Artificial Lift Gas Flow Control System for Oil-Producing Wells

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Abstract: The research was geared toward the development of a flow control system for oil-producing wells through artificial gas lift using the Network Data Acquisition System (Net-DAS), to optimize the operations carried out by Remote Terminal Units (RTU) located in the control cabins near oil producing wells. The study was limited to the Gas Lift wells in the Carito field of Petroleos de Venezuela. S.A. (PDVSA). The variable to be measured is the gas flow that is injected into said wells through a control valve that is activated by an actuator that works in four operating states in the Net-DAS. However, variables such as pressure and temperature can also be viewed from the Supervisory Control and Data Acquisition (SCADA) system. The proposed control system is based on the LinPAC-8381 RTU with Net DAS architecture. The proposal enables the establishment of a local control by migrating the programming logic controller (PLC) control logic to the Net-Das architecture. This allows the plant operator to work in four states to control the amount of flow to be injected into the well: local control and remote control, which in turn is divided into manual, automatic and optimized remote control, which maximizes the extraction of crude oil.

Keywords: NET-DAS, RTU, SCADA, control system, gas lift

Sistema de Control de Flujo de Gas para Pozos Productores de Petróleo Mediante Elevación Artificial

Resumen: La investigación se orientó al desarrollo de un sistema de control de flujo para pozos productores de petróleo mediante Levantamiento Artificial por Gas utilizando Sistema de Adquisición de Datos en Red (Net-DAS), para optimizar las operaciones realizadas por las Unidades Terminales Remotas (RTU) ubicadas en las cabinas de control. cercanas a los pozos productores de petróleo. El estudio se limitó a los pozos Gas Lift del Campo Carito de Petróleos de Venezuela. S.A. (PDVSA). La variable a medir es el flujo de gas que se inyecta en dichos pozos a través de una válvula de control que es activada por un actuador que trabaja en cuatro estados de operación en el Net-DAS. Sin embargo, variables como la presión y la temperatura también pueden ser visualizadas desde el Sistema de Supervisión, Control y Adquisición de Datos (SCADA). El sistema de control propuesto se basa en la RTU LinPAC-8381 con arquitectura Net DAS. La propuesta permite establecer un control local migrando la lógica de control del Controlador Lógico Programable (PLC) a la arquitectura Net-Das, lo que habilita al operador de la planta a gestionar en cuatro estados para controlar la cantidad de flujo a inyectar en el pozo: control local y control remoto, que a su vez se divide en manual, automático y control remoto optimizado, que maximiza la extracción de crudo.

Palabras claves: NET-DAS, RTU, SCADA, sistema de control, gas lift

1. INTRODUCTION

Industrial automation has become a fundamental means to improve the performance and efficiency of processes of a modern industrial company (Li et al., 2022; Nicolae et al., 2023; Ronceros et al., 2023a). Processing and control of operations allow the acquisition of data in real time, thus facilitating more effective operational, tactical, and strategic decision making, regardless of the nature of the company (García et al., 2018; Kiangala & Wang, 2019; Wu et al., 2022). In this sense, automation has been transforming and innovating processes for humans, mechanizing processes (Cotrina, 2018; Lu et al., 2022; Viraktamath et al., 2019), and reducing the sensory and mental needs of people. This has made it possible to simplify and streamline processes that were previously carried out manually, improving production quality, offering safety, lowering costs, reducing labor, and also reducing response time in a timely and reliable manner (Chaparro et al., 2021; Diaz, 2019; Ronceros & Pomblas, 2023; Ronceros et al., 2023a).

In this scenario, the basic strategies in the automation of industrial processes aim to increase the efficiency of

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operations and processes (Al-Naumani & Rossiter, 2016; Slabinoha et al., 2019; Tomar & Kumar, 2020; Yu & Xue, 2022), by integrating advanced technologies in the field of electronics, information technology, and telecommunications. These strategies work in synergy with the best practices of human resources, through the automation of manual and repetitive activities (Inzunza et al., 2020). Additionally, they provide procedures, equipment, and systems that allow information to be available in a timely and reliable manner at the desired time and the reduction of costs using less energy and maintaining minimum inventories (Chakraborty et al., 2022). For the oil industry, having optimal systems and cutting-edge technology for industrial automation is key (Chan, 2015; Ronceros, 2022), as there is a greater control and supervision of field instrumentation variables (Estrada et al., 2017; Pino, 2013; Villalba, 2019; Zhang et al., 2019).

