TRABAJO DE FIN DE GRADO

Grado en Ingeniería Electrónica Industrial y Automática

MIGRATION AND REDESIGN OF THE CONTROL SYSTEM FOR THE PROCESS OF SYNTHESIS AND UNLOAD OF LIQUEFIED PETROLEUM GAS

Report

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Abstract

This project presents the modification for the optimization and updating of the control system of a plant's specific area, which is dedicated to the LPG (Liquefied petroleum gas) synthesis and unload process.

In this area, there is a control system pending renewal, both in hardware and software, as well as an error in the unloaded material values of around 10% and 15%.

A solution has been developed to face these problems, which is based on:

The process automation program has been redesigned and implemented in a new PLC. In addition, the piping and actuators installation that takes care of the process, has been extended. Thanks to these modifications, errors in unloaded LPG quantities are minimized and the PLC system is migrated to an improved model with greater capacity and execution power.

The entire SCADA system has also been renewed, which is characterized by using a simplified communications system and having an optimized integration to work with the new PLC. This new SCADA system provides a quality improvement in the process control system and allows a future union with the rest of the plant control system.

Overall, this renovation provides greater reliability, expansion capacity and integration with the rest of the plant, and a longer lifetime for the LPG synthesis and unload process control system.

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Resum

Aquest projecte presenta la modificació per a la optimització i actualització del sistema de control d'una regió específica d'una planta, que està dedicada a la síntesis i descàrrega de LPG (Liquefied petroleum gas).

En aquesta regió, hi ha un sistema de control pendent de renovar, tant en hardware com en software, així com un error en els valors de matèria dosificada de l'ordre del 10% i 15%.

Davant d'aquestes problemàtiques, s'ha desenvolupat una solució la qual es basa en:

S'ha redissenyat el programa d'automatització del procés i s'ha implementat en un nou PLC, a més, s'ha ampliat de la instal·lació de canonades i actuadors que s'encarrega del procés. Gràcies a aquestes modificacions es redueixen al mínim els errors en les quantitats de LPG descarregades i es migra el sistema PLC a un model millorat amb major capacitat i potència d'execució.

També s'ha renovat tot el sistema de SCADA que es caracteritza per utilitzar un sistema de comunicacions simplificat i tenir una integració optimitzada per a treballar amb el nou PLC triat. El nou sistema SCADA proporciona un salt de qualitat en el sistema de control del procés i permet una futura unió amb la resta del sistema de control de la planta.

En general, aquesta renovació proporciona una major fiabilitat, capacitat d'expansió i integració amb la resta de planta i una major vida útil al sistema de control del procés de síntesi i descàrrega de LPG.

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Resumen

Este proyecto presenta la modificación para la optimización y actualización del sistema de control de una región específica de una planta, que está dedicada a la síntesis y descarga de LPG (Liquefied petroleum gas).

En esta región, hay un sistema de control pendiente de renovar, tanto en hardware como en software, así como un error en los valores de materia descargada de orden del 10% y 15%.

Ante estas problemáticas, se ha desarrollado una solución la cual se basa en:

Se ha rediseñado el programa de automatización del proceso y se ha implementado en un nuevo PLC, además, se ha ampliado de la instalación de tuberías y actuadores que se encarga del proceso. Gracias a estas modificaciones se reducen al mínimo los errores en las cantidades de LPG descargadas y se migra el sistema PLC a un modelo mejorado con mayor capacidad y potencia de ejecución.

También se ha renovado todo el sistema de SCADA que se caracteriza por usar un sistema de comunicaciones simplificado y tener una integración optimizada para trabajar con el nuevo PLC escogido. El nuevo sistema SCADA proporciona un salto de calidad en el sistema de control del proceso y permite una futura unión con resto del sistema de control de la planta.

En general, esta renovación proporciona una mayor fiabilidad, capacidad de expansión e integración con el resto de planta y una mayor vida útil al sistema de control del proceso de síntesis y descarga de LPG.

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Glossary

AND: *Logic and code block*

FB: *Composed code block*

FT: *Flow Transmitter*

FTRIG: Falling edge detector code block

FU: *Basic code block*

HMI: *Human-Machine Interface*

HV_x: *Two-states Valve num. x.*

I/O: *Inputs and Outputs*

LI: *Level Indicator*

LPG: *Liquefied Petroleum Gas*

MD: *Mode*

OP: *Process order of a variable*

OR: *Logic or code block*

P_x: *Pump num. x.*

PIC: *Pressure Integral Control*

PT: *Pressure Transmitter*

PV: *Process Value of a variable*

RS: *Set-Reset code block (Reset-dominant)*

RTRIG: Rising edge detector code block

RV_x: *Regulating Vale num. x.*

SEL: *Selector code block*

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SP: *Set Point*

SR: *Set-Reset code block (Set-dominant)*

TOFF: *Off delay code block*

TON: *On delay code block*

TT: *Temperature Transmitter*

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1. Introduction

This project presents the modification and updating of a control system for a sector of a production plant, which is dedicated to the synthesis and supply of LPG (Liquefied petroleum gas). LPG is a mixture of liquefied gases, in practice a mixture of butane and propane, which at ambient temperature and pressure are gases, but they are easy to liquefy. LPG is the leading alternative in fossil fuels such as gasoline and diesel, their demand is currently on the rise.

Currently there are dosing errors between 10% and 15%, in addition to other limitations in the PLC program and the SCADA system. There are a set of errors and possible improvements already described, but the control system will be analysed in detail in order to optimize it to as much as possible.

This project is jointly directed by the collaborating company, great importance is given to research work with the new control systems proposed for modification and to redesign a control system from scratch. With this, the company gains an experienced worker in the latest control systems proposed by the manufacturers.

In the sections bellow, the objectives and the scope of the project will be detailed. The motivation to undertake this work and the justification for choosing the project to be developed will also be described.

1.1. Objectives

The main objectives of this project are to renew and improve the automation of a process that is currently in operation, reducing errors in supply and renewing the control system. Some of the improvements have been proposed by the client and others by the collaborating company or by own initiative.

The specific objectives are:

- In-depth study of industrial automation in order to obtain a better knowledge of the advanced concepts of this kind of process automation.
- Study of the control system currently in use and analysis of its problems and possible improvements.

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- Research of available alternatives, proposal of a new control system and analysis of the new tools and advantages it offers.
- Development of the newly porposed a control system from scratch in.

1.2. Motivation and Justification

Having the opportunity to link the final degree project with an internal project of the company in which I work, I did not hesitate and saw that this was my best option. The fact of being able to do the work and simultaneously progress in my practical knowledge, to be able to use them in future work projects, is a great opportunity, besides that I was able to obtain facilities for the assignment of paid software.

Being able to have an automation project, which could be built from scratch and of a suitable size, was a perfect option to be able to link it with the final degree project of the university.

That was the reason why I finally chose this project and no other more extensive or specific possibilities that I had, since in those I could not have finished or could not have investigated in the different competences of an industrial automation project.

1.3. Project scope

The scope of the project will focus on planning a modification to improve the effectiveness of the control system, improve its accessibility and improve its software technological features.

All this will be done through the development and study of the following concepts:

- Study of the current control system (both software and hardware), its control interface and communications between the two.
- Study of the chemical processes of the system.
- Problems of the current system, possible solutions and improvements.
- Research work with the new control software chosen.
- Design and development of new control software to improve system execution
- Implementation and design of the new communications system and control interface.
- Tests with a custom-designed simulation system.
- Project planning, documentation and budget.

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2. Current status analysis

In this section, the analysis made in the control system that is currently installed will be described. It will detail the operation of the thermodynamic process of synthesis and supply of LPG and all the infrastructure that automates the process: The PLC, the software used to programme it and the SCADA system.

2.1. Process description

First of all, there is a chart that has been built to visualize the system's assembly so that it can be referenced in the following explanation. In the **Figure *2.1*** chart,the thicker lines symbolize the system piping, and the thinner lines symbolize a schematic of the analog signal processing of the sensors.
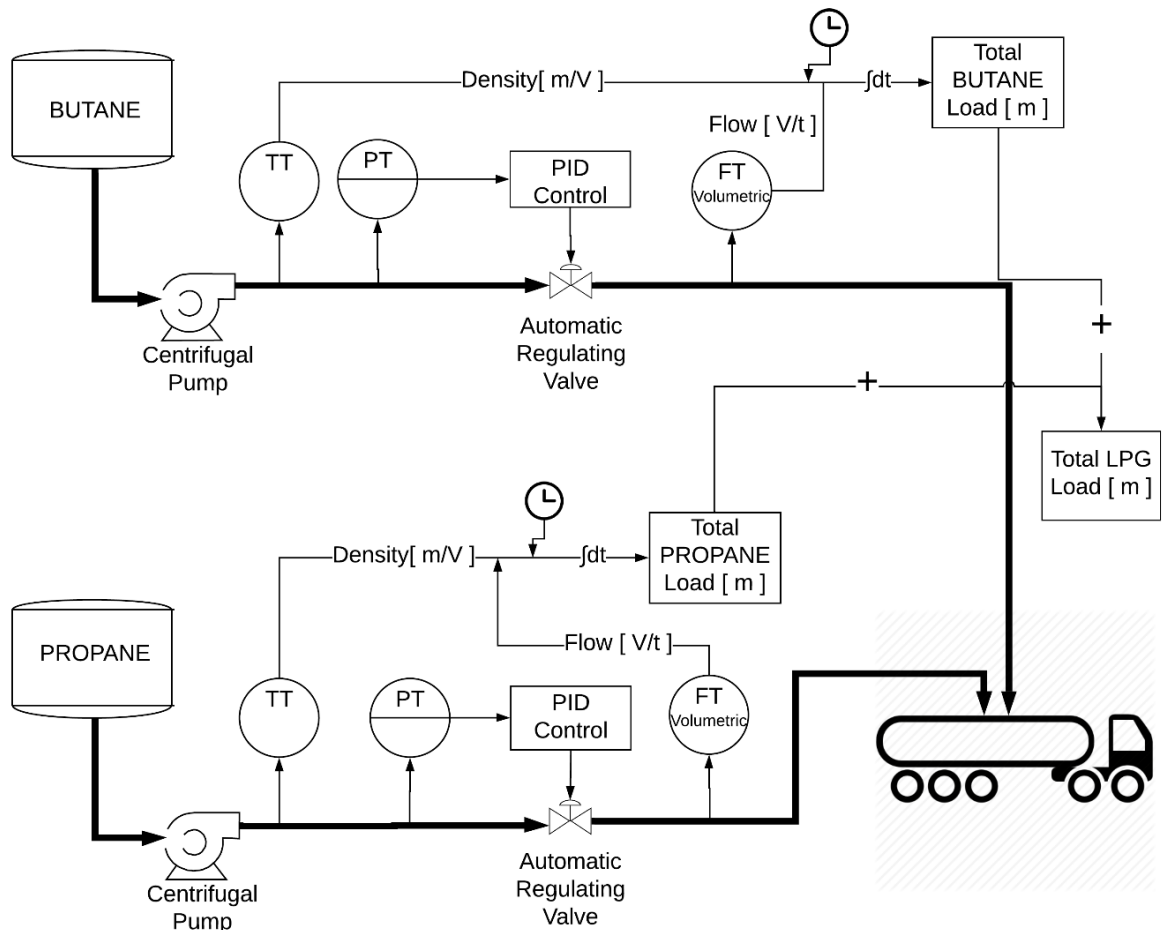

Figure 2.1 Actual LPG synthesis and loading system chart

As can be seen in the **Figure** *2.1*, the process is based on a double supply from two non-automated source tanks, one for butane and one for propane. The customer did not require any loading control of the source tanks, so there is no tank sensor connected to the dosing control system.

Currently, the sensor of each supply line consists of a temperature sensor, a pressure sensor and a flow meter. Also each of the supply lines consists of a centrifugal pump and an automatic regulating valve with PID (later specifications on the instrumentation will be given).

In order to be able to unload and mix the gases correctly, it is necessary to work with them in a liquid state. This is the function of the automatic regulating valves, which, by means of a PID control, modify the flow through the pipe in order to increase its pressure and temperature and maintain the gases in a liquid state. For this purpose, pressure and temperature sensors are used, as well as being able to calculate the density of the fluid in real time and control the process value of the pressures for PID control.

Nowadays this unloading process is entirely autonomous from the rest of the plant, both in the control system and physically. This supply process does not depend on other plant systems, it is treated as a continuous process and not as a Batch process, as there is only one supply line from the tanks of source to the product outlet and there are no other possible supplies.

2.1.1. Thermodynamic system concepts

As mentioned above, in order to transport butane and propane and mix them, they must be in a liquid state. To achieve this, the pressure and temperature of the product must be regulated.

Both butane and propane are easy to liquefy gases and the change of state is determined by their vapour pressure. Temperature and pressure are related by the difference of energies and volumes of both coexisting phases, deduced by the Frenchman Émile Clapeyron in 1834. Such behavior is theorized in the Clausius-Clapeyron equation (Martínez 1992, 113-114).

$$\frac{\mathrm{d}p}{\mathrm{d}T} = \frac{\Delta H}{T \Delta V}$$

Equation 2.1

Where dp is the pressure differential, dT the temperature differential, ΔH the phase change enthalpy and ΔV the volume variation.

In our process, an approximation of the Clausius-Clapeyron ecution, proposed in 1888 by the Frenchman Louis Charles Antoine, is used to determine the vapour pressure:

$$\ln(p) = A - \frac{B}{T + C}$$

Equation 2.2

Where p is the pressure (kPa), T the temperature (°K) and the factors A, B and C are empirical parameters, specific to each substance (Martínez 1992, 115).

These parameters in the case of butane and propane can be found in the annex to the above-mentioned book (Martínez 1992, 611).

Table 1 Antoine equation parameters for Butane and Propane

Substance	Formula	A	B	C
n-Butane	C_4H_{10}	13.98	2292	-27.86
Propane	C_3H_8	13.71	1873	-25.10

With this data we can plot the equations and compare with the LPG physical properties data provided by the client in order to verify the process.

The tables and graphs provided by the client are shown below. In the graphs, a mixture of LPG of 100% butane and 0% propane is determined, so the green line is butane and the blue line is propane (in **Figure 2.3**, propane is represented by red). In the tables three reference values of each magnitude are taken, then we will compare these points according to **Equation 2.2**.

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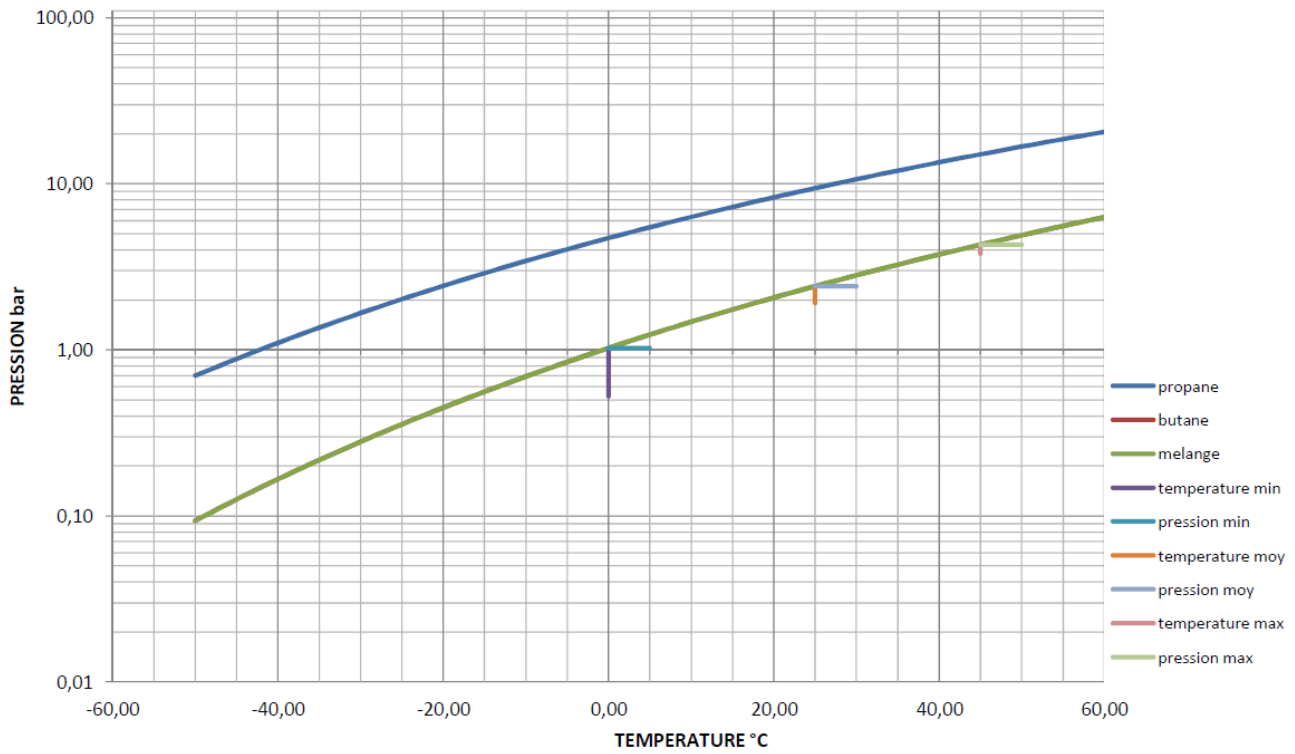
TENSION DE VAPEUR

Figure 2.2 LPG vapour pressure graph (Source: Client database)

