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# Analysis of the Possibilities of Using Automatic Control Systems for Operating Gas Engines for a Chilled Water Production

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# Analysis of the Possibilities of Using Automatic Control Systems for Operating Gas Engines for a Chilled Water Production

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**Abstract.** The publication presents the impact of using automatic control systems for operating gas engines aimed at a chilled water production. The purpose of the work is to analyse the possibilities of using automation systems to regulate gas flow. An important parameter of fuel supplied to gas engines used in the production of cold is its amount, which depends on the pressure. Unstable operation of gas distribution systems caused by an extensive network, many customers and operation of devices working with different loads causes improper, unpredictable operation of other devices working in the network. Uncertainty of fuel parameters results in unstable operation of gas engines, their load, and variable production of electricity, heat and cold. Ensuring proper and stable production is a key element of production processes. The concept of building a gas pressure regulation system based on its amount in the network will ensure the required, stable operation of gas engines and refrigeration units coupled with them, and thus provide a guarantee of production of generated media. The presented solution provides a solution to existing problems. The system is based on two dampers coupled to each other and controlled by an automation system controlled by a superior SCADA system.

## 1. Introduction

Energy obtained from the power system comes from a number of sources. Energy in various forms is converted into electricity in generators. The cogeneration unit is formed from the expansion of the generating set with an element for heat recovery, which leads to the use of primary energy contained in the fuel for the production of electricity and heat. Cogeneration is the production of heat and electricity in the most efficient way, because in one technological process. It is characterized by greater energy efficiency of the system by up to 30 percent than in the case of separate production of electricity and heat [1]. Expansion of cogeneration units with additional installations allows optimizing energy use and creates a polygeneration solution that allows better use of energy. Trigeneration systems are used in the medium and high power range systems [2]. Trigeneration is the technologically associated production of thermal, mechanical (or electrical) energy and utility generated chilled water, aimed at reducing the amount and cost of primary energy necessary to produce each of these forms of energy separately. In heating systems, in the summer, it improves the cost-effectiveness of electricity production in combination with low heat demand and existing demand for chilled water [3]. The fuel used to power the polygeneration systems may be gaseous fuels. The main problem is ensuring acceptable gas quality by the internal combustion engine. One of the features of coking coal deposits, which comes from the mine, is the release of large amounts of methane gas ($CH_4$) during mechanical mining of coal seams. This causes a serious threat to safety for miners working underground due to the explosion of this gas, which occurs in the range of 4.5% to 15% of the mixture with air. To eliminate this threat, the mines have extensive methane drainage systems, which include underground methane drainage pipeline network and surface methane drainage stations [4 – 6]. The role of the methane drainage station is to extract methane from the bottom of the mine, and then compress it to a pressure enabling its injection and transport by gas network to the heat and power plant. From the beginning of operation, the power units of the plant have been prepared for methane combustion. Gas burners have been installed on steam boilers of these plants for both coal ignition and continuous combustion of methane as an additional fuel. The power of the burners was matched to maximize the use of available methane amount. The next stage of work was the construction of power generators based on piston gas engines aimed at the most effective use of methane. The analysed installation currently operates 7 gas engines.

The aim of the research is to determine a correct and stable process of a gas pressure regulation system. After careful analysis of the technical condition of the existing configuration, a response was prepared that provided a solution to existing problems. The system was based on two dampers coupled to each other and controlled by an automation system controlled by the superior SCADA system. The carried out studies show the effect of constructional and exploitation efforts to increase the efficiency of the chilled water production installation.