This investigation is oriented with the use case in PDVSA, which is made up of several businesses, among which is the Production business which is made up of the Executive Directors of Production East, West, Faja, and South Center. The Executive Directorate of Eastern Production is formed by the Furrial Division and the Punta de Mata Division. The PDVSA Punta de Mata division is made up of the Carito and Pirital fields. The Carito field has a total of 31 artificial gas lifts (gas lift), in which an adequate rate of gas must be injected to reduce the fluid density of the column of fluids from the well, causing it to lose weight and allowing the flow of crude from the subsoil to the surface, thus guaranteeing the target production (Ronceros & Pomblas, 2022; Ronceros et al., 2023b).

When pressure is not enough to extract crude naturally, the use of techniques that provide said pressure is required to achieve a greater extraction of crude; among these techniques, the artificial lift by gas method stands out (Gulyaev et al., 2015; Ronceros et al., 2023a). Artificial lift gas wells have a surface system, comprised of a manifold that supplies gas to the well, a control valve that allows the operator to open or close, allowing or preventing the injection of gas into the well, and measurement devices that allow visualization of external factors immersed in the process, such as pressure and temperature (Liu et al., 2018). It is extremely important to control the valve of each well, as the amount or portion of gas supplied to the well is subject to various parameters that will depend on the type of crude to be extracted, such as its density and pressure (Ronceros et al., 2023a; Pashchenko et al., 2022), and thus allow a better use of the reservoir, causing the recovery factor of the well to decrease considerably.

Currently, there are Control Booths located in the Carito field, made up of devices that are in charge of controlling the fluid that is injected into the well. Depending on the proximity of each well, there is a control booth for them. These devices receive and send signals from a Programmable Logic Controller (PLC) to regulate the valves that supply the Gas Lift. Automatic wells work in remote locations, where oil extraction is achieved by injecting the required gas rate, which is supported by a technological platform whose function is to control and transmit field data from the process. Operational, such as head pressure, casing pressure, and line pressure and temperature, to the operational control and supervision center, as well as the controlled variable in this process, which is the gas flow and other variables from the gas lift manifold.

Currently, there is a PLC (programmable logic controller) for the 31 gas lift wells located in the Carito field; these PLCs perform the calculations for the valve control. The PLC sends signals via radio to an RTU (Remote Terminal Unit) located in the control booth, which is only in charge of read and write operations (Chaparro et al., 2021; Galloway and Hanckee, 2013; Ronceros et al., 2023a). It should be noted that the PLC is distant from the said control booths and there is a risk of losing the connection between them, thus leaving the wells without a mechanism that controls the amount of flow that will be supplied to the well, causing large level losses of production.

The RTUs located inside each of the Control Booths have functions similar to those of the PLC but have not yet been put into practice. In other words, the RTUs through Net-Das are able to control the flow of gas, thus allowing the wells to have control locally, avoiding jeopardizing their control due to a failure in the signal between PLCs and Control Booths. Net-Das is a Venezuelan development that guarantees the operability and productivity of wells operating with gas lift as well as PLCs. The PLCs, for their part, carry out an efficient control; however, they are extremely expensive and would generate large expenses for the industry to place one of them in the Control Booths to obtain the required local control.

It is more feasible to optimize the operations carried out by the RTUs by making them operate at 100% of their capacity; in this sense, the need to establish local control is raised by migrating the PLC control logic to the Net-Architecture. Das, thus developing a flow control system for oil producing wells by Artificial Lift by Gas, which will allow the plant operator to work in 4 states such as: local control and remote control which is divided into in turn in manual, automatic, and optimized remote control, resulting in maximum use when extracting crude oil. The rest of this study is organized as follows: Section II describes the methodology used to conduct the investigation and develop the gas flow control system proposal. Section III provides for the development of the artificial gas flow control system for oil producer wells through artificial gas lift. Section IV concludes the document and highlights future work.

2. METHOD

The development of the PDVSA proposal was based on the Management Guide for Capital Investment Projects (MGCIP). The MGCIP is structured into five phases which are: visualize, conceptualize, define, implement, and operate. The project only covered the first three phases since it is an automation proposal, so the final activities of the implementation and operation phase are outside the scope of the project (MGCIP, 1999). Each of the phases is detailed below:

Phase I: Visualize. In this phase, the visualization of the proposal is carried out. Among the activities carried out in this phase are the following: description of the artificial lift of gas in the oil producing wells of the Carito field and description of the technological architecture of the oil producing wells by artificial lift of the Punta de Mata Division.

Phase II: Conceptualize. In this phase, an evaluation of the technologies to be implemented was carried out. The activities carried out were: technological evaluation of the control units and technological evaluation of the transmitters.