DENSITE
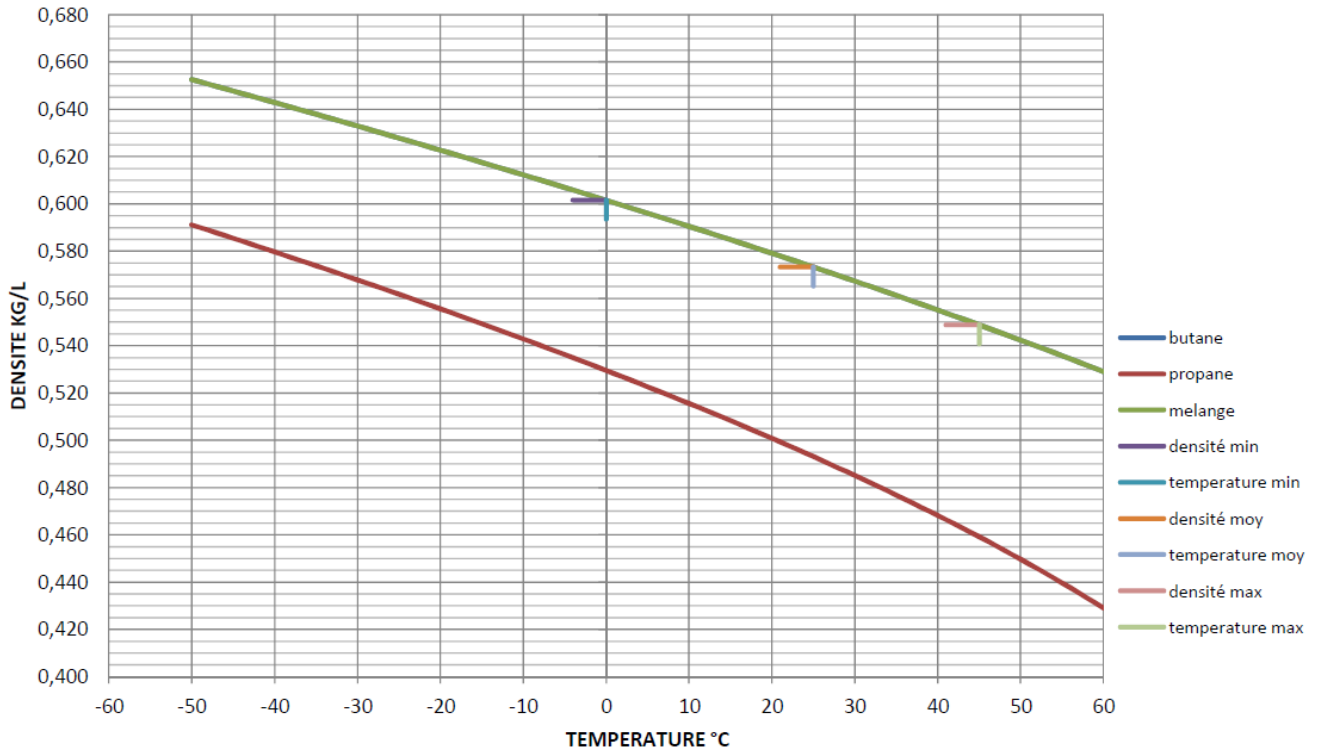
Figure 2.3 LPG density variation with temperature graph (Source: Client database)

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Table 2

BUTANE	Temperature (°C)	Vapor Pressure (bar)	Density (kg/m^3)
Minimun	0	1.026	601.540
Mean	25	2.417	573.274
Maximum	45	4.302	548.802

Table 3

PROPANE	Temperature (°C)	Vapor Pressure (bar)	Density (kg/m^3)
Minimun	0	4.715	529.533
Mean	25	9.422	493.101
Maximum	45	15.055	459.181

In order to compare with **Equation *2.2***, this must first be adapted in order to be able to work with the same units (in this equation one works in kPa and the temperature in °K), therefore the conversion factors of temperature and pressure are remembered.

$$1 \ bar = \ 10^5 \ Pa = 10^2 \ kPa \qquad\qquad 0 \ °C = 273.15 \ °K$$
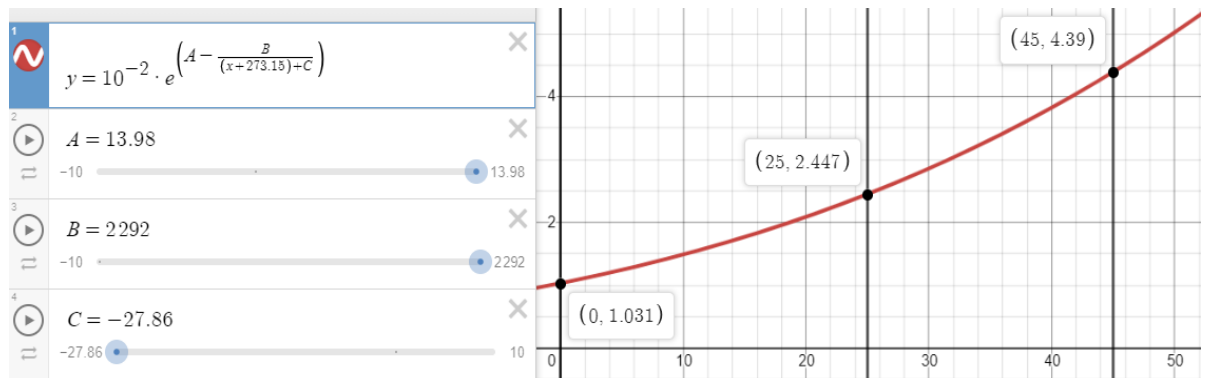
Equation 2.3   **Equation 2.4**
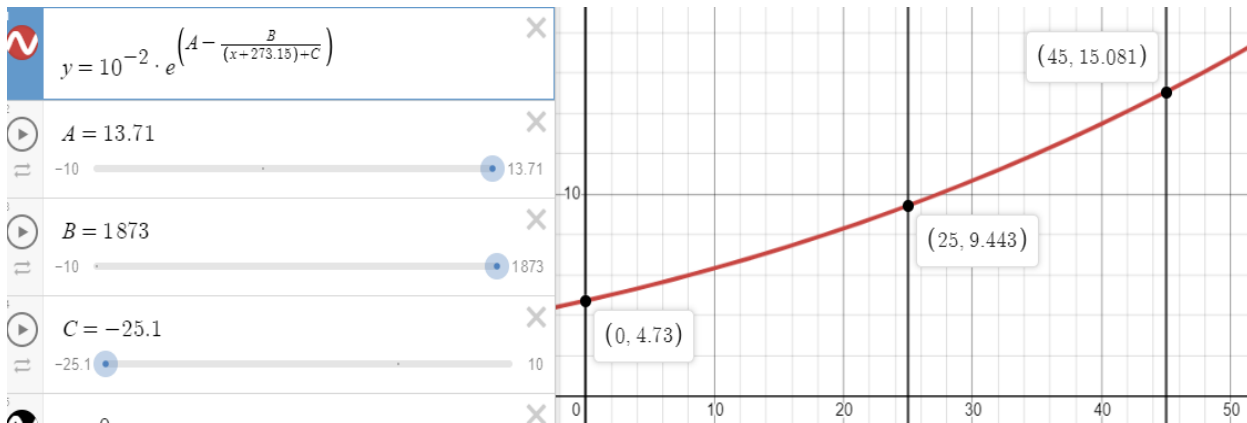
$$p(bar) = 10^{-2} \cdot e^{A - \frac{B}{C + (273.15 \ + T(^0C))}}$$

Equation 2.5

Figure 2.4 Antoine equation for Butane. Y axis = Pressure (bar), X axis =Temperature (°C)

Figure 2.5 Antoine equation for Propane. Y axis = Pressure (bar), X axis =Temperature (℃)

As you can see, the Antoine equation perfectly approximates the variation of vapour pressure with temperature. As previously mentioned, in this process it is necessary to work in a liquid state for the correct synthesis and transport of fluids. To achieve this, the temperature and pressure are regulated with the opening percentage of the automatic regulating valve.

The variation in pressure due to the action of the regulating valve is described by the Bernoulli equation and the continuity equation. The Bernoulli equation describes the behaviour of a fluid along a current line.

$$\int_1^2 \frac{\partial v}{\partial t} ds + \int_1^2 \frac{dp}{\rho} + \frac{v_2^2 - v_1^2}{2} + g(z_2 - z_1) + w_{roz\ 1-2} = 0$$

Equation 2.6

Where v is the fluid velocity, dp is the pressure differential, ρ the fluid density, g is the gravitational constant, z is the distance from the centroid on x-y plane, and $w_{roz\ 1-2}$ are the friction losses.

The equation is simplified to unsteady frictionless flow along a streamline, compressible flow, steady state and negligible elevation changes. For simplify the equation, pressure is considered not temperature dependent, but the process fluids are not incompressible, therefore we consider the density temperature dependant. The final Bernoulli's equation to be use will be (White 2011, 169-172).

$$\frac{p_2 - p_1}{\rho(T)} + \frac{v_2^2 - v_1^2}{2} = 0$$

Equation 2.7

In order to determine the velocities, deducing from the law of conservation of mass and applying the equation of continuity, the velocity will be considered exclusively dependent on the pipe section and the volumetric flow rate that passes through it.

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$$m_{syst} = const \implies \dot{M}_{in} = \dot{M}_{out}$$

Equation 2.8

$$\dot{M} = \rho \cdot \dot{V} \implies \dot{V} = A \cdot v$$

Equation 2.9

$$\rho_1 \cdot A_1 \cdot v_1 = \rho_2 \cdot A_2 \cdot v_2$$

Equation 2.10

Constant density and volumetric flow are considered. It is also considered that the automatic regulating valve modulates the output section, therefore:

$$A_2 = \frac{x}{100} \cdot A_1$$

Equation 2.11

Where $\dot{M}$ is the mass flow rate (kg/s), $\dot{V}$ is the volumetric flow rate (m^3/s), ρ the density (kg/m^3), v is the fluid velocity (m/s^2), A is the pipe section (m^2) and x is the opening percentage of the automatic regulating valve (%), considering 100% as the maximum opening and 0% as the closed valve.

$$v_1 = \frac{\dot{V}}{A \cdot x} \qquad v_2 = \frac{\dot{V}}{A}$$

Equation 2.12

With both **Equation *2.7*** and **Equation *2.12*** the final equation is obtained, which will be used to determine the pressure according to the position of the regulating valve. p_1 Will be considered as the initial pressure at which the fluid is in the source tank.[1]

$$p_2 = p_1 + \frac{1}{2} \cdot \rho(T) \cdot \left(\frac{\dot{V}^2}{A^2 \cdot x^2} - \frac{\dot{V}^2}{A^2} \right)$$

Equation 2.13

To determine the variation in density with temperature, a second-degree regression will be made in the point cloud of the **Figure *2.3*** graph provided by the client.

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[1] Information provided by the client

x_1	y_1	e_2	x_2	y_2	e_2
−50	653	0.37995603	−50	590	0.25249677
−40	643	−0.078784272	−40	580	0.56264098
−30	633	−0.21040935	−30	568	−0.30992569
−20	623	−0.014919198	−20	555	−1.3652032
−10	612	−0.49231382	−10	545	1.3968083
0	601.54	−0.10259322	0	529	−1.023891
10	590.5	0.034242609	10	515	−0.62730122
20	579	0.038193664	20	500	−0.41342232
25	573.27	0.1828374	25	493	0.50000055
30	567.5	0.36925995	30	485	0.6177457
40	555	0.027441454	40	468	0.46620283
45	548.8	0.029200418	45	460	1.1969148
50	543	0.51273819	50	450	0.13194907
60	529	−0.67484985	60	430	−1.3850156

Figure 2.6 Data tables from **Figure 2.2**
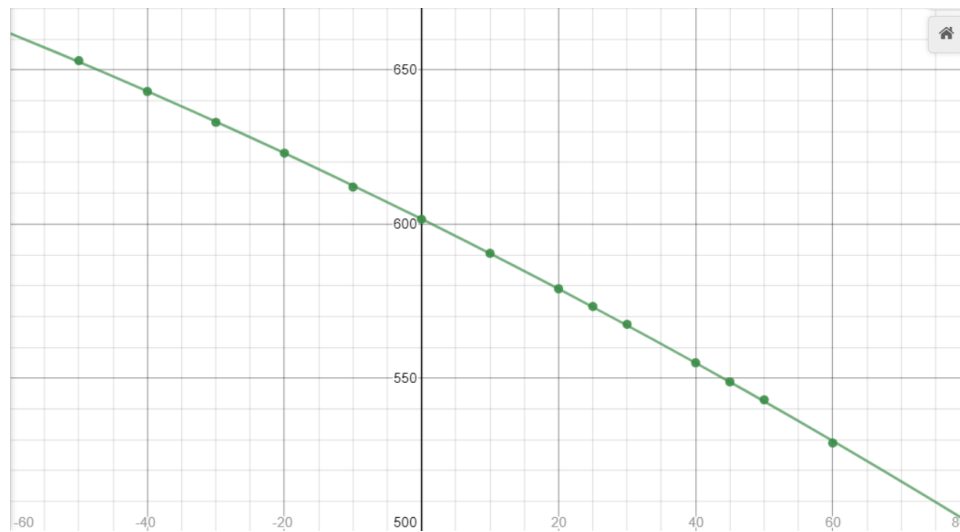

Figure 2.7 Second-degree regression of butane density variation with temperature

$$y_1 \sim ax_1^2 + bx_1 + c$$

ESTADÍSTICA   RESIDUOS

$R^2 = 0.9999$ e_2

PARÁMETROS

$a = -0.00163558$ $b = -1.10133$
$c = 601.643$

Equation 2.14

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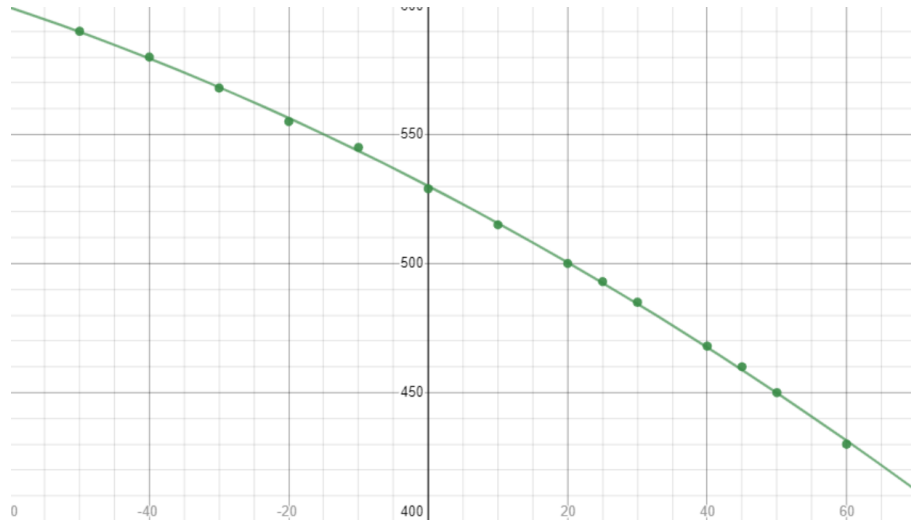
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Figure 2.8 Second-degree regression of propane density variation with temperature

$$y_2 \sim ax_2^2 + bx_2 + c$$

ESTADÍSTICA   RESIDUOS

$$R^2 = 0.9997 \qquad e_2$$

PARÁMETROS

$$a = -0.00408645 \qquad b = -1.39879$$
$$c = 530.024$$

Equation 2.15

After obtaining the equations **Equation *2.13***, **Equation *2.14*** and **Equation *2.15***; the simplified mathematical approximation of the entire thermodynamic process is complete.

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2.2. Control system

Bellow the entire control architecture currently installed is presented, starting with the hardware and instrumentation devices, the control PLC software, the SCADA system and the communications system. **Figure** *2.9* is a basic chart of the control system currently in operation at the plant.
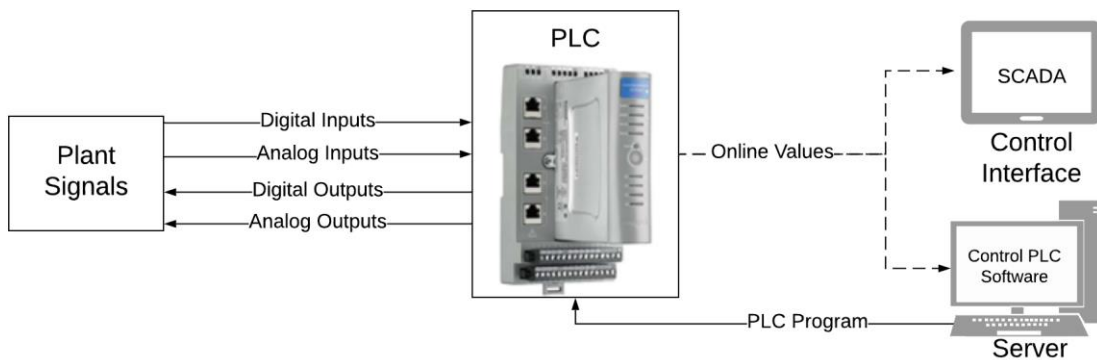
Figure 2.9 Control system architecture chart

2.2.1. PLC Controller

The main control device for industrial processes is the PLC. A PLC (Programmable Logic Controller) are essentially digital computers used to control electromechanical processes. The PLC is designed for multiple inputs and output arrangements, extended temperature ranges, immunity to electrical noise, and resistance to vibration and impact. Programs to control machine operation are typically stored in battery-backed or non-volatile memory.

It is also an example of a real-time system since output results must be produced in response to input conditions within a bounded time; otherwise, unintended operation will result. The main difference from other computers is that PLCs are armoured for severe conditions and have the facility for extensive I/O modules[1], these connect the PLC to sensors and actuators (Lamb 2013, 62-63).

Currently the PLC in charge of automating this process is isolated from the rest of the plant control system, as well as the process itself. Previously this device was chosen to exclusively control this process, so, in its day, this was the best solution.

