ANALYSIS ON AUTOMATION SOFTWARE FOR SUPERVISION AND COMMAND OF A SCREW ELECTRO-COMPRESSOR CONTROL ROOM

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Seven screw electro-compressors are in operation at the Icoana compression station, Olt, Romania. In order for the station to be monitored and controlled, two project phases were developed for a control room. The article aims to describe the architecture of the control room automation system and the HMI computer, emphasizing the novelty obtained through the implementation of software solutions. The article first presents the control room project which has an original approach on software developing for the SIS system. A station upgrade is performed and original features are described such as HMI computer new software capabilities.

Keywords: Safety Instrumented System, Screw Electro-Compressor, Human Machine Interface, Automation, Programmable Logic Controller

1. Introduction

The screw electro-compressor contains two screw-shaped rotors that rotates in opposing directions. Precise rotors manufacturing allows for reduced rotor clearances but increases the risk of direct rotor contact, which can lead to temperature rise, deformation, increased contact forces, and rotor failure. Designing these rotors to minimize those risks is crucial [1-2].

The industrial landscape has witnessed significant advancements in automation and control systems, revolutionizing the operational efficiency and reliability of complex machinery and processes. Within this realm, screw electro-compressors have emerged as vital components in various industrial sectors, facilitating the compression of gases and playing a crucial role in ensuring seamless operations. As the reliance on these electro-compressors continues to grow, the need for robust and intelligent automation software to supervise and command their control rooms has significantly increased [3-5].

The article study aims to explore the contributions made in the development of automation software designed specifically for screw electro-compressors. The escalating demands for enhanced productivity, safety, and

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environmental sustainability have impelled researchers and engineers to design innovative software solutions capable of precisely monitoring and controlling the electro-compressor operations in real-time.

The comprehensive integration of automation software with screw electro-compressor systems brings forth multifaceted advantages [6]. Notably, it empowers operators with real-time data analytics, predictive maintenance capabilities, and intuitive graphical interfaces, augmenting their decision-making process and streamlining the supervisory tasks. This synergy contributes to minimized downtime, increased energy efficiency, and prolonged electro-compressor life, thereby optimizing the overall operational performance [7].

The Icoana electro-compressor station presented in Fig. 1 exhibits the capability to compress approximately 200,000 Nm^3/day of dry gases originating from the Ciurești production sector to TRANSGAZ, specifically the Corbu delivery point. This station was constructed as part of the electro-compressor station modernization program in collaboration with the COMOTI institute during the period of 2007-2008. The initial stage of the station consists of two electro-compressors, designated as K1A and K1B, while the second stage consists of four electro-compressors, designated as K2A, K2B, K2C and K2D. Following the second stage, the gas reaches a maximum pressure of 30 barg and a maximum temperature of 50°C. However, during the summer season, when gas demand decreases, the pressure in the TRANSGAZ network to the SRM Corbu delivery point gradually increases, as the network pressure will eventually reach 40 barg.

Fig. 1. The Icoana electro-compressor station

The term "screw electro-compressor control room" refers to a centralized command center that includes the hardware and software components necessary for supervising and managing multiple screw electro-compressors simultaneously. The automation software provides a unified platform that hosts a diverse range of industrial applications, including but not limited to petrochemical, manufacturing, and energy sectors.

This scenario necessitates the discharge of a substantial gas volume, approximately 50,000 Nm^3/day, into the atmosphere [8], due to the limited discharge line pressure. To address this issue, and to ensure seamless operations at 45 barg, the installation of a third compression stage within the Icoana station becomes imperative. This third stage aims to augment and maintain adequate pressure for the gas production delivered during the summer period.

Through a comprehensive review of literature, technical documentation, and field implementations, this article seeks to identify the key elements constituting an effective automation software solution for screw electro-compressor control rooms [8-9]. Furthermore, the article aims to critically assess the challenges encountered during development and deployment phases, as well as the methodologies employed to overcome these obstacles.