## 2. The issue of chilled water production

Chilled water installations are used as cold water distribution systems and are used in chemical and process engineering. Cooling installations working for the needs of chilled water production are selected depending on the availability of energy carriers, which are heat or electricity. An important feature of cooling installations based on chilled water is the high cost of building the installation, which is also associated with an appropriate control and automation system, and relatively low operating costs. This is the reason why chilled water installations are installed in combined heat and power plants. In chilled water systems, the distribution of cold water to heat exchangers is done by circulating pumps and pipelines connected to the chilled water aggregate. Chilled water produced in combined heat and power plants is generally used in nearby industrial facilities carrying out technological processes where there is a demand for cold. Chilled water power plant systems can operate on the basis of compressor, absorption or jet systems. Absorption systems are powered by thermal energy. They enable chilled water to be obtained at a relatively low supply temperature. These systems are reliable enough and do not need to be steam powered [7].

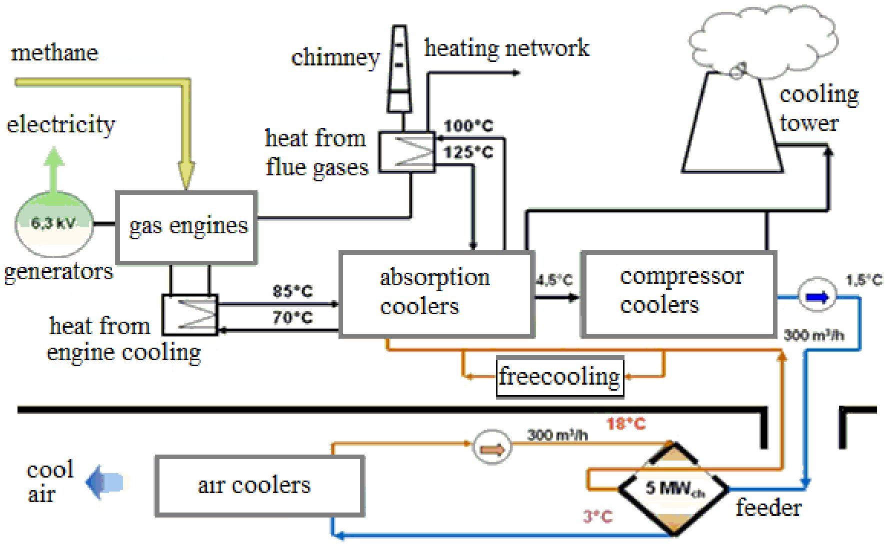


**Figure 1.** The trigeneration installation diagram.

The general concept of the project is to generate electricity using generators driven by lean methane piston gas engines, recovering heat from exhaust gases and engine bodies, transmitting cold using chilled water at a set temperature generated in absorption coolers powered by heat from engines and in compressor coolers powered by electricity from generators. Surpluses of electricity and heat are sold to the electricity and heating networks. Cold water is sent to the bottom of the mine and after reduction of static pressure, it is directed to air coolers, as shown in the Figure 1. The gas engine installation coupled with the cooling system uses methane gas as the fuel. The pressure range and gas concentration have a significant impact on the operation of the gas engine, its stability and performance. For purposes of the project, the range of correct pressure parameters for the gas engine accurate work is 4kPa - 30kPa while the concentration should be higher than 45%. The concentration smaller than 45% causes the UART (universal asynchronous receiver-transmitter) operation that results in unloading the engine until it stops completely. Due to the large diameter of gas pipelines (DN500) and the considerable distance from the methane intake station, the gas pressure is very unstable. Maintaining gas pressure at a level that ensures stable operation has become a problem, regardless of pressure fluctuations in the network.

## 3. Analysis of control and operation of gas regulation systems

The existing system consisted of two DN500 valves (shutoff valve was used for regulation, as well), as shown in the Figure 2. Its design and installation on such a large diameter allowed only a small pressure regulation within a range 5% of the valve diameter. Above this range, there were no changes resulting in a adjustment in pressure. A DN250 gate valve with AUMA electric drive with manual control was installed. The control was performed by the service (close / open) based on the pressure indication. This solution did not guarantee a quick response from the service. This affected the unstable operation of the systems until they were completely turned off. This resulted in production losses.

