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AUTOMATION OF WORK SUPERVISION AS AN ELEMENT OF ENSURING SAFETY OF HEATING MATERIAL TRANSFER FOR A SELECTED HEATING STATION

Zbigniew **Łukasik** [1,*], Daniel **Pietruszczak** [2,*], Mariusz **Białas** [3]

[1] Casimir Pulaski Radom University, Faculty of Transport, Electrical Engineering and Computer Science, Malczewskiego 29, 26-600 Radom, Poland, e-mail: z.lukasik@urad.edu.pl, https://orcid.org/0000-0002-7403-8760

[2] Casimir Pulaski Radom University, Faculty of Transport, Electrical Engineering and Computer Science, Malczewskiego 29, 26-600 Radom, Poland, e-mail: d.pietruszczak@urad.edu.pl, https://orcid.org/0000-0001-8943-0805

[3] Casimir Pulaski Radom University, Faculty of Transport, Electrical Engineering and Computer Science, Malczewskiego 29, 26-600 Radom, Poland , Graduate of the Faculty (Album No.: 109023), https://orcid.org/0009-0007-9891-110X

* Corresponding author

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Abstract – The paper addresses the issue of pipeline transport safety using the example of automation of the supervision of the operation of a selected heating plant. Presents in it the process of automatic control and supervision of the operation of a heat exchanger substation. Initially operated by humans, these substations have transformed into fully automated devices, the operation of which is managed by SCADA master systems. An analysis of the correctness of the operation of the heat substation was carried out using remote supervision systems, which offer a number of functionalities allowing remote control of the most important parameters of the heat transfer process to the end user. The benefits resulting from the appearance of automatic supervision and regulation devices in heat substations were presented, as well as the possibilities of using IT systems for remote analysis of the correctness of the course of the substation operation control process.

Key words – pipeline transport, automatic control, process visualization, SCADA systems

JEL Classification – L11, R11, R19

INTRODUCTION

Logistics is the process of planning, implementing and controlling the efficient and economically effective flow of raw materials, materials, finished products and appropriate information from the point of origin to the point of consumption in order to meet customer requirements [1-3]. The tasks of heating substations undoubtedly fit into the logistics processes, of which the one operated by Radomskie Przedsiębiorstwo Energetyki Cieplnej was considered as an example in the work [4-6].

The paper presents the process of automatic control and supervision of the operation of a heat exchanger substation [7-8]. Initially operated by humans, these substations have been transformed into fully automated devices, the operation of which is managed by SCADA master systems [9-12]. An analysis of the correctness of the operation of the heating substation using remote supervision systems is presented, which offer a number of functionalities allowing remote control of the most important parameters of the heat transfer process to the end user. The benefits resulting from the use of automatic supervision and regulation devices in heating substations are shown, as well as the possibilities of using IT systems for remote analysis of the correctness of the course of the substation operation control process.

1. COMPUTER SYSTEMS FOR VISUALIZATION AND SUPERVISION OF THE HEATING PLANT OPERATION

The heat transfer process, like any technological process, requires a safe and reliable form of supervision of its course. For many years, dynamically developing computer supervision systems that collect, analyze and visualize process data have been gaining popularity.

Industrial plants, including heating companies, use SCADA supervision systems on a large scale. Their main task is to collect current process data, visualize the process status on synoptic screens, generate alarms, register and archive data.

The SCADA system is the superior system for the entire process [9-10]. The automation of modern thermal transmission networks and their nodes based on PLC controllers manages the operation of devices connected to it. Based on temperature readings, whether external or in control circuits, the PLC controller affects the actuators in a way that ensures the proper implementation of the regulation process. In the next step, the controller sends the data to the SCADA system, where it is processed and a process visualization is created based on it. In addition to access to data, alarms, process trends, the system operator also has the ability to set process parameters, stop or start it.

Similarly to other logistics and transport processes, it is also possible to switch to manual process control if necessary. SCADA systems are built based on specialist programming environments that allow, among other things, for creating synoptic screens, declaring variables, handling scripts and cooperation with databases. The databases used in these systems are usually based on SQL technology, which ensures compatibility with other IT areas in the company. The databases store current information on the status of the technological process being serviced, historical information and data on alarm situations. Some of the most frequently used SCADA systems in Poland are: WinCC, In Touch, FIX and Control Maestro. SCADA supervision systems are characterised by the possibility of cooperation with automation devices (PLC controllers, recorders, sensors, etc.) from different manufacturers, in contrast to ready-made automation systems that often require the use of devices from a single manufacturer. Automation systems supervised by the master system can operate independently of it. This is extremely important, e.g. in the event of a lack of communication with the object, the automatic regulation system works by executing a given algorithm.

Figure 1. shows one of the SCADA control system screens visualizing the operation of a single heating substation.