This article strives to shed light on the remarkable progress made in advancing automation software for the supervision and command of screw electro-compressor control rooms. By providing a comprehensive account of the current state of the art, the article contributes to the collective knowledge base in the field of industrial automation, optimizing electro-compressor performance, enhancing productivity, and ensuring a sustainable industrial process.

2. Background

The solution considered for the implementation of the automation system within the Icoana electro-compressor control room was the work carried out at the Abram electro-compressor station located in Bihor, Romania. Within this station, two screw electro-compressors are in operation. The two electro-compressor units work in turns, each screw electro-compressor fulfilling the role of reserve for the other electro-compressor which is in operation.

From the point of view of automation, there is a major difference between the two Abram electro-compressors. The automation system of compressor A involves a soft starter for powering and controlling the main motor that drives the compression unit. In the case of compressor B, a frequency converter is used in the automation system to power and control the main motor that drives the compression unit. In conclusion, compressor A is driven only at the nominal speed of the main engine and compressor B is driven with variable speed of the main engine. The automation of the Abram control room is designed with a Safety Instrumented System (SIS) that has a different architecture than the one in the Icoana control room. Abram station control room is composed of two components:

- A safety and control system, having a PLC without an operating panel as the central element of the SIS system and which is isolated from the rest of the automation system. All critical signals received from station key points enter this equipment. The PLC has implemented a software that ensures the shutdown of the entire station if a threshold has been reached for one of those critical signals.
- A station monitoring system, having a PLC with display on an operator panel, in which the rest of the signals taken from the station transducers are integrated.

Abram station control room is also equipped with a computer which runs a developed application that only has the role of monitoring the station and the two electro-compressors, without the possibility of controlling or sending commands to the station, as shown in Fig. 2.

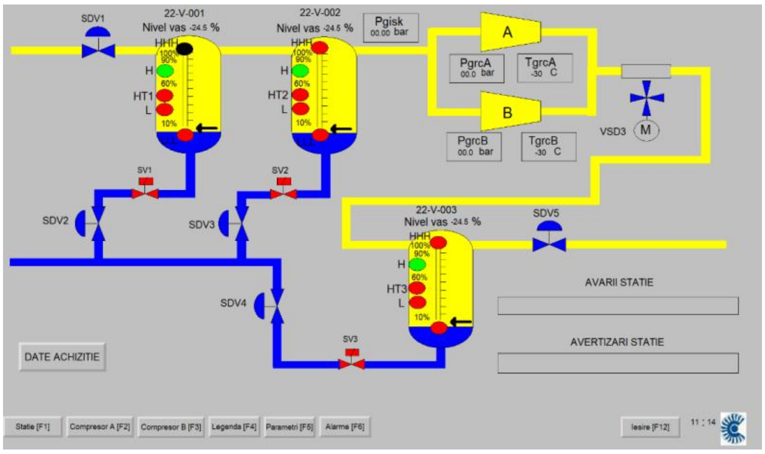


Fig. 2. Abram computer station screen

In the screen related to the station, the state of the station valves, the key values of pressures and temperatures of compressors A and B, the critical levels of three existing station vessels and the real-time liquid position in them are monitored. Warning and fault messages have been displayed for station parameters.

The parameters related to electro-compressors A and B are monitored simultaneously on Abram station computer through a dedicated screen. The current and speed of the main motor of electro-compressor B, temperatures, pressures, valve status, digital parameters, warnings and faults can be viewed in this screen for both electro-compressors, as presented in Fig. 3.