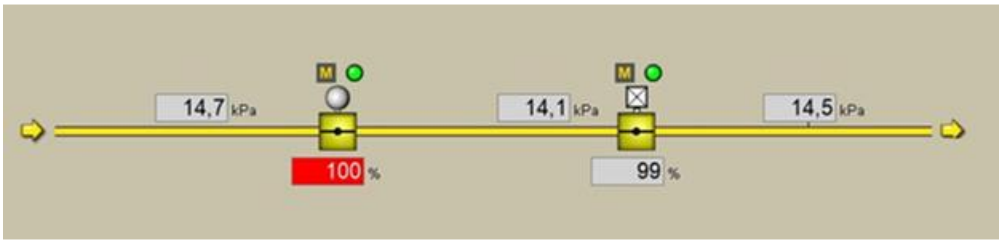


**Figure 2.** The gas regulation system diagram.

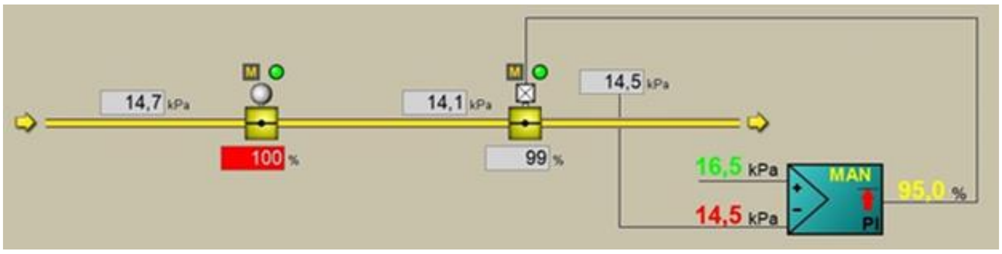


**Figure 3.** The gas pressure regulation diagram supplemented with a control element.

The design and implementation of an automatic gas regulation system based on and using existing devices and infrastructure was carried out. Industrial valves are used to control the resulting flow rate by opening or closing the valves. The concept of the new solution was based on the creation of an automatic control system that maintained a stable pressure. Two additional measurements were used for this purpose, as shown in the Figure 3. These were pressure measurements before and after the regulating valves. Data from analogue sensors and the position of the gate valve has been introduced to the superior control system based on the Siemens Simatic controller. Manual control has been preserved, which means that it can be controlled independently from the automation systems. The automatic control system was built based on the pressure measurement signal behind the throttle valve, as shown in the Figure 3. Setting the pressure in relation to the measured pressure measurement causes the throttle valve to open or close until the fixed pressure is reached. Determining the selected pressure is done by entering its value into the set pressure box in the control system (green in the Figure 3.).

Due to the structure of the system in which the control takes place, we can choose between control systems operating in the open and in the feedback system. The purpose of the open control system is to shape the output signal according to the program determined by the assumed signal. The assumed signal can be introduced by human, by measuring devices informing about the occurrence of a particular state of the system, or by devices that change signals according to the assumed program, as shown in the Figure 4. A characteristic feature of the open control system, both manual and automatic control systems, is the lack of information about output signal values and lack of guarantee of full control purpose achievement. These systems perform relatively simple functions and do not allow obtaining high control precision. Low accuracy of open control systems is associated with the occurrence of interference in the operation of the installation.

