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Smart Applications in Heat and Power Systems

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***Abstract*—Development and implementation of information-analytical systems in heat-and-power engineering are considered. The different ways of automatic data acquisition from smart meters in telemetry networks are shown. A multi-agent system for data collection from heat meters to analytical data center by using smart GSM modems is proposed. The advantages of automatic control in heat supply systems are shown. The heat energy consumption analysis of buildings is conducted and the estimation of energy savings due to smart heating controllers is carried out. The software for smart applications in heat-and-power systems is developed.**

Keywords—energy saving, heating controller, information system, smart GSM modem, heat meter, telemetry, analytical data center

I. INTRODUCTION

One of main activities in the Institute for Automation and Control Processes is development, implementation and support of information and analytical systems (IAS) in the heat-and-power industry [1]. The IAS are based on interconnected software and hardware and consist of (Fig 1):

- Telecommunication devices for collecting and remote data reading through wireless networks.
- Database management system for storing measurements.
- Software for monitoring, technical diagnostic, data mining and retrospective analysis as well as further support decision making.

Constant growth of tariffs compels owners of buildings to look for ways of energy savings in order to reduce payments, particularly the bills of heating and domestic hot water. Under current Russian law, consumers should move to apartment heat metering. The general aim of owners involved in such activities as commercial metering is the energy saving. Often heat energy consumption is an excessive from a district heating network. As a result heating systems are not effective and energy surplus is simply vented to atmosphere through open windows. The problem may be solved by using automatic heating systems that providing the comfort temperature and energy savings. In recent years, an intense process to install heat meters for energy accounting is observed due to the federal law for energy saving and increasing energy efficiency in the Russian Federation came into force. A heat meter accumulates measurements of heat-transfer agent parameters for a predetermined time period (hour, day, month, year) and stores measured and calculated values in its memory as ready-made archive data. There is an access to archive data on a request via a communication interface. It is necessary to reach the energy saving by effective heating control of buildings.

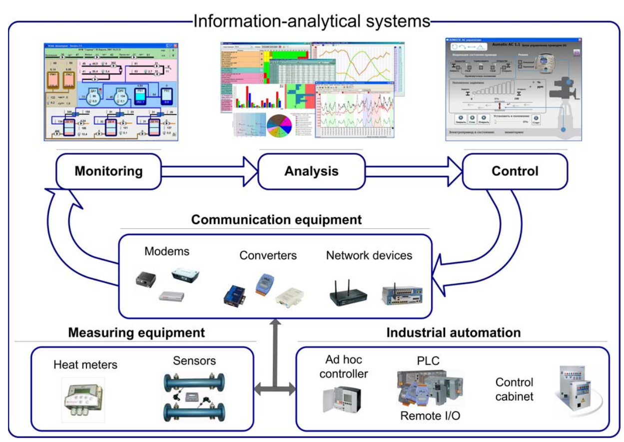

Fig. 1. Information-analytical systems for monitoring, analysis and control

II. DATA COLLECTION

Smart heat meters have special communication interfaces to be integrated in telemetry systems. This opportunity is actively used in data collection and processing centers in order to provide automated commercial heat metering in heat supply systems. The most common tools for data collection in heat-and-power industry are SCADA systems [2] (Supervisory Control and Data Acquisition) and software based on OPC technology [3] (OLE for Process Control). However, these tools is hard to use for automatic reading heterogeneous information from a large number of distributed heat meters taking into account the cost-effectiveness of mobile communication (a periodic connection by schedule rather than a permanent one). Data collection systems interact with heat meters by the sending and receiving

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of data packets (requests/responses). The packets processing is coordinated with a special set of rules called the device communication protocol. There are the following steps of communication session with a heat meter in data collection process:

- Setting up a connection to a remote heat meter;
- Reading a device configuration;
- Reading an instant measurements;
- Reading an events log;
- Reading a historical data (archive of measurements);
- Disconnection from the remote heat meter;
- Transformation data to unified structure;
- Saving structured information into database.

The automatic data collection system starts this communication process for each device in according to its schedule and priority. The priority is evaluated on statistics of successful and unsuccessful attempts of communication with the device. The queue of devices by priority allows taking into account the constantly changing communication quality and automatically adjust the data collection system in order to achieve better performance and reduce communication costs.