Phase III: Define. The objective of this phase was to develop the detailed engineering of the proposal. The activities carried out were: elaboration of the system flow diagram and development of the automatic system for gas flow control in the gas lift wells.

3. RESULTS AND DISCUSSION

3.1 PHASE I: Visualize

3.1.1 Description of the artificial gas lift in the oil producing wells of the Carito field

The gas lift basically consists of providing an additional volume of gas to the well fluids to decrease the density of the two-phase mixture and thus reduce pressure losses in the reducer tubing. If the well produces through the production string, the gas will be injected into the annulus or vice versa (Ronceros et al., 2023a). The basic objective of a gas lift design is to rig the well in such a way as to allow maximum production with minimal gas injection. The injection is carried out through a control valve, which is activated by an actuator. This valve is placed at a depth that depends on the pressure available in the gas supply system on the surface and the production rate required for certain conditions. given flow conditions. Obviously, the higher the pressure available, the greater the depth of the injection point can be. Additionally, the greater the injection depth, the smaller the injection volume required so that the pressure losses remain unchanged.

The Carito field of PDVSA, Punta de Mata Division, is located between the Furrial and Pirital fields, it is made up of four flow stations called: Carito, Musipan, Muri, and Amana Operations Center (AOC), which are in charge of collecting all the coming from the wells of the field, be it crude oil, gas, and water, which are separated and treated to later use them for commercial purposes or of any previously established nature.

For the oil industry, the use and reuse of resources is of great importance, for this reason, the gas to be injected is the same as the gas obtained from the extraction of crude oil from the wells, which, in this case, is treated for that purpose. In the High Pressure Gas Injection Plant (HPGIP I) located in the Muscar complex, also belonging to Campo Carito, the gas said goes through a long preparation process until it reaches what is known as the Gas Lift multiplex, which is in charge of providing each well with the gas required for injection, in order to provide it with the necessary pressure, decreasing the density in order to extract the maximum amount of crude possible and extending the productive life of the well. The Carito field has 5 of these multiple gas lifts, among which are distributed the 31 wells that receive the previously prepared gas, as shown in Table 1.

The amount of gas injected depends on the qualities of each one of the wells, since these have different characteristics that allow the variation of the gas flow, which is regulated by the operator in two states, the local state which refers to the manual operation of the operator that by default must exist in all systems, and the manual remote state that allows positioning the valve in percentage quantity (0 to 100%), entered and sent from the Guardián del Alba SCADA system, which is located in the master station of the operations center located in PDVSA's Carito field, Punta de Mata Division.

Table 1. Multiple Gas Lift

Multiple Gas Lift	Associated Gas Lift Wells
multiple 1	MUC_9 CRC_35 CRC_21 MUC_164CRC_40
multiple 2	MUC_97 MUC_116 MUC_8 MUC_148 MUC_146 MUC_96 MUC_95 MUC_72 MUC_137 MUC_46 MUC_162 MUC_165 MUC_128
multiple 3	SBC_12 SBC_130 MUC_113 MUC_166
multiple 4	SBC_146 SBC_23 SBC_40 SBC_10 SBC_63 SBC_107
multiple 5	CRC_30 CRC_36 CRC_31 MUC_9 CRC_35 CRC_21 MUC_164CRC_40

3.1.2 Description of the technological architecture of the oil producer wells by artificial lift of the Punta de Mata Division

- Field level: Transmitters (temperature, pressure, and multivariable) and actuator. Transmitters fulfill the function of capturing a certain process variable and transmitting it remotely to a device or controller element. For its part, the actuator provides the force to move the control valve.
- Control Level: There is the Net-Das RTU. The contractor will be in charge of carrying out the control and supervision operations of the injection of gas into the well.
- Supervision Level: PDVSA uses the SCADA GALBA system for the supervision and control of wells.
- Management Level: PDVSA is at the highest level of the automation pyramid with its GALBA WEB application, this being the one that allows viewing the information of all operations regarding the extraction of crude oil, be it logistics, inventories, resource humans, among others.

3.2 PHASE II: Conceptualize

In relation to the minimum requirements required by the control system to be proposed, the following criteria were established:

- Costs
- Hardware Interoperability
- Programming language
- Standardization of Open Protocols
- Technical Support

- Maintenance
- Security.