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[1] I/O is understood as inputs and outputs. An I/O module is a specific device that is in charge of processing the inputs or outputs wired to this module in order to get the PLC to work with them correctly.

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The currently installed controller is Honeywell ControlEdge RTU2020, this was designed specifically to work in harsh environments and separate or isolated from the control centre. Its main features are:

- Operates in harsh environments with low power consumption.
- On-board I/O, expansion I/O modules and wireless I/O solution.
- Built-in HART[1] I/O.
- Electronic Flow Metering (EFM) capability for both gas and liquids.
- Block-valve automation.
- Ideal for gas stations.
- Low power consumption.
- Ideal for remote installation and operation on solar power (ControlEdge RTU 2014).

In this installation, the controller's own I/O ports are enough, so there is no need extra I/O modules. The wiring of electrical signals and planes is not part of the company's competence; therefore, relative information is not attached.

Figure 2.10 ControlEdge RTU2020 Controller *(ControlEdge RTU 2014)*

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[1] HART is the global standard for sending and receiving digital information across the 4-20mA analog current loops that connect the vast majority of field instruments with distributed control systems. HART technology offers a reliable, long-term solution for plant operators who seek the benefits of intelligent devices with digital communication, while preserving existing investments in analog instrumentation and plant wiring (HART communication protocol 2018).

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2.2.2. Sensors and devices

As mentioned above, the instrumentation in this project is not within the competence of the collaborating company, so only basic information will be given on the sensors and devices.

The system currently consists of an automatic regulating valve for each supply line, which deals exclusively with product control. Each one contains two output signals: An analog 4-20 mA[1] valve position and a digital valve status, which is always active unless there is an electrical failure in the valve, in that case, it would be set to 0.

These valves are controlled by a 4-20 mA analog output from the PLC, which provides an electric current equivalent to the desired opening percentage, so the regulated valves also have a 4-20 mA analog input. The opening percentage that is required is given by the internal PID algorithm of the PLC itself, so that, as previously mentioned, the products can be kept in a liquid state.

The pumps used in this system are centrifugal pumps, which pump the product through the piping system, transforming the mechanical energy of the impeller into kinetic energy of the fluid. The pumps used in this system have 3 digital signals: An output signal referring to the state of the pump (with the same operation as in the valves), an output signal indicating whether the pump is running or not and finally an input signal, which is used to give the start or stop order to the device.

On the part of the sensors, the pressure sensors are determinant in the control of this process, the feedback of the PID algorithm is given by the value measured by the pressure sensor (The behaviour and function of the PID algorithm will be specified in the following sections). The system also has an emergency stop button to stop the process and lock the devices in case of emergency.

As mentioned above, each supply line contains a pressure transmitter, a temperature transmitter and a volumetric flowmeter. The temperature sensor is the least influential in the process, is a measure for monitoring and calculate the instantaneous density of the products, applying the **Equation 2.14** and **Equation 2.15**.

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[1] 4-20 mA is a standard for analog signals, currently the dominant standard in most industries. 4-20 mA refers to the analog signal being scaled between 4 mA as 0% and 20 mA as 100%. Its most outstanding features are its advantage for long distance wires in comparison to voltage standards and the easy detection of signal failure. The fact that 0% is 4mA, if there was a fault in the signal and it had a value of 0 mA, there would be no doubt as to whether it is a fault or a 0% value.

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On the other hand, the flowmeter is mainly used to totalize, operating with the instantaneous density of the product, the exact amount of product loaded.

- The pressure sensors operate with an analogue 4-20 mA signal regulated between 0 and 20 bar.
- The temperature sensors operate with an analogue 4-20 mA signal regulated between 0 and 50 °C.
- Volumetric flowmeters operate with a 4-20 mA analog signal regulated between 0 and 40 kg/m^3.

An output signal from a device is an input signal for the PLC and vice versa. From the following section, all the signals will be referred from the PLC controller's viewpoint.

2.2.3. PLC programming software

The software used to control the Honeywell Control Edge RTU2020 PLC is Honeywell RTU Builder. This software provides the engineer a tool for editing the logic of the program that will be executed by the PLC for the correct operation of the automatisms. The program will be in charge of managing the inputs and outputs of the system components, as well as created variables, in order to correctly execute the automation of the process.

The Honeywell RTU Builder software is programmed through a block structured programming, this is based on the interconnection of blocks and variables to simplify programming and make it more visible. A code block is a section of code already programmed; it is like a function, that giving it the necessary input values returns one or more values.

These blocks always have at least one input and one output, the block operates the information connected to the inputs, with the logic programmed internally and returns the results at the outputs of the block. In RTU Builder, these blocks are called FB and FU. FB are FU, but their internal programming is made with more FU, that is, they are blocks programmed with blocks; in practice they are the same.

An example of FU is the selector (SEL), as can be seen in **Figure *2.11***, this FU has 3 inputs and one output. The input 'G' is connected to a BOOL type variable that will control the output of the FU. If the variable connected to 'G' is equal to 0, the output will be equal to the variable or value connected to input 'IN0', if input 'G' is equal to 1, the output will be equal to the variable or value connected to input 'IN1'.

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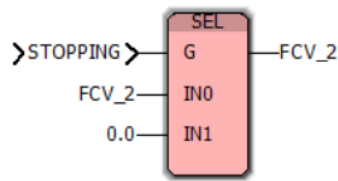
Figure 2.11 Selection FU 'SEL' (Source: Honeywell RTU Builder)

There is a great variety of FU and FB in the internal libraries of the software, from the most basic as an AND to totalized control blocks for an analog variable. I/O variables are those that are wired to the internal ports of the ControlEdge RTU, internal variables are all those that are used in the program and external variables are internal variables that you want to see or control from the SCADA control interface.

In this programming environment there are different groups of variables, the most important and used are Input and Output variables, external variables and internal variables. I/O variables are those that are wired to the internal ports of the ControlEdge RTU, internal variables are all those that are used in the program and external variables are internal variables that you want to see or control from the SCADA control interface.

The program is structured in different worksheets, in each one there is the logic referring to a part of the process, a device or a function of the program. A worksheet is a place where the programmer interconnects variables, programming blocks and data to build the program. In the program that is currently running while waiting for its update, it is structured in seven worksheets:

- **Channel_I:** There is the processing of input variables, as well as the initialization of other global variables.
- **Chanel_O:** As before, the output variables are processed in this worksheet.
- **COM:** In this section, the operation of the process control variables (Start, Stop, and Run) is programmed. As well as the safety conditions that must stop the process, from now on they will be known as interlocks.
- **FT_PID y PT_PID:** They are the programming of the functionality of the PIDs that regulate the automatic regulating valves.
- **TOT:** There is the programming related to the totalization of the flow metter signal, as well as the final conditions of the product supply.
- **Alarms:** The last worksheet is in charge of managing the possible alarms that can generate any of the analog inputs of the system.

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Next, a set of parts of the program that have been analysed for the detection of errors or possible improvements will be seen and commented.

As can be seen in **Figure *2.12***, the system alarms only contemplate the analog inputs being out of upper or lower range. The rest of the digital inputs that can affect the stop conditions are in **Figure *2.13***, in the left side, the digital inputs are processed and in the right side, you can see the conditions to set the 'RUN' variable to value 0, which is in charge of starting the supply.
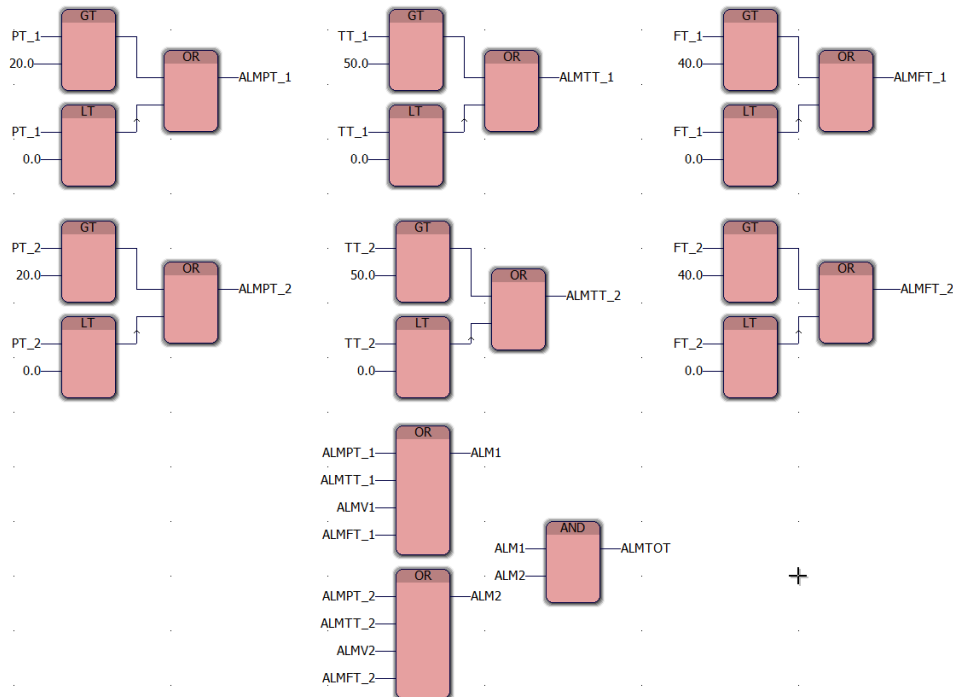
Figure 2.12 Alarms worksheet (Source: Honeywell RTU Builder)
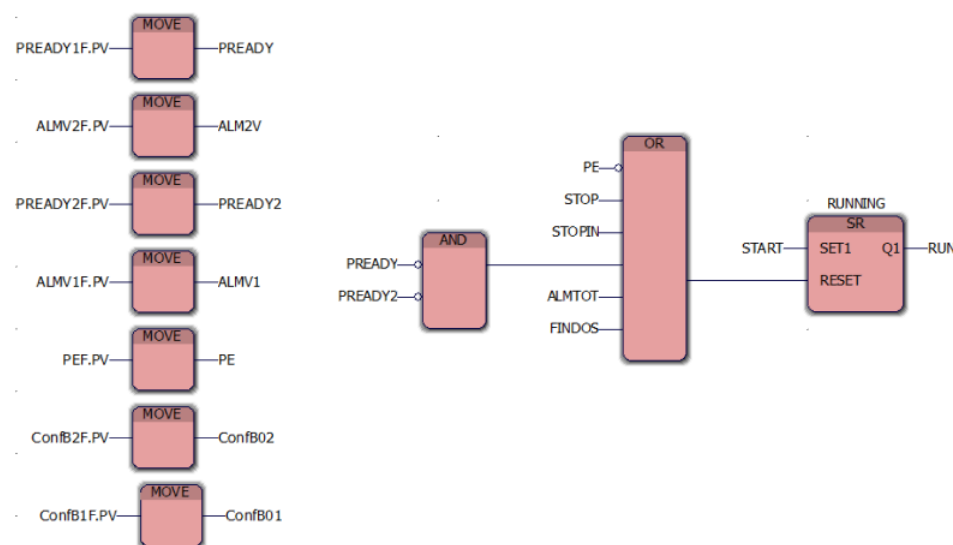
Figure 2.13 Processing of other alarm signals (Source: Honeywell RTU Builder)

There are three variables that do not appear in the security conditions that stop the process, these are the ones seen in **Figure** *2.14*. In the last column, you can see the access in the worksheets of these variables; in this case, there is no read access. Therefore, the internal alarm of the propane automatic regulating valve 'ALM2V' and the analog inputs for checking the position of the automatic regulating valves, 'POS_PVC1' and 'POS_PVC2', are not considered in the process. A malfunction of an automatic regulating valve would not be detected and could cause problems in the process.

Figure *2.15* shows the management of the variable 'PCV_2' that controls the position of the automatic propane regulating valve. As you can see, there is an FB of the PID algorithm that, in the inputs you have the regulation parameters (KP, TR and TR) and the necessary analog inputs, among other inputs, to get the analog output value to control.

In the safety conditions in which the valve is to be closed, the output variable 'PCV_2' is acted upon directly. It should be managed from the PID system itself, controlling the set point (SP).

Figure 2.14 Analysis of the references of 3 signals (Source: Honeywell RTU Builder)
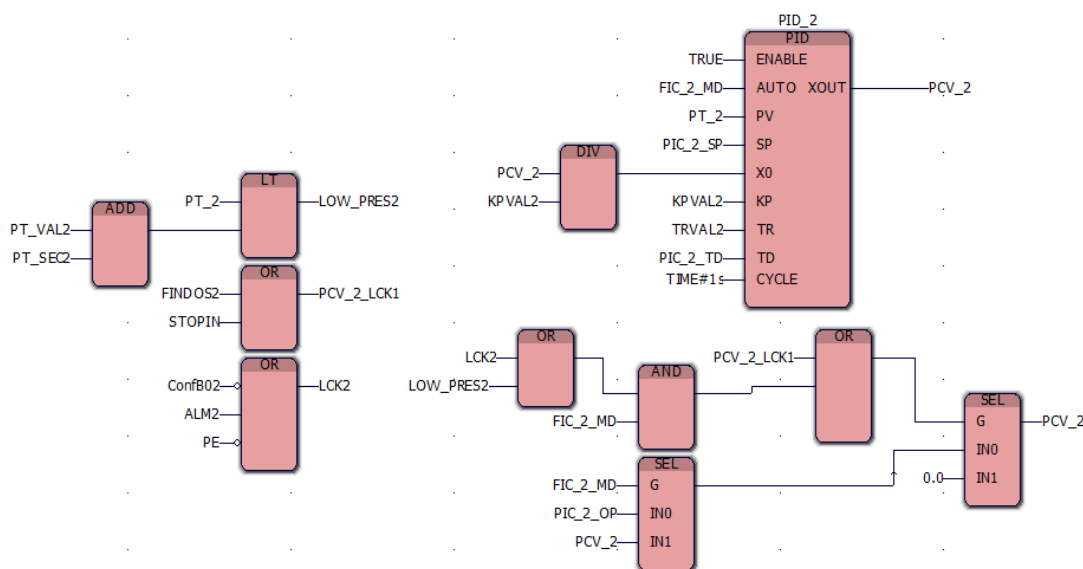
Figure 2.15 Programming example (Source: Honeywell RTU Builder)

Lastly, as can be seen in **Figure *2.16***, most variables do not have a description of their role, this delays the study of the automation program for any other programmer.

	Name	Type	Usage	Description	Address	Init
45	LOW_PRES	BOOL	VAR_GLOB...			
46	PCV1PF	ANA...	VAR_GLOB...	Presion		
47	PCV2PF	ANA...	VAR_GLOB...	Presion		
48	PCV_1	REAL	VAR_GLOB...			
49	PCV_2	REAL	VAR_GLOB...			
50	PE	BOOL	VAR_GLOB...			
51	PIC_1_KP	REAL	VAR_GLOB...			1.0
52	PIC_1_KP_R	REAL	VAR_GLOB...			
53	PIC_1_MD	BOOL	VAR_GLOB...			
54	PIC_1_OP	REAL	VAR_GLOB...			
55	PIC_1_PV	REAL	VAR_GLOB...			
56	PIC_1_SP	REAL	VAR_GLOB...			
57	PIC_1_TD	REAL	VAR_GLOB...			
58	PIC_1_TR	REAL	VAR_GLOB...			1.0

Figure 2.16 Declaration of some external variables (Source: Honeywell RTU Builder)

2.2.4.   SCADA

Once the process is automated thanks to the program that has been downloaded into the PLC controller, a tool is required for plant operators to monitor and control the automated process. Although the control software engineer could control the process from the online mode of the PLC programming software, understanding and accessibility must be facilitated in order to reduce the time operators spend on controlling the process.

The tool used to get an accessible and simple interface to control the process is called a SCADA system. SCADA (Supervisory Control and Data Acquisition) is the set of software and hardware used to communicate, control and supervise various field devices, as well as remotely control the entire process. In addition, it incorporates a system of displays to be able to navigate through the different sectors of a plant, control the possible production processes and visualize data in real time (Pérez-López 2015).

The SCADA system consists of a set of hardware (Stations and independent screens) and a software system to manage the control screens, users and sectors.

In the current system, the control interface that is used is Honeywell HCiW07-TE, the features of this interface match perfectly with the ControlEdge RTU controller. It is designed to control a specific process and place it in the plant to operate with it in situ; it is a screen independent of the rest of the control interface system and connects directly to the PLC via serial port.

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Figure 2.17 Honeywell HCiW07-TE (Source: Honeywell)

In this independent unit is not necessary the Sector Control System, normally this is used to restrict the information to be displayed in each sector of the plant. In this case there is also no system of operators, only contains a general access key for any user.

In the Honeywell HCiW07-TE the set of displays to visualize and control the process are loaded by USB port or network to the internal memory. The data that is loaded contains all the displays files, as well as the basic configuration of security, users, menus and others.

To edit the data the software XDesignerPlus of the manufacturer M2I Corp was used, this software allows editing the displays and the previously mentioned configuration.

The system of displays that was installed in his day is very simple, consists of 4 displays:

- **Main screen:** In this display, you can select the quantity and percentage of LPG to be unloaded. There are also the process control buttons, START and STOP, as well as the process status display and some alarms.
- **Auxiliary screen:** Here you can view the status of the system devices, the values of the analog sensors and the amount of LPG loaded. In addition, analog input alarms can be visualized.
- **PID Tuning 1 y 2:** In these two screens you can see the analog variables that the PID has in a graph. You can also edit the control parameters and the mode of operation of the PID.

We can see in the following examples that the designs are simple and only the basic information is represented. **Figure *2.18*** is the display when edited in XDesignerPlus. As we can see, the 'Out of range' alarms are visible, if they were in online mode on the Honeywell HCiW07-TE screen they would only be displayed if the alarm were active.