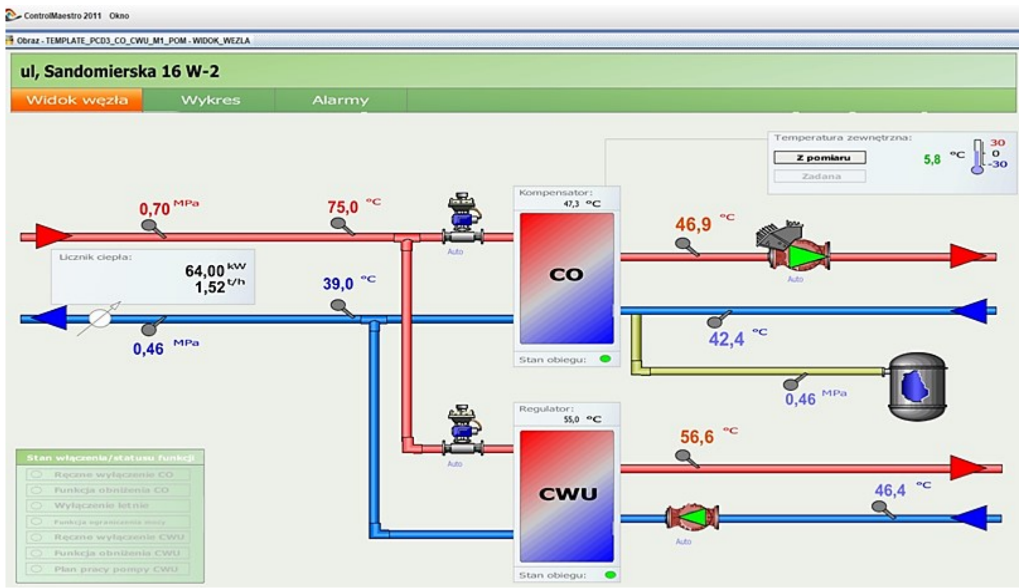

Fig. 1. Visualization of the operation of a heating substation [own study]

Similarly to other pipeline transport processes, the synoptic screen on Figure 1. allows for the control of basic operating parameters of a dual-function heating unit, which consists of a central heating (C.H.) circuit and a domestic hot water (DHW) preparation circuit. These parameters are: pressure and temperature at the inlet and return of the high parameter of the heating medium (WP), supply and return temperatures of the

C.H. circuit, supply temperature of the DHW together with the circulation temperature. In addition, the screen shows the pressure at the inlet of the expansion vessel, the outside temperature and information from the heat meter about the momentary energy consumption and the momentary flow of network water. Two vertical rectangles, which illustrate the operation of the C.H. and DHW heat exchangers, allow for the reading of set temperatures, with the DHW temperature set by the operator, while the C.H. temperature is calculated from the heating curve based on the outside temperature. The status of the circuits is presented by indicator lights: green – active circuit, red – circuit off. A working pump displays a green triangle directed in the direction of water flow, similarly, a closing actuator signals this with a green arrow pointing downwards and an opening one upwards. The status of available functions is displayed in the lower left corner of the screen, in the above case the function of temporarily lowering the central heating temperature is active. From the Node View screen, you can go to the next two screens: Graph and Alarms on Figure 2.

The Graph screen allows you to observe all the above-mentioned parameter values over time, which allows for a detailed analysis of the node's operation, while the Alarms screen provides insight into all alarm situations that occurred in a specific time period.

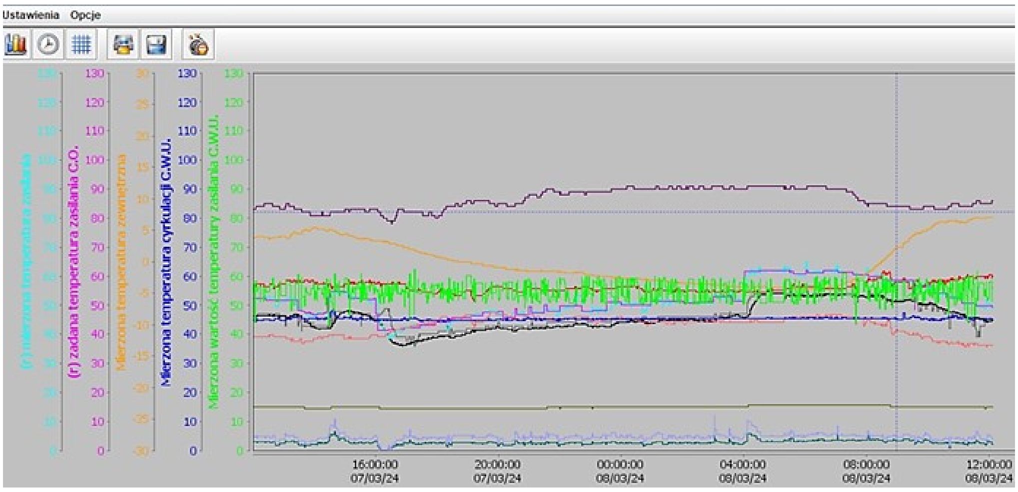

Fig. 2. Graph and Alarms screen [own study]

The Graph screen allows you to observe all the above-mentioned parameter values over time, which allows for a detailed analysis of the node's operation, while the Alarms screen provides insight into all alarm situations that occurred in a specific time period. The superior control system allows you to monitor and supervise the operation of the entire technological process of the company.