3.2.1 Technological evaluation of control units

Control system_1: is a high performance control platform, suitable for sequential process and motion control. This system can be connected to the Net Linx open network architecture and offers a wide range of digital, analog and especially input and output modules. These systems operate with multitasking, multiprocessing, and operating systems that support the same set in multiple programming languages. The programming software incorporates NetLinx's open network architecture for communication via Ethernet, ControlNet, and DeviceNet. The control system platform_1 provides fully integrated, scalable solutions for the full range of automation disciplines, including discrete, motion control, process and batch control, drive control, and safety applications using a single development environment and a single open communication protocol. The system is modular, so it can be efficiently designed, built, and modified.

Control system_2: It is an architecture applied to the supervision and control of industrial field processes and, as such, it is made up of a platform made up of hardware and software components. It is a technological solution that integrates in a single vision, the functionalities of remote terminal unit, programmable logic controller, human-machine interface and business applications. The hardware component of said architecture is based on a device called PAC (Programmable Automation Controller); the controller offers controller support for the use of its features through an open-source Linux distribution presenting good performance.

Control System_3: It is a robust type remote terminal unit, which provides support for applications that require wide temperature ranges and low power consumption and remote applications powered by solar cells or wind energy. Among its main features are: 32-bit processor with multiple integrated tasks; Operating System: RTOS; 8 analogue inputs, 2 analogue outputs, 8 discrete inputs, 4 discrete outputs, and 3 pulse inputs; 6M Flash, 1M RAM, and 32K ferroelectric RAM for long-term storage of configured parameters; Standard industrial design and DIN rail mounting option; Multidrop interface; native protocols include Modbus RTU, Modbus ASCII, and Modbus TCP. Figure 1 shows the control unit selection matrix.

In this figure, see that control system 2, is the one that meets the requirements, obtaining 138 points, surpassing the other options proposed. Regarding the Cost criteria, this influences the choice of equipment, so the control system 2 obtained 20 points, and, compared to the other options, it generates lower costs, in addition to providing technological advantages. The hardware interoperability gave a score of 12, the same as the other two options, indicating that the device can support hardware heterogeneity regardless of the technology consortium to which they belong. In the programming criterion, the control system_2 obtained a weighting of 45 points; thus, it is demonstrated that the architecture of the control system_2 has strengths in terms of self-diagnosis, control, reading, and writing of data, communication, among others.

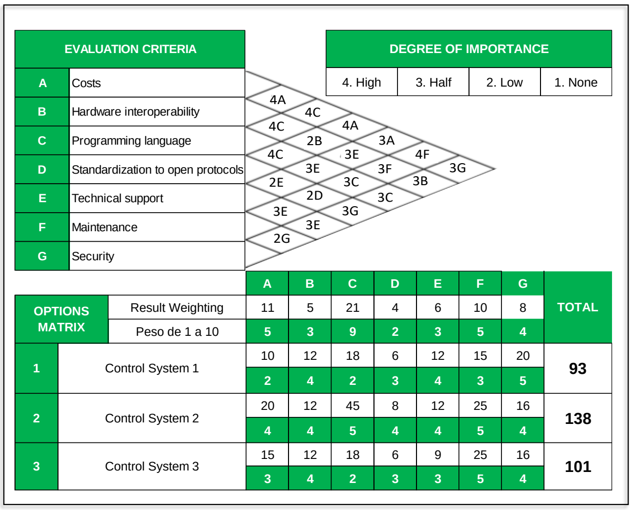


Figure 1. Control unit selection matrix

3.2.2 Technological evaluation of transmitters

Transmitter 1: flexible platform, standard for differential, gauge, and absolute pressure measurement. Characteristics:

- Performance with an accuracy of up to 0.04%.
- Solutions that use manifolds, primary elements and seals.Protocolos HART de 4-20 mA, HART de 1-5 low power VCC, Fieldbus Foundation and Profibus PA.
- Amplitudes and ranges calibrated from 0.25 mbar to 276 bar (0.1 in H2O at 4000 psi).

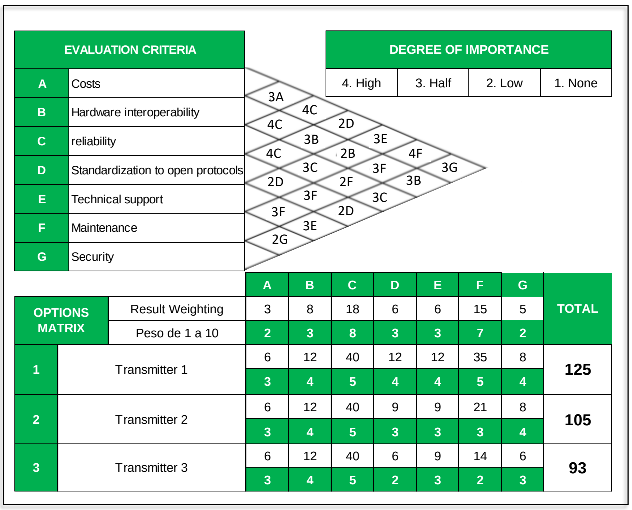
Transmitter 2: The most notable characteristics of these transmitters are the numerous communication modules, the types of boxes, and the approvals. Transmitter_2 is a true Coriolis mass-flow transmitter with multiparameter measurement. Characteristics:

- MODBUS RTU RS232/485 interface for standalone operation via MODBUS RTU master or connection to SIMATIC PDM.
- Direct integration into the SIMATIC S7 automation system.
- Standardized user interface: SIMATIC Manager, PCS7, SIMATIC PDM.
- Ultra-compact construction, economical, and with little space required, in a 40/80 mm (1.57"/3.14") box.
- Integrated counters, batch control, and extensive process diagnostic functions.
- The SENSORPROM allows true Plug & Play functionality.

Transmitter 3: It is a metallic sensor that uses a neck to dissipate the temperature. It is typically used in the process industry for continuous level measurement in liquids, even at high temperatures. The integrated HistoROM data module makes it easy to manage process and equipment parameters. Designed according to IEC 61508 for applications with SIL 3 safety degree. Features:

- Maximum safety thanks to a second line of defense with safety functions up to SIL 2/3, certified according to IEC 61508.
- Easy menu-driven commissioning from the local display, 4 to 20 mA with Hart, Profibus PA, Foundation Fieldbus.
- HistoROM data management concept for easy commissioning, maintenance, and diagnostics.
- Cost savings due to the modular concept for easy replacement of sensor, indicator, or electronics.
- Direct and independent integration into the system (HART/PA/FF).

Figure 2 shows the transmitter selection matrix.



EVALUATION CRITERIA	
A	Costs
B	Hardware interoperability
C	reliability
D	Standardization to open protocols
E	Technical support
F	Maintenance
G	Security

DEGREE OF IMPORTANCE			
4. High	3. Half	2. Low	1. None

OPTIONS MATRIX		A	B	C	D	E	F	G	TOTAL
	Result Weighting	3	8	18	6	6	15	5	
	Peso de 1 a 10	2	3	8	3	3	7	2	
1	Transmitter 1	6	12	40	12	12	35	8	125
		3	4	5	4	4	5	4	
2	Transmitter 2	6	12	40	9	9	21	8	105
		3	4	5	3	3	3	4	
3	Transmitter 3	6	12	40	6	9	14	6	93
		3	4	5	2	3	2	3	

Figure 2. Ttransmitter selection matrix

Transmitter_1 is the one that meets the required requirements, obtaining 125 points, surpassing the other evaluated transmitters. Hardware interoperability yielded a score of 11, surpassing the other two options, indicating that the device can support hardware heterogeneity regardless of the technology consortium to which it belongs. Regarding reliability, transmitter_1 obtained 40 points, due to the consistency it presents in the measurements.

3.3 PHASE I: Define

3.3.1 Prepare the system flow chart

Next, Figure 3 shows the monitoring and control information flow process between the GALBA SCADA system and the field devices, starting with access to the SCADA system using access authentication, then the processes begin. Both monitoring and control, for the first case the system is only responsible for reading the variables gas flow or, pressure and temperature, coming from the transmitters located in the Carito field. This, in addition to reading the variables, also sends a notification to the operator through the SCADA system in the event that the values returned by the instruments are not within the established range. In the case of the control process, it specifically refers to the actuation of the valve to inject the necessary rate of gas into each well. If this condition is satisfactorily met, the system continues advancing towards the reading of variables, and, otherwise, the process starts monitoring again so that the operator can view this variable and manipulate it until the desired value is obtained.

