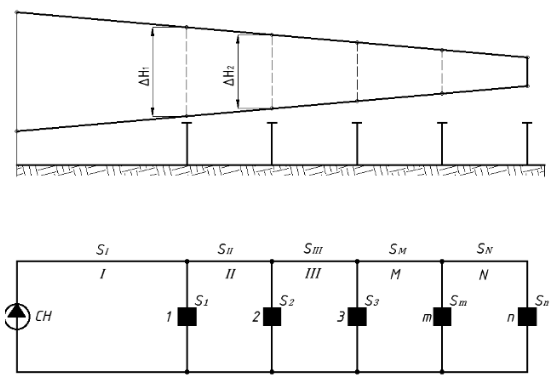

Figure 3: Piezometric graph. ΔH-disposable pressure, S-hydraulic resistance, CH network pump.

To constantly maintain in automatic mode, the optimal thermal-hydraulic parameters of the heat supply system, a neurocontrol complex is proposed that operates according to the following algorithm.

The SCADA (Supervisory Control And Data Acquisition) software package collects the necessary information online from sensors installed at characteristic points of the system and outdoor air temperature sensors. All information is transmitted to the ZuluOPC software package with built-in support for OPC (Open Platform Communications) technology to receive data from the SCADA system. The obtained data is sent to the ZuluGis software package, which includes the ZuluThermo module, with a loaded digital information model of the heat supply system. Based on the received current parameters, the module continuously recalculates the actual thermal and hydraulic modes. Data on optimal and actual modes are transmitted to the neurocontrol module for comparison and management decision making. The decision is sent to the appropriate controller to initiate action to change one or another parameter (Lund, Werner, Wiltshire, Svendsen, Thorsen, Hvelplund, Mathiesen, 2014; Lauenburg, 2016).

Multilayer neural networks of MLP (Multi Layered Perceptron) type are used as a neurocontrol module in the systems under consideration. MLPs have one input layer, one output layer, one or more intermediate layers. The number of neurons in each of the layers can be any and does not depend on the number of neurons in other layers. The number of input layer neurons is determined by the number of input factors of the task, the output layer by the number of output factors. Schematic diagram of an artificial neuron is shown in Figure 4.

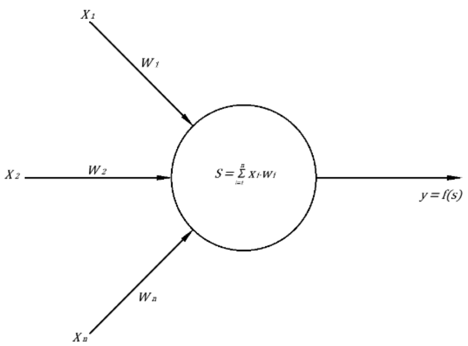

Figure 4: Scheme of an artificial neuron.

The value of the signal received by the neuron is multiplied by the weight coefficient of the signal, the obtained values are summed up. The output signal of a neuron is formed as a function of the sum of the products of the input signals by the values of the weight coefficients and is called the activation function. Neuron learning in this case is mainly based on the correction of weight coefficients.

The organization of the control system is shown in the block diagram shown in Figure 5.

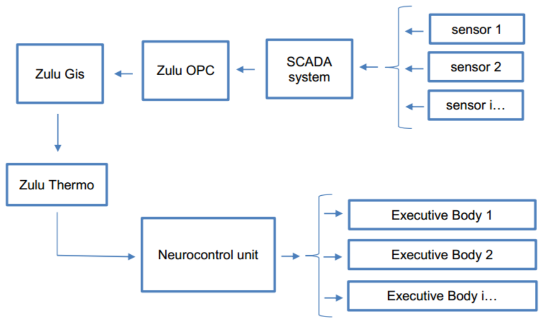

Figure 5: Organization of the management system.

Specify the management of heat supply system parameters.

In the qualitative method of heat load regulation, the neurocontrol module generates and transmits the output signal to the body that controls the output of the heat generator. When generating the control signal, the inertia of heat processes in the heat generator, as well as the time of the temperature wave travel from the heat source to the end user of the system must be provided.

When regulating the heat load by the quantitative method, the output signal generated in the neurocontrol unit is fed to the control body of the frequency-controlled drive of the heat source network pumps to change the flow rate of the coolant. A significant advantage of this method of regulation is the almost complete absence of inertia, since the created impact propagates at the speed of sound in the water.

The implementation of maintaining the optimal hydraulic mode can be implemented as follows.

The developed digital information model undergoes a thorough calibration (verification) stage, as a result of which an almost complete coincidence of the calculated hydraulic parameters and parameters obtained as a result of measurements on the real (physical) system is achieved. The actual system must first undergo a complete thermal-hydraulic tuning and adjustment process. Based on these data, the ZuluThermo module calculates and builds the optimal piezometric diagram for a given system. Then, in online mode, ZuluThermo receives a dynamic stream of data from the pressure and flow sensors of the system, based on which it plots the current piezometric graph. In case of discrepancy between optimal and current schedules, the neurocontrol module generates an output signal to the control body of the frequency-controlled electric drive of network pumps and (or) pumping stations of supply and return lines. If necessary, the control signal is transmitted to the flow controllers installed in the individual heating substations of the subscribers.

As a result of the implementation of neurocontrol, the district heating system operates at maximum energy efficiency at any given time and provides comfortable conditions for heat consumers.

4 DISCUSSION AND CONCLUSION

A technology for the development of a digital information model for the elements of the heat supply system at all stages of its life cycle is proposed. Creating a digital 6D information model of the heat supply system will allow to move to a higher level: intelligent dynamic control of a complex energy system (neurocontrol). The application of intelligent control will contribute to a significant improvement in the quality of decisions made, the energy efficiency of heat supply systems and the quality of services provided to the end consumer.

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