In addition to visualizing the operation of the heating nodes, the staff have at their disposal, among others, screens supervising the operation of two heating plants and a network pumping station.

The visualization of the operation of each heating plant also allows access to subsequent screens monitoring the operation of all its components. The technological processes of the example heating company are physically scattered throughout the city. Implementing all the tasks resulting from the specificity of the company's operation without the support of superior control systems would be technically very complicated and expensive. It would take a lot of time, at the same time increasing the need for greater involvement of the service staff. These systems improve the safety and effectiveness of task implementation and affect the quality of the process.

Figure 3. shows a screen illustrating the basic parameters of the operation of two heating plants. With its help, it is possible to observe all the most important values that may affect the operation of networks and heating nodes, as well as edit and analyze their values over time.

The presented SCADA system is widely used in all branches of the economy. They are subject to continuous development and constantly increase their capabilities. They focus all information from the supervised process in one place, which allows for quick decision-making, preventing the risk of failure or improving the operation of the process.

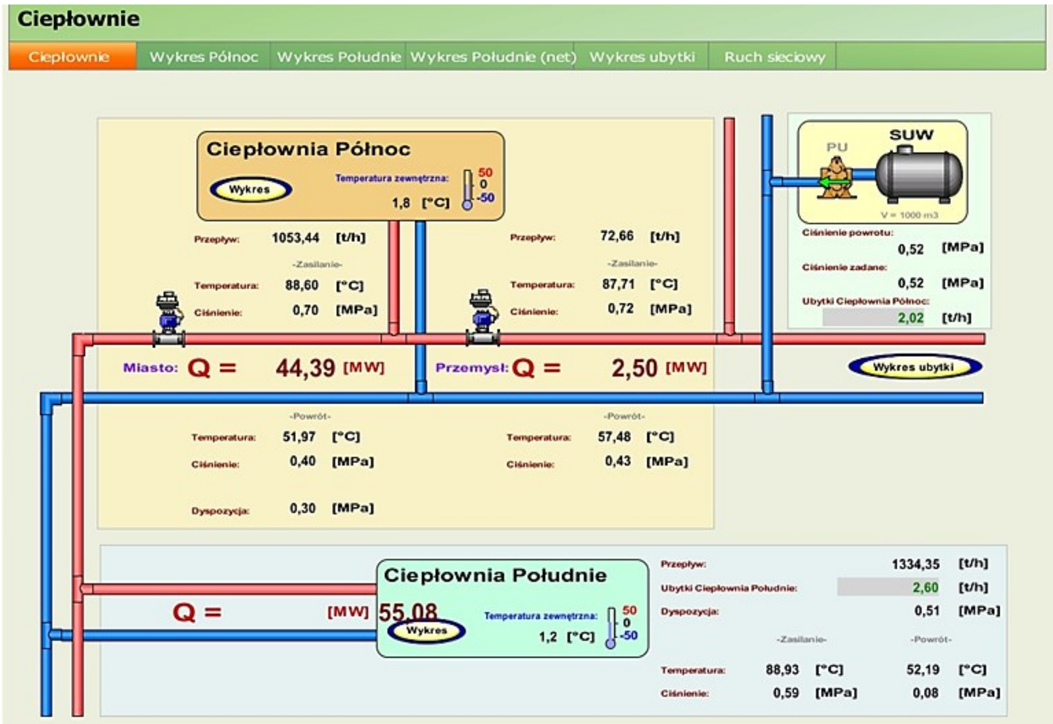

Fig. 3. Heating plant screen [own study]