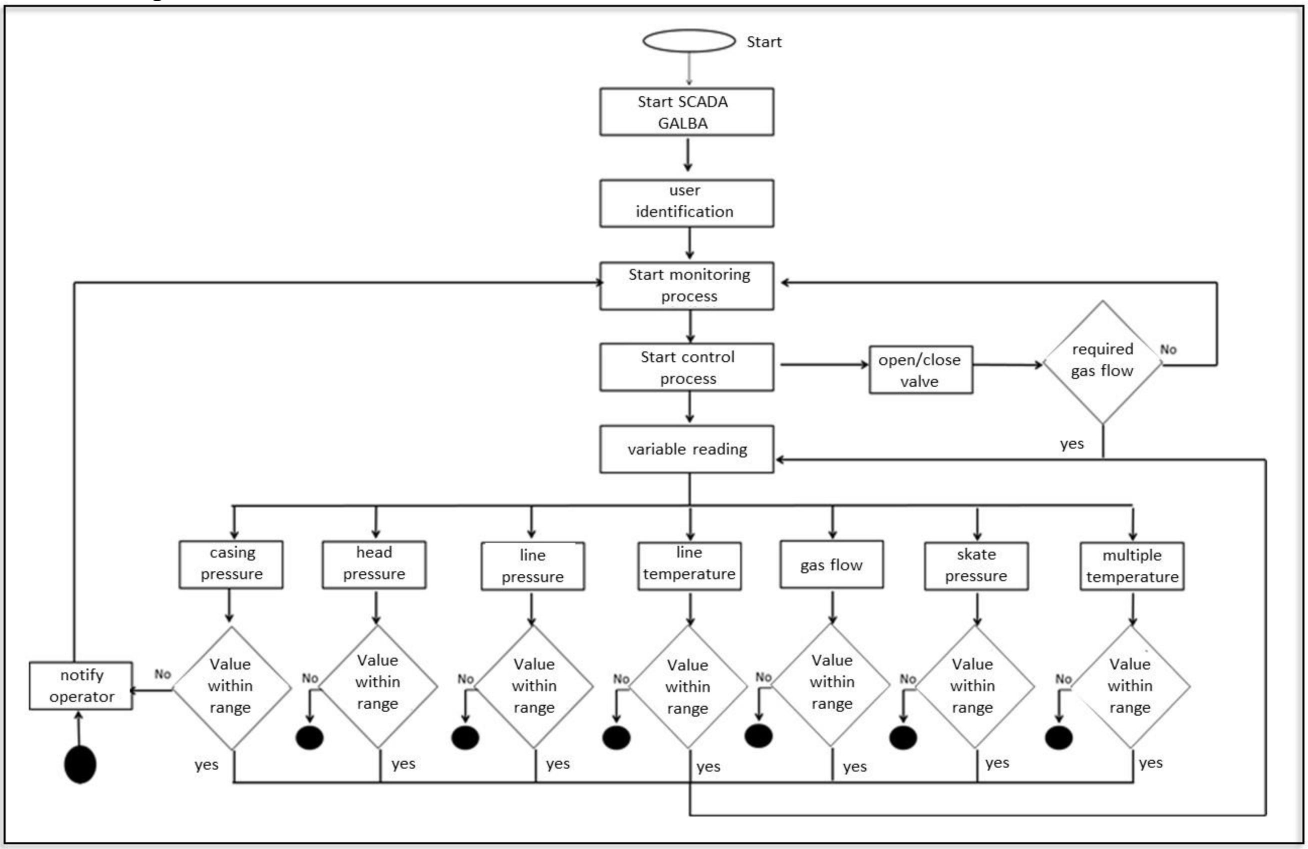


Figure 3. system flow chart

3.3.2 Develop an automatic system for gas flow control in gas lift wells.

The control logic was developed in its 4 states: Local, when the operator moves the valve manually. Remote, which is when the operator decides the percentage of opening or closing of the valve. Automatic, which will make use of a setpoint to write the amount of gas flow you want to inject into the well, and finally an optimized state where, depending on some internal calculations from the measurements from the transmitters in the field, the valve will open or close automatically.

The gas flow control logic for the gas lift wells was carried out, in the Interface Development Environment (IDE) Beremiz, which is found within the most recent Net-DAS images, as a selectable suite for development of programs in the languages contemplated by the IEC61131-3 standard, such as: instruction list (IL), structured text (ST), contact diagram (LD), functional block diagram (FBD), which for the purposes of this research, the programming was carried out in the language of contacts or ladders (LD), since it also allowed the use of function block diagrams which were necessary for the development of the same. Subsequently, the system variables were declared, which refer to the analog and digital signals, as well as other variables required throughout the program.

Figure 4 shows the first condition that refers to the first of the four operating states, called the Local State, and allows the operator to manually manipulate the actuator to open or close the valve, as the case may be. The variables CMD_LOCAL_REMOTO and EDO_LOCAL_REMOTO are of the Boolean type, therefore they are activated or deactivated through a bit, as shown in the previous figure, when CMD_LOCAL_REMOTO is zero (0) and when EDO_LOCAL_REMOTO is set to one (1), the local state is activated. In addition, the CMD_MAN_AUTO condition is activated, ensuring that when this state is deactivated, it will be the first to be activated rather than one of the other two states, and also allows knowing the position in which the valve is remaining, as well as the gas flow in the SCADA and move it to the SP_MANUAL variable for later use. When CMD_LOCAL_REMOTO and EDO_LOCAL_REMOTO are one (1) and zero (0), respectively, the manual remote state will be activated. This state will allow the system to read the percentage value entered by the operator from SCADA. Therefore, it is necessary to use an EHReg block, which will allow saving the valve position in its respective Modbus register in the Net-DAS (See Figure 5a).