In **Figure *2.19*** the picture is taken from Honeywell HCiW07-TE itself with the PLC running, so you can see the values and graphs live. This is the usual visualization state in a SCADA display.
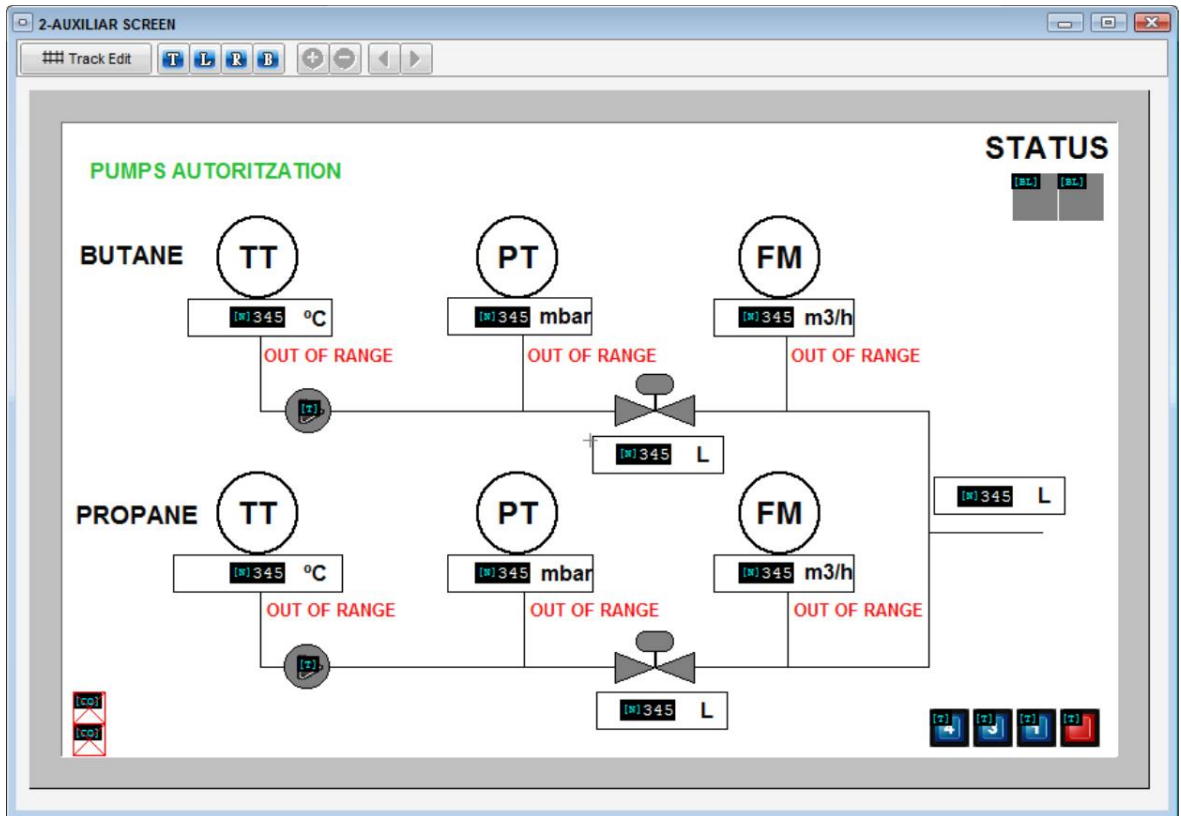
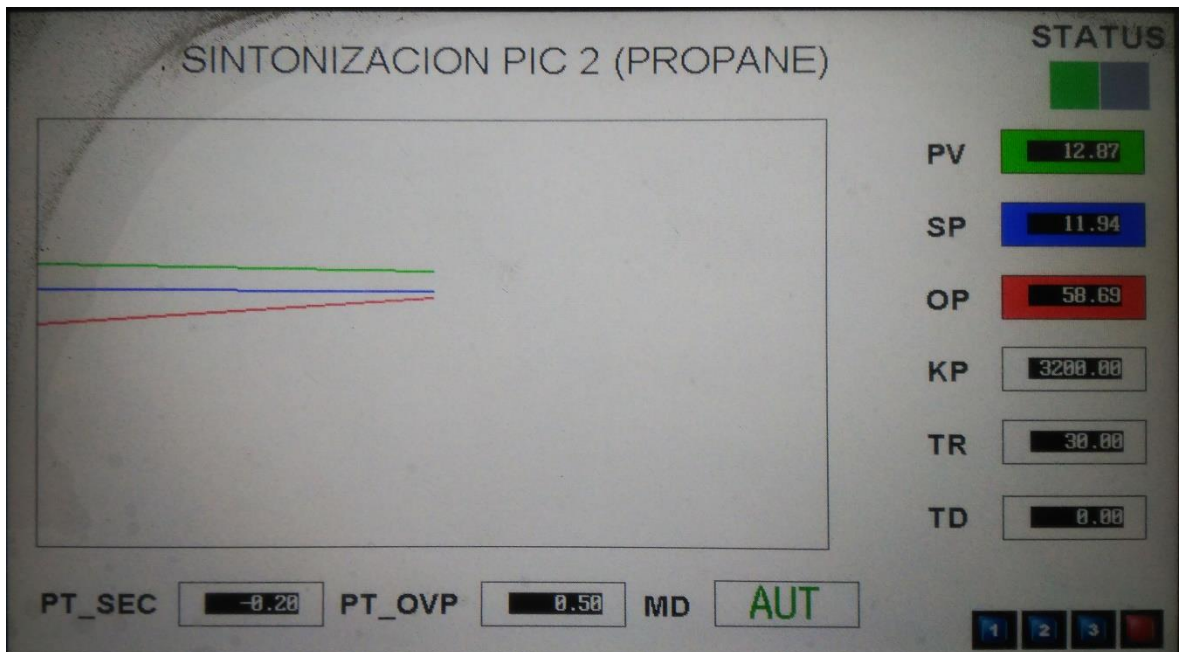**Figure 2.18** Auxiliary screen display in edition mode

Figure 2.19 PID Tuning 2 display in online mode

2.2.5. Communications

As can be seen in **Figure** *2.9* the different devices that make up the system are connected to each other. Each device can communicate by various methods with the others, it also depends on the data you want to send or receive, a specific communication method has to be chosen. First, the communication between plant signals (from devices and sensors) with the PLC will be explained.

As previously commented, in the current installation pending renovation, no additional I/O modules are used, ControlEdge RTU's own modules are enough, so the plant signals are physically connected directly to the PLC controller ports. The internal PLC ports are configured directly from the PLC software control, in this case the Honeywell RTU Builder.

The PLC software control is located on the plant server, and this must be connected to the same Ethernet network[1] as the PLC controller in order to communicate. This way you can download the program and the configuration correctly to the PLC.

For the correct communication of values between the PLC, the server and the SCADA interface control, the binding protocols must be configured, also from Honeywell RTU Config. The currently implemented system communicates in the controller's own internal protocol, RTU Configuration Protocol, and a protocol of general use in the industry, the Modbus TCP Slave[2].

Figure 2.20 Modbus communication configuration (Source: Honeywell RTU Config)

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[1] Ethernet is a technology that connects wired local area networks (LANs) and allows the device to communicate with each other through a protocol that is the common network language.

[2] Modbus is a serial communication bus protocol initially used for PLC, characterized by having a simple and robust structure, was established as standard to communicate electronic devices at industrial level. The company Modicon created it in 1979. TCP Slave is a specific protocol for servers.

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The Modbus is the protocol that was chosen for this system, in the previous figure its configuration can be appreciated

The external variables, which are the ones that you want to communicate with the PLC and the SCADA control interface, to be able to manipulate or supervise them in the displays, you have to assign them a Modbus address, this is also configured in Honeywell RTU Config.

	Modbus Address	Variable Name
☐	1	@GV.START
☐	2	@GV.STOP
☐	3	@GV.RESET
☐	4	@GV.PIC_1_MD
☐	5	@GV.FIC_2_MD
☐	6	@GV.ALMPT_1
☐	7	@GV.ALMPT_2
☐	8	@GV.ALMTT_1
☐	9	@GV.ALMTT_2

Figure 2.21 External variables Modbus address configuration (Source: Honeywell RTU Config)

Lastly, in order to visualize the data of interest, to be able to modify the load consignments and to control the operation of the process; it is necessary to connect the PLC controller with the interface control. As previously mentioned, these two are connected by serial port, whose configuration is also done from the RTU Config. In **Figure *2.22***, COM4 serial port configuration of the Honeywell ControlEdge RTU2020 can be appreciated.

Figure 2.22 Serial Port Configuration (Source: Honeywell RTU Config)

2.3. Problems and potential improvements

So now, we have seen the control system that is currently implemented in the plant, in this section we will see the problems that this currently presents and possible improvements that could be applied to the system.

- For the PLC controller that is used now, this is a 2014 hardware. There are better alternatives on the market nowadays.
- It is also a limited controller, is not intended for large applications or sectors and is not the best option if you want to unify the plant control system.
- Currently the I/O ports are all in use, you could not do a small extension without getting a new I/O module, and these will eventually become incompatible with ControlEdge RTU2020.
- LPG unloading made until today show errors of between 10% and 15%.
- The communications protocol and each of the external variables have to be configured manually, the Honeywell RTU Config software has no direct integration with the SCADA system.
- Nor do they have the latest Honeywell bookstores.
- In the current programme, the programming of the butane and propane supply lines are not independent of each other. For example, if the propane centrifugal pump fails, it will affect the entire process.
- Programming is very limited and does not consider extra details that could help operators; the same can be applied to displays.
- The program is not well structured; it has many blocks of code in unrelated worksheets.
- The devices have a very simple programming. Only the logic for the output command is programmed. Failures in the devices or their alarms are not considered, this could cause errors in the automation.
- There is no specific alarm, only pump failure or analog inputs.
- The equations used for the measurement of vapour density and pressure could be more accurate.
- In the program, the quantity that remains in the pipes when stopping pumps and closing valves are not considered and could cause errors in the product supply.
- Variables and program code do not have explanatory descriptions. Possible future modifications are difficult.
- The reset control to initial conditions is not fully automatic.
- On the display, there are no graphs of the evolution of certain measures of interest such as temperatures, loaded quantity of each product and opening percentage of the automatic regulating valves.

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- The HCiW07-TE control interface is very limited. It can only be used for a single application and is not a part of the station system.
- The four displays that are loaded on this control interface contain very few information. Information about system variables, their status or if there is an error cannot be accessed.
- The alarm system is very limited and there is no exclusive display for it.

The new improvements proposed and requested by the client are:

- To have access to the control displays of this process from more stations of the plant.
- Reduce unload errors as much as possible.
- To have the two product supply lines independent of each other, from the program point of view, in order to avoid that an error in a device or sensor of the butane line hinders a possible load of butane alone.
- A renewal of the control system: New hardware and software.
- Have more detailed displays and user profiles in order to control the process.
- Able to increase the number of automated processes in the same PLC.

2.4. Suggested solutions

The solutions proposed to correct the errors and implement the improvements proposed in the previous section will be shown below. All proposals will be based on Honeywell products and will be sorted in ascending order according to the size of the system modification.

- **Modification 1:**

  The most basic proposal offered is to modify the most relevant program errors, as well as to add basic functions that do not exist right now. This improvement could slightly reduce the errors in the unloaded product quantities, also by programming a calibration system of the remaining quantity in the piping system when closing the devices. Another essential program modification would be to improve the management of the devices, in order to improve the security and robustness of the system.

  In addition, a modification of the displays to make them more complete and comfortable to use for the operators. The architecture of the control system would not be modified; all the changes would be made in the software that is used right now.

- **Modification 2:**

  This second option contemplates the same program changes as in the first modification proposal, with the same PLC, but proposes a new SCADA system in which all the displays will be redesigned to control and supervise the process.

  It is proposed a new SCADA system that can be integrated with the rest of the plant system, the system is Honeywell Experion HS. This software has detailing variables default displays, advanced alarm control, displays in auto scalable format HMTL[1], management of users and integrated plant areas, among others. A great advantage it also has is that it has open connectivity to facilitate the integration of the project (Experion HS 2018).

- **Modification 3:**

  In this proposal both the PLC, the control software and the SCADA system are changed. The modification of the new SCADA system will be the same as in the previous proposal.

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[1] HTML (Hypertext Markup Language) is the standard code used to structure and visualize a web page and its content.

The Honeywell ControlEdge is proposed as a new PLC, when combined with the SCADA system Experion HS, reduces integration costs for balance of plant operations, minimizes downtime through unified support, decreases risk with embedded cyber security, and lowers total cost of ownership through extended system lifecycle. It also provides greater flexibility and expansion capacity, more power than the one currently in use and a wider range of communication protocols available (ControlEdge PLC 2018).

With the new PLC control, software the whole program would be programmed from scratch to implement all the proposed improvements and solve problems.

- **Modification 4:**
  The last proposal is based on the whole modification of the SCADA system, new PLC and new control program, as well as on the previous proposal. However, in order to minimize unloading errors to practically zero and make automation much more solid, it is proposed to improve the current installation.

  A new automatic bottom valve is proposed for each product tank, to be able to control with more precision the supply, as well as to add another final automatic valve shared by the two supply lines, to be able to have a more exact control of the supply cut.

  It is also proposed to adapt the refilling system of the source tanks to be able to manage the unloads to the tank from other sectors of the plant, complementing it with a low-pressure sensor in each source tank to automate when they have to be refilled.

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2.5. Solution Choice

After proposing and studying the possible solutions between the client and the collaborating company, it has been decided that modification 4 is the best for the future; the process is fully optimized and would be implemented with the rest of the plant. It has been organized to make the modification in two parts:

The first part, on which this bachelor's thesis will be based, will renew the entire LPG supply and synthesis process, implementing new PLCs and new software, as well as the extension of the installation with the new devices.

The second will include the progressive migration of the rest of the plant to the new system proposed for the specific LPG process, therefore, the automation and refilling of the original tanks will take place in the second part of the project.

The most complete modification has been chosen because it involves a long-term project with the customer, as well as the in-depth exploration of the new products that Honeywell offers for the industry.

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3.   Solution Implementation

3.1.   Control system architecture

As previously decided, the solution to be implemented entails a change of the entire control system that had been described in the previous sections. Each of the new control devices and the software used to programme them are presented below. In addition, new actuators and devices for the process.

The control system will maintain the same structure: A system of sensors and automatic actuators to automate the process, a PLC that will control the previous devices' variables, a SCADA system that will create a process control environment and a group of software to program the different systems.

3.1.1.   Sensors and Devices

To achieve error reduction in product unloads, the plant infrastructure must be expanded and improved.

As mentioned in previous sections, it was decided to add a series of valves to each supply line in order to be able to unload LPG more accurately. Lastly, each supply line will be formed by:

- A low-pressure sensor in the source tank that will indicate when it is not possible to unload a certain product. "LI" in **Figure *3.1***.
- An automatic bottom valve for each of the origin tanks will help make the supply cut off more instantly to avoid overloading. "V_01" and "V_02" in **Figure *3.1***.
- A centrifugal pump that pumps the product through the piping system. "P_01" and "P_02" in **Figure *3.1***.
- A pressure sensor and a temperature sensor to control the process variables. "TT" and "PT" in **Figure *3.1***, "PIC" means pressure-integral-control, in reference to the PID control according to pressure of the automatic regulating valve.
- An automatic regulating valve that will regulate the pressure so that butane and propane are unloaded in a liquid state. "RV_01" and "RV_02" in **Figure *3.1***.
- A volumetric flow meter to display the amount of product being pumped. "FT" in **Figure *3.1***.
- An automatic valve at the end of the piping system, shared for the two supply lines, which, like the bottom valves, will help to control more accurately the amount of product unloaded. "V_03" in **Figure *3.1***.

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The system will also include two source tanks for butane and propane as well as an output vessel to unload the final product. "T-01", "T-02" and "T-03" respectively in **Figure *3.1***. As well as an emergency stop button of the process, it is not shown in the P&ID.
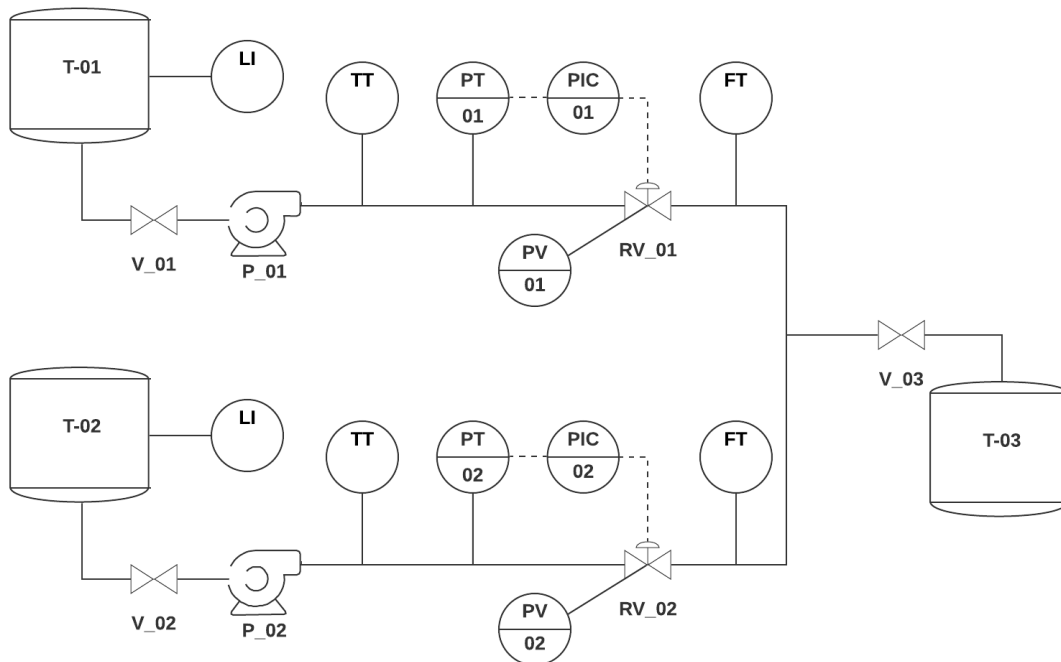
Figure 3.1 New plant infrastructure P&ID (Source Instrumentation company data)

3.1.2.   PLC Controller

The new PLC to be used will be Honeywell ControlEdge PLC, Release 151.1 of November 2018. This new PLC is the latest in the next-generation family of ControlEdge controllers. ControlEdge PLC offers a higher level of connectivity at all levels, optimized operations, maintenance efficiencies that release personnel from manual processed and is one of the first controllers supporting Honeywell's IIoT-ready initiative.