2. Analysis of the operation of the heating unit

Cyclic analysis of the correct operation of a heating substation is of great importance for ensuring its effective and reliable operation [7]. In addition to regularly performed inspections of the technical condition of the substation and the rooms in which they are located, the correctness of their operation should be checked periodically by assessing the values of all process variables, which are flows, pressures and temperatures. The desired value of these values depends on the value of the power ordered by the recipient (flows) and the adopted slope of the heating curve (temperature). On the other hand, the pressures on the so-called High Parameter (H.P.) side of the substation on the supply and return are dependent on the pressures prevailing in the pipeline supplying the substation (heating network), and the task of the service in this case is to check the correctness of the setting of the available pressure difference on the pressure difference regulator and the flow limitation. On the installation side of the heating substation, the so-called Low Parameter (L.P.), the pressure to which the receiving installation is filled depends on the height of the building. The height of the building affects the static pressure of the entire system, i.e. the pressure generated between the highest element of the installation and the inlet of the expansion tank, by a column of water of this height. Both network (W.P.) and installation (N.P.) flows in the heating substation result directly from calculations, and the main factor influencing their size is the value of the ordered power. The operating temperatures of the substation are calculated based on the outside temperature. The temperature of the WP supplying the substation is determined by the power dispatcher based on observations of the outside temperature and weather forecasts. He calculates or reads from tables the so-called heat load coefficient and provides its value to the heat sources with an appropriate advance resulting from the time of distribution of network water from the source to the furthest objects. The temperatures of the heating medium flowing from the substation to the recipient for the needs of central heating are determined on the basis of a heating curve, the slope of which depends on the recipient. Their values are regulated using a weather controller, PLC controller or, in the case of domestic hot water circulation, also using a direct-acting controller.

The correct operation of the heating substation is indicated not only by the temperatures at the supply of the high and low parameter circuits, but also by the temperatures of their returns. Both incorrect supply and return temperatures indicate irregularities in the operation of the entire heat transfer system.

The correct operation of heating substations connected to the master control systems is checked, if possible, on an ongoing basis, every day. Facilities not equipped with remote monitoring systems are checked by the service, depending on the needs, several times a week and in the event of changes in the value of the ordered power. Such changes require adjustments and their cause may be, for example, an earlier incorrect calculation of the demand or the performance of thermal modernization works in buildings, which results in a reduction in the demand for heat. From the user's point of view, such changes provide measurable benefits in the form of financial savings, because the fee for thermal power depends on its size.

3. Principles of operation of a heating plant

The main criterion determining the method of operation of the nodes is the agreement concluded between the heat supplier and the recipient. It specifies the principles of cooperation between the parties, such as:

- Delivery limit – based on this, the recipient is classified in a specific tariff group. The tariff group determines the place of separation of ownership of heat exchange devices. From the side of the heating network to the delivery limit, the supplier is responsible for the correct operation of the installation, then the recipient. The recipient's affiliation to a given group affects the amount of fees for the supplier.
- Temperature table – a heating curve, the slope of which determines the supply temperatures of the recipient's installation as a function of the outside temperature.
- Amount of ordered power – based on which the nominal flow of the heating medium supplied to the node is calculated. This is the maximum value of thermal power that the recipient can draw from the network.
- Pressures in the system – determined on the basis of technical documentation.
- Possible decreases in the supply temperature of central heating or domestic hot water and their duration – determined at the individual request of the recipient or group of recipients.
- Start and end date of heating – depending on the date of receipt of the application from the recipient.

Based on the above principles, inspection and maintenance activities are carried out, which should include:

- Inspection of parameters, and in the case of incorrect values, their cause should be determined.
- Inspection of the tightness of all elements under pressure and removal of any leaks.
- Inspection and cleaning of filters and sludge traps in accordance with the manufacturer's instructions.
- Checking the correct operation of the circulation and circulating pumps.
- Checking the settings of the regulators and, if necessary, correcting the settings.
- At least once a year, and in particular before the start of the heating season, the pressure value in the expansion tank should be checked and corrected if necessary.
- Checking the correct operation of the differential switch at least once a month, and at least once a year, the correctness of electrical connections should be checked.
- Periodically, the sealing and operation of heat meters and water meters should be checked.
- Checking the correctness of the indications of control devices such as manometers, thermometers, temperature and pressure transducers.
- Keeping hydraulic, electrical and control devices clean.

4. Control of node parameters based on data from remote supervision systems

After selecting a specific node from the list of all nodes supervised by the SCADA system, a visualization screen on Figure 1. should be displayed- the status of the most important variables responsible for the correct course of the process. Based on their values, the correctness of the device operation should be analyzed, for which in this case the total value of thermal power ordered by the recipient is 351 kW, of which 221 kW for central heating and 130 kW for domestic hot water. The temperature table adopted for this node corresponds to a heating curve with a slope of 1.6. The total network flow in the winter is G_s=5.03 t/h, while for the summer period for domestic hot water the flow G_{s2cwu} = 3.73 t/h. The pressure in the supply pipeline is 0.7/0.46 MPa, and the network water temperatures are 75/39^{0}C, respectively. Based on the outside temperature of 5.8^{0}C according to the table, the compensator calculates the temperature of the installation water at 47.3^{0}C. The domestic hot water preparation circuit, according to the law, should provide a water temperature of not less than 55^{0}C and not more than 60^{0}C in order to provide adequate comfort to users. It should also provide the possibility of performing temporary thermal disinfection during which the water should reach a temperature of at least 70^0C. This disinfection is intended to get rid of bacteria, fungi and especially legionella pneumophila bacteria from the inside of the installation, which cause lung diseases. The domestic hot water temperature read from the node visualization screen of 56.6/46.4^0C is therefore as correct as possible.