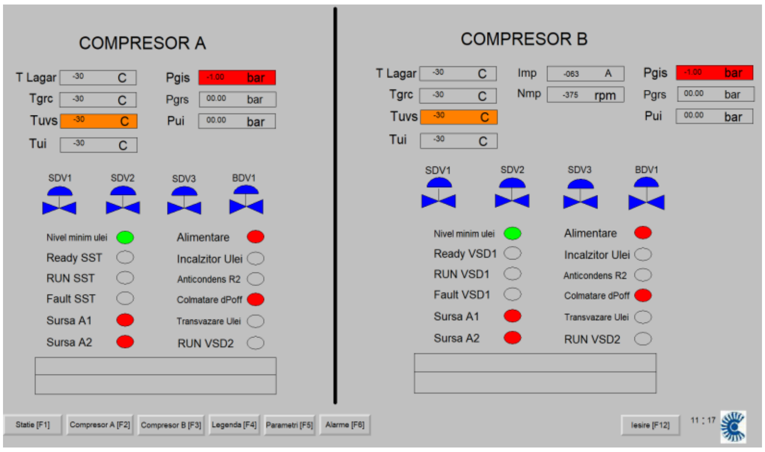


Fig. 3. Abram electro-compressor A and B screen displayed on computer

The automation solution presented for the Abram control room was used as a starting point for the design of an automation solution for the Icoana control room. In order to identify the right automation solution for the Icoana control room, the theme of the project required not only monitoring functions as implemented at the Abram station, but the development of a command architecture of the SIS system for elements such as the station valves.

Icoana Safety Instrumented System (SIS) is composed of the 87-JP-001 cabinet that ensures the safety function of the station, the Monitoring and Control Cabinet (MCC) that ensures the retrieval of all parameters, a console with Emergency Shut Down (ESD) buttons and a Human Machine Interface (HMI) station for which a software application has been developed.

The automation cabinet related of a Icoana screw electro-compressor has the role of monitoring, commanding and controlling the compressor unit. The Programmable Logic Controller (PLC) of each compressor unit will interface with the measurement lines of the transducers located in the installation and will control the entire process. Through measuring lines, parameter values of the related compressor unit are transmitted to the PLC.

From the PLC of each Icoana electro-compressor through the ethernet port, the information reaches the operating panel of the automation cabinet and the HMI computer which, through a dedicated software application, displays the parameter values in real time. Therefore, any moment variation, departure from the normal range or lack of one or more parameters are displayed on the operating panels and on the HMI computer.

The Icoana HMI computer application includes a data recording procedure performed on all station parameter values and electro-compressor units. The data acquisition system periodically records all parameters configured by the software, the state of the installation and generates the records in a data file for interpretation and processing.

Another key capability of the Icoana upgraded control room is that the SCADA system runs continuously seven Modbus servers that performs parameter values communication of the SIS and electro-compressors to a remote beneficiary SCADA system. All parameter values can be accessed by the beneficiary through protected channels of Internet network, a firewall being used for this purpose.

The Icoana Fire and Gas (F&G) detection device will permanently monitor the concentration of gases in the field and will signal their presence to the ESD emergency system. The F&G device consists of sensors that signal any danger. There are 3 types of sensors: flame, gas, and smoke. Their condition will be strictly monitored. If these sensors signal the presence of flame or the presence of smoke, the station will receive the ESD command. For gas concentration, there are 2 limits implemented, one for warning and one for danger. At the warning limit, the operator is optically signaled on the F&G device or in the F&G screen of the HMI computer. At the danger limit, the F&G device unit transmits an ESD signal to the SIS system and the station is automatically shut down.

3. The control room project

In 2018, the control room project at Icoana station was put into service and it was composed of the 87-JP-001 cabinet, the Monitoring and Control Cabinet or MCC cabinet, a console with Emergency Shut Down (ESD) buttons and an HMI computer.

Within the HMI computer application, screens were programmed to follow the real-time evolution of each station and electro-compressor parameter. Accessing the parameters is done by calling the memory addresses where the parameters are stored in the station PLCs by the software program. Thus, for example, to display and record the parameter PT001, the software programmed in the HMI computer application is programmed to interrogate the address from the PLC and it will send back to the HMI computer station its value stored in memory. When the HMI project application is launched, the first screen viewed by the operator is the general screen of the station, presented in Fig. 4. This screen shows the general schematic representation of the station: the electro-compressors K1A and K1B related to stage I, the electro-compressors K2A, K2B, K2C and K2D related to stage II, the electro-compressor K3A related to stage III, the separator, the station chimney and the gas drying station.