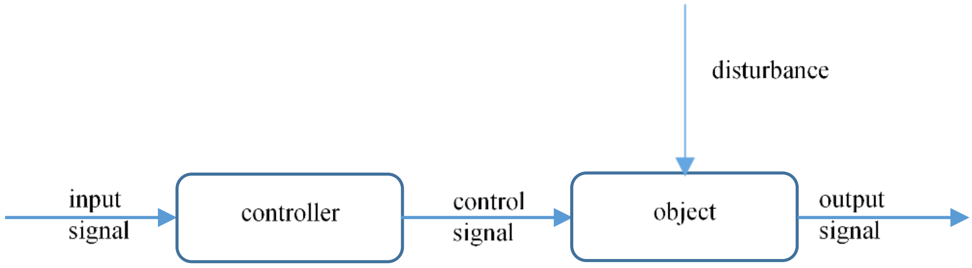


**Figure 4.** The general block diagram of the open loop system.

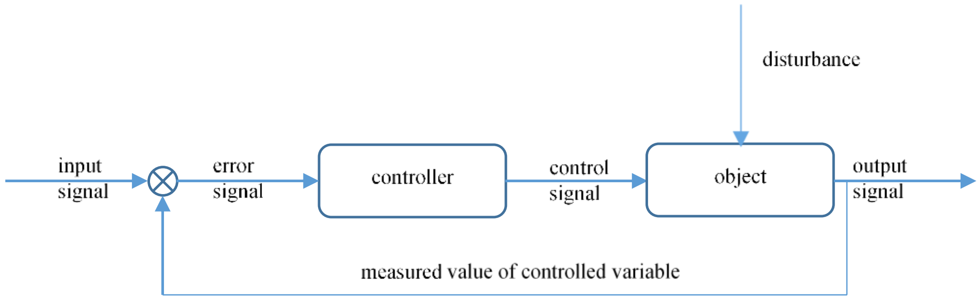


**Figure 5.** The general block diagram of a feedback control system.

The output value should be measured to compensate for the effect of interference on the output signal, then compare with the set value, and use the result of the comparison for corrective operation of the control device. Implementation of this action is carried out due to the existence of the negative feedback, as shown in the Figure 5. The advantages of using such a control system are that you can take corrective action that occurs regardless of the source and type of interference and there is no need to make a detailed process model. In addition, the versatility and reliability of the solution does not require complete knowledge about the process. When changing requirements, you only need to tune the controller for the proper functioning of the installation. The existence of the feedback loop is a characteristic feature of closed control systems and this resulted in the implementation of the solution into the project.

The new system's supervision and control system fulfils the following tasks:

- a visualization of the state of technological drives on mnemotechnical diagrams displayed on computer screens
- a drive control
- a visualization and archiving of analogue values
- archiving of alarm messages with the possibility of viewing and analysing
- provides native both historical and real-time trends and analysis using charts, as shown in the Figure 6; all the measurements are recorded by the system.

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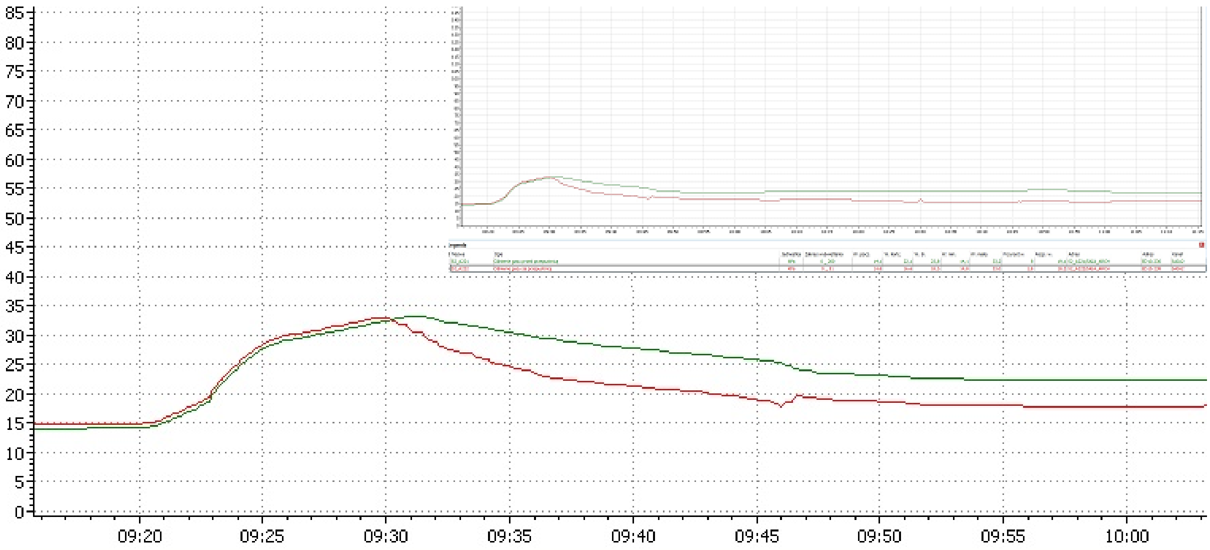