In the next step of the analysis of the operation of the heating substation, it is necessary to look at the water temperatures and flows before and after the heat exchangers. During normal operation of the device, the temperature of the network water returning to the network (W.P.) should be lower than the temperature of the water supplying the receiving installation (N.P.). This is because the exchangers are usually connected counter-currently, which means that the water in the primary circuit circulates in the opposite direction than in the secondary circuit. This allows for a higher water temperature at the outlet of the exchanger to the recipient than at its return to the heating plant. A situation in which these temperatures equalize or the return temperature of the high parameter side is higher than that at the outlet of the low parameter may indicate contamination of the exchanger and, consequently, incorrect heat exchange between the circuits. This may result in difficulties in achieving the required temperature of the heating medium supplied to the recipient and the risk of the recipient filing a complaint.

The correctness of heat supply is influenced by both temperatures, both supply and return water. If the supply temperature is correct and the return temperature is too low (significantly different from the temperature table), it can be said that the return is too cool, which can have several causes. It is easier to determine them when the secondary circuit is equipped with a flow measurement (heat meter, circulation pump with flow meter). Usually, the reason for the significant cooling of the N.P. return is dirty filters or the circulation pump generating too low a flow, inadequate to that resulting from the ordered power. This may be related to incorrect pump setting or a drop in efficiency caused by its wear. Too low a flow, manifested by excessive return cooling, can also lead to underheating in the part of the supplied building. In turn, an inflated N.P. return temperature can indicate too high a flow and excessive heat injection, which the receiving installation does not need and is not able to receive, which is also an undesirable situation. In special cases, despite correct temperatures on the installation side of the heating substation, underheating or shortages of domestic hot water may occur at the recipients. This may be due to improper hydraulic regulation of buildings leading to problems with obtaining the appropriate flow in all parts of the installation.

An important functionality of the synoptic screen is the ability to view the W.P. flow and the current power consumed by the node what is shown in Figure 4. This data can be downloaded to the SCADA system from the heat meter via the M-Bus/RS232 converter.

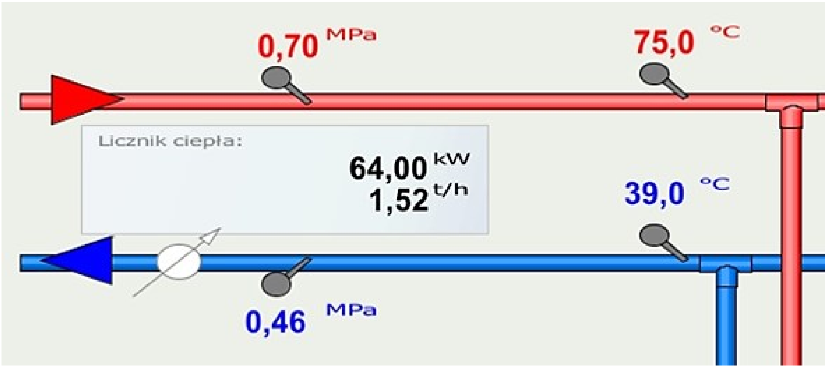

Fig. 4. High Parameter data view [own study]

Analysis of these values allows for verification of the power consumed by the device in relation to the ordered power. If, for example, at external temperatures oscillating around zero, the node is already drawing the maximum ordered power, it means that in the case of lower temperatures this power will be exceeded and should be increased. After the current analysis of the node's operation, its operation over time can be checked based on the graph generated by the SCADA system. This graph, together with the description, is shown in Figure 5.

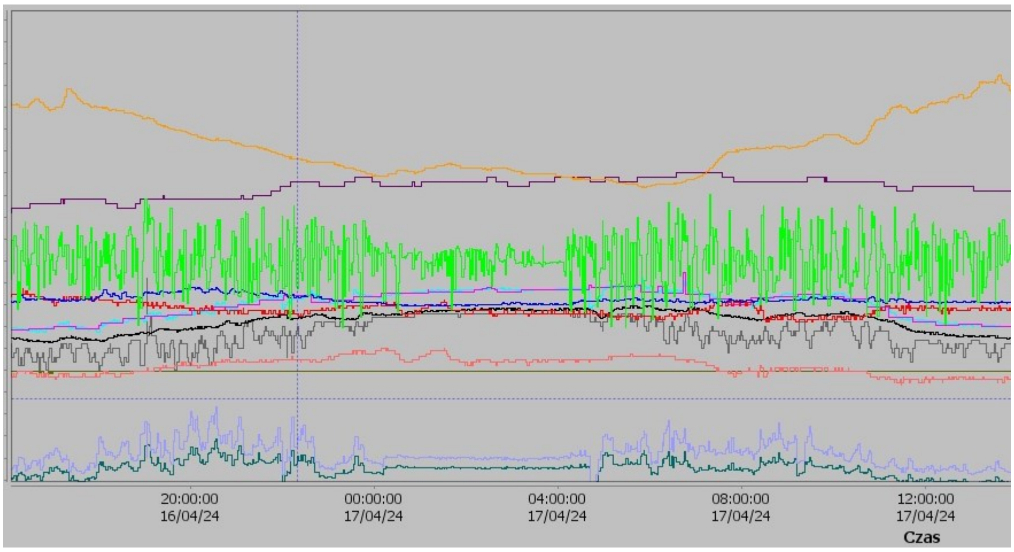

Fig. 5. Diagram of the heating plant operating parameters [own study]