Compressor units are depicted as a trapezoid which is red when the electro-compressor is stationary. When the electro-compressor is running, the color of the trapezoid is green. In Fig. 4, the electro-compressors K1A, K2A, K2B, K2C are in operation, and the electro-compressors K1B, K2D and K3A are stationary.

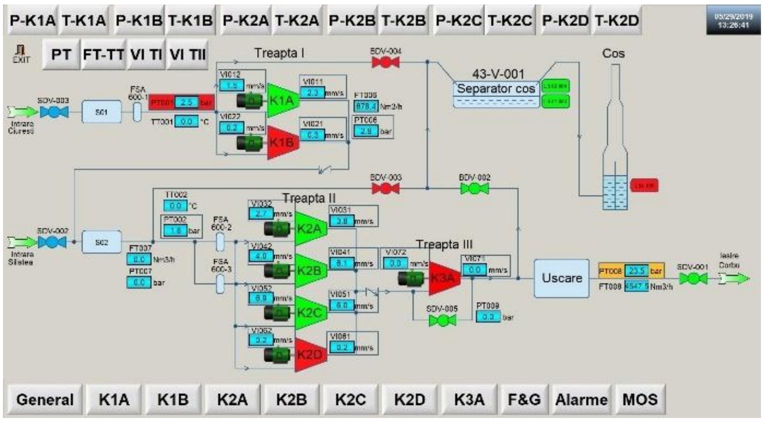


Fig. 4. General HMI station screen

Station valves are represented in the general screen. The gas enters the station through valves SDV-003 and SDV-002 and leaves the station through valve SDV-001. Station valves BDV-002, BDV-003 and BDV-004 are also represented, which connect stages III, II and I, respectively, to the station chimney. The green color of a valve means that it is open, the red color shows that it is closed, and the blue color shows that the valve is in operation.

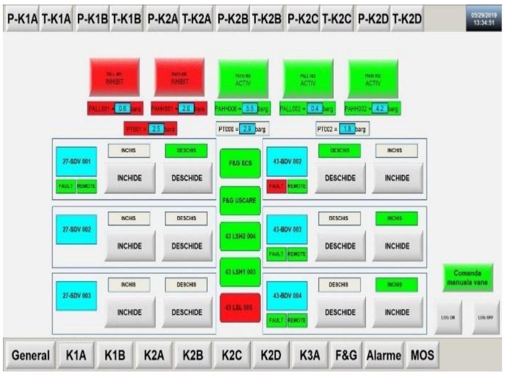
On the general screen, the values of the temperature, pressure and flow parameters of the transducers mounted in the station are displayed. For each electro-compressor, the values of the vibration parameter from the compressor unit, respectively from the motor, are also displayed.

Alarms are differentiated by colors in a dedicated screen. If the alarm is active, the color used for the alarm text is red. If the alarm becomes inactive, the color of the alarm text is turquoise. The messages of all alarms are recorded in chronological order. Therefore, the parameter value that exceeded the configured limit and the message assigned for exceeding this limit are recorded.

The station SIS screen is presented in Fig. 5a and can be accessed via the MOS button on the application footer. A series of limits are configured in the screen as follows:

- PALL001 = 0.6 bara as inferior limit and PAHH001 = 2 bara as upper limit for the station transducer PT001;
- PAHH006 = 5.5 barg as upper limit for station transducer PT006;
- PALL002 = 0.4 barg as inferior limit and PAHH002 = 4.2 barg as upper limit for station transducer PT002.

The value read by the PT001 transducer is 2.5 bara. The value is greater than the limit imposed by PAHH001 = 2 bara. As a result, exceeding the limit is signaled by the red color around PT001 and its read value in real time.