During the operation of the data collection system implementing on centralized architecture for the geographically distributed network of heat meters were found out certain shortcomings. For example, when we replicate the data collection system on some new servers the non-optimal performance and non-easy administration was detected: the complex poll schedule, the increasing of idle time of server communication equipment, the growth of communication costs due to multiple connections on same day. It is advisable to apply the multi-agent approach to improve the effectiveness of data collection in distributed network of heat meters. Multi-agent technology allows eliminating the listed shortcomings on the level of architecture. The improvement of efficiency and reliability of data collection are expected by using smart agents within this technology. The agents of the data collection system interact directly with each other according to the predefined rules and the protocol for service information exchange. The multi-agent data collection system (MADACOSY) has developing in order to reduce costs, improve the efficiency and performance as well as to eliminate the bottlenecks of the single-server automatic data collection system (Fig. 6). Any agent can perform the data collection process of any device (heat meter) from the united queue or/and private one as soon as there is an available modem with the desired telecommunication service provider or the opportunity to create a new TCP socket on a server. The MADACOSY immediately spread meaningful information out to all agents. Thus it is possible making synchronization of data collection processes on many servers and avoiding any collisions because each heat meter has only one connection at the day cycle. The team work of agents lets us to make easily replication of the data collection system on virtual machines that lead to reliability improvement and reducing of communication costs. The main advantages of MADACOSY are followings:

- Each agent carries out a data collection process for a heat meter based on all available communication equipments taking into account statistics of previous processes providing by other agents;
- Data collection continues from all devices in the case of failure of anyone agent or data collection server;
- Smart load of all communication facilities and performance optimization of data collection servers;
- The redundancy in the data collection schedule is the lowest because a single list of devices is used and there is no longer a duplication of devices on particular data collection servers.

The following test was carried out. On the same day the data collection systems with centralized architecture and with multi-agent architecture were running on different servers. Each data collection server had the necessary time shift in the schedule. The results showed that the centralized architecture system collected data from devices of the test sample for 4 hours on the one server. The multi-agent architecture system collected data from devices of the same sample on two servers for 3 hours. The centralized architecture system was running on 2 servers increasing the performance but also communication expenses raised and errors occurred due to connections to the same device simultaneously.

III. Automatic Control

In recent years, there are progressive installations of heat meters, flow meters and heating controllers in Vladivostok city, Russia. Those metering tools allow the counting of heat consumption and automatic control of heating that lead to the energy savings. The heating controller HC (Fig 2) regulates inlet temperature t_1 of the heating system according to outdoor temperature t_a by the heating curve and the schedule. The principle of heating control based on outdoor temperature consists in following. Mass flow M_1 and heat energy Q are changed according to weather conditions. At night, mass flow grows up while outdoor temperature is a cold. In daytime, mass flow (hence heat energy consumption) is reduced while outdoor temperature rises. At evening hours, the valve CVA is triggered to open and flow rate is increased according to required heat load while outdoor temperature falls down. The settings of the heat curve and the control parameters are carried out for each building BLD and a kind of heating system HS individually. Optimal settings of automatic control system allow the reaching both comfortable indoor temperature and energy savings. We have the existing experience obtained on the implementation of specific projects in apartment houses. It shows house owners may reduce heating bills by 30-40% [4]. A heating system of an apartment house can be fully automated. It is available to provide automatic meter reading of heat meter HM via Internet directly to a billing center as well as monitoring and remote control of energy consumption in real time. Nevertheless it is impossible without innovative communication and information technologies.

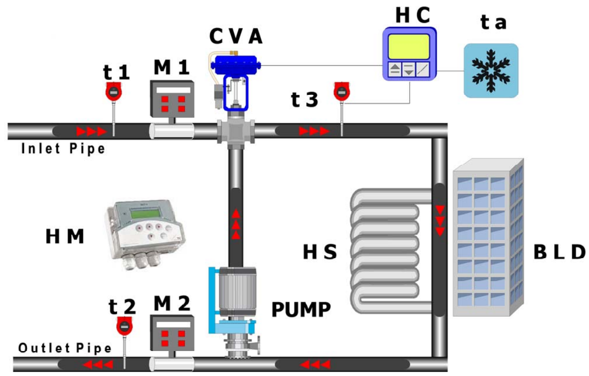

Fig. 2. A heating substation with automatic control system

The heating controller supports various interfaces for data reading. The communication protocol depends on the interface. Modbus RTU is used for RS-485 interface and Modbus TCP for Ethernet respectively. MODBUS protocol is open and widespread as well as it is supported in SCADA-systems. It makes an easy to integrate the controller into automation projects of various scales. Fig. 3 shows two common ways of an interconnection between a controller and a host. Each communication way is often used in practice.