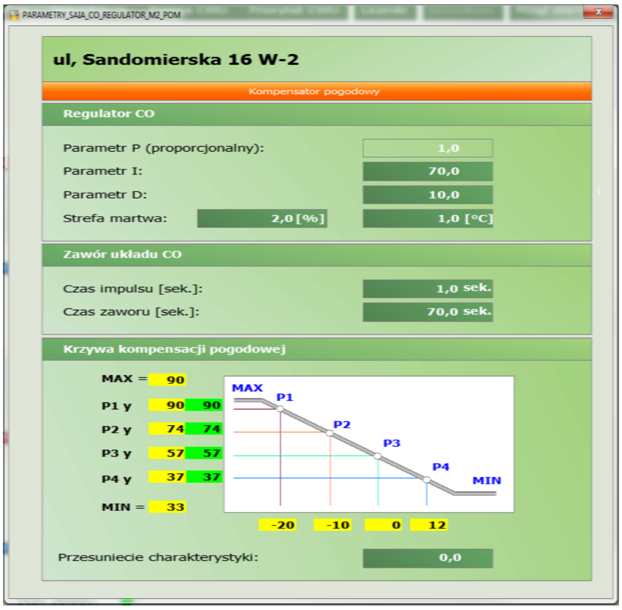

Fig. 6. Weather compensator settings [own study]

The Figure 5. presents the time courses of all process variables, each of which is drawn in a different color. Their analysis is very useful in the event of any irregularities in the operation of the node. These courses can be used to read how the temperature or pressure values changed over time and at what external temperature. In the event of water losses on the installation side of the node, the data from the graph can be very helpful in determining their size and cause. Also, in the case of irregularities reported by heat recipients, viewing historical data allows you to verify their validity and, if necessary, is helpful in diagnosing the problem. When analyzing the graph, pay attention to the course of the set central heating supply temperature calculated by the compensator and the course of its actual value measured by the sensor. The colors of these graphs are purple and light blue, respectively. In the analyzed graph, these courses are very similar to each other, and the more they overlap, the better the quality of regulation. The measured value of the supply temperature (light green graph) shows oscillations related to the large consumption of hot water, which decrease significantly during the night hours. In addition to the temperatures on the installation side, the graph can be used to read the pressure in the system, the supply and return pressures, and the flow on the network side of the node, the thermal power drawn by the device. The SCADA application provides a weather compensator settings screen for central heating and a controller settings screen for domestic hot water.

The Figure 6 shows the screen with the weather compensator settings. It allows viewing all of its settings and, if necessary, allows the user with the appropriate authorizations to make corrections. The central heating controller is a PID controller, whose proportional element gain value is k_p=1, doubling (integration) time T_I=70*s*, lead time (time constant of the derivative action) T_D=10*s*. After the central heating controller settings block, there is a control valve settings block, with the valve transition time, i.e. the time that will elapse from its complete closing to its complete opening. The pulse time, on the other hand, is the duration of a single pulse in both the opening and closing direction. Both values of these times affect the so-called valve speed, which depends on the rapidity of the node's process parameters. In the domestic hot water preparation circuit, faster valves are usually used, allowing for an appropriate response in the event of increased hot water consumption. The last of the settings blocks is the weather compensation curve, which is responsible for the central heating supply temperature. as a function of the outside temperature. It is determined on the basis of four outside temperature values, to which the desired flow temperature values are assigned.

5. Operation of the heating unit in the heating system

The correct operation of heat distribution nodes has a major impact on the correct operation of the entire heating system. It should be remembered that heat distribution nodes are only part of a large heat transfer system, which they create together with heat sources and transmission networks. These system elements must cooperate with each other from both a technical and financial point of view. The dependencies and mutual influence of individual system elements are mostly caused by the time-changing operating parameters of the nodes. Changes in external temperature cause changes in the degree of opening of control valves, which in turn affects the size of the resultant mass flow of the heating medium in the remaining parts of the system.