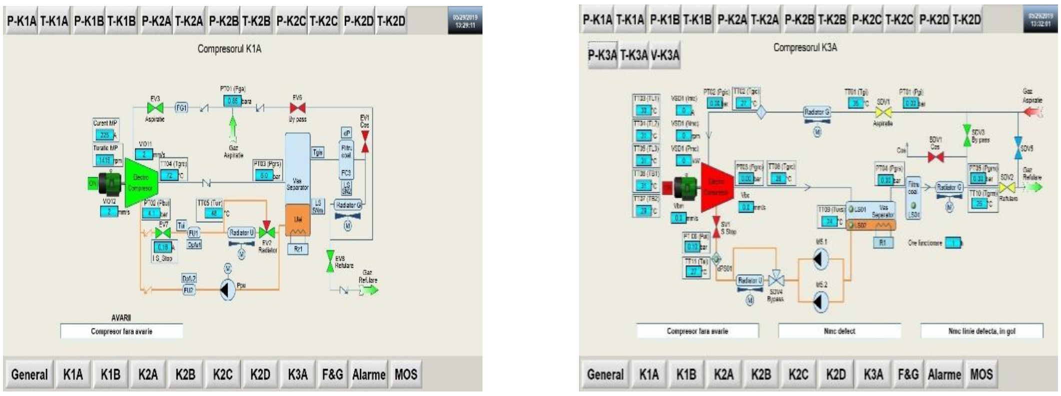
(a)

(b)

Fig. 5a. SIS screen with manual controls
Fig. 5b. SIS screen with commands suspended

All these imposed limits can be ACTIVE or INHIBITED. If the limits are active and the value received from the target transducers exceeds a limit, an ESD signal is transmitted. In order to be able to switch between activating or deactivating the limits, 3 levels of access were developed. Through the Close and Open buttons related to each valve, commands can be given to the station valves SDV001, SDV002, SDV003, BDV002, BDV003, BDV004. If the valve will not receive the open or close confirmation signal in time, a Timeout message in red above the button will appear. For the valves SDV001, BDV002, BDV003 and BDV004, the states of "Fault" valve and "Remote" control of the valve are indicated by a suggestive color message under the name of the valve. In the middle part of the screen, the ESDs related to the F&G device are displayed. The ESDs receives signals from the gas drying station and from the electro-compressors. The green color represents the absence of the ESD signal. Depending on the ESD signal, when it is triggered, the color of the F&G ECS message or the F&G DRY GAS message will turn red, and a message describing the respective situation will be recorded into the alarm screen. In the middle of the screen, the state of maximum and minimum fluid levels in the station are displayed.

By pressing the button in the right corner above the log in/log off buttons, all the command buttons to the valves can be suspended as seen in Fig. 5b. This procedure was carried out to prevent the operator from sending accidental commands to the station valves. For K1A electro-compressor, the values of the temperature, pressure, current and speed parameters can be observed on Fig. 6a in real time along with the state of the valves. The rest of the screens of stage I and II electro-compressors are similar to the one presented in Fig. 6a.



(a) (b)

Fig. 6a. Electro-compressor K1A screen on the HMI computer
Fig. 6b. Electro-compressor K3A screen on the HMI computer

Stage III K3A skid and automation are different from the rest of electro-compressors related to the Stages I and II of compression. Therefore, K3A screen presents a different technological diagram in Fig. 6b.

4. The control room upgrade

An upgrade of the automation systems related to the 6 electro-compressors that make up the I and II compression stages of the Icoana station, as well as the HMI computer, was carried out during 2023 and 2024,

The automation systems related to each electro-compressor were put into operation once with the station between the years 2007-2008 and included PLCs with integrated digital operator panels that were outdated and had defects.

New systems were provided with the latest generation equipment and software that offer new facilities and increased safety in operation. The old PLCs and digital operator panels were replaced with a last generation PLCs and operator panels with touch screen and dedicated software.

An important step of the upgrade project was the replacement of the HMI computer. Its software application component has been reprogrammed so as:

- to send commands to each electro-compressor directly from the HMI computer application;
- to have an integrated control interface for the speed loop algorithm depending on the suction pressure of each electro-compressor;
- to visualize the evolution trends on multiple parameters;
- to have an integrated cause-effect diagram screen for each electro-compressor;
- to have the facility to communicate all parameter values taken from the electro-compressor automation systems and parameter values taken from

the SIS system with the beneficiary remote SCADA system located far away from the compression station.