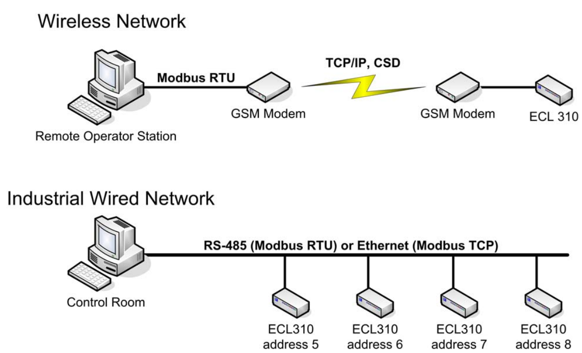

Fig. 3. Remote access to heating controllers

The new software has been developed for remote control of ECL Comfort because of requirements to provide technical support of serviced heating substations. We analyzed advantages and disadvantages of available software tools as well as we take into account unsolved problems and our experience of exploitation. The innovative software has following main features:

- Data reading in industrial local networks via RS-485 or Ethernet;
- Data reading via GSM networks by using special communication equipment;
- Automatically search of connected controllers in network;
- Remote configuration of controllers by network;
- Monitoring of controller parameters in real time;
- Visually diagnose the quality of communication as well as the accuracy of data;
- Recording of received measurements into the database for subsequent retrospective analysis;
- Saving of the controller configuration in a XML-file to recover or to reuse those settings on other controllers;
- Integration of the software with SCADA in large scale projects.

The user interface of telecontrol software is shown on Fig. 4:

- **Information Panel** contains basic controller settings, date and time as well as control buttons.
- **Monitoring Panel** shows the values of temperature sensors and the states of valve and pump.
- **Heat Curve Panel**. It is for choosing of a heat curve for heating or domestic hot water (DHW). Here it's available to change the settings of desired temperatures.
- **PID Control Panel** is used to set up the PID coefficients of the controller.

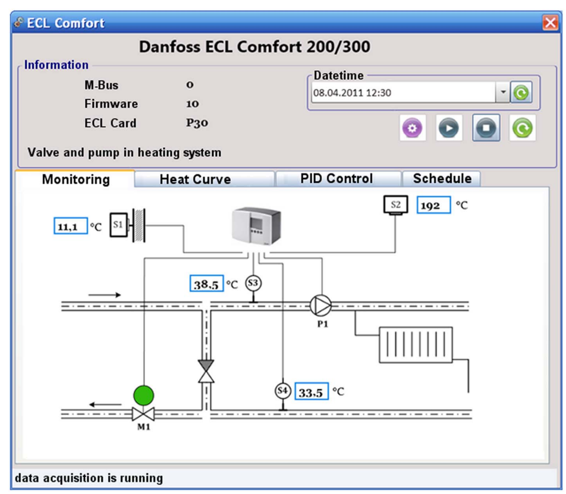

Fig. 4. Monitoring of heating controller

IV. ANALYSIS OF CONTROL PROCESS

There are two fundamentally different ways of heating regulation. The first way is qualitative control (by temperature). The second way is quantitative control (by flow). The qualitative method of regulation in district heating systems is commonly used in Russia. Its essence is that the heating is regulated by a heat curve at combined heat and power (CHP). It's expected that flow rate in a thermal point of a consumer remains a constant value during a heating season. There is another way. A quantitative method of regulation is when temperature of heat-transfer agent is a constant value (as rule a sufficient high value). The heating is regulated by changing flow rate using a consumer's equipment for automatic control. The reality of district heating shows that the qualitative control is implemented with significant deviations from the normal operation mode. For example, a water temperature is not a sufficiently hot in a cold season, but it has an excess level in off-season. Consumers use local heating controllers to provide energy savings and more comfortable conditions inside buildings. As a result, there is a combination of qualitative and quantitative methods. However, it's not an easy to evaluate the effectiveness of mixed regulation. The effectiveness of automatic control in a heating system has been evaluated by regression analysis [5].