In this state, the GALBA_POS variable refers to the value entered by the SCADA operator, which is written to register 203 of the Net-DAS. In this case, it is necessary to carry out another scaling, since the operator enters a value percentage (0 to 100%), which cannot be understood by the actuator that uses the 4-20mA protocol, and thus must be transformed with a scaling similar to the previous one; in this case the minimum value of its range is subtracted (in this case is 0), it is multiplied by the difference of the values of the engineering range (16000), then it is divided by the maximum of its range (100), and finally four thousand (4000) is added, and this value is written to modbus holding register 201 (See Figure 5b).

By deactivating the remote manual state, the automatic state is activated, which allows the operator to directly place the SetPoint, for the programming of this state, a PID0 block was used with proportional and integrative actions with values of TK=-3 TRI =0.6 and TD=0, this according to the guidelines established by PDVSA for this type of system. In the Figure 5c, programming for automatic state is displayed.

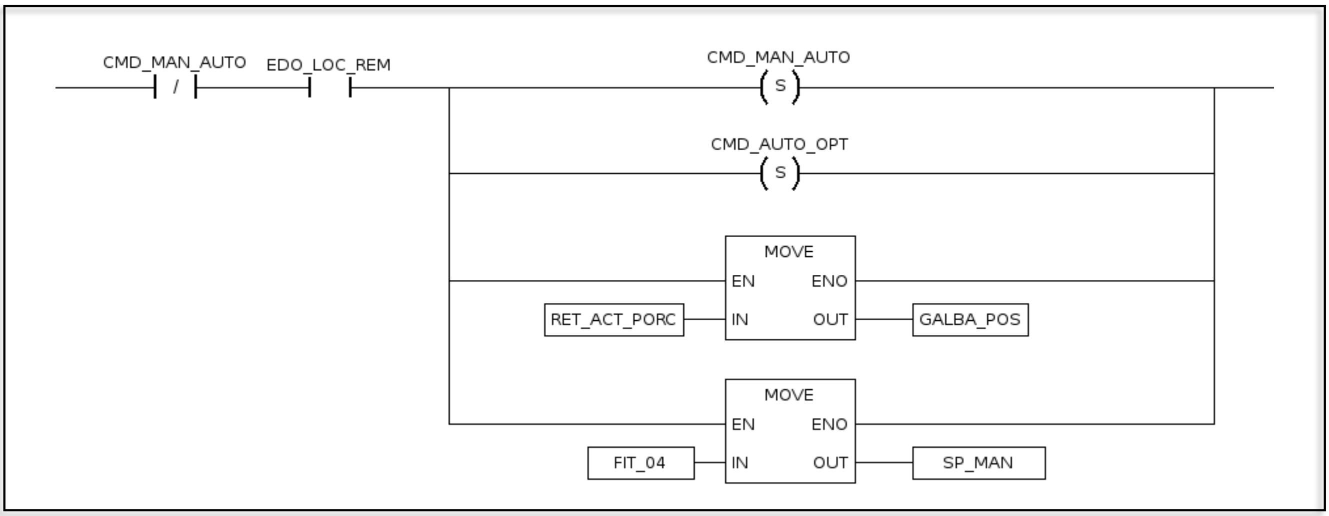
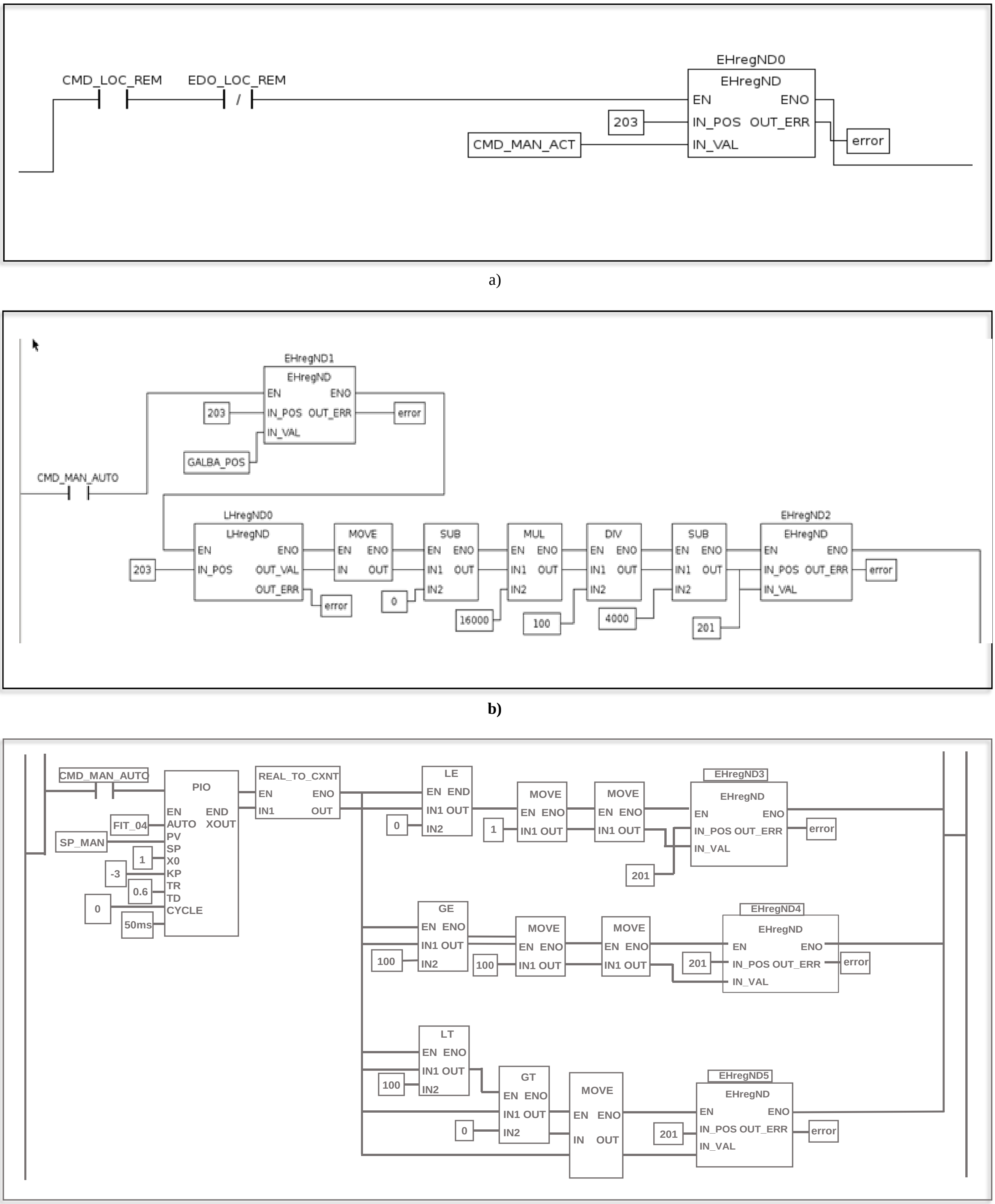