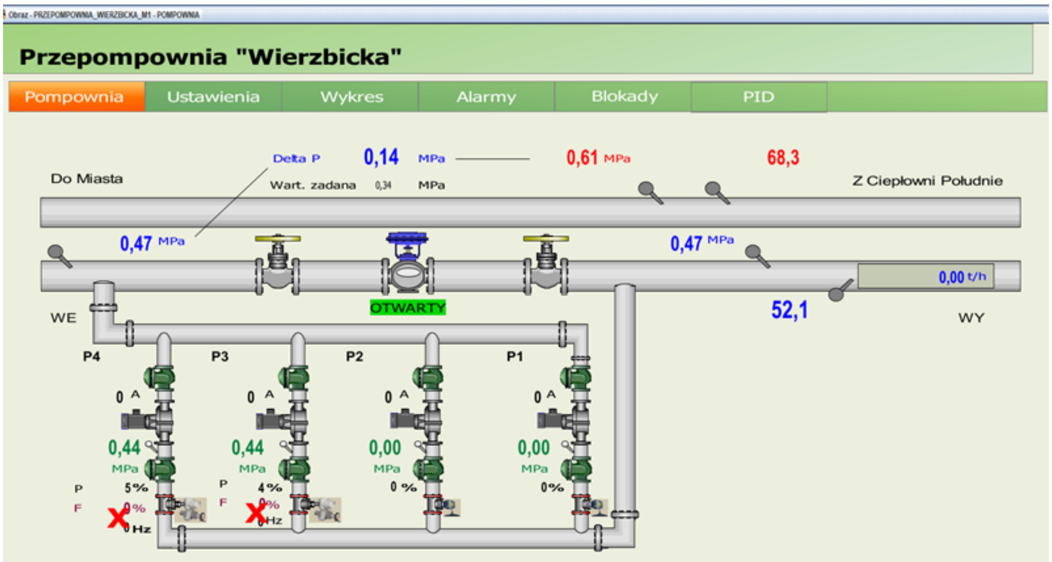

Fig. 7. Control screen of the network pumping station operation [own study]

If there is a change in the parameters with which heat sources operate, it will also affect the degree of opening of control valves in the nodes. This means that individual system elements are interconnected and dependent on each other, and their correct balancing (hydraulic) has a major impact on its correct operation. This balancing consists in selecting the mass flow of the heating medium in the heating network so that it corresponds to the current demand of the heat distribution nodes. The pressure difference generated by the source must ensure the appropriate heat supply parameters for each recipient, including those most distant from the heating plant, which may prove very difficult and sometimes even impossible. The pressure in the source may be raised to a certain value for technical and economic reasons and if it is not sufficient, network pumping stations are used to support the operation of the system. It is good when they are supervised and monitored by superior systems, which allows for the control of the pumping station depending on the available pressure difference at the nodes located at the ends of the network. If the appropriate pressure differences and flows are obtained at these nodes, it means that other nodes operating in the system have also achieved the required parameters.

The synoptic screen supervising the operation of the network pumping station is shown in Figure 7.

It allows for monitoring of all the most important parameters of its operation, mainly pressure and flow. This pumping station is connected to the main pipeline on the return to the network. During increased network load, it supports the return of network water to the source. The pumping station pumps work in pairs (parallel operation of pumps), they are powered by inverters controlling their speed, the instantaneous percentage value of which can be observed on the screen. An important element of the system is the pneumatic valve, the closing of which forces circulation through the pumping system. In the event of disturbances or a power outage, it is immediately opened automatically, which protects the network against excessive pressure increase. The system works mainly in automatic mode, but also provides manual mode. In automatic mode, it is possible to operate the pumps based on the pressure difference of the pumping station (the pumps maintain its constant value), and on the basis of the pressure difference of the node with the least favorable parameters. The choice of the node on which the pumping station works is decided by the power dispatch (dispatcher on duty), based on data obtained from the SCADA system. The pumping station only operates when necessary, when external temperatures drop significantly due to the costs it generates. These are mainly related to electricity consumption, as the power of each of the installed pumps is 132 kW. Users with appropriate authorizations can use the supervision system to view the parameter settings of the frequency converters and the PID controller controlling the operation of the pumps. This allows full control over the operation of the pumping station and ensuring appropriate operating parameters of the network and heating nodes.

The Figure 8 and the Figure 9. show the windows for setting the parameters and the PID controller settings, which are responsible for the correct operation of the pumping station.