An IIoT-ready platform enables more direct access to cloud based applications for visualization and analytics. Direct access and reduced gateways offer easier maintenance and reduce costs and risks.

The ControlEdge Programmable Logic Controllers (PLCs), designed and developed by Honeywell are based on the proven platform of racks and power supplies, as can be seen in the **Figure *3.2***. This advanced line of controllers, compliant with the IEC 61131-3 standard, offers impressive scalability for different environments and provides robust control in a wide range of applications.

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Figure 3.2 ControlEdge PLC *(ControlEdge PLC 2018)*

ControlEdge PLC can work with any SCADA system, but one of its best features is the integration with Honeywell's SCADA system, the Experion. Improved ControlEdge PLC and Experion integration over an OPC UA interface offers pre-built PLC diagnostics in the Experion system, an integrated alarm summary, integrated history, trend and reporting; resulting in fast and easy integration with significant cost savings. The **Figure *3.3*** shows a chart of the interconnection of control system devices.
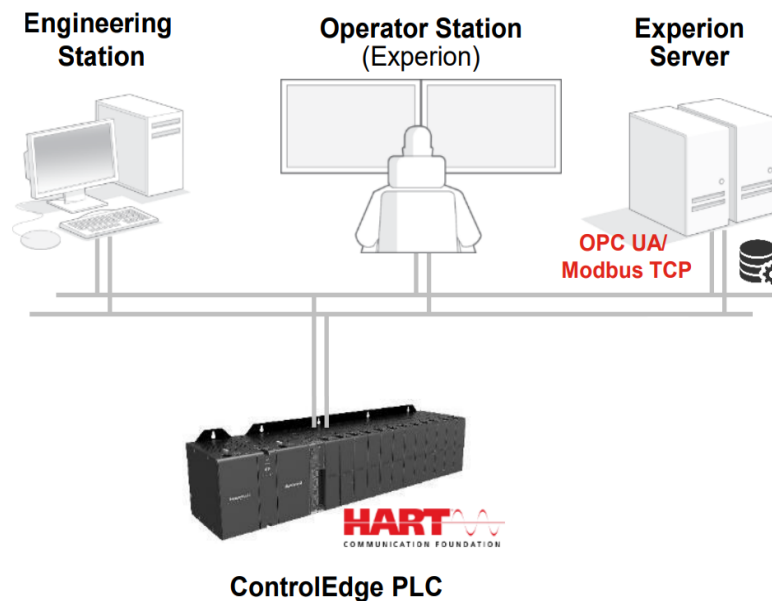
Figure 3.3 ControlEdge PLC and Experion integration *(ControlEdge PLC 2018)*

Auto-configuration of PLC data points provides a significant reduction in the cost of integration, easy updates on the Experion Server, and faster project development. In addition, OPC UA named variable based mapping eliminates address-mapping efforts.
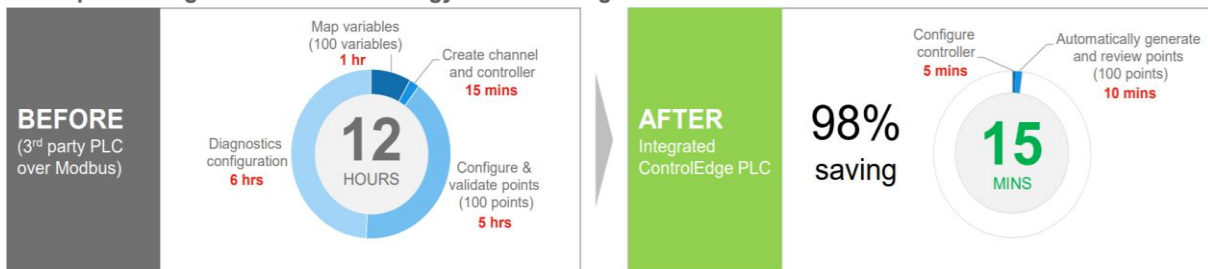
Figure 3.4 Dramatically Improve Experion Integration Workflow *(ControlEdge PLC 2018)*

ControlEdge PLC offers a variety of I/O choices for flexibility and reduced system cost, HART enabled I/O means no additional costly hardware to support HART protocol. It is the first PLC to offer Universal I/O, allowing I/O channels to be quickly configured to serve as analog or digital and as input or output. Engineers can easily make late changes remotely with a simple software configuration adjustment. ControlEdge PLC connectivity also supports a connection between I/O Racks and CPU in a star network (using Switch) or a ring connection between all the rack system.
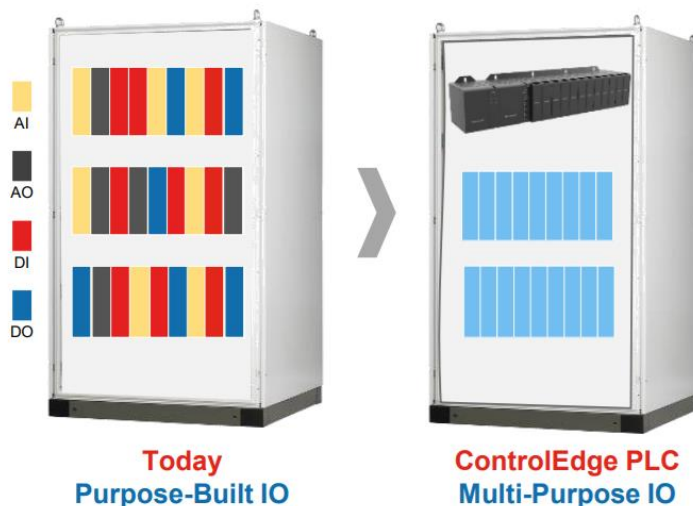
Figure 3.5 Universal IO flexibility on ControlEdge PLC *(ControlEdge PLC 2018)*

ControlEdge PLC supports encryption, easy configuration and certificate-based authentication. Embedded cyber security supports compliance, reduced risk, and availability. Features include secure

boot to prevent uploading of unauthorized software, a built-in firewall to reduce exposure to denial-of-service attacks and message flooding, and a certified secure development lifecycle to ensure security is built-in from the start.

For this process, a specific configuration of modules will be used to satisfactorily cover the needs of this process. Taking into account the number of field signals of the old system plus those added in the modification, the following modules will be required:

- One ControlEdge PLC with a rack of at least 8 modules.
- One Control Processor Module, 900CP1-0200 model.
- One 120/204 VAC Power Supply Module, 900P01-0301 model.
- One 24 VDC Power Supply Module, 900P24-0301 model.
- Digital Input 120/240 VAC Module, 900G03-0202 model.
- Digital Output 120/240 VAC Module, 900H03-0202 model.
- Universal Input/output Module, 900U01-0100, HW Revision E, Version 02 in Builder model.

(ControlEdge PLC Specification 2018).

All modules compatible with release 151.1 November 2018. No external communications module will be required for the moment; the first part of the company's project only contemplates the automation of the LPG synthesis and supply process.

For testing during the design process in the office, the manufacturer Honeywell provides a CPU simulator model 900CP1-200, Release 151.1. This simulator is a virtual machine that must be configured in the same network as the programming software in order to download information to the PLC simulator and be able to perform the relevant tests before start-up.

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3.1.3.   PLC programming software

The software used to program, design and configure ControlEdge PLC is ControlEdge Builder, which also includes the functions previously executed by the RTU Builder software to configure the I/O cards and PLC communications.

The software for programming the ControlEdge PLC and the ControlEdge RTU is very similar, therefore, they share many basic features already commented in the section 2.2.3, for example:

- It has the same types of variables and data types.
- It is also programmed through a block structured programming.
- The basic FU/FB libraries are the same

The I/O variables have a physical address, which the electrical technician will wire to the I/O ports of the PLC. In normal operation, the output variables can only be written, and the input variables can only be read. The output variables have an equal input variable, the readbacks, which are used to read the value of the Outputs. The types of data found in the group of I/O variables are:

- **Digital_Input_Type:** A data structure[1] that contains the digital input value (PV) and its status (STS).
- **Analog_Input_Type:** Like the previous one, it is a data structure, which in addition to the process value (PV) and the status (STS), contains 4 alarm signals, referring to the high and low limits of the scaling of the analog signal (HHALM, HALM, LALM, LLALM). The HighHigh and LowLow alarms are extra alarms in case the value is far from the upper or lower scale respectively.
- **Digital_Output_Type:** This is a single variable data structure, which is the process order (OP) for the corresponding actuator.
- **Analog_Output_Type:** Like the previous one, it is a data structure that only contains the process order (OP).
- **Digital_Output_Readback_Type:** As previously commented, the output signals are only for writing, but the copies of these, the reedback, are a data structure that allow reading the process order (OP) and consulting the signal status (STS).

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[1] A data structure is understood as a variable that has more than one signal, such as a group of related signals. The subvariables of a data structure can be accessed through a point, for example: There is a data structure called 'Temp_1', in order to access the process value variable (PV), it must be accessed as 'Temp_1.PV'.

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- **Analog_Output_Readback_Type:** As in the previous one, this data structure is used to read the process order (OP) or the signal state (STS) of an analog output.

Input IO Variables				
FT_1	ANALOG_INPUT_TYPE	VAR_GLOBAL	Caudal BUTANO	%IB0
FT_2	ANALOG_INPUT_TYPE	VAR_GLOBAL	Caudal PROPANO	%IB24
TT_1	ANALOG_INPUT_TYPE	VAR_GLOBAL	Temperatura BUTANO	%IB48
TT_2	ANALOG_INPUT_TYPE	VAR_GLOBAL	Temperatura PROPANO	%IB72
PT_1	ANALOG_INPUT_TYPE	VAR_GLOBAL	Presión BUTANO	%IB96
PT_2	ANALOG_INPUT_TYPE	VAR_GLOBAL	Presión PROPANO	%IB120
PRV_1	ANALOG_INPUT_TYPE	VAR_GLOBAL	Posición Válvula Regulada BUTANO	%IB144
PRV_2	ANALOG_INPUT_TYPE	VAR_GLOBAL	Posición Válvula Regulada PROPANO	%IB168
PL_1	DIGITAL_INPUT_TYPE	VAR_GLOBAL	Indicador de presión baja depoósito BUTANO	%IB258
PL_2	DIGITAL_INPUT_TYPE	VAR_GLOBAL	Indicador de presión baja depoósito PROPANO	%IB260

Figure 3.6 Example of I/O variables declaration (Source: Honeywell ControlEdge Builder)

In the figure above, you can see an example of declaration of inputs and outputs. From left to right the columns are: Variable name, data type, variable type, definition and address.

Internal variables are all variables (that are not I/O) that are used in the program. They do not have an assigned address, since they are internal to the program itself and can have an initial value. The internal variables can be a large variety of data types, the majority are universal data types for all types of programming, the most used in this kind of applications are:

- **BOOL:** They are the most basic type; they represent a bit, a signal that can only be two values, or 0 or 1.
- **INT:** An integer is formed by two bytes (set of 8 bits), there is a great variety of integers, the DINT, LINT, SINT, UDINT, UINT, USINT, WORD, BCD … These represent an integer and are generally used for counters, enumerations, classifications and others.
- **REAL:** A real, or FLOAT in many other languages, is formed by 4 bytes and is a real number, there are also LREALs, which are the same because they are formed by 8 bytes.
- **STRING:** They are text data types and are made up of two bytes.
- **TIME:** They are a type of REAL but specific to time counting.

Lastly, external variables are those internal variables that the programmer wants to use in the control interface, therefore they must communicate with the SCADA system, and this procedure will be specified in 3.1.5 and 3.3 sections.

In order to access the ControlEdge Builder online mode, where you can see the value of the variables in real time, you must first download the program to the PLC controller.

To download the program, first you have to compile all the worksheets and not have any error, if there are warnings you can continue the download. Once everything is compiled, access the configuration panel. In this, the first thing to do is to connect the PLC; this must be in the same network as the server

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from where ControlEdge Builder is to communicate correctly. It will be detailed more in the communications section.

When the PLC is connected, it is possible to download. There are two types of download. First, the Bootproject is downloaded, this Bootproject will be a backup copy in case of any problem and then the program will be downloaded again to have the PLC updated with the latest modifications made.

Once all the above conditions are accomplished, the PLC can be started and go online mode in ControlEdge Builder. The online mode is very useful in the review and testing period, as you can analyse the changes in real time.

ControlEdge Builder adds a new native Honeywell library, which contains programming blocks to control devices, more complete algorithms of totalizers and PID systems among others. The design of the program and the operation of the new FB library will be described in section 3.2.

3.1.4. SCADA system

The new SCADA system to be used will be Honeywell Experion HS, it is a new software that integrates the entire SCADA system efficiently, it can be used with PLC of any manufacturer, but is specifically designed to integrate easily with Honeywell ControlEdge controllers.

Thanks to the optimized integration of Experion HS and ControlEdge PLC, an integrated configuration environment is obtained that allows configuration changes online and offline and minimizes process interference. Experion HS and ControlEdge PLC are very recent and there is no online information to learn how to use them. The manufacturer's manuals are used to learn the whole scope of the functions they offer and to understand how they work.

It incorporates MatrikonOPC's robust industrial power technology, which provides equipment data connectivity to all control systems based on the OPC standard and extends supervisory control functionality. This open connectivity allows Experion HS to operate seamlessly with a variety of third-party controllers and devices.

The system has built-in detail screens based on Honeywell's partnership with Abnormal Situation Management (ASM)[1] to define principles and practices for safe screens. Experion HS contains prebuilt

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[1] The Abnormal Situation Management (ASM) Consortium is a group of leading companies and universities involved with process industries that have jointly invested in research and development to create knowledge,

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standard screens to facilitate and reduce display setup time. Some of these screens are process group screens, point detail, trends, alarms and curve programmers.

Experion HS works with HMIWeb screens, these give a lot of advantages and possibilities to have a more complete and adaptable interface, some of them are:

- Drop-down menus and toolbars to set up a simpler and more intuitive navigation system.
- Ability to have graphics of a maximum of 32 different variables simultaneously, with integrated markers and default settings.
- Much more intuitive and flexible HMI (Human-Machine Interface) environment, auto-scalable screens and standard HTML and XML technology.

Process data is a crucial element in manufacturing. Increasingly, industries require documented data of the manufacturing process before obtaining permission to sell their products, also to improve the process and have the data stored in case any network or memory error causes the loss of data.

That is why Experion HS has an integrated historian to collect data and events, allowing instant access to process data that interest or are critical. For this purpose, there are also commonly used industry standards and the Microsoft Excel™ add-in, which offers more options for generating reports from process data (Experion HS 2018) .

Figure 3.7 All stations are connected to the same Experion HS History system *(Experion HS 2018)*.

Unlike the SCADA system currently installed, the new Experion HS system will be installed in the general station network, as shown in *Figure 3.3*. Previously we could only see the control displays on the

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tools and products designed to prevent, detect and mitigate abnormal situation that affect process safety in the control operations environment (ASM 2019).

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Honeywell HCiW07-TE screen, attached to the rest of the system. With the new system, the LPG unload and synthesis process can be controlled from all the stations of the plant, or just from those that are wanted.

It has been decided to design the new displays that are going to be made based on a new trend that is presented increasingly in SCADA displays in the industry. This new design trend is stipulated by the ISA 101, which sets standards and recommendations for human-machine interfaces (HMI).

The ISA 101 main features are:

- An HMI system should not use the graphic toolkits used until now and its design should be based only on the P&ID[1].
- Object animation should be simple and effective, as well as navigation through the display system.
- Consistent colours, process objects from a common toolkit, embedded trends will be used.
- Grey backgrounds will be used to minimize glare and objects high contrast.
- Bright colours should only be used for alarms and abnormal situations. These colours should not be used for other purposes in order to relate certain colours to specific events.
- Use more graphs instead of indicators that only give instantaneous information.

(Hawryo 2016).
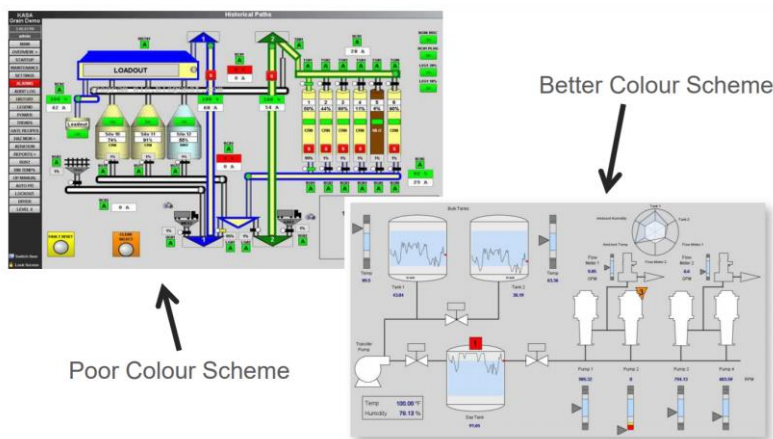
Figure 3.8 ISA 101 aplication example *(Nasby 2017)*.