Let's consider the heating building in Vladivostok city. The heating controller has been installed on the thermal point to regulate heat consumption of the building. The heating controller provides (by changing the flow rate) the inlet hot water temperature in accordance with the current outdoor air temperature T_{air}. M_1, M_2 - mass flow of heat-transfer medium in inlet and return pipes (tons per hour). T_1, T_2 – the temperatures of the heat-transfer medium in inlet and return pipes (in degrees Celsius). It should be noted that the values (M_1, M_2, T_1, T_2, T_{air}) are measured by appropriate sensors and an available for analysis. The two samples of history data have been taken from the heat meter for analysis. The first sample is data for the time period from 18.01.2009 until 28.02.2009 (sample A), and the second one is data for the time period from 4.03.2009 until 1.04.2009 (sample B). We analyze the effectiveness of heating regulation with taking into account that there is mixed regulation mode (both qualitative and quantitative). Let's see the visual analysis of the regulation effectiveness in the thermal point. The plots show trends $Q(T_1)$ (Fig. 5) or Q(M_1) (Fig. 6) for the sample A. The plots (Fig. 7 and Fig. 8) display the same dependences for the sample B. Indeed, the $Q(T_1)$ dependence can be traced in Fig. 5 (coefficient of determination shows the accuracy of approximation: $R^2 = 0.92$), but there is the absence of the dependence from M_1 in Fig. 6 ($R^2 = 0.056$). Such dependencies are typical for a sufficiently effective qualitative regulation of the heating when quantitative one is absence. The plots are observed on Fig. 7 and Fig. 8 indicating the dominant effect of quantitative regulation. Obviously the plots on Fig. 5 correspond to the situation without quantitative regulation (there is no the correlation between Q and M_1, therefore, we can conclude that the heating controller does not work). The plots on Fig. 8 show that, of course, the controller carries out its functions.

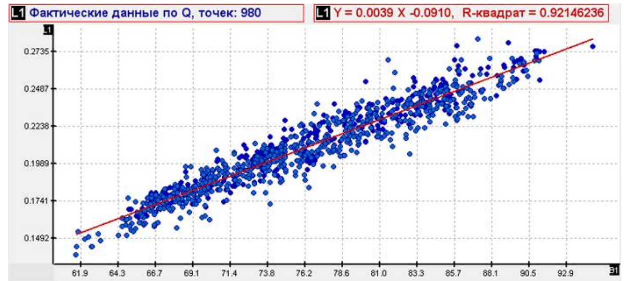

Fig. 5. *$Q(T_1)$* for sample A

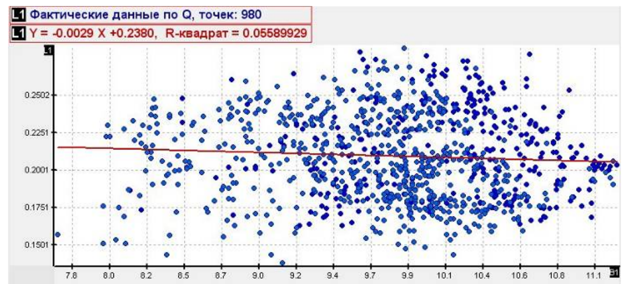

Fig. 6. *$Q(M_1)$* for sample A

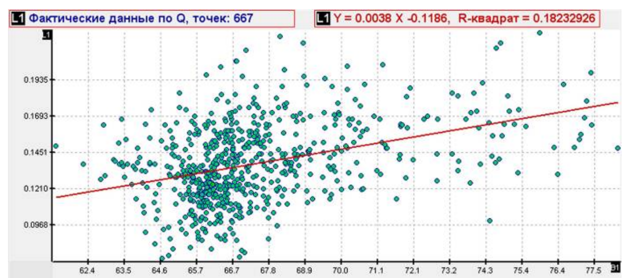

Fig. 7. *$Q(T_1)$* for sample B

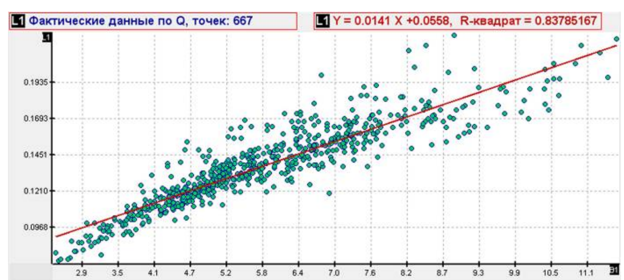

Fig. 8. *$Q(M_1)$* for sample B

V. Smart Applications

Since 2000, IACP FEB RAS has developing information and analytical systems (IAS) [1]. Those IAS are aimed at smart solutions of energy consumption, energy audit and energy saving problems as well as some specific tasks. The software for data collection from heat meters [6], telecontrol of heating controllers [7], the efficiency estimation of heat energy consumption [8] and support of optimal heat supply modes has been implemented into IAS. Let us consider the two software modules of the system for commercial accounting and thermal energy regulation (SCATER).

A. Heating Control Curve

A heating curve is a calculated indicator of the heat supply quality according with the defined dependence of heat-transfer agent temperature from the outdoor temperature. A heat supply contract requires that the heat-transfer agent temperature must correspond to the heating control curve taking into account permissible deviations from it. The heating control curve of an inlet pipe connected to a heating network must be maintained by a heating service provider. The heating control curve of outlet pipe that returns used heat-transfer agent back to a heating network must be maintained by a heating service consumer.