**Figure 6.** The visualization of graphs (trends) of analogue measurements.

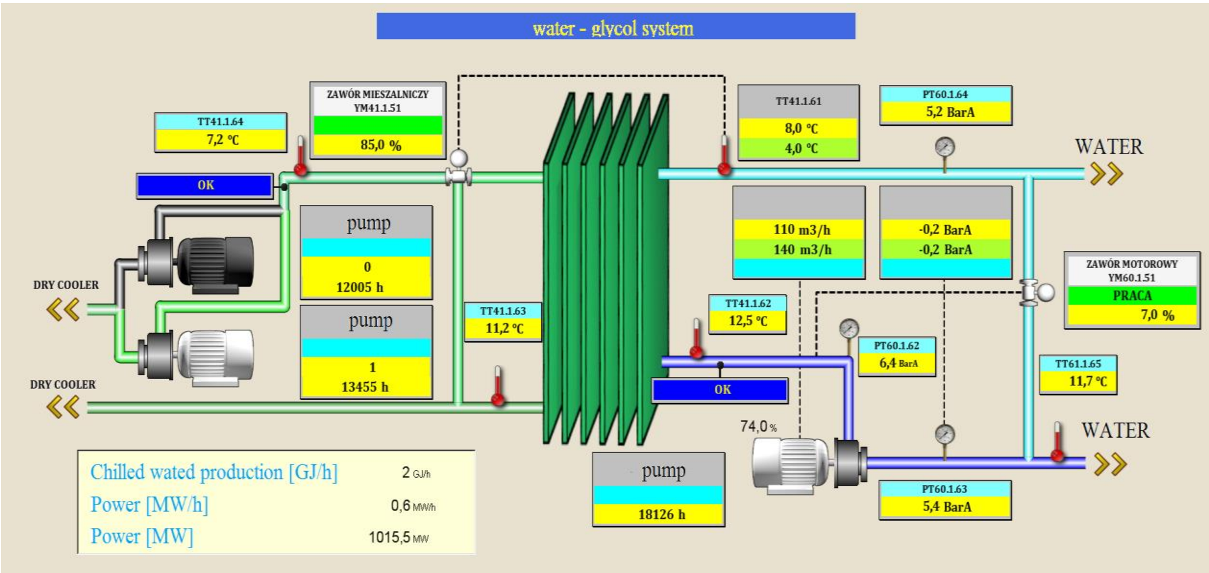


**Figure 7.** The graphic user interface display.

The graphical interface of prepared the ASIX SCADA system offer a plant representation spread over some levels. The graphic user interface, as shown in the Figure 7, includes:

- drive icons
- throttle / valves opening controls
- information about analogue measurements
- indicator for setting controller parameters
- graph of regulator.

Detailed views offer the possibility of observing several parameters. At this level, all the details can be displayed. The prepared system have several types of display demonstrating:

- a valve drive control
- a station view.

The throttle / valves opening control can be implemented on the drive control display. The control can be implemented immediately, as shown in the Figure 8, by '+' and '-' buttons and by the slider control on the display.