The initially installed HMI computer only allowed the visualization of parameter values, but without the user being able to send commands to the compression unit. Before the upgrade of the control room, commands could only be transmitted from the operator panel located on the automation cabinet of each electro-compressor. After the upgrade, the user could unlock the start, cancel the start, start the electro-compressor and stop the electro-compressor by using virtual buttons within the screen of each electro-compressor. In Fig. 7, one of the electro-compressor screens developed for the new HMI computer software is shown.

The operating mode of an electro-compressor can be imposed as manual mode or automatic mode and can be now selected from the developed screen related to each electro-compressor. Manual mode involves the user setting of an operating speed for the electric motor that drives the electro-compressor. The speed can be set between 2000 rpm and 3000 rpm.

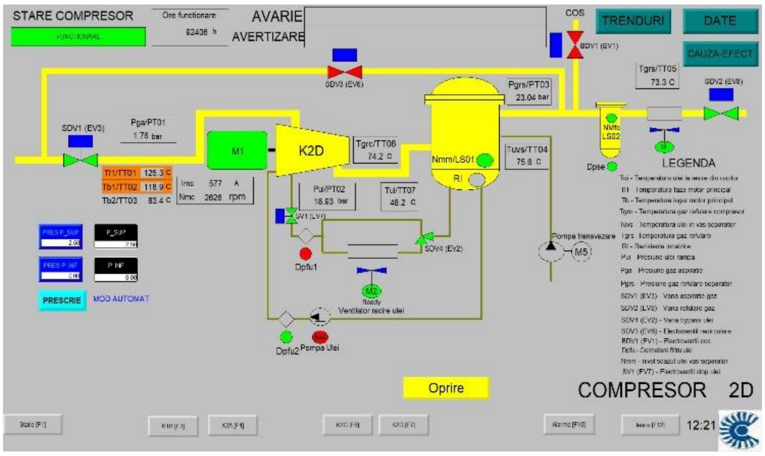


Fig. 7. Electro-compressor K1D screen after the control room upgrade

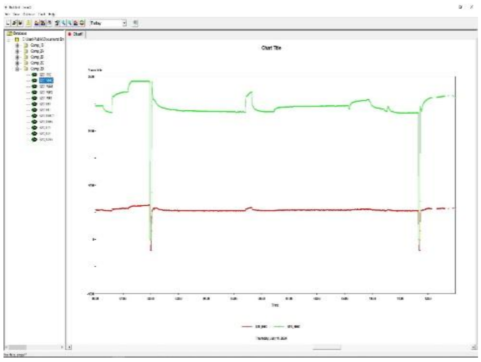
Automatic mode has behind a custom developed control loop algorithm. It involves to set a lower suction pressure threshold and an upper suction pressure threshold. Depending on the evolution of the suction pressure and the configuration of these two thresholds, the speed of the main electric motor evolves linear having a value between 2000 rpm and 3000 rpm. Outside of these thresholds, the speed remains at 2000 rpm when the suction pressure is below the lower threshold and at 3000 rpm when the suction pressure is above the upper threshold. In the left part of Fig. 7, it can be seen that the operating mode of the K2D electro-compressor is automatic. The lower threshold setting of the suction pressure is 0 bar and the upper threshold setting of the suction pressure is 2.5 bar. The suction pressure Pga has a value of 1.78 bar, so it is between the two thresholds. Consequently, the engine speed has a value of 2628 rpm, which can decrease or increase linearly, depending on the suction pressure real-time evolution.

The new software application developed for the HMI computer has another new facility implemented, namely the display of trends for all parameters of each electro-compressor.

The trends are actually the graphs of the evolution over time of one or more parameters. The user can go back in time up to 6 months and follow the evolution of any parameter in the form of a graph. This functionality is very useful for troubleshooting a defect of a electro-compressor, performing predictive maintenance, interpreting certain behaviors during operation, etc.