Figure 4. Local status condition



c)

Figure 5. a) Remote manual command. b) Manual remote status and escalation. c) Automatic status

CONCLUSIONS

The proposal allows establishing a local control by migrating the PLC control logic to the Net-Das architecture, allowing the plant operator to work in four states such as local control and remote control, which is divided into in turn in manual, automatic and optimized remote control, resulting in maximum use when extracting crude oil. The proposed control system is based on the RTU LinPAC-8381 with the Net DAS architecture, and this is because it has open access. In the control logic implemented, two additional operating states of the control valve are added to those that already exist in

PDVSA, which is called automatic state, where the operator can write a Set Point from SCADA, referring to the amount of flow you want to inject into the well. The proposed system will allow the wells to be in constant communication with the operator and will not use the PLC to carry out control, supervision, and monitoring actions; this is because of the optimization of the use of the RTU and Net-DAS.

The proposed control system will allow for improving security, cost savings in terms of installation and maintenance of devices in the wells to execute the functions of local control, supervision, and optimization of operations, and also providing web service, operating system in real time and integration with open communication standards, allowing one to obtain data from the field instrumentation efficiently, necessary for the indicators and business plans. The developed proposal can be applied to other production wells through gas lift with similar operating characteristics, or if the corresponding modification is not feasible, the corresponding modification can be made to adapt to new operating characteristics. The proposal focuses on maximizing the use of RTUs at the control level, allowing local control of the gas injection system in producing wells.

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