The application "SCATER—Heating Control Curve" is aimed to estimate the efficiency of weather compensation in heat supply systems based on the heating curve analysis for qualitative and quantitative heating control (Fig. 9).

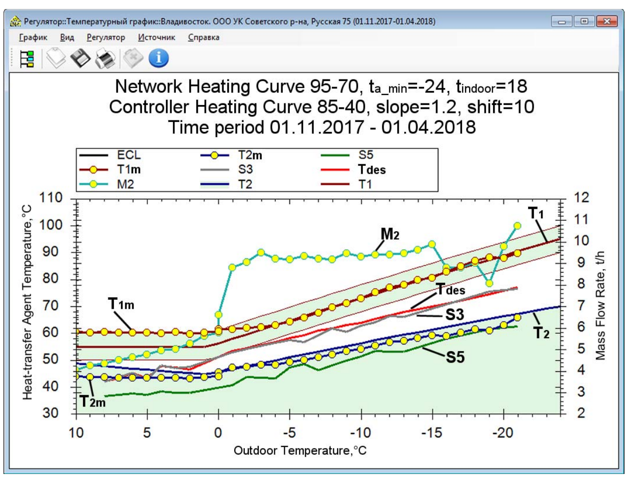

Fig. 9. Heat supply quality control according to the heating curve

The application has the functionality as follow:

- Calculate and draw the heat control curve based on four parameters: maximum and minimum heat-transfer agent temperatures, slope and parallel shift of the curve;
- Calculate and draw the heating curve of a heating network based on six parameters: maximum temperatures in the inlet and outlet pipelines, comfortable indoor air temperature, estimated outdoor temperature of the coldest five-day period by statistics, the lower and upper cutoff of the heating curve;
- Display measured parameters of a heat-transfer agent from a heat meter and a heating controller;
- Evaluate an effectiveness of qualitative and quantitative methods of heating control.

B. Analysis of Control Modes

The application "SCATER—Analysis of Control Modes" was developed for comparison of various controller settings and configurations that relating to the regulation in heat supply systems. The application allows to conduct the analysis of heating controllers operations based on regression models fitted from measurements of heat-transfer agent parameters. The application has the functionality as follow:

- Compare the measured heat supply parameters with those are calculated by a linear regression model;
- Compare the heat supply parameters calculated by regression models corresponding to different temperature and hydraulic operational modes;
- Draw a distribution chart of model data and actual data by the outdoor temperature, temperature and flow rate of heat-transfer agent as well as by hours and days of a week;
- Use the regression models (diagnostic functions) for real-time check-up of new measurements in the appplication "SKYTER—Verification";
- Evaluate the effectiveness of control processes for regulating heat supply.

The estimation of efficiency of heat supply control modes in real life is shown on Fig. 10.

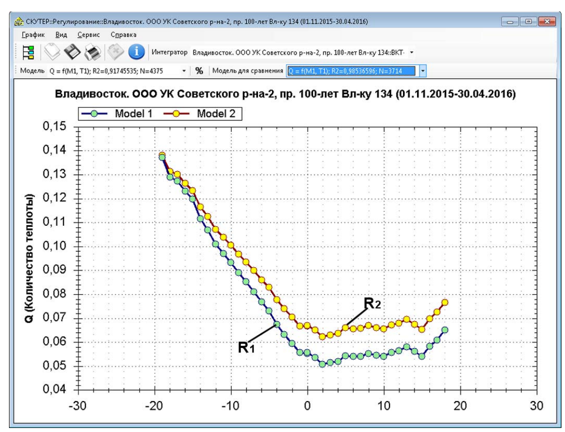

Fig. 10. Comparative evaluation of heat supply control modes

VI. Conclusion

The efficiency and the quality of heat energy consumption is provided by the developed information and analytical systems in heat-and-power engineering [9] using smart meters, GSM modems and modern information technologies. The heat energy consumption of buildings is reduced due to automatic control systems. The automatic control systems eliminate energy loss (overheating) during a thaw and normalize a hydraulic regime as well as a result it provides energy savings in range of 5 to 40%. The smart applications improve efficiency, flexibility and simplicity of heating system maintenance in buildings and provide energy savings. The IAS capabilities are focused on ensuring uninterrupted and high-quality heat supply, maintaining energy-efficient operational regimes of heat-and-power facilities as a consequence obtaining energy savings and tariff restraint for heat energy and hot water.

Acknowledgment

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