Section 3.3 will detail the entire design and configuration process of the Experion HS SCADA system.

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[1] Piping and instrumentation diagram (P&ID) is a diagram showing the process flow in the pipe system, as well as the installed equipment and instrumentation.

3.1.5. Communications

Thanks to the new PLC and the new SCADA system chosen, communications are greatly simplified compared to most systems in this sector of the industry. As can be seen in **Figure *3.3***, the entire system will be connected to the same redundant Ethernet network, so you only need to configure the PLC to connect properly to Experion HS.

As previously mentioned, a CPU simulator model 900CP1-200, Release 151.1 was used to work and develop the project before its start-up. To simulate that the PLC is connected to the same network as the development station, the 3 Network Adapter of the virtual machine must be configured in "Bridged" mode, this mode simulates that the virtual machine is in the same address as the Host.
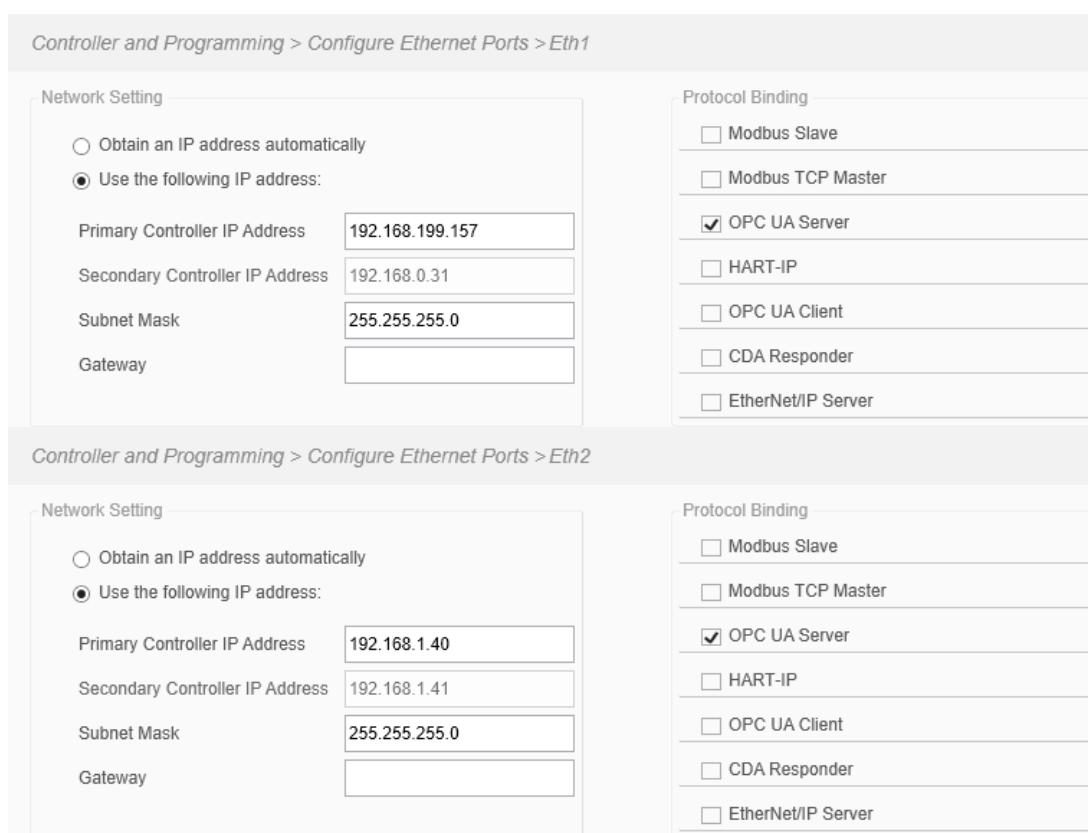
Figure 3.9 ControlEdge PLC Ethernet configuration (Source: ControlEdge Builder Configuration)

To configure the PLC communications, it must be accessed from the ControlEdge Builder, more specifically in the Configuration Window section. Once there, it is possible to access the Ethernet ports configuration, the first two ports will require configuration, assigning them the IP address in which PLC has been configured, that is, the system common network.

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The protocol is then selected in the same Ethernet port configuration section. The protocol that will be used to communicate in this system is the OPC UA, this is a multi-platform industrial communication technology, open, service-oriented, secure, and with extensive information models. This technology perfectly complements the communication between ControlEdge PLC and Experion HS.

As mentioned in the previous sections ControlEdge PLC and Experion HS have a direct integration, therefore, in our case, the stations connected to the network that you want to include in the Experion system have to be configured. The configuration of the communication and the integration between PLC and SCADA will be detailed in the section 3.3.2.

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3.2. PLC program

This section will present all the PLC configuration and programming built with the ControlEdge Builder software. The software is divided into two parts: One of them for the configuration of various PLC features (Configuration Window) and the other one for the development of the PLC program.

To be able to start developing the program it is necessary to do a previous configuration:

- When the program is created the CPU must be chosen, in this case 900CP1.
- Name the PLC to work with, configure the starting status of the PLC, configure whether it is a redundant PLC or not and configure the Ethernet ports (see section 3.1.5).
- Configure the date, time and access password to connect the PLC.
- Within the program development window, the Hardware window must be opened, from there the PLC type must be configured, to develop before the start-up a simulator is used that involves a special configuration. PLC type: eCLR. Processor type: I486_LE_GCC3.
- The program code execution type should be configured in this case: Cyclic Task type. The specific configuration can be seen in **Figure *3.10***.
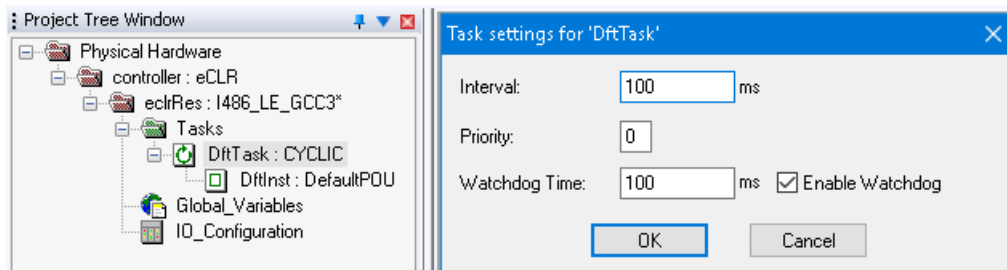
- **Figure 3.10** PLC program task setting (Source: Honeywell ControlEdge Builder)

- Lastly, in the libraries window the libraries you want to activate or import have to be configured. Unlike the RTU Builder, in ControlEdge Builder a new native Honeywell library can be imported. This library contains device control FB and other more complete and perfected algorithms. The operation of the new FBs used will be detailed in the following sections.

The following sections will detail the variables declaration and the I/O configuration; it will also explain the entire process automation program, the new algorithms used and the differences between the used in the previous program. Lastly, the development of the simulation system and its justification will be detailed.

3.2.1. Program structure

As in the previous program, this one is structured in different worksheets that are divided according to their function. By making the automation program more complete, this project has been divided into more specific parts, in order to be able to navigate more easily and not have too much programming blocks gathering in a single worksheet.

The programme will be divided into the following parts:

- **Main:** This worksheet contains the part of the program related to the start conditions of the process and the determination of products set points.
- **Finish:** The conditions to finish the process and restart the conditions are located in this worksheet.
- **Alarm_Locks:** The conditions to stop the process, interlock devices and the alarm management are programmed in this worksheet.
- **Simulation_Devices:** This small section manages the activation and control of the devices to be able to work in simulation mode.
- **Simulation_BUTANE and Simulation_PROPANE:** In these worksheets, you will find the simulation programming of the analog inputs of each product.
- **Status_Word:** The status word of the process is configured among other tasks.
- **Analog_IN:** The system's analog inputs are configured.
- **Analog_IN_2:** Auxiliary configuration of the analog pressure inputs.
- **Valves_Devices:** Management of the automation of the system's automatic valves.
- **Pumps_Devices:** Management of the automation of the system's centrifugal pumps.
- **Totalisers:** Configuration of the flowmeters totalization for each product, calculation of the instantaneous product density and calculation of final product variables of interest.
- **PID_1 and PID_2:** The instantaneous vapour pressure of butane and propane respectively is calculated and the PID control algorithm is implemented for each automatic regulating valve.

3.2.2. Variables definition and I/O configuration

As explained in section 3.1.3, the variable types are the same as in RTU Builder. This section will present the internal variables definition, the choice of external variables and its justification and the I/O variables configuration.

As already mentioned, internal variables are, all those that are used in the program and are automatically created in the DefaultPOUV list. FBs are also referenced in the list as internal variables, but they can never be declared as external variables.

62	FINISHED	BOOL	VAR_EXTE...	Status 7
63	FT_1	ANALOG_INPUT...	VAR_EXTE...	BUTANE flowmetter Anal_In
64	FT_1_HWDACA	HWDACA	VAR	HWDACA BUTANE flow
65	FT_2	ANALOG_INPUT...	VAR_EXTE...	PROPANE flowmetter Anal_In
66	FT_2_HWDACA	HWDACA	VAR	HWDACA PROPANE flow
67	GLP_A	REAL	VAR_EXTE...	Desired total quantity of LPG to unload
68	GLP_P	REAL	VAR_EXTE...	Percentage of butane in LPG desired

Figure 3.11 Example of internal variables declaration (Source: Honeywell ControlEdge Builder)

The external variables that have been chosen have increased as the displays have been developed and taken their final form. External variables will be used to display data, to animate an object, or to write a variable value in the control interface. Being able to differentiate between internal and external variables simplifies the integration of the points with the Experion HS system, as only the variables of interest have to be configured. Section 3.3.1 and 3.3.2 details the use and integration of these variables.

Thanks to ControlEdge Builder the I/O modules configuration is simplified and speeded up a lot. Next, the configuration of the 3 I/O modules used in this system will be shown, as well as some examples of analog or digital inputs or outputs configuration.

Figure 3.12 Universal I/O module configuration

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First, the I/O module to be configured must be selected; section 3.1.2 specifies all the necessary models. It is necessary to select the number of rack in which it will be installed and its position, the slot, that will be connected. It is also possible to configure the scanning time and universal I/O modules, I/O type have to be configured.

Figure 3.13 Channel 1: Analog Input configuration. Channel 14: Digital Input configuration.
(Source: Honeywell ControlEdge Builder)

The variables previously declared as I/O must be linked to each channel of the I/O module, which generates a unique address for each of the I/O variables. The I/O module does not need to use all ports; they can be left empty without configuration, to use in future expansions.

The following parameters must be configured for analog inputs or outputs: sensor type, whether the device is HART type or not, maximum and minimum ranges, unit of measurement and fail-safe value. For digital devices, the following must be configured: Addressing type and state description.

3.2.3. Process managing

This section will include most of the program; the process control is built in different worksheets, which will be explained in detail below.

To begin with, the process has been divided into states, in each one actions will be performed. Next, there is a GRAFCET, a step and transition control diagram, which schematise the different states of the process and the transitions between them.
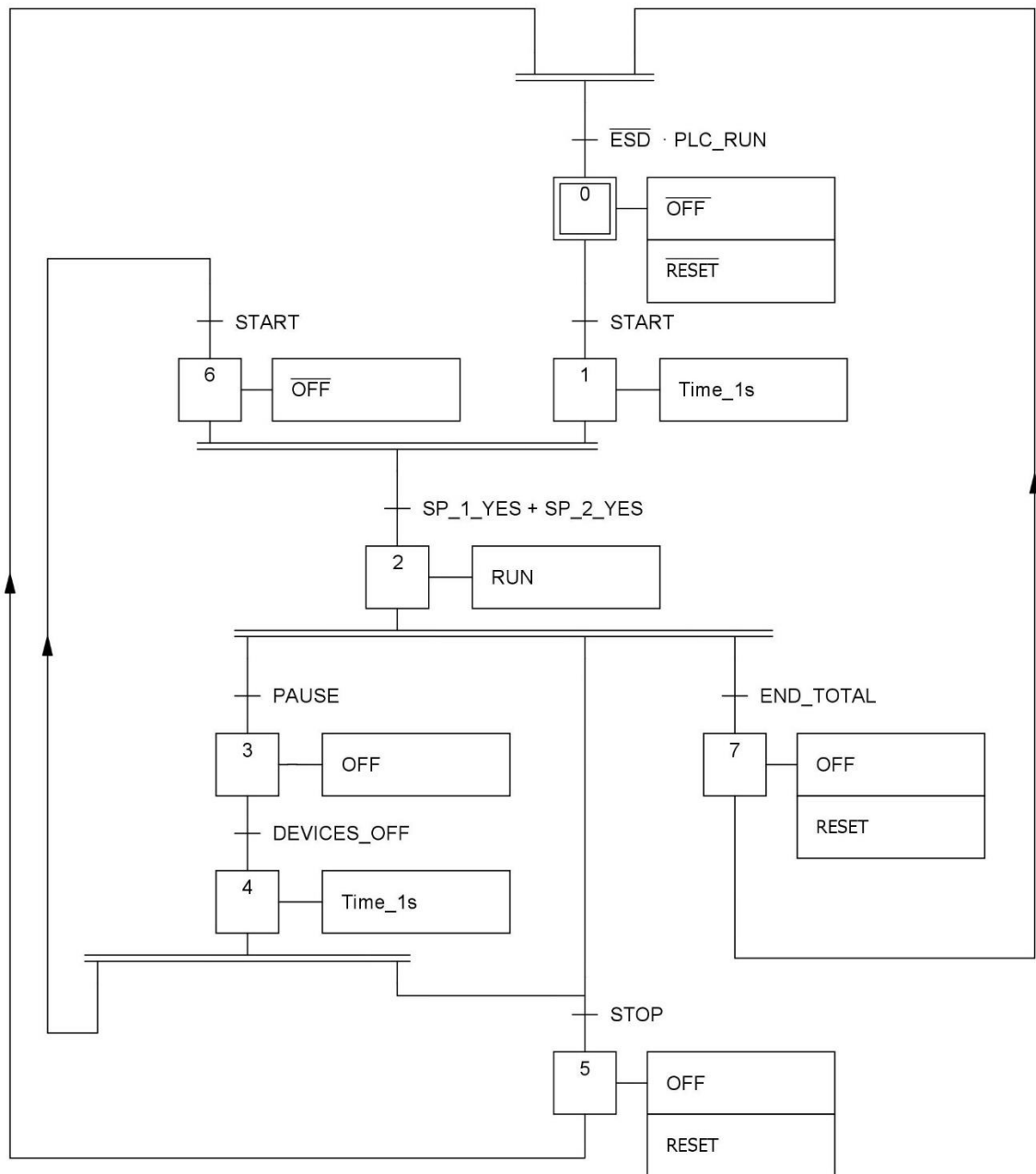
Figure 3.14 Process Status GRAFCET

Where:

- Steps numbered from 0 to 7 are the process states, listed from 0 to 7: IDLE, STARTING, RUNNING, PAUSING, PAUSED, STOPPING, RESTARTING and FINISHED.
- ESD is the activation of the emergency shutdown button.
- PLC_RUN is a variable that is automatically created and activated when the PLC is connected and running.
- START, PAUSE and STOP are the clicked button indicators for process start, process pause and process stop buttons respectively.
- DEVICES_OFF is the check that all devices are closed or turned off.
- SP_1_YES and SP_2_YES are the confirmation that you want to unload product 1 or 2 respectively.
- END_TOTAL is the confirmation that the unload has been successfully completed.
- OFF is the command to stop the process and RUN is the process activation.
- The RESET action consists of resetting all the initial conditions to zero, such as: Resetting the desired quantity of product, ending the operation of the totalizers, among others.

As we can see it is a process with very few variations, so it has been programmed as a continuous process, each unload will start from the IDLE state.
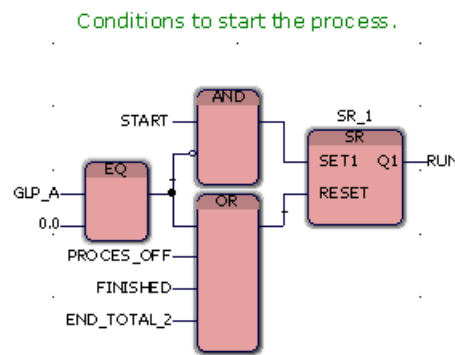
Figure 3.15 PLC program content. Worksheet: Main (Source: ControlEdge Builder)

First, an "SR" block determines the value of the RUN variable, which activates the process. In order to activate RUN, there must be a unload setpoint greater than zero and the START button must be clicked. To deactivate it, the process stop variable must be activated or the unload must end.

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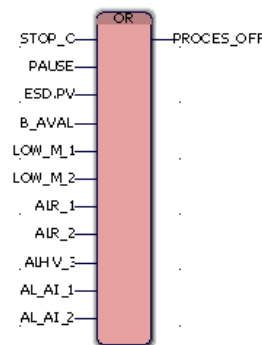
Figure 3.16 PLC Program content. Worksheet: Alarms_Locks (Source: ControlEdge Builder)

To activate the previously mentioned stop process variable, the STOP_O (Stop order), PAUSE or Emergency Shutdown button must be activated, also if any alarm or security condition is activated.

The process control buttons (START, STOP and PAUSE), which are manually activated from the control interface, have been programmed as momentary switches, i.e. they will return to their inactive position if several events occur. They are also restricted to certain process states:

- The START button can only be used in the IDLE and PAUSED states.
- The PAUSE button can only be used in the RUNNING state.
- The STOP button can only be used in the RUNNING, PAUSING and PAUSED states.