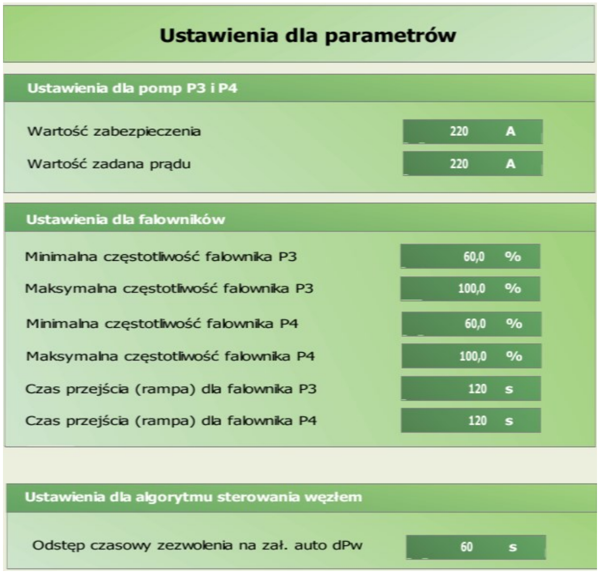

Fig. 8. Network pumping station inverter settings [own study]

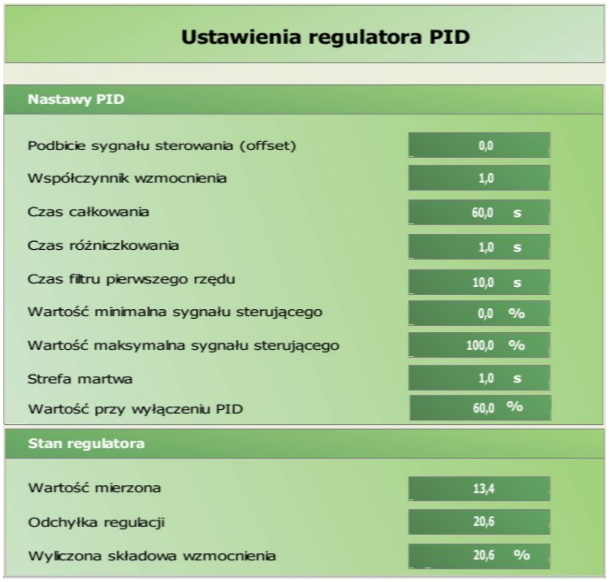

Fig. 9. Network pumping station PID controller settings [own study]

In addition to the above functionalities, it is possible to generate charts, set alarm thresholds with an optional link to the rescue section or introduce blockades in the system.

CONCLUSIONS

The paper analyses the possibilities offered by the use of computer systems in the control, visualisation and safe management of heat transfer devices. Rapidly developing supervision systems play a key role in activities aimed at reducing the consumption of both thermal and electrical energy, and consequently adapting heating companies to the safety requirements set by the European Union institutions in the field of environmental protection. EU requirements increasingly emphasise the rational and economical use of natural resources, including all types of energy carriers. Increasingly high requirements are placed on newly constructed facilities in terms of energy efficiency and emission. Thermal modernisation works are also recommended in existing buildings. Automatic supervision systems for the operation of devices that monitor the technological process in continuous mode allow for a quick response in the event of irregularities in their operation, and provide the possibility of analysing historical graphs, which greatly facilitates the optimisation of their operation.

The paper focuses on the analysis of the operation of the heat distribution centre and the devices and systems supporting and influencing its proper functioning. The analysis of the operation of the selected heating node was presented, the quality of the regulation process of all its parameters was checked, as well as the method of regulating the system supported by the operation of the network pumping station.

The analysis of safe systems and technologies of supervision and automatic regulation indicates great possibilities and benefits related to their use. It allows us to conclude that their further development is inevitable and very necessary. It can be assumed that in the future, the use of automatic regulation and remote supervision in combination with artificial intelligence algorithms will allow for a significant improvement in the efficiency of energy systems and a reduction of dangerous failures and emergency states. Practical research and tests in real conditions should be continued to verify the effectiveness and correctness of the implemented solutions.

AUTOMATYZACJA NADZORU PRACY JAKO ELEMENT ZAPEWNIENIA BEZPIECZEŃSTWA PRZESYŁU MATERIAŁU GRZEWCZEGO DLA WYBRANEGO WĘZŁA CIEPLNEGO

Artykuł naukowy podejmuje problematykę bezpieczeństwa transportu rurociągowego na przykładzie automatyzacji nadzoru pracy wybranego węzła cieplnego. Przedstawiono proces automatycznego sterowania i nadzoru nad pracą wymiennikowego węzła cieplnego. Węzły te początkowo obsługiwane przez człowieka, przekształciły się w pełni zautomatyzowane urządzenia, których pracą zarządzają systemy nadrzędne SCADA (z ang. Supervisory Control and Data Acquisition). Przeprowadzono analizę poprawności pracy węzła cieplnego z wykorzystaniem systemów nadzoru zdalnego, które oferują szereg funkcjonalności pozwalających na zdalną kontrolę najważniejszych parametrów procesu przekazywania ciepła do odbiorcy końcowego. Zaprezentowano korzyści wynikające z pojawienia się urządzeń automatycznego nadzoru i regulacji na węzłach cieplnych oraz możliwości wykorzystania systemów informatycznych do zdalnej analizy poprawności przebiegu procesu sterowania pracą węzła.

Słowa kluczowe: transport rurociągowy, automatyczne sterowanie, wizualizacja procesu, systemy SCADA.

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