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DEVELOPMENT OF AUTOMATION AND CONTROL SYSTEM OF THE TECHNOLOGICAL PROCESS FOR SULFUR PRODUCTION

Abstract

Given the sophisticated technologies that modern industrial organizations are equipped with, monitoring and diagnostics of equipment condition are critical tasks. The current study aims to develop an improved diagnostic system for industrial equipment in the oil and gas industry using Schneider Electric M241 and M340 programmable logic controllers (PLCs). The first step in this process is to analyze the faults that occur during equipment operation, as well as to study the signal processing methods used in the oil and gas industry. The second step is to use PLCs for automated data collection, parameter monitoring and diagnostics of equipment condition. This approach allows for real-time control of key technological processes, reducing the probability of failures and increasing the reliability of production equipment. The study examined the impact of various data processing strategies on the efficiency of industrial equipment diagnostics. PLC data collection and analysis methods were considered, including continuous parameter monitoring, threshold control and trigger events. Based on these methods, diagnostic algorithms were developed and implemented in the EcoStruxure Machine Expert and EcoStruxure Control Expert, which provide automatic fault detection and alarm generation.

Key words: Industrial equipment diagnostics, programmable logic controller, sulfur production, PID control, Modicon M340, Modicon M241.

Introduction

Sulfur and its derivatives takes a huge applicational meaning in a wide range of industrial systems. In the realm of chemical production, approximately half of the global sulfur output is dedicated to the synthesis of sulfuric acid, while another quarter contributes to the creation of sulfites. Also, sulfur serves as a crucial component in the manufacturing of insecticides, accounting for up to 15% in the production of pesticides for grapes, cotton, and other crops. Also, sulfur is indispensable in the production of polymers and synthetic fibers, as well as in the formulation of pyrotechnical and explosive mixtures such as gunpowder and match head compositions. The paper industry also relies on sulfur for processing and subsequent production. Those factors make sulfur extremely useful material for humanity.

The production of certain steels with specialized properties is impossible without the involvement of sulfur. Additionally, sulfur plays a vital role in disinfecting agricultural facilities like vegetable storage warehouses, poultry houses, and basements. In the process of wine-making, the preservation of vegetables and fruits necessitates the involvement of sulfur. Sulfur also finds application in the creation of modified asphalt pavements and diverse types of concrete possessing specific properties, as well as in organic synthesis and the production of pharmaceuticals designed for addressing skin conditions.

Materials and methods

Claus process

The Claus method is still remains as a fundamental technique in gas desulfurization, primarily which is used for extracting elemental sulfur from hydrogen sulfide-rich gas streams. A method was introduced in the late 19th century by Carl Friedrich Claus and then the process has since evolved into a multi-stage industrial standard. Its widespread adoption is largely due to its ability to process waste gases from refining and natural gas treatment plants, converting them into usable sulfur through a combination of thermal and catalytic reactions. A hydrogen sulfide, which is produced, for example, during of the process of hydrodesulfurization in refinery naphthas and some other crude oil products, is being transformed into sulfur in a Claus reactors [1].

The Claus process involves two main stages:

$$2\ H_2S + 3\ O_2 \rightarrow 2\ SO_2 + 2\ H_2O \quad (1)$$

$$4\ H_2S + 2\ SO_2 \rightarrow 3\ S_2 + 4\ H_2O \quad (2)$$

Elemental sulfur serves as a valuable component in both fertilizer and pesticides. The Claus process can be divided into two stages: thermal and catalytic.

Thermal stage

In thermal stage of the Claus process, the hydrogen sulfide-rich gas is partially combusted under the substoichiometric conditions at the high temperatures which are above 850°C. This controlled reaction initiates the conversion of H_2S into sulfur dioxide (SO_2), releasing significant heat in the process. As the hot gas mixture cools, elemental sulfur begins to condense and is subsequently extracted in a gas cooling unit. This step not only drives the initial transformation of sulfur compounds but also ensures thermal decomposition of unwanted byproducts such as ammonia and hydrocarbons, preventing catalyst fouling in the subsequent stage. Claus gases are acidic gases and with no additional combustible substances aside from the hydrogen sulfide, are being ignited in a lances arranged around a central muffle through the whole following chemical reaction:

$$2\ H_2S + 3\ O_2 \rightarrow 2\ SO_2 + 2\ H_2O\ (\Delta H = -518\ kJ\ mol{-}1) \quad (3)$$

This is a highly exothermic process of complete combustion of hydrogen sulfide, resulting in the formation of sulfur dioxide, which undergoes further reactions. Of particular significance is the Claus reaction:

$$2\ H_2S + SO_2 \rightarrow 3\ S + 2\ H_2O \quad (4)$$

The overall equation looks like this:

$$2\ H_2S + O_2 \rightarrow 2\ S + 2\ H_2O \quad (5)$$

The temperature in the Claus furnace exceeds 1050°C. This guarantees the destruction of BTEX compounds like benzene, toluene, ethylbenzene, and xylene, which would otherwise go to the downstream of Claus catalyst. The gases that contains ammonia, like those from the sour water stripper at the refinery, or hydrocarbons, are transformed inside of the burner muffler. A sufficient amount of air is introduced into the muffler to ensure the complete combustion of all the hydrocarbons and ammonia present. The air-to-acid gas ratio is carefully regulated so that one-third of the total hydrogen sulfide (H_2S) present is converted into SO_2. Usually, from 60 to 70% of the total amount of all elemental sulfur produced in the process is obtained in the thermal process stage. The bulk of the heated gas emerging from the combustion chamber traverses the conduit of the process gas chiller, undergoing a cooling process that allows the sulfur generated during the reaction to condense. The sulfur forms in the thermal phase as highly reactive S_2 diradicals which combine exclusively to the S_8 allotrope:

$$4\ S_2 \rightarrow S_8 \tag{6}$$

The thermal energy expelled by the process gas, coupled with the latent heat associated with condensation, is harnessed to generate medium- to low-pressure steam. The congealed sulfur is extracted at the liquid discharge segment of the process gas chiller.

Catalytic stage

Following the thermal step, the Claus process enters its catalytic phase, where the remaining hydrogen sulfide reacts with sulfur dioxide in the presence of a solid catalyst – commonly based on activated alumina or titanium oxide. This stage significantly increases the overall sulfur recovery rate by facilitating the main Claus reaction under milder temperature conditions, typically ranging from 200 °C to 330 °C. To prevent sulfur condensation and maintain catalyst activity, the process gas is reheated before entering each catalytic reactor. As the reaction progresses through multiple beds, additional sulfur is formed and then condensed downstream. Effective temperature control and catalyst management at this stage are essential for sustaining efficiency and minimizing byproduct formation.

During the Claus process, a significant amount of hydrogen sulfide (H_2S) reacts with sulfur dioxide (SO_2), which is produced during combustion, in the reaction chamber. This reaction leads to the formation of gaseous elemental sulfur:

$$2\ H_2S + SO_2 \rightarrow 3\ S + 2\ H_2O\ (\Delta H = -1165.6\ \text{kJ mol}{-1}) \tag{7}$$

The tail gas from the Claus process still containing combustible components and sulfur compounds (H_2S, H_2 and CO) is either burned in an incineration unit or further desulfurized in a downstream tail gas treatment unit.

Process Block Diagram

The first step of the process includes the preliminary treatment of the feed gas that generally consists of hydrogen sulfide (H_2S) as well as other constituents. The feed gas is then heated at a higher temperature inside a furnace, where the conversion of the hydrogen sulfide into sulfur dioxide (SO_2) occurs. It's referred to as thermal decomposition (Refer to Figure 1).