The operator will write the desired value of total quantity to unload, GLP_A, will select if the quantity measurement units is Litres or Kilograms, UNITS, and will write the percentage of butane of the mixture, GLP_P. With this information, it will be calculated with the blocks of **Figure 3.17**, butane and propane quantity to unload, M_SP_1 and M_SP_2 respectively. It should be noted that to calculate the quantity in litres, the ambient temperature density of the products is used.
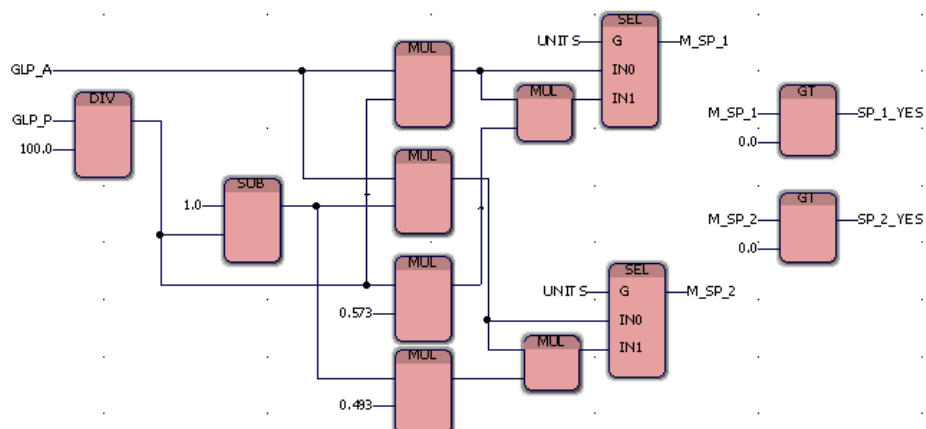
Figure 3.17 PLC program content. Worksheet: Main (Source: ControlEdge Builder)

As a specific request from the client, they wanted to be able to have the opportunity to load only butane or propane and in case one unloading line had a failure, it could be loaded without problem from the other line. In order to isolate the control of each unload line, the variables SP_1_YES and SP_2_YES are constantly consulted in the program, which indicate whether the butane and propane unload line, respectively, is required to make the desired LPG unloading.

When the quantity loaded, MC_1 and MC_2, of butane or propane reaches the SP of these, variables END_1 and END_2 are activated respectively. Then, according to the type of unload desired (Only butane, only propane or mixture of both); END_TOTAL_2 will be activated and the unload will be end. Last, when the unload is finished or when the STOP button is clicked, the initial LPG set points are restarted, therefore, all the conditions are in place to return to the initial IDLE state.

In **Figure** *3.18* the configuration of the status word can be seen. The STATUS variable is INT type, for each condition that determines a state of the process, an integer is added to it, and it is multiplied by the value of the condition if it is activated or not, therefore only the active states are added in the final summation.
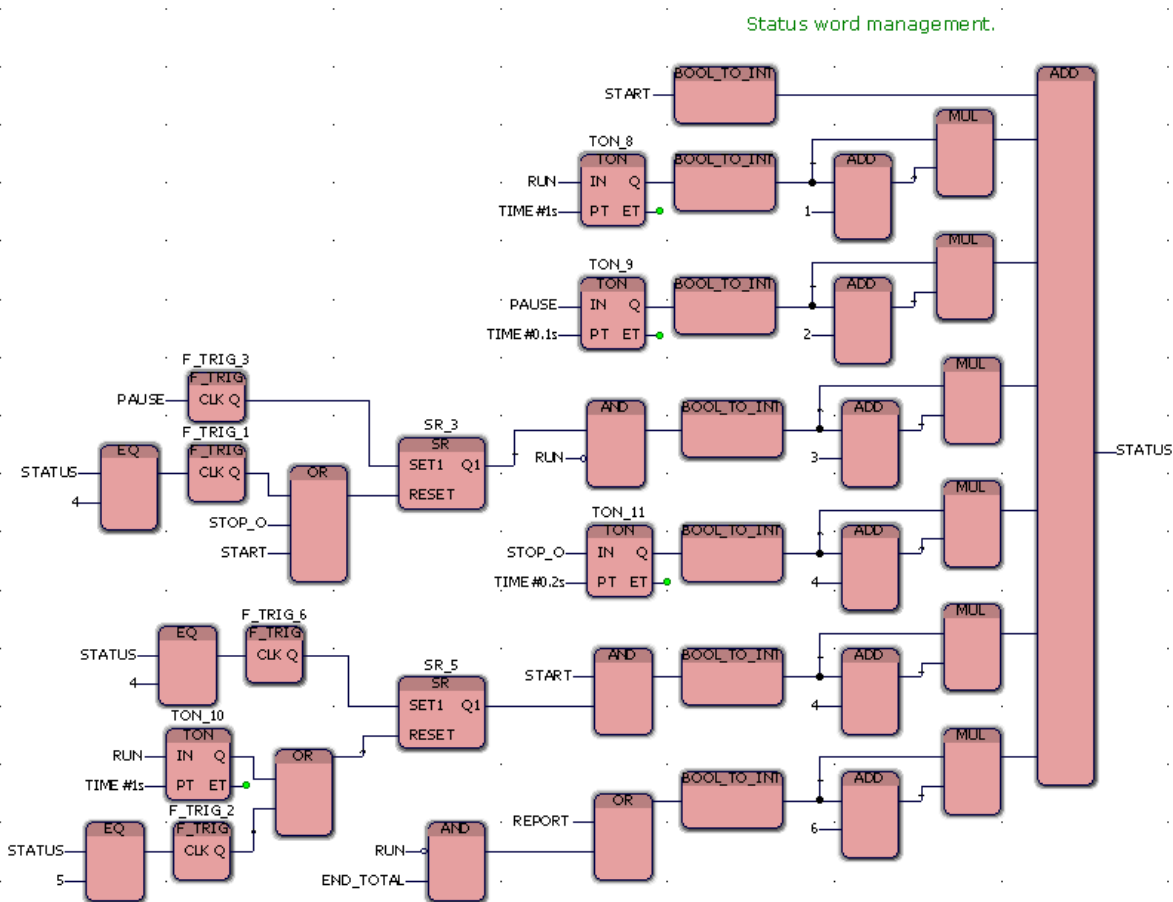
Figure 3.18 PLC Program content. Worksheet: Status_Word (Source: ControlEdge Builder)

A brief explanation of each state's conditions:

- IDLE: Any condition is active.
- STARTING: The START variable is active. START is deactivated when RUN has been activated for 1 second.
- RUNNING: As long as RUN has been activated for more than 1 second.
- PAUSING: While PAUSE is active.
- PAUSED: When the devices are stopped or STOP_O is enabled, PAUSE is disabled. When the falling edge of the PAUSE variable is detected, the PAUSED state is activated.
- STOPPING: While the STOP_0 is active. It is deactivated once all devices in the process have stopped.
- RESTARTING: It is activated if START is clicked and it is detected that the state is no longer PAUSED. This state will not happen after a stop, only after a pause.
- FINISHED: It is activated when the unload end is detected, it is deactivated when the REPORT window in the control interface is quit, this will be detailed in section 3.3.1.

All the system configuration process states, has already been presented, now the operation of the RUNNING state will be explained, in this state the system actuators are operated. Another GRAFCET is created to visualize the product unloading process (**Figure *3.19***).

If it is necessary to unload product 1 or 2, SP_1_YES and SP_2_YES respectively, activate the opening of the whole corresponding unload line. If the unloading proceeds normally, PID will automatically regulate the automatic regulating valve until the unloading end is activated.

Once the unload is finished, the devices will be progressively closed, each unloading line separately. First, the supply valves will be closed, all remaining material in the pipelines will be pumped and the centrifugal pumps and automatic regulating valves will be switched off.

In the last step, the unloading valve will be closed. This procedure will avoid that residues remain in the piping system that could affect later unloads.

When STOP or PAUSE is activated, the system stops all devices. When all the devices are turned off, if PAUSE has been clicked, the system waits again for the START order to return to the first state and continue the pending unload.

If STOP has been clicked, the unload set points will be restarted and the IDLE status will return to wait for START to start a new unload. In the same way, when unload is finished successfully, if DONE is activated, it will proceed in the same way as STOP, restarting variables and returning to IDLE state.

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DONE is manually activated with the control interface by the operator to finish an unloading. START and RUN are shown together, because as explained above if the conditions are right they are both activated 1 second, **Figure** *3.15*.

During the automatic unloading process, alarms or safety conditions could happen that will stop the devices, activating the PROCESS_OFF variable, and affect the process.
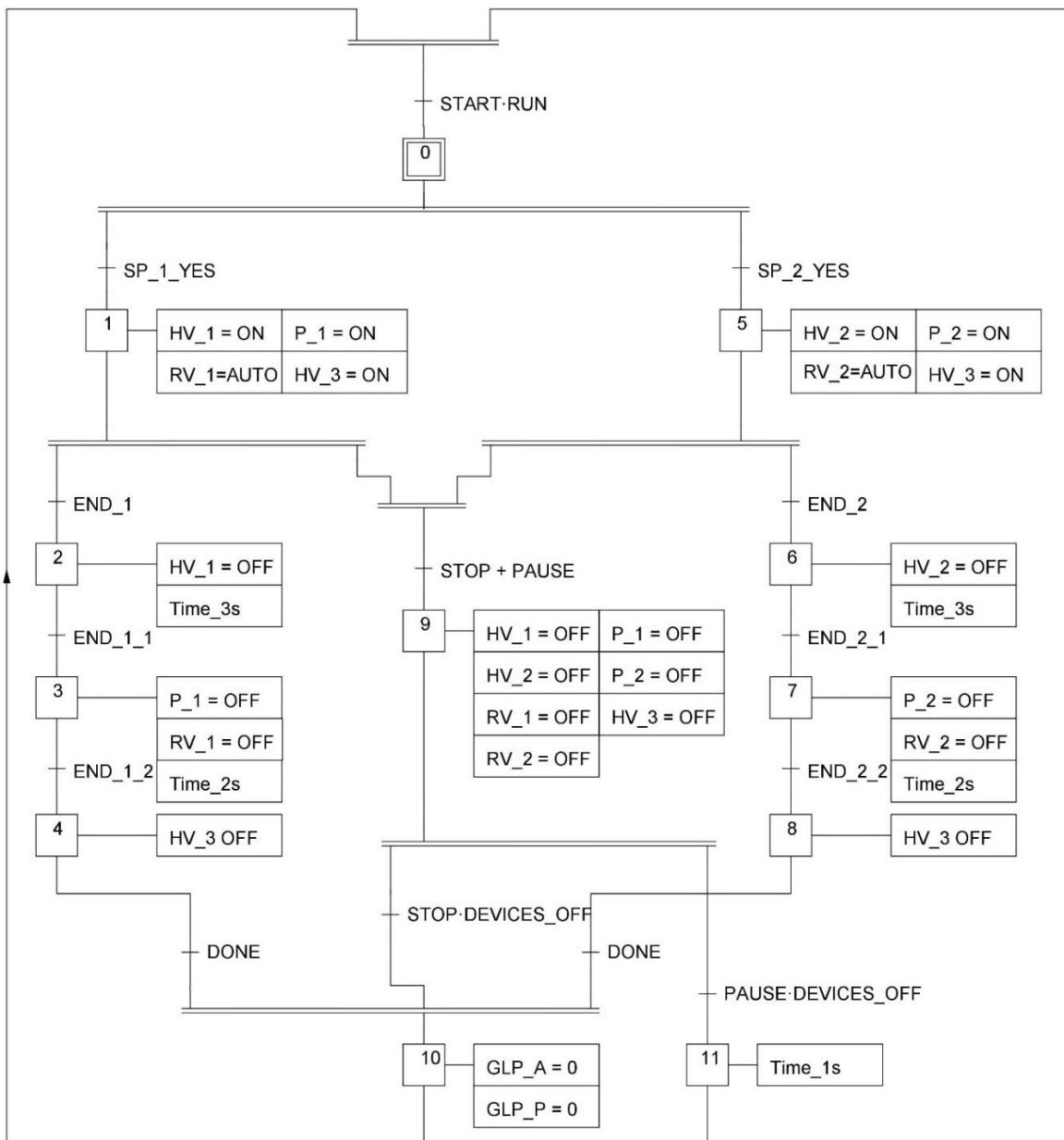

Figure 3.19 Running status GRAFCET

Physical device alarms are checked as well as logical failure alarms in the device programming blocks. Physical alarms are digital inputs and are consulted by adding the suffix '. PV' to the variable name, as shown in **Figure** *3.20*. It has also been programmed so that a failure in, for example, the centrifugal propane pump does not block a 100% butane load.
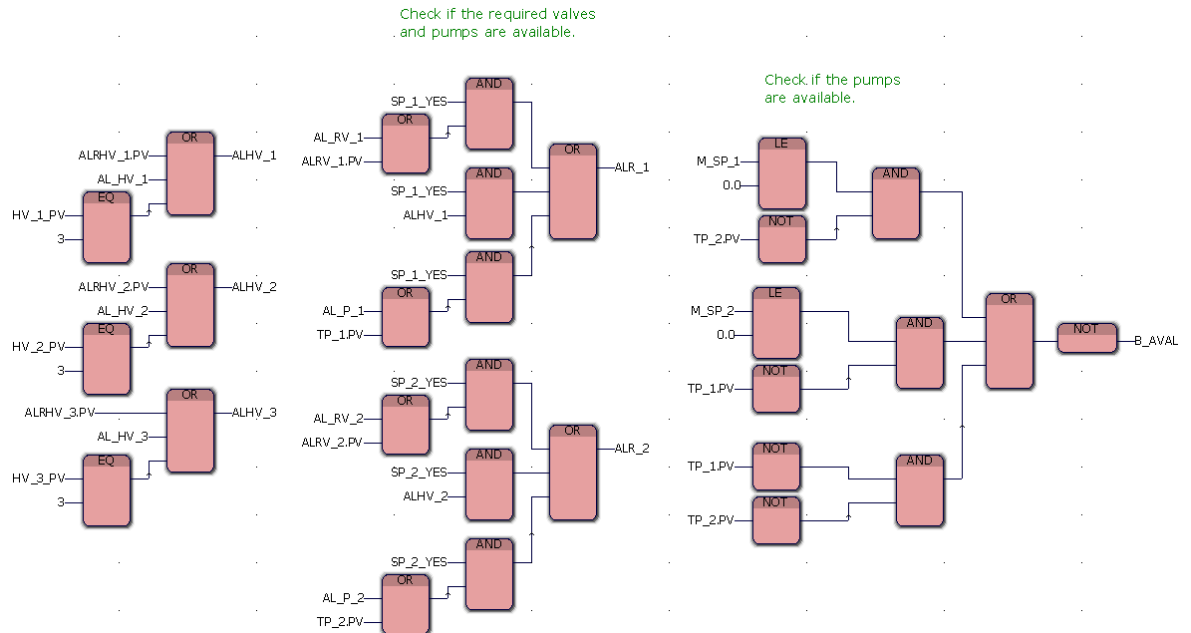
Figure 3.20 PLC Program content. Worksheet: Alarms_Locks (Source: ControlEdge Builder)

Lastly, the possible faults produced by the analog inputs are checked, using the 'HWDACA' block (in **Figure** *3.21* the blue block). This FB belongs to the new Honeywell library of ControlEdge Builder; it is used to manage the analog inputs. The alarm outputs are connected to activate AL_AI_1 and AL_AI_2 in case of activation while a unload of the product being measured is required.
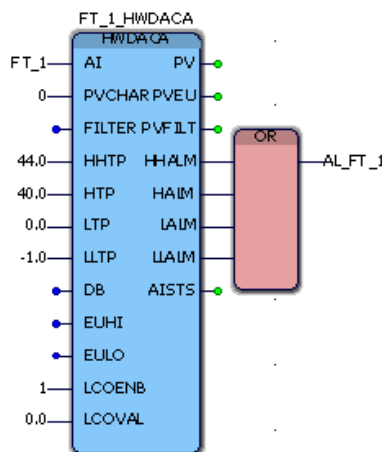
Figure 3.21 PLC Program content. Worksheet: Analog_IN (Source: ControlEdge Builder)

To calculate the butane and propane density the temperature measurement, **Equation *2.14*** and **Equation *2.15*** are used. In this way, the exact density of the product is obtained and no averages are used, with the density we can obtain the mass flow rate, in this case in kg/min, which is also displayed on the control interface. In the **Figure *3.22*** the calculation of the density of butane can be seen.
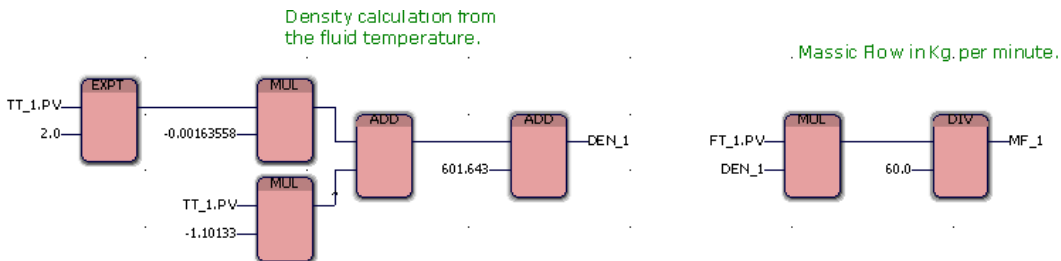
Figure 3.22 PLC Program content. Worksheet: Totalisers (Source: ControlEdge Builder)