On each electro-compressor screen there is available a "Trends" button which opens an application dedicated for viewing trends. Through the HMI computer software programming, the evolution of temperatures, pressures, main motor speed and current over time can be visualized.

Fig. 8a shows a trend that contains the evolution over 12 hours of the main engine speed and its current for the K2D electro-compressor. From this trend it can be determined that this electro-compressor stopped twice during the 12 hours.


(a)

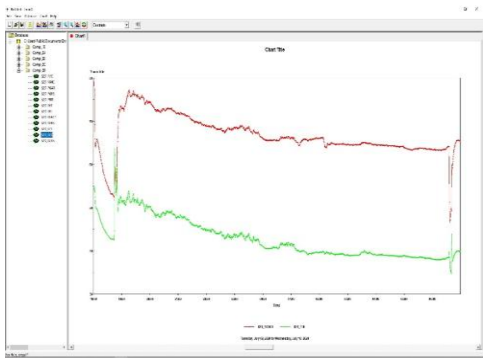
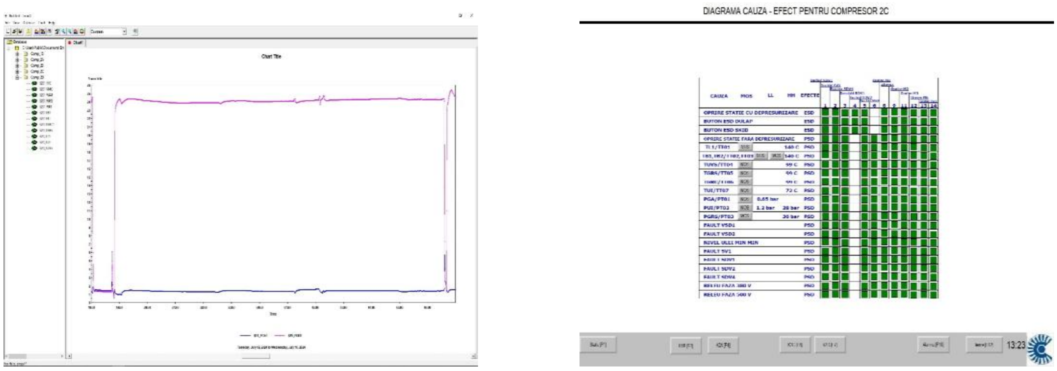

(b)

Fig. 8a. Trend for main motor speed and current during 12 hours of K2D electro-compressor operation

Fig. 8b. Trend for gas discharge temperature and oil temperature during 12 hours of K2D electro-compressor operation

Fig. 8b shows the discharge gas temperature in the same trend as the oil temperature during 12 hours for the K2D electro-compressor. This trend can highlight the dependence between the compressed gas temperature and the oil circuit temperature during the compression process.

Fig. 9a illustrates the trend that contains the suction pressure and the discharge pressure over 12 hours of operation for the K2D electro-compressor. The trend shows the appearance of peaks in the discharge pressure due to the two shutdowns of the K2D electro-compressor and thus the sudden drop in the suction pressure.



(a) (b)

Fig. 9a. Trend for gas discharge pressure and suction pressure during 12 hours of operation
Fig. 9b. Cause-effect diagram for PSD and ESD shutdown

A cause-effect diagram describes the automatic operation of the skid equipment performed in electro-compressor operating phases such as occurrence of critical events. The automatic cycles initiated by such events are controlled by the PLC.

A screen of cause-effect diagram was implemented in computer HMI for each electro-compressor related to Stage I, Stage II and Stage III. The types of shutdowns are shutdown with depressurization ESD and shutdown with pressurization PSD. On the left side of the diagram appear all the causes that can trigger the emergency shutdown of the electro-compressor. On the right side are the effects represented by sequences of valves, engines and heating resistance. A screen of cause-effect diagram of the K2C electro-compressor is illustrated in Fig. 9b.