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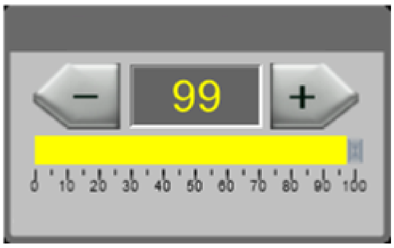


**Figure 8.** The drive control display.

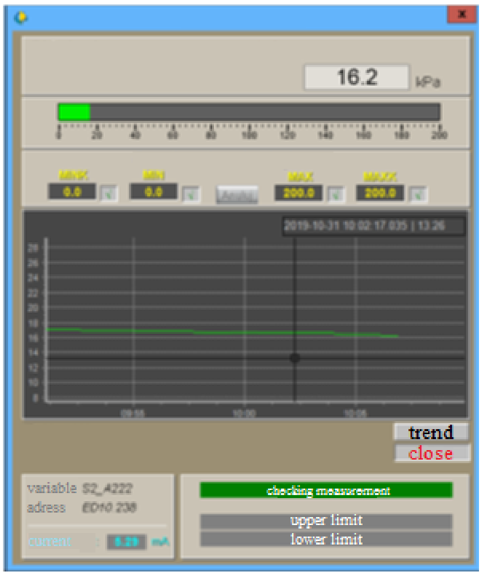


**Figure 9.** The analogue measurements and trend display.

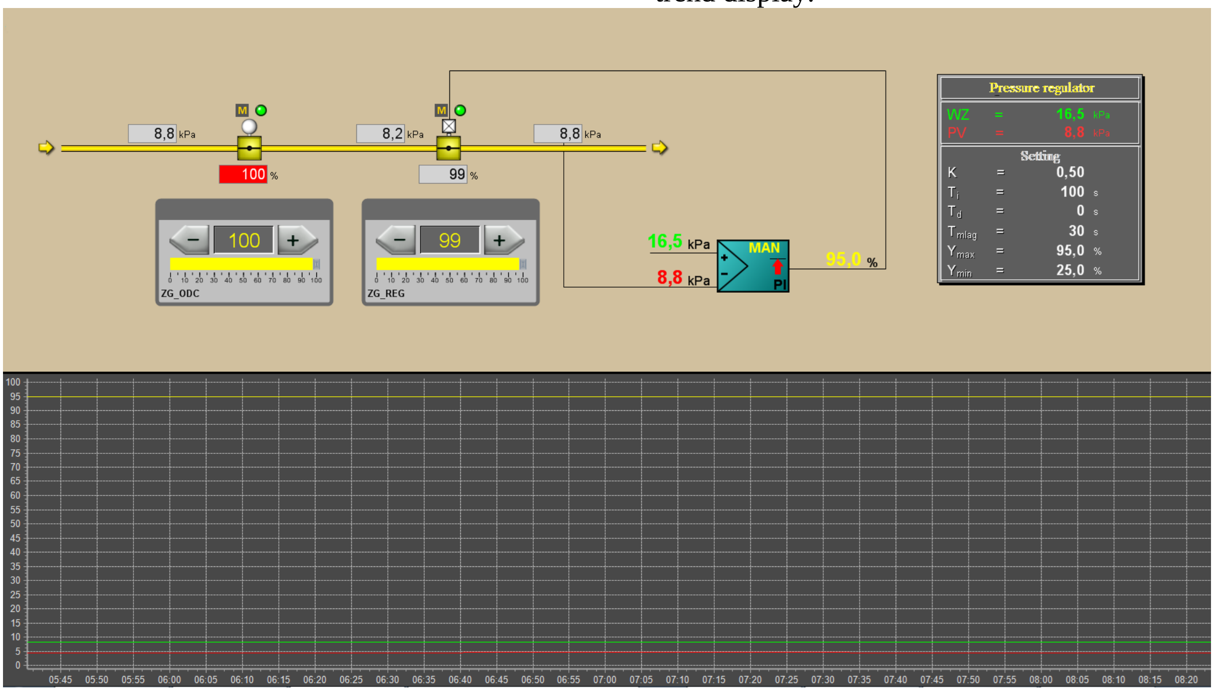


**Figure 10.** The information on gas quality and gas network operation status display.

The analogue measurement display, station view, can be opened to check the value of any analogue measurement. The display, as shown in the Figure 9, can provide the following information about a variable: description, unit, analogue value recorder, analogue value displayed as a number, analogue value in the form of a bar, display name and trend button provides native both real-time and historical measurement and trends. Modern devices are equipped with automation systems to facilitate work. HMI (Human Machine Interface) interfaces look like screens through which you can enter information into the system, as well as download and display production data.