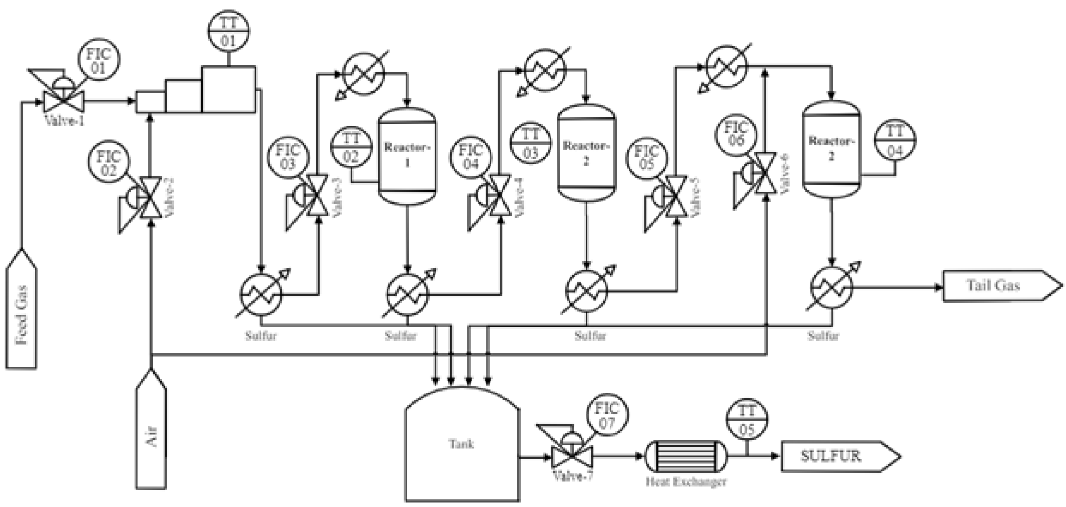

Figure 1 – Claus process, thermal stage

The remaining gas blend is then sent to a set of scrubber units such as the waste heat boiler and then the LP steam generating the sulfur condenser, where they remove any leftover sulfur constituents like carbonyl sulfide (COS) and the disulfide of carbon (CS_2). Sulfur gets condensed and extracted in the condenser of the sulfur.

Description of the general parameters

The Claus process is a tried and tested procedure utilized within the petroleum industry for the production of sulfur from sour gases. It has been used for many decades and its effectiveness relies on a number of crucial parameters such as temperature, pressure, residence time, and the feed gas composition. The raw material, which consists mainly of hydrogen sulfide, is fed into a steam boiler provided with gas tubes where it will go through a process of thermal conversion. In the combustion chamber of the boiler, temperatures of about 1100 °C are reached, progressive cooling to 350 °C as the gases make their way through the bundle of pipes. At this stage, water vapor at a pressure varying between 2.0 and 2.5 MPa is created.

Table 1 indicates general characteristics while Table 2 indicates general parameters.

Table 1 – Characteristics of purified VD/SD/ND gas and acid gas

Parameter	Purified VD gas, mol %	Purified SD gas, mol %	Purified ND gas, mol %	Acid gas, mol %
Temperature, °C	≤ 50	≤ 62	58	≤ 50
Pressure, bars	≤ 65	≤ 26	4.5	≤ 1.1
H_2S content, ppm about	≤ 15	≤ 35	≤ 15	not standardized

The reaction vessel residence time is a key variable for the Claus process as a measure of the exposure of the gases to the reaction conditions. Short residence times may lead to a lack of complete recovery of the sulfur present, while longer residence times may cause equipment fouling.

Table 2 – General Parameters on Installations

Parameter	Unit of measurem-ent	Accura-cy %	Acceptable range of technologi-cal parameters, des.	Acceptable range of technolo-gical parameter-rs, real	Recommend-ed optimal value
The water level in the steam collector	%	2.52	0–100	40–70	60–65
Steam pressure	Bars	0.82	33	20–30	27–29.5
…	…	…	…	…	…
Catalyst temperature	°C	1	400	260–370	310–320

The ratio of the composition of the feed gas, including hydrogen sulfide (H_2S) and carbon dioxide (CO_2), is another significant factor of the process. The source of most of the sulfur added by the feed comes from H_2S and depends on its concentration and the level of impurities present. The process requires high recovery rates of the sulfur, and these are obtained by careful management of residence time and carefully optimized composition of the feed. The operators are able to improve the efficiency and sustainability of the Claus process by recognizing and controlling these factors. The gas from the top of the contactor is sent directly to the afterburning furnace where the remaining sulfur compounds are oxidized into SO_2. The level of SO_2 present within the flue gas is then detected using the flow analyser. The temperature of the furnace is kept at around 800°C with the assistance of the control of the temperature indicator. The flue gas fuel comes from two sources: the separator where the gas comes from the two separators and the flare, as well as the separator where the recycle streams of the top products of the fuel gas contactor and the phlegm of discharge from the diethanization tower. [16].

Description of the Control Object:

A heat exchanger is a device used for the exchange of heat energy between two or more fluids without physical mixing. The functioning of a heat exchanger is regulated by a host of parameters like the temperature difference between the fluids, the surface area exposed for the exchange of heat, the flow of fluids, and the respective modes of movement of the fluids. Heat exchangers are utilized on a large scale in multiple industries such as petroleum refining, food industry, manufacturing of petrochemicals, power production, nuclear power production, and even spacecraft system designing. There exist various types of heat exchangers consisting of [17]:

- Shell-and-tube heat exchangers (Figure 2): Such heat exchangers are made of a number of tubes having one type of fluids flowing inside the tubes and another flowing externally over the tubes within a shell. Shell-and-tube heat exchangers are commonly used in petroleum engineering because they are very effective and have the ability to withstand very high pressures.late heat exchangers: These types of units use thin plates as the separating medium between fluids and are generally smaller and more efficient for some uses, although they might be less long-lived than shell-and-tube types.
- Plate heat exchangers: These types of units use thin plates as the separating medium between fluids and are generally smaller and more efficient for some uses, although they might be less long-lived than shell-and-tube types.
- Air-cooled heat exchangers: These use air rather than water or other liquids as the cooling agent and thus are ideal for places where water supply is scarce.

Heat exchangers have a key role to play within petroleum engineering as they are used for numerous processes including:

- Heating crude oil or cooling it for the purposes of processing.
- Cooling water from the production of oil to avoid damage to the equipment and ensure ideal working conditions.
- Harnessing industrial process waste heat to make electricity or steam.
- Air-cooled heat exchangers: These use air rather than water or other liquids as the cooling agent and thus are ideal for places where water supply is scarce.

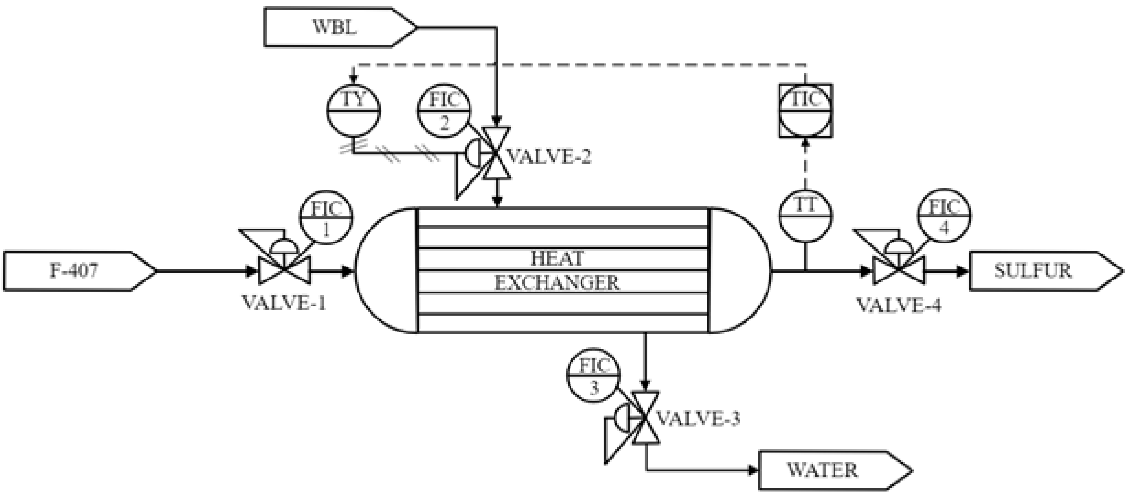

Figure 2 – Heat Exchanger's structural scheme

Specification and calculation of the general parameters of the mathematical model