As it can be seen in the columns on the upper right of Fig. 9b, in case of electro-compressor PSD shutdown, suction valve SDV1 closes, oil stop valve SV1 closes, oil radiator by-pass valve SDV4 is operated in the by-pass position, chimney valve BDV1 remains closed, discharge valve SDV2 closes, suction discharge valve SDV3 opens, main engine M1 stops, engine M2 stops, M3 engine stops, engine M6 stops and the heating resistance Rz1 in the separator vessel remains inactive. As for the case of a ESD shutdown, the only difference from a PSD shutdown is that chimney valve BDV1 opens and the suction discharge valve SDV3 remains closed. In this manner, all existing critical events from the cause-effect diagram for each electro-compressor and station were developed in the control room automation software.

Another new feature of the control room is that it has been implemented the function of transmitting the input values of all parameters to a SCADA system of the remote beneficiary. The communication protocols used is Modbus TCP/IP and Emerson Ethernet. All electro-compressor parameter values are programmed to be moved to individual addresses on a Modbus server programmed in relation to the addresses in the PLC. A Modbus server is defined in each operating panel from each electro-compressor to transmit data from stage I, II and III to a remote beneficiary SCADA system. Parameters are taken from the SIS system with the help of the HMI computer and are transmitted through a script that runs continuously in the developed software application of the HMI computer to two electro-compressor PLCs and from there to its corresponding operating panels hosting each a Modbus server. Two Modbus servers were chosen so that to have redundancy in the event that one server is unavailable for the SIS parameter communication. From the two Modbus servers, the values of the SIS parameters reach further, to the remote beneficiary SCADA system, similarly to the parameters related to the electro-compressors.

Fig. 10 shows the architecture through which both local communication and communication with an external remote SCADA system of the beneficiary is achieved.

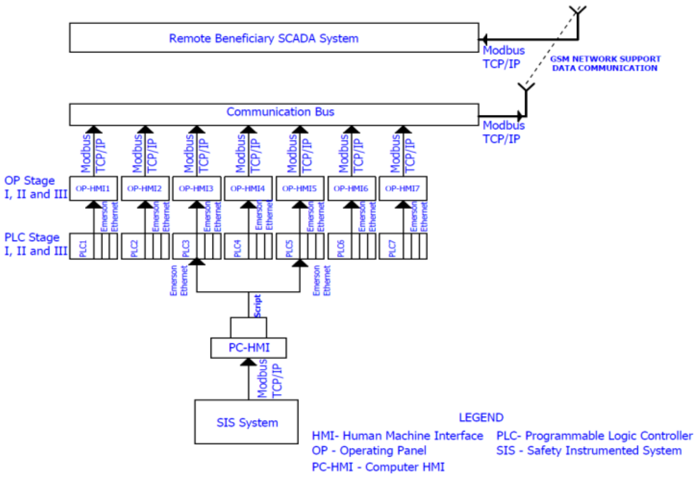


Fig. 10. Communication architecture of the Icoana Control Room

5. Conclusions

The findings of this article reveal that instances of parameter fluctuations, deviations from the established limits, or the absence of specific parameters are visually exhibited through the interfaces associated with the automation cabinets. Furthermore, these manifestations are also presented within the software application of the Human Machine Interface computer.

An original result obtained is the programming within the computer HMI application of a control room SIS system, as part of an electro-compressor station. The dynamic graphical screens are meticulously documented, thereby facilitating subsequent consultation in the eventuality of applying these results on a similar control room project.

To ensure the requisite vigilance and control of the station in a secure operational mode, an upgrade of the control station has been meticulously documented to present the original results obtained for the HMI computer such as developing a real-time screen for an industrial electro-compressor, an integrated control interface for the developed speed loop algorithm, a data communication to a remote SCADA system, real-time trends for each parameter and cause-effect diagrams custom developed.

Therefore, the obtained results can be used as reference data for other compression stations to perform safety according to the cause-effect diagram, to acquire data for each individual electro-compressor, to allow visualization in real time in the form of a trend of each parameter, to transmit data to remote external systems, to supervise and command the operation mode of each electro-compressor according to an authentic algorithm, to transmit commands to the station valves and to impose ESD limits for station parameters by accessing buttons conditioned by specific access levels.

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