The **Figure *3.23*** shows the use of FB from the new Honeywell library, HWTOTALISER, which is used to calculate the amount of product unloaded totalizing the flowmeter analog input.
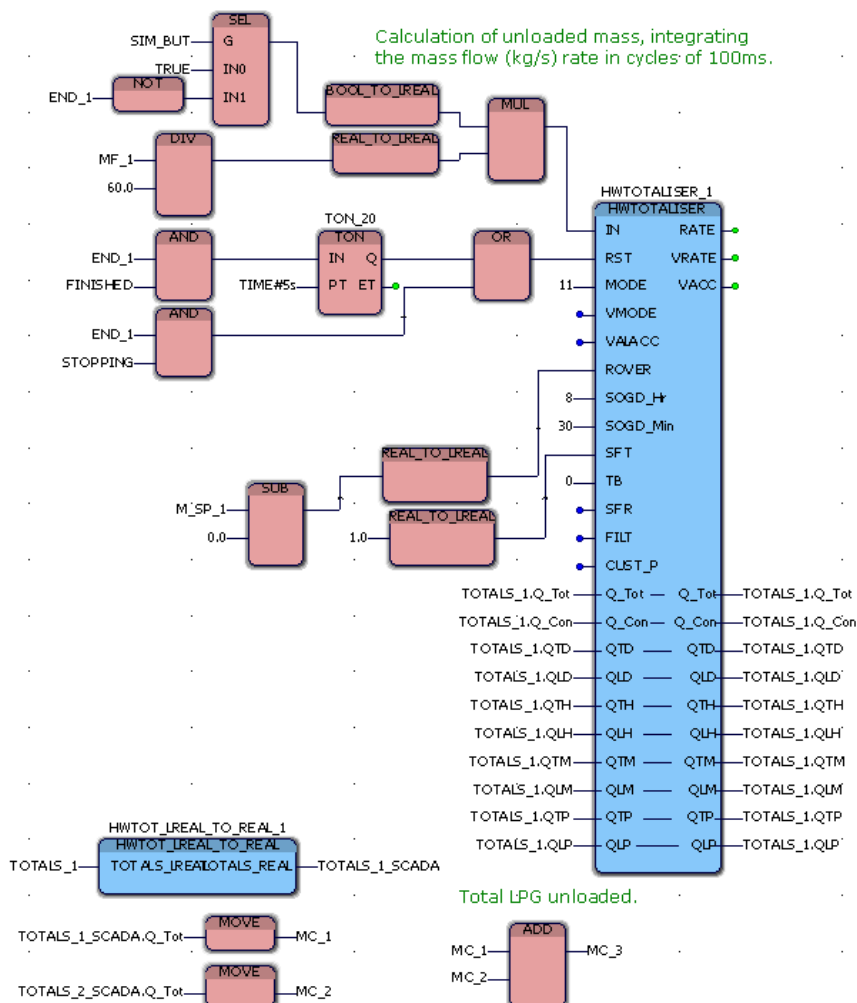
Figure 3.23 PLC Program content. Worksheet: Totalisers (Source: ControlEdge Builder)

This FB has more operation possibilities than the one used in the RTU Builder, you can configure what kind of input the FB receives with the MODE input and the operation mode when receiving NaN data. Because there is an analog signal flowmeter, it is configured to work in input integration mode and in kg/s units. For butane, for propane the HWTOTALISER configuration is the same, each one with its particular variables.

In the RST input of the block the conditions are configured to reset the totalizer count, if STOP is activated it resets instantaneously, if the unload is finished correctly, it waits until the last valve is closed to consider the remaining product of the pipes. You can also configure the rollover value, which, like the progressive shutdown times, must be measured at start-up to be more accurate.

The output of the HWTOTALISER is a data structure that is contained in the variable TOTALS_1_SCADA and is used to create a table of unloaded material data every hour, day, etc. For this program only the total of each unload is used, which is assigned to the variables MC_1 and MC_2 which summed are the total amount of unloaded LPG, MC_3.

In order to have more information in the control interface, two more variables are created related to the LPG unload. The M_P variable is created to see what percentage of the desired quantity has been unloaded and MC_P is the butane percentage of the unloaded LPG quantity.

M_P is described in **Equation *3.1*** **Equation *3.2*** and **Figure *3.24***. If the process is not running, the value is zero and to avoid a division by zero, as long as no GLP_A setpoint has been assigned, MC_3 will be divided by one.

MC_P is described in **Figure *3.25*** and **Equation *3.1*** **Equation *3.2***, but the equation is only applied if butane and propane both are unloaded, if the unloading is a single product, the values are automatically written in 100% or 0% in each case. Like M_P, to avoid a division by zero, while the MC_2 value is less than 1 kg, it will be divided by 1, as soon as its value is greater than 1 kg, the corresponding equation will be applied.

For both variables, if the calculated value is greater than 100%, due to a malfunction caused by a program execution time failure, it is set to 100% to avoid giving erroneous and confusing information.

$$M\_P = \frac{MC\_3}{GLP\_A} \cdot 100\% \qquad\qquad MC\_P = \frac{MC\_1}{MC\_1 + MC\_2} \cdot 100\%$$

$$\textbf{Equation 3.1} \qquad\qquad\qquad\qquad \textbf{Equation 3.2}$$
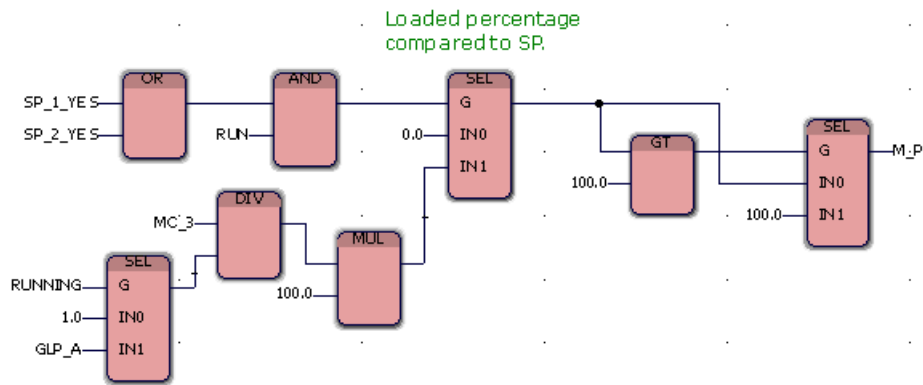
Figure 3.24 PLC Program content. Worksheet: Totalisers (Source: ControlEdge Builder)
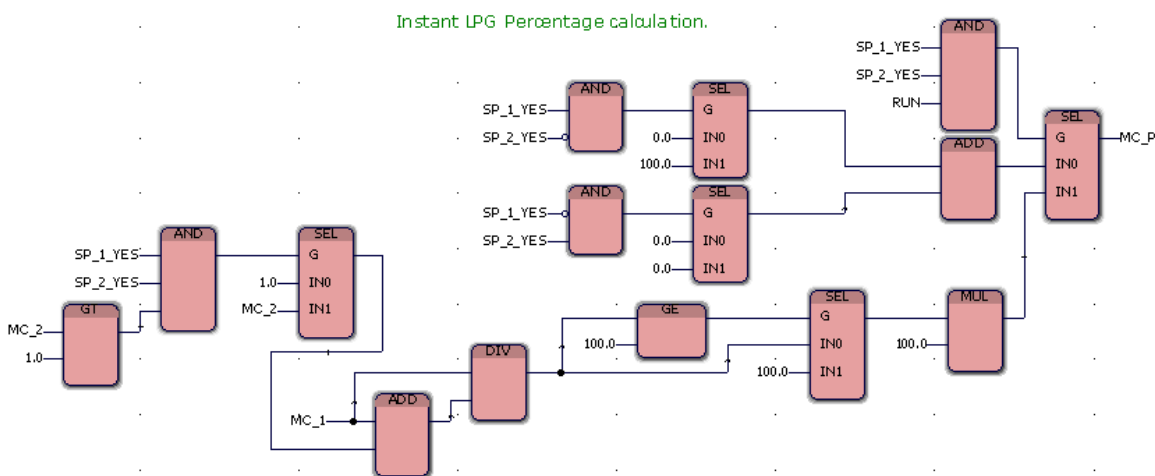

Figure 3.25 PLC Program content. Worksheet: Totalisers (Source: ControlEdge Builder)

At the end of the unload, an unloading report will be provided, in order to visualize exactly the real unloading parameters and be able to check the error percentage of the process automation. The report will show the total amount of unloaded product (MC_3), the percentage of butane of the unloaded product (MC_P) and the unloading time (TIME_LPG).

To visualize MC_3 and MC_P, once the unload ends these values return to 0 for the next unloading, for that reason they are copied before being restarted in an auxiliary variable to show it in the control interface.

To calculate the unload time, a TON acts as a counter is activated with a rising edge of the RUN variable, so if it is paused, the counter does not stop, it will only stop if STOP is activated or the unload ends.

The unloading report can be visualized once the unload has finished correctly, once the operator confirms as finished unload, the whole process is restarted and it returns to IDLE state. The report operation will be detailed in section 3.3.1.

3.2.4.   Devices managing

The new Honeywell library that incorporates ControlEdge Builder also has FB for device management, which are used in this program. The automatic regulating valves are controlled by a PID system FB and it will be detailed in the next section. The automatic valves and centrifugal pumps have been programmed with the HWSDV and HWMCC blocks respectively.

For the two-state automatic valve control block shown in the **Figure** *3.26*, two limit sensors are required for each valve, for open and closed confirmation; these are connected to the ZCS and ZSO inputs (The simulation of the digital inputs will be detailed in section 3.2.6). The OP and MD inputs are variables that will be controlled from Experion HS's predefined device screens, and are used to control the operating mode and process order in manual mode.
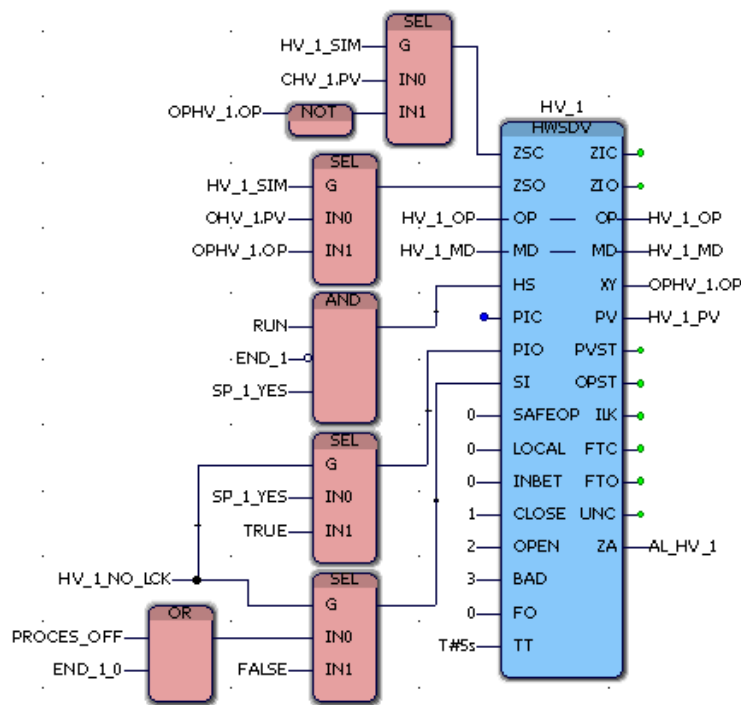
Figure 3.26 PLC Program content. Worksheet: Valves_Devices (Source: ControlEdge Builder)

In automatic mode the valve opening is controlled with HS input, which is active when RUN is active and some product is required for unloading, SP_1_YES or SP_2_YES. There are also three kinds of interlocks for the valve, the PIC, which are conditions for to close the valve, PIO, conditions to open the valve and SI, safety conditions that will override other controls and set the valve in the fail-safe position.

An additional configuration added to all devices is the deactivation of the interlocks; this is achieved by activating the variable, in **Figure** *3.26*, HV_1_NO_LCK, which deactivates SI and PIO interlocks. The safety position is determined in the SAFEOP input, in this program; the valve safe-position is closed.

Other HWSDV configurations are:

- **LOCAL:** When active, the valve control is performed manually from the physical valve, in this system, the valves cannot be operated manually, so the LOCAL input is zero.
- **FO**: The fail-safe position is configured in case of power failure, in this program, the fail-safe position is closed.
- **TT:** Maximum time for valve position change, if the valve takes longer than the time stipulated in TT, an alarm be activated. In this program, 5 seconds are set as a reference; the final configuration is made at start-up.
- **INVET, CLOSE, OPEN, BAD**: Integer value assignment for each possible valve state.

The outputs of the HWSDV are XY, the digital output that will control the automatic valve is connected. PV output provides an INT data to consult the valve status. ZA is the common alarm for the whole HWSDV block, this signal will be used to supervise the valve alarms.

To control the centrifugal pumps of the system the HWMCC FB is used (Blue FB in **Figure** *3.27*), which operates very similarly to the HWSDV, therefore, only the configuration and operating differences between these FB will be explained. This FB contemplates pumps that can run in reverse mode, for this process, they have only been configured for two states, forward run and stop.
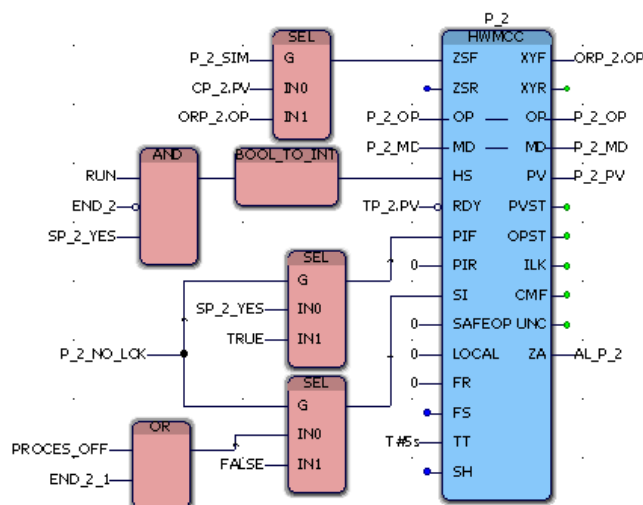
Figure 3.27 PLC Program content. Worksheet: Pumps_Devices (Source: ControlEdge Builder)

The start and stop confirmation digital input is connected to the ZSF input, the ZSR input is for reverse run confirmation, it is not used. The other digital input, which indicates a pump fault, is connected inversely to the RDY input, if the input is active, the pump can be managed. The PIF and PIR inputs allows forward run and reverse run respectively. Lastly, FR is used to allow the transition from forward to reverse run. The outputs are the same as for the HWSDV, but in this case, only the XYF output is connected, which gives the forward run command.

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3.2.5. PID configuration

The automatic regulating valves are controlled by a PID system, which is managed by the new FB HWPID. The calculation of the pressure set point to achieve a liquid unload is explained below.

Equation *2.5* represents the Antoine's equation used to determine the vapour pressure, for butane and propane in this process. To have liquid products unloaded and mixed, it is necessary to work at a higher pressure than vapour pressure.

$$y = 10^{-2} \cdot e^{\left(0.15 + 13.98 - \frac{2292}{(x+273.15)-27.8}\right)}$$

+0.15 to be above the critical line

$$y = 10^{-2} \cdot e^{\left(13.98 - \frac{2292}{(x+273.15)-27.86}\right)}$$

$$y = 0.001334 \cdot e^{\left(15.67 - \frac{2154.9}{x+238.58}\right)}$$

BUTANE vapour pressure

$$y = 10^{-2} \cdot e^{\left(0.05 + 13.71 - \frac{1873}{(x+273.15)-25.1}\right)}$$

+0.05 to be above the critical line

$$y = 10^{-2} \cdot e^{\left(13.71 - \frac{1873}{(x+273.15)-25.1}\right)}$$

$$y = 0.001334 \cdot e^{\left(15.72 - \frac{1872.46}{x+247.84}\right)}$$

PROPANE vapour pressure

Equation 3.3 (Green) and **Equation 3.4** (Red)   **Equation 3.5** (Green) and **Equation 3.6** (Red)

The blue equations represent the previously described Antoine's Equation, the red equations are the ones used in the previous program and the green equations are the ones used in the new program.
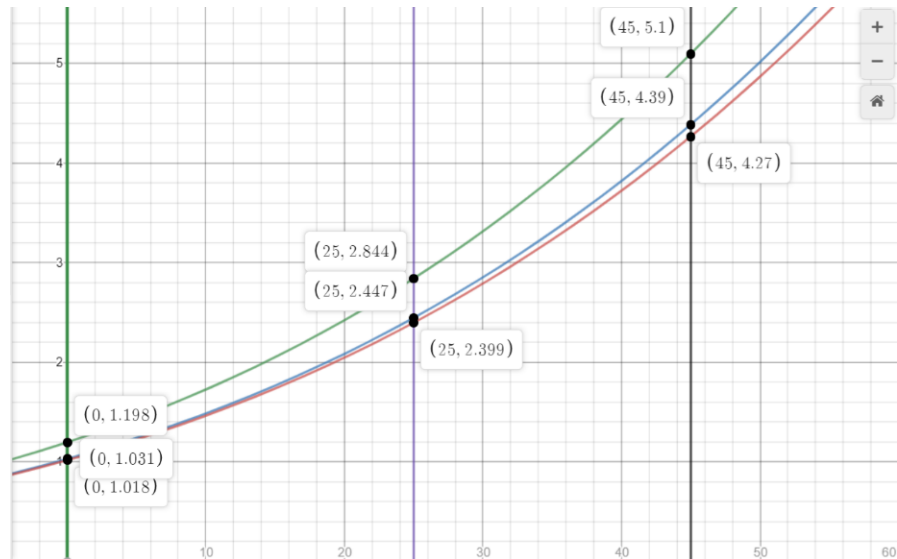
Figure 3.28 Butane vapour pressure equations