By given parameters like the temperature of inlet and outlet sulfur it's possible to calculate the mathematical model for heat exchanger. Determining the thermal energy balance:

$$Q = G_s C_s (T_{s,in} - T_{s,out}) = G_w C_w (T_{w,in} - T_{w,out}) \quad (8)$$

The temperature of inlet sulfur is 220 C and the temperature of outlet is 130 C.

$$Q = G_s C_s (220 - 130) \quad (9)$$

Mass consumption of sulfur will be around 5 kg/s.

$$Q = 5 \times 0.73 \times (220 - 130) = 328.5 \quad (10)$$

The transfer function of the heat exchanger is described by an aperiodic link of the first order with a precise delay:

$$W(p) = \frac{K_t}{T_t p + 1} e^{-p\tau_t} \quad (11)$$

$$K_t = \frac{Q}{G_s C_s (T_{s,in} - T_{s,out})} \quad (12)$$

$$K_t = \frac{328.5}{5 \times 0.73 \times (220 - 130)} = 1 \quad (13)$$

After finding the transfer coefficient and time it's possible to find the transfer function of heat exchanger.

$$T_t = \frac{\rho_s V_s}{G_s} \quad (14)$$

$$T_t = \frac{1810 \times 0.5}{5} = 181 \quad (15)$$

A transfer function of a heat exchanger with precise delay:

$$W(p) = \frac{1}{181p + 1} e^{-p\tau_t} \quad (16)$$

For the convenience of analysis, we use the first-order Pade approximation.:

$$e^{-p\tau_t} = \frac{1 - \frac{p\tau_t}{2}}{1 + \frac{p\tau_t}{2}} \quad (17)$$

$\tau_t = 10$ s.

$$W(p) = \frac{1}{181p + 1} \times \frac{1 - 5p}{1 + 5p} \quad (18)$$

$$W(p) = \frac{1 - 5p}{(181p + 1)(5p + 1)} \quad (19)$$

The final transfer function looks like:

$$W(p) = \frac{1 - 5p}{905p^2 + 186p + 1} \quad (20)$$

After determining the final transfer function it's possible to use it for further analysis. The transfer function is needed to mathematically describe a dynamic system [2]. Some purposes of using the transfer function. Determination of the dynamic properties of the system. The transfer function of a system determines all its dynamic properties, so the primary task of calculating a control system is to determine its transfer function. The transfer function describes the system's response to a change in the input parameter, including the reaction delay and the rate of change in the output value [3]. Restoring the output signal. If the transfer function and the input signal of the system are known, then the output signal can be restored. In Figure 3 is shown a system of heat exchange with control valve and temperature indicator in transfer functions that was designed in a Matlab Software in Simulink tool. The system has 3 different PID regulators with different coefficients and creation of a regulator based on fuzzy logic principles was considered [4]. The need for a mathematical model of the selected control object lies in the ability to predict and evaluate the behavior of the process [5]. It is a differential operator that expresses the relationship between the output and input of a linear stationary system [6].

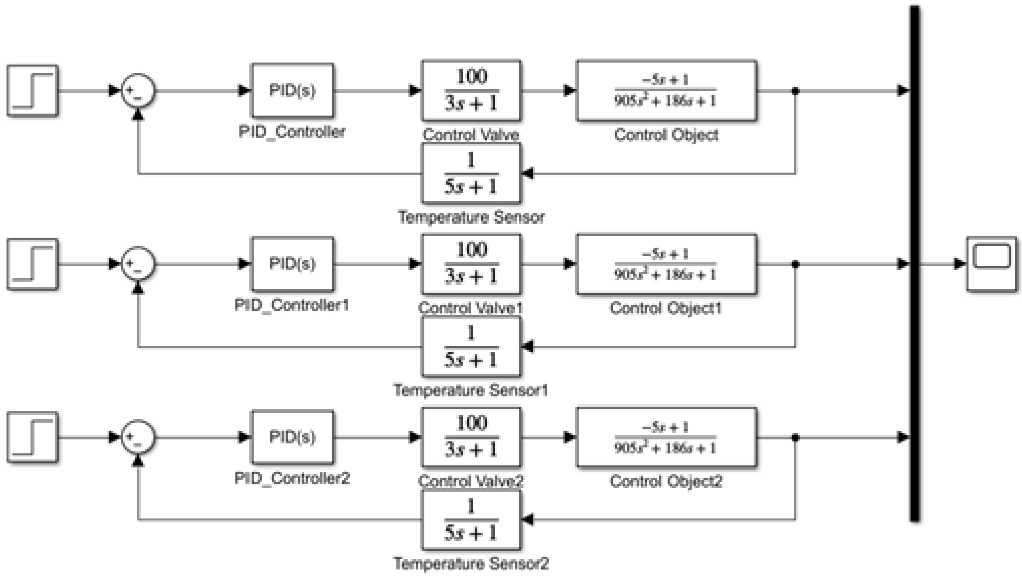

Figure 3 – Simulink heat exchange system with PID regulators

In Figure 4 a graph of the scope of each system with different PID coefficients is shown and Table 3 shows them.

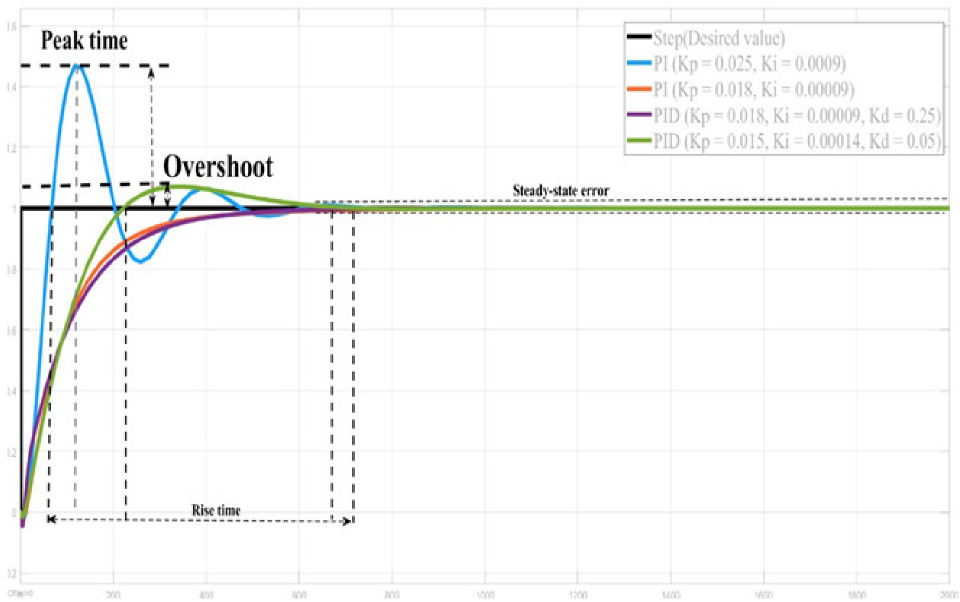

Figure 4 – Scope of each system with different PID coefficients

Table 3 shows the different PID coefficients for each system with the same transfer function.

Table 3 – Different PID coefficients

Color	Kp	Ki	Kd
Yellow	0.0187	0.00009	0.13
Blue	0.0150	0.00014	0.12
Red	0.1000	0.00015	0.15

Development of automation and control system on the basis of PLC

Programmable logic controllers (PLCs) are the basis of industrial automation, as it is a hardware and software component that directly interacts with sensors, actuators, and other field devices. A PLC provides access to control and monitoring of many machines connected to it and the software system integrated with them. PLCs can effectively work with various communication protocols, analyze data, perform conversions, interact with I/O modules, process signals, etc. PLCs are fully programmable by the user using the development environment and standard IEC 61131-3 programming languages, such as ST, FBD, SFC, LD, IL. EcoStruxure Control Expert is a software platform for developing, configuring and maintaining control systems in various industries. Its necessity is due to the ability to simplify and improve control processes, increase operational efficiency and ensure smooth integration of various automation components. EcoStruxure Machine Expert is a software from Schneider Electric that is used for the design, programming and maintenance of machines and equipment in industry. Configuration software EcoStruxure Operator Terminal Exper screen designed to create and save applications for automating control systems for Mageli GTU (Premium and Open units)/ STO Color/GTO terminals and Magelis industrial PCs (elpan and unit) [7]. In Figure 5 is shown «Industrial automation Lab» (Schneider Electric).

Figure 5 – Sulfur production control system
realization in «Industrial automation Lab» (Schneider Electric)

«Industrial automation Lab» (Schneider Electric) was used for achieving the goal of a construction of a system for sulfur production. In Figure 6 a connection of controllers of 2 Masters M340 with 3 Slaves M241 each connected by TCP Modbus protocol and by one controller connected on HMI Harmony Panel with Ethernet network. If one of the connections with the controller broke the indicator will show exactly what controller connection were broken is shown from the laboratory.

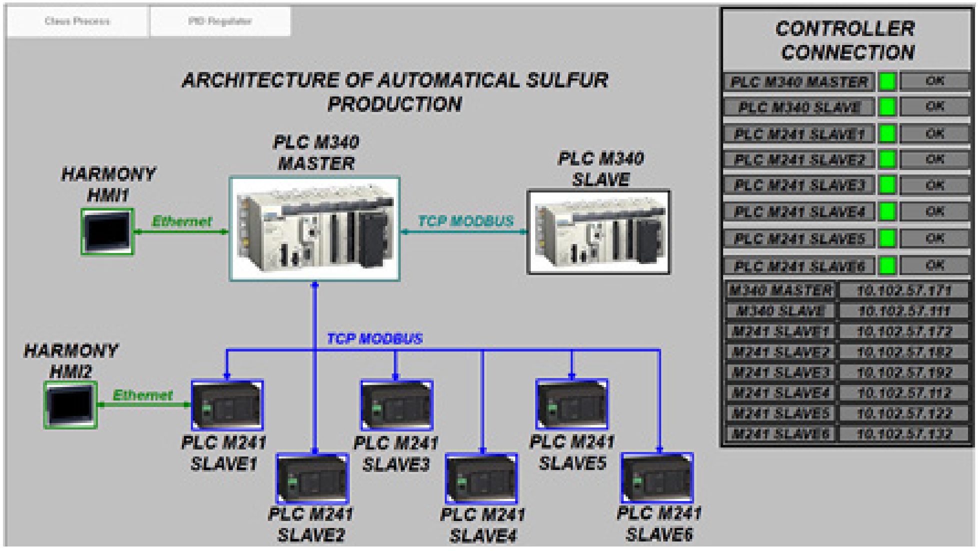

Figure 6 – Architecture of controller connection

Figure 7 represents us a control plant of sulfur production. Having reaction furnace which is RF – 100, 4 condensers C-XXX, 3 reheaters, 1 huge tank – T-100 and heat exchanger HE-100.

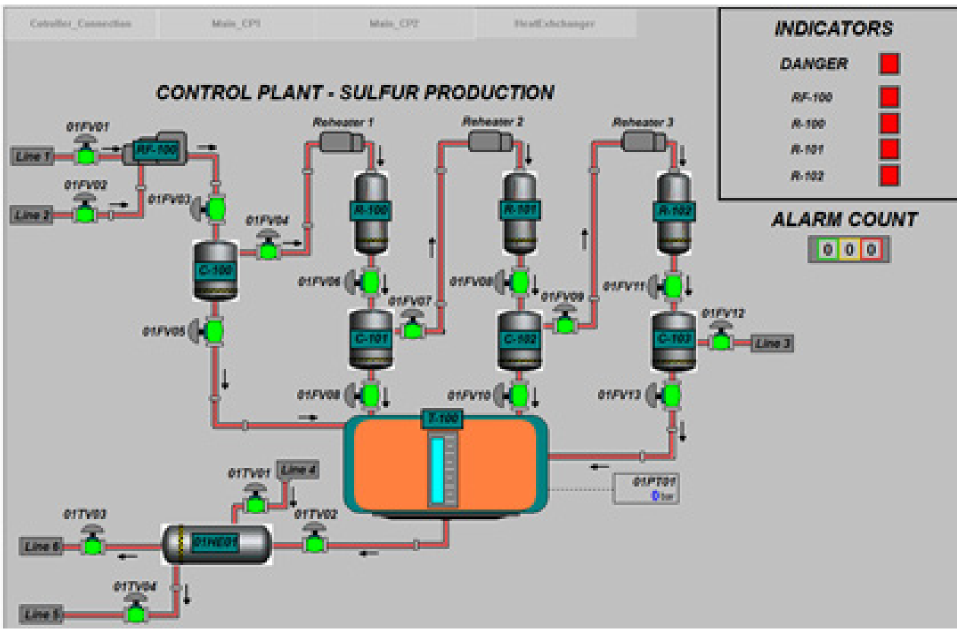

Figure 7 – Development of the operator screen
for sulfur production in EcoStruxture Control Expert

In Figure 8 all the equipment of a Stand from the laboratory is shown that it were used for the construction of the system.

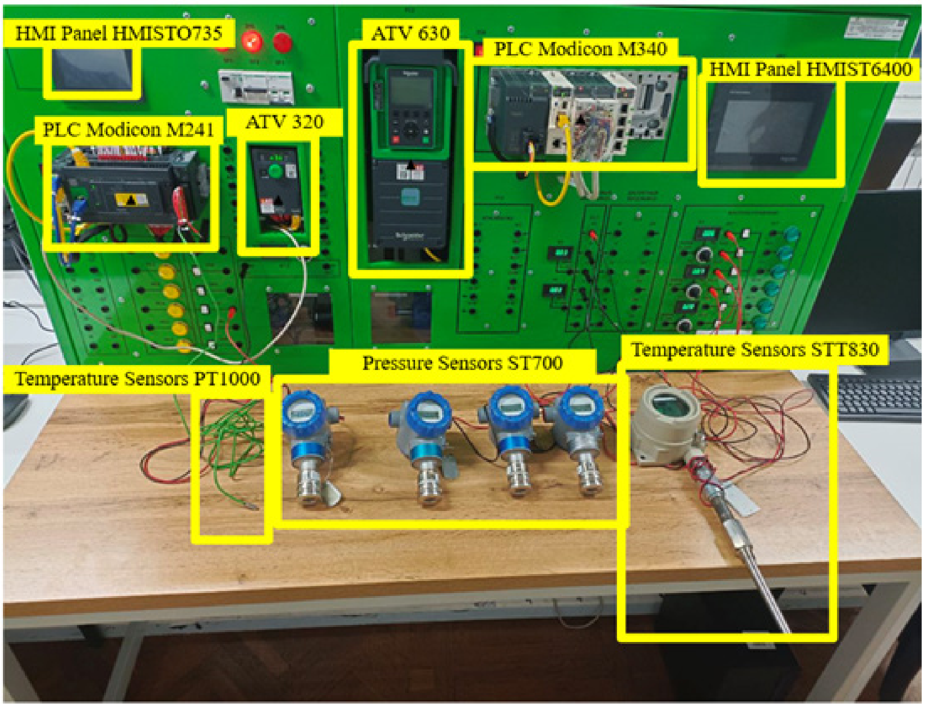

Figure 8 – Realization on stand

Figure 9 represents the view of an HMI panel for monitoring the control object.

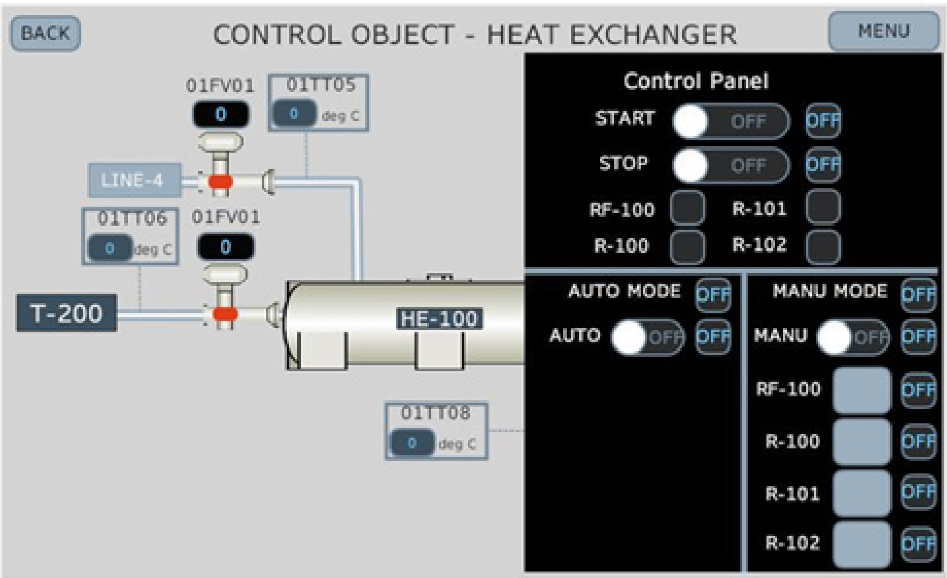

Figure 9 – Development HMI display on the basis of HMIST6400 Panel with EcoStruxture Operator Terminal Expert

Figure 10 shows software for Panels EcoStruxure Operator Terminal Expert.

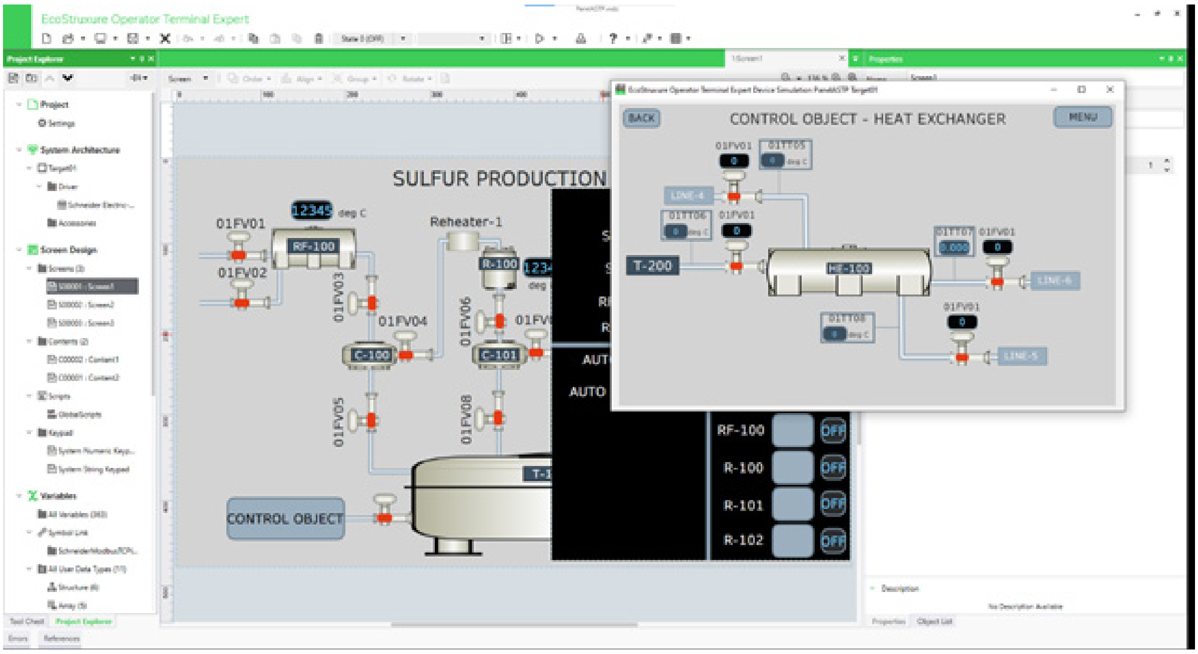

Figure 10 – EcoStruxure Operator Terminal Expert

The PLC connections are based on a sending pulse signal from Slave to Master controller for indication of controller connection. In Figure 11 an HMI panel with an opened PID graph which is realized with program on M340 controller by using the special software EcoStruxure Operator Terminal Expert.

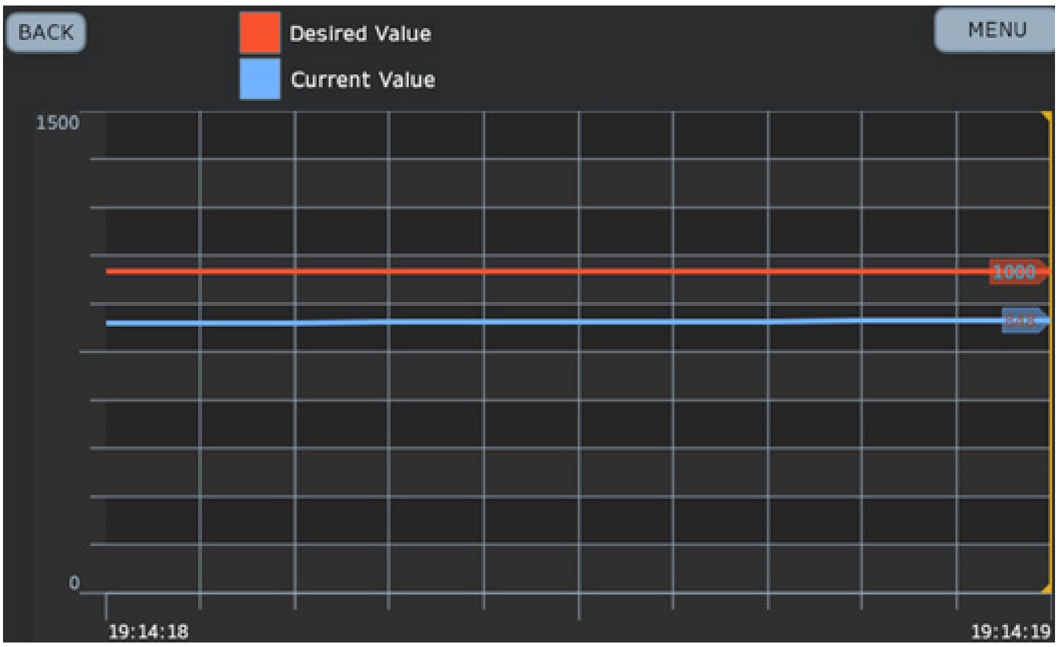

Figure 11 – PID graph on HMIST6400

In Figure 12 an HMI panel with an opened PID graph which is realized with program on M241 controller by using the special software EcoStruxure Operator Terminal Expert.

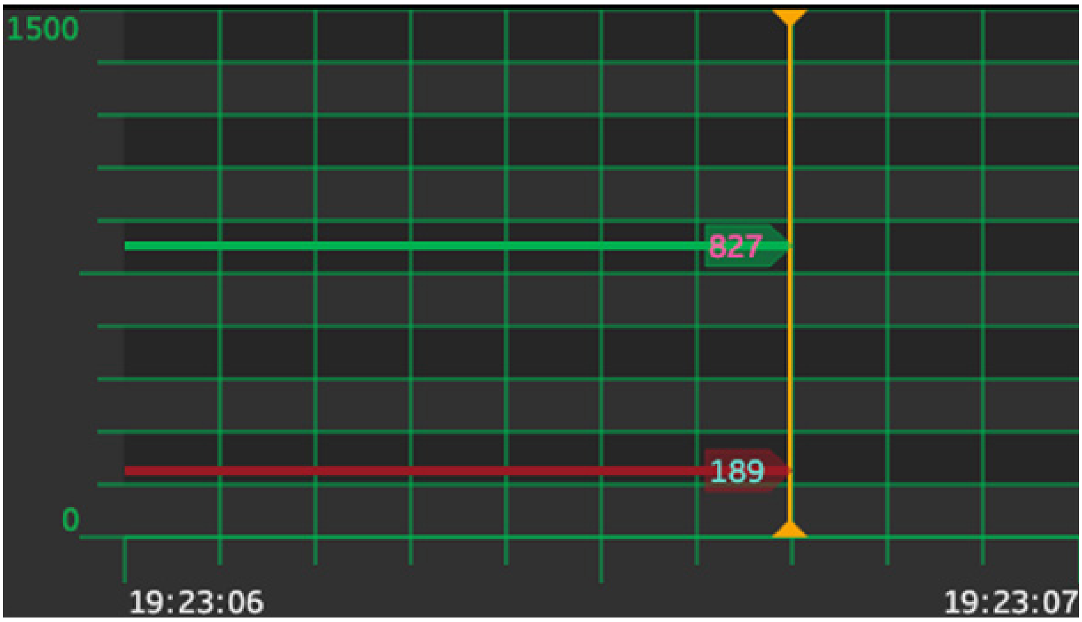

Figure 12 – PID graph on HMISTO735

By using the WebVisu from EcoStruxure Machine Expert it's possible to share the visualization that was realized in a Software to other devices that connected to the same network as PLC by using it's address with WebVisu extension. In Figure 13 is shown the exact phone connection to PLC for Emergency Shut down in case if operator would have troubles with control point/room.