The implementation of the regulation system, as shown in the Figure 10, has allowed the identification of problems and a simple solution to fluctuations in gas pressure supplied to gas engines [8]. As a final effect, stabilization of system operation was observed, which results in the stability of chilled water production [9].

## Conclusions

This paper presents the use of the regulation system, the use of which for one element of the system, has resulted in significant benefits for the entire system for chilled water production obtained from the absorption heat pump working in the heat power plant system. The assembly and implementation of the described regulation system, in a simple way, allowed solving the problem of fluctuations in gas pressure supplied to gas engines, which stabilized the work of devices producing chilled water, resulting in work efficiency, as well. The implementation of the proposed solution resulted in the high predictability operation of the steam power plant equipped with an absorption system. Because of the solution used, the stability of gas pressure regulation for devices using it as fuel increased, which results in stable operation, operational reliability, reduction of failure frequency and occurrence of defects. An important aspect is also reducing the role of supervision by the staff over the important process of gas pressure regulation, which results in focusing the attention of the staff on other important elements of the process.

Most automation systems work in the assistance of man because human-machine interactions are important in current control systems, and automation system operators can affect production parameters. Implementation of the control system allows achieving effects in the form of improved system efficiency and more efficient system management. The implemented system provided an assistance in the analysis of the system work. Another conclusion could be a design solution that protects the unstable system operation [10]. This simple solution enabling the trouble-free operation of the system. In the analysed chilled water production system due to automation systems operating conditions, obtaining the required chilled water parameters has become more predictable. Implementation of the control system allows achieving effects in the form of improved system efficiency and more efficient system management [10]. The prepared system contributes to an increase in the reduction of system failure provides the necessary information about the operation of the system [11 - 13].

## References

[1] Thumann A and Mehta D P 2013 *Handbook of Energy Engineering, Seventh Edition. 7th Edition* (Fairmont Press)
[2] Ganapathy V 2017 *Steam Generators and Waste Heat Boilers: For Process and Plant Engineers, 1st Edition* (CRC Press)
[3] Dunning S and Katz L S 2017 *Energy Calculations and Problem Solving Sourcebook: A Practical Guide for the Certified Energy Manager Exam. 1st Edition* (Fairmont Press)
[4] Porpatham E Ramesh A and Nagalingam B 2012 *Fuel* **95** pp 247–256
[5] Porpatham E Ramesh A and Nagalingam B 2008 *Fuel* **87** pp 1651 – 1659
[6] Przybyła G Postrzednik S and Żmudka Z 2013 *Scientific Magazine - Combustion Engines* **3 (154)** pp 114-115
[7] Schroeder A Łach J and Poskrobko S 2009 *Archives of Waste Management* **11 (3)** pp 63–74
[8] Prauzner T and Ptak P 2011 *Journal of Technology and Information Education* **1** pp 292–296
[9] Herold K E Radermacher R and Klein S A 2016 *Absorption Chillers and Heat Pumps. 2nd Edition* (CRC Press)
[10] Pytel K Suchanicz J Livinsh M and Sternberg A 2013 *Condens. Matter Phys.* **16(3)** 31706
[11] Xu P Ma X Zhao X and Fancey K 2017 *Applied Energy* **203** pp 761–777
[12] Zhukov V Melnik O Logunov N and Chernyi S 2019 E3S Web of Conferences. **135** 02015
[13] Alpatov V and Soloviev A 2018 MATEC Web of Conferences **196** 01008

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