Figure 13 – Mobile PLC Modicon M241 control
with Webvisu and EcoStruxture Machine Expert

In Figure 14 is shown another software EcoStruxure Machine Expert with visualization and it's WebVisu configuration for generating a website based on controller's IP address.

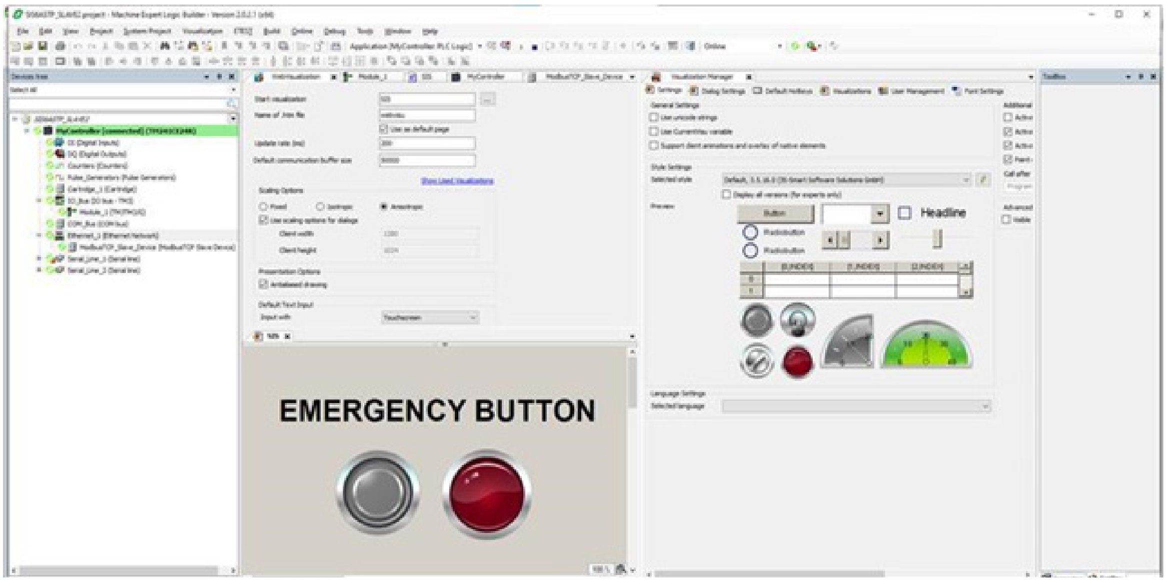

Figure 14 – EcoStruxure Machine Expert

Figure 15 represents HMI panel with opening menu and starting the Manu mode of the Automated Sulfur production system by using the special software EcoStruxure Operator Terminal Expert.

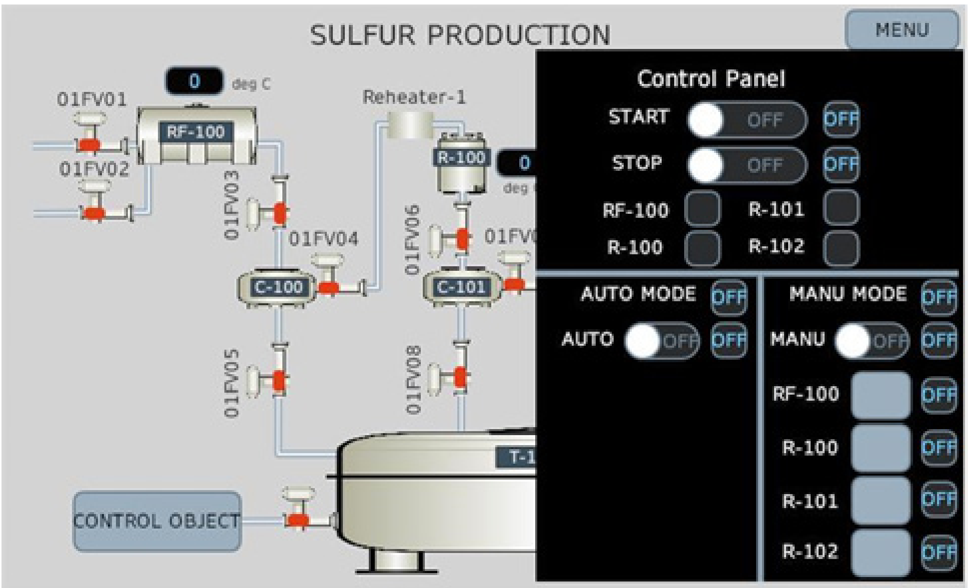

Figure 15 – Menu and Manu mode from HMI Panel

As the representation of control objects were chosen ATV630 (Figure 16a) as Reaction Furnace and ATV320 (Figure 16b) for valve opening control with 3 PID controllers – 1 for M340 and 2 for M241. Summarizing this part of the project, the strengths of the program realization is the implementation of overall 8 PLC controllers with 17 sensors including 10 pressure sensors and 7 temperature sensors. The system has an HMI control with Auto and Manu modes and control objects as frequency converters like ATV320 and ATV630. System also has an emergency shut down by phone manipulation for remote control of the safety in case of trouble in operator’s room or system.

a) ATV630 frequency converter　　　b) ATV320 frequency converter

Figure 16 – Description of the frequency converter in the system

The PLC connection is based on a TCP Modbus connection with Ethernet connection to HMI Panels. On stand realized the indicators based on a simple lamp that uses the Discrete output from the modules of PLCs

AI IMPLEMENTATION IN PLC SYSTEM

By using a software Modbus Poll it’s possible to collect the data from sensors using Modbus addresses. In Figure 17 is shown an Exel table that was collected from Pressure sensors ST700 and Temperature sensor PT 1000.

The temperature at the inlet and outlet is an important parameter for diagnosis, as temperature changes may indicate a decrease in heat exchange efficiency. Inlet and outlet pressure – pressure drop or sudden fluctuations may also indicate clogging or other problems in the system.

This data can be used to create a model that will track anomalies and warn of possible accidents. For example, to predict clogging, you can build a model that will take into account changes in temperature and pressure as signs of deterioration of the heat exchanger.

Availability of accident data on previous accidents can be very useful for training an AI model. Typically, in industrial systems such as heat exchangers, data on accidents and failures is stored in an event log or in a maintenance database (CMMS - Maintenance management system). This data can be useful for training a machine learning model that will look for patterns in the behavior of the heat exchanger before an accident.

As a little experiment a simple code was written in a Google Colaboratory using a Python programming language to analyze and detect anomaly from collected data from sensors.

In Figure 18 is shown an Excel file that was gained from the result of Google Colaboratory. It used the Isolation Forest algorithm to detect the anomaly score from sensors. Isolation Forest is an algorithm for detecting anomalies. He does not build a density model but tries to isolate outliers. A tree is built where each node randomly selects one feature and a random split value. The data is divided recursively until each point is in its own separate sheet. A point is considered an anomaly based on how quickly it was isolated (the shorter the path, the more anomalous). If an object separates in just a couple of steps, it means that it is very out of the picture

	A	B	C	D	E	F
4	2025-04-17 11:54:14.976	2,5	0,4	0,9	24,5	1,2
5	2025-04-17 11:54:15.093	2,5	0,4	0,9	24,5	1,2
6	2025-04-17 11:54:16.865	2,5	0,4	0,9	24,5	1,2
7	2025-04-17 11:54:17.861	2,5	0,4	0,9	24,5	1,2
8	2025-04-17 11:54:18.898	2,5	0,4	0,9	24,5	1,2
9	2025-04-17 11:54:19.895	2,5	0,4	0,9	24,8	1,2
10	2025-04-17 11:54:20.892	3,6	0,4	0,9	25	1,2
11	2025-04-17 11:54:21.904	5,5	0,4	0,9	25,2	1,2
12	2025-04-17 11:54:22.918	6,4	0,5	0,9	25,4	1,2
13	2025-04-17 11:54:23.959	6,8	1	0,9	25,7	1,2
14	2025-04-17 11:54:24.955	7,3	1,4	0,9	25,9	1,2
15	2025-04-17 11:54:25.960	7,5	1,5	0,9	26,1	1,2
16	2025-04-17 11:54:26.988	6,5	1,1	0,9	26,2	1,2
17	2025-04-17 11:54:28.003	5,7	0,6	0,9	26,4	1,2
18	2025-04-17 11:54:29.008	5,8	0,5	2,6	26,5	1,2
19	2025-04-17 11:54:30.023	6,3	0,4	5	26,6	1,2
20	2025-04-17 11:54:31.028	6,6	0,4	6,1	26,7	1,2
21	2025-04-17 11:54:32.054	6,6	0,4	6,5	26,7	1,2
22	2025-04-17 11:54:33.071	6,4	0,4	5,8	26,8	1,2
23	2025-04-17 11:54:34.081	4	0,4	2,7	26,8	1,2
24	2025-04-17 11:54:35.086	2,9	0,5	1,4	26,8	1,2
25	2025-04-17 11:54:36.095	2,6	1	1,1	26,9	4,2
26	2025-04-17 11:54:37.124	2,5	1,3	1	26,9	6,8
27	2025-04-17 11:54:38.136	2,5	1,5	0,9	26,9	7,4
28	2025-04-17 11:54:39.162	2,5	1,5	0,9	26,9	7,5
29	2025-04-17 11:54:40.175	2,5	1,4	0,9	26,9	5,9

Figure 17 – Collected data

Type log name here	Unnamed: 1	Unnamed: 2	Unnamed: 3	Unnamed: 4	Unnamed: 5	Anomaly_Score
Poll definition: ID = 1, Function = 03, Address = 0, ScanRate = 1000						
	Pres_Sen_1	Pres_Sen_2	Pres_Sen_3	Temp_Sen_1	Pres_Sen_4	
2025-04-17 11:54:14.976	2,5	0,400000006	0,899999976	24,5	1,200000048	0,304535275
2025-04-17 11:54:15.093	2,5	0,400000006	0,899999976	24,5	1,200000048	0,304535275
2025-04-17 11:54:16.865	2,5	0,400000006	0,899999976	24,5	1,200000048	0,304535275
2025-04-17 11:54:17.861	2,5	0,400000006	0,899999976	24,5	1,200000048	0,304535275
2025-04-17 11:54:18.898	2,5	0,400000006	0,899999976	24,5	1,200000048	0,304535275
2025-04-17 11:54:19.895	2,5	0,400000006	0,899999976	24,79999924	1,200000048	0,304535275
2025-04-17 11:54:20.892	3,599999905	0,400000006	0,899999976	25	1,200000048	0,304535275
2025-04-17 11:54:21.904	5,5	0,400000006	0,899999976	25,20000076	1,200000048	0,304535275
2025-04-17 11:54:22.918	6,400000095	0,5	0,899999976	25,39999962	1,200000048	0,304535275
2025-04-17 11:54:23.959	6,800000191	1	0,899999976	25,70000076	1,200000048	0,304535275
2025-04-17 11:54:24.955	7,300000191	1,399999976	0,899999976	25,89999962	1,200000048	0,304535275
2025-04-17 11:54:25.960	7,5	1,5	0,899999976	26,10000038	1,200000048	0,304535275
2025-04-17 11:54:26.988	6,5	1,100000024	0,899999976	26,20000076	1,200000048	0,304535275
2025-04-17 11:54:28.003	5,699999809	0,600000024	0,899999976	26,39999962	1,200000048	0,304535275
2025-04-17 11:54:29.008	5,800000191	0,5	2,599999905	26,5	1,200000048	0,304535275
2025-04-17 11:54:30.023	6,300000191	0,400000006	5	26,60000038	1,200000048	0,304535275
2025-04-17 11:54:31.028	6,599999905	0,400000006	6,099999905	26,70000076	1,200000048	0,304535275
2025-04-17 11:54:32.054	6,599999905	0,400000006	6,5	26,70000076	1,200000048	0,304535275
2025-04-17 11:54:33.071	6,400000095	0,400000006	5,800000191	26,79999924	1,200000048	0,304535275
2025-04-17 11:54:34.081	4	0,400000006	2,700000048	26,79999924	1,200000048	0,304535275
2025-04-17 11:54:35.086	2,900000095	0,5	1,399999976	26,79999924	1,200000048	0,304535275
2025-04-17 11:54:36.095	2,599999905	1	1,100000024	26,89999962	4,199999809	0,304535275
2025-04-17 11:54:37.124	2,5	1,299999952	1	26,89999962	6,800000191	0,304535275
2025-04-17 11:54:38.136	2,5	1,5	0,899999976	26,89999962	7,400000095	0,304535275

Figure 18 – Anomaly detection result

A code for building the trees is shown in Figure 19. The total number of trees that were built was 50. By using those trees code detects points and then calculates the anomaly score for the analysis.

```
[20] class InternalNode:
         def __init__(self, split_feature, split_value, left_subtree, right_subtree):
             self.split_feature = split_feature
             self.split_value = split_value
             self.left = left_subtree
             self.right = right_subtree

     def IsolationTree(data, current_depth, max_depth):
         if current_depth >= max_depth or len(data) <= 1:
             return ExternalNode(size=len(data))

         split_feature = random.choice(data.columns)
         values = data[split_feature].values
         split_value = random.uniform(min(values), max(values))

         left_data = data[data[split_feature] < split_value]
         right_data = data[data[split_feature] >= split_value]

         left_subtree = IsolationTree(left_data, current_depth + 1, max_depth)
         right_subtree = IsolationTree(right_data, current_depth + 1, max_depth)

         return InternalNode(split_feature, split_value, left_subtree, right_subtree)

     def IsolationForest(data, num_trees=100, max_depth=10):
         forest = []
         for _ in range(num_trees):
             sample_data = data.sample(frac=1, replace=True).reset_index(drop=True)
             tree = IsolationTree(sample_data, 0, max_depth)
             forest.append(tree)
         return forest

     numeric_data = data.select_dtypes(include=[np.number])
     numeric_data = numeric_data.fillna(numeric_data.mean())
     forest = IsolationForest(numeric_data, num_trees=50, max_depth=8)
     print(f"Num of trees: {len(forest)}")

     Num of trees: 50
```

Figure 19 – Isolation Tree code

By using matplotlib.pyplot library it was possible to construct the plot to visually see the anomaly detection of collected data (Figure 20). The closer coefficient gets to 1 the more anomaly appears, and it means a very short path in the trees. As it's possible to see from a plot a collected data is closer to 0 which means that it's closer to a normal. The Isolation Forest algorithm has shown its effectiveness in spotting anomalies in a collected data set. By using the same principle it's possible to build a Model which can detect and predict the accidents and prevent them if it has access to database of sensors in a real time.

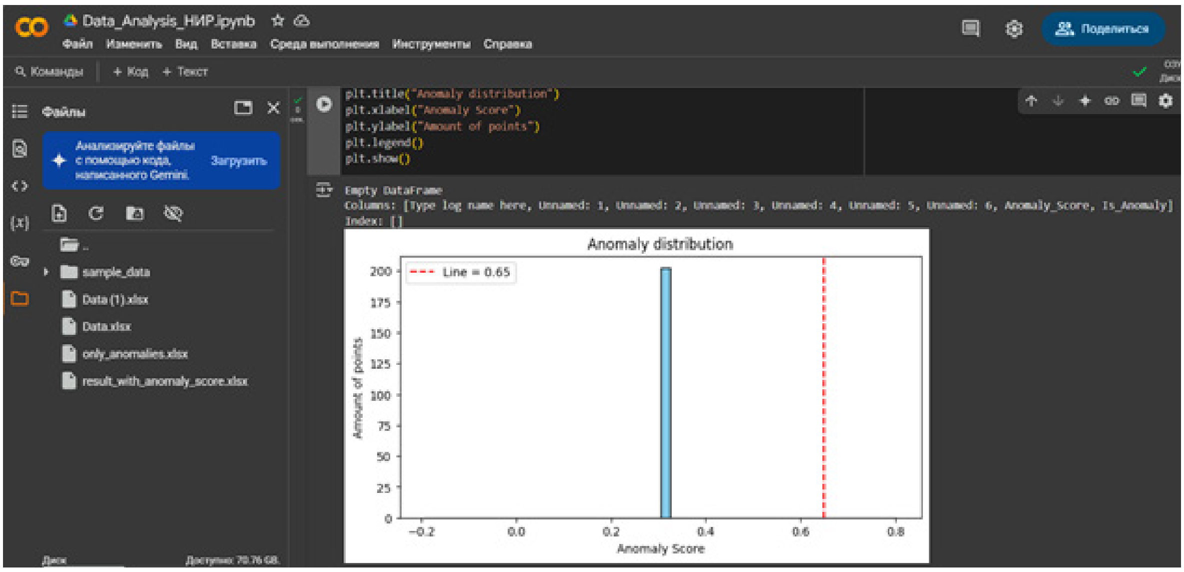

Figure 20 – Matplot of anomaly distribution

However, for safety reasons it would be better to limit access to control of plants from that model. By limiting model from full control of automation systems it's possible to prevent them from damaging the system. The last choice must be made by a professional and qualified person.

This small experiment showed the potential in combining machine learning and artificial intelligence with automation and control of production processes, as well as in other areas. If narrow down the created model to analyzing the data it receives in real time, it is possible to create an effective incident prevention system that will significantly reduce the costs of many companies.

Results and discussion

This section presents and discusses the main results obtained during the research. Figure 7 shows the builtup control system which is based on Programmable Logic Controllers (PLC) by using TCP Modbus protocols. In Figure 8 shown the scheme of process control logic of the technical process. Figure 14 demonstrates the implementation of remote monitoring and control using WebVisu from EcoStruxure Machine Expert. Figure 19 presents a summary table of data collected from sensors, and Figure 20 shows the results of anomaly distribution analysis performed using Python programming language.

The Modbus TCP based architecture demonstrated the ease of integration with industrial sensors and the ability to scale. The key performance indicators of the system include data exchange latency, polling frequency, and channel stability under peak loads. In the future, it is recommended to conduct systematic network measuremetn and analyze their impact on the performance of control algorithms for technological processes.

The analysis of data from sensors using machine learning methods made it possible to identify patterns and detect deviations from the normal behavior of the equipment. The obtained distribution of anomalies (as shown in Figure 21) indicates the presence of localized spikes on individual sensors and periodic deviations, which makes it possible for surgical intervention. For an objective assessment of the anomaly detector's effectiveness, accuracy and completeness metrics are highly required as well as testing on a dedicated deferred samples.

Conclusiion

Modernization of automatic control systems for sulfur production is necessary for efficient production. The state of automation affects the efficiency and functionality of production systems. The issue of improving automated systems is acute. The article contains research on the analysis of an automated sulfur production system using Schneider Electric techniques.

The utilization of mathematical modelling, particularly through the MATLAB software, plays a pivotal role in understanding and optimizing the control system. The study involved examining the mathematical model of the heat exchange process.

During the study, a connection structure was created from several PLCs using Schneider Electric software and the network configuration and system architecture were implemented. During this process, a PID controller was designed, which allowed for better productivity. Automated systems at strategically important facilities and enterprises must comply with all applicable standards and function promptly.

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КҮКІРТ ӨНДІРУ ТЕХНОЛОГИЯЛЫҚ ПРОЦЕСІН АВТОМАТТАНДЫРУ ЖӘНЕ БАСҚАРУ ЖҮЙЕСІН ДАМЫТУ

Аңдатпа

Заманауи өнеркәсіптік ұйымдарда күрделі технологиялардың кеңінен қолданылуын ескере отырып, жабдық жағдайын бақылау және диагностикалау маңызды міндеттердің бірі. Бұл зерттеу Schneider Electric M241 және M340 бағдарламаланатын логикалық контроллерлерін (PLC) пайдалану арқылы мұнай-газ өнеркәсібіндегі өндірістік жабдықтарды диагностикалаудың жетілдірілген жүйесін әзірлеуге бағытталған. Зерттеудің алғашқы қадамы – жабдықты пайдалану барысында туындайтын ықтимал ақауларды талдау, сондай-ақ мұнай-газ саласында қолданылатын сигналдарды өңдеу әдістерін зерттеу. Екінші қадам – автоматтандырылған деректерді жинау, параметрлерді бақылау және жабдық жағдайын диагностикалау үшін PLC қолдану. Ұсынылған тәсіл негізгі технологиялық процестерді нақты уақыт режимінде басқаруға, істен шығу ықтималдығын азайтуға және өндірістік жабдықтың сенімділігін арттыруға мүмкіндік береді. Зерттеу барысында әртүрлі деректерді өңдеу стратегияларының өнеркәсіптік жабдықты диагностикалау тиімділігіне ықпалы қарастырылды. PLC негізінде деректерді жинау және талдау әдістері, соның ішінде үздіксіз параметрлер мониторингі, шекті мәндерді бақылау және триггерлік оқиғаларды тіркеу зерттелді. Осы әдістердің негізінде EcoStruxure Machine Expert және Unity Pro бағдарламалық орталарында ақауларды автоматты түрде анықтау және дабыл қалыптастыруды қамтамасыз ететін диагностикалық алгоритмдер әзірленіп, іске асырылды.

Тірек сөздер: Schneider Electric, өнеркәсіптік жабдықтың диагностикасы, контроллерлер, күкірт өндірісі.

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РАЗРАБОТКА СИСТЕМЫ АВТОМАТИЗАЦИИ И УПРАВЛЕНИЯ ТЕХНОЛОГИЧЕСКИМ ПРОЦЕССОМ ПРОИЗВОДСТВА СЕРЫ

Аннотация

Учитывая сложную технологию, которой оснащены современные промышленные организации, мониторинг и диагностика состояния оборудования являются критически важными задачами. Целью настоящего исследования является разработка усовершенствованной системы диагностики промышленного оборудования в нефтегазовой отрасли с использованием программируемых логических контроллеров (ПЛК) Schneider Electric M241 и M340. Первым шагом в этом процессе является анализ неисправностей, возникающих в процессе эксплуатации оборудования, а также изучение методов обработки сигналов, используемых в нефтегазовой отрасли. Вторым шагом является использование ПЛК для автоматизированного сбора данных, мониторинга параметров и диагностики состояния оборудования. Такой подход позволяет в режиме реального времени контролировать ключевые технологические процессы, снижая вероятность отказов и повышая надежность производственного оборудования. В исследовании изучалось влияние различных стратегий обработки данных на эффективность диагностики промышленного оборудования. Были рассмотрены методы сбора и анализа данных ПЛК, включая непрерывный мониторинг параметров, пороговый контроль и триггерные события. На основе этих методов разработаны и внедрены в среды EcoStruxure Machine Expert и Unity Pro алгоритмы диагностики, обеспечивающие автоматическое обнаружение неисправностей и генерацию аварийных сигналов.

Ключевые слова: Schneider Electric, диагностика промышленного оборудования, контроллеры, производство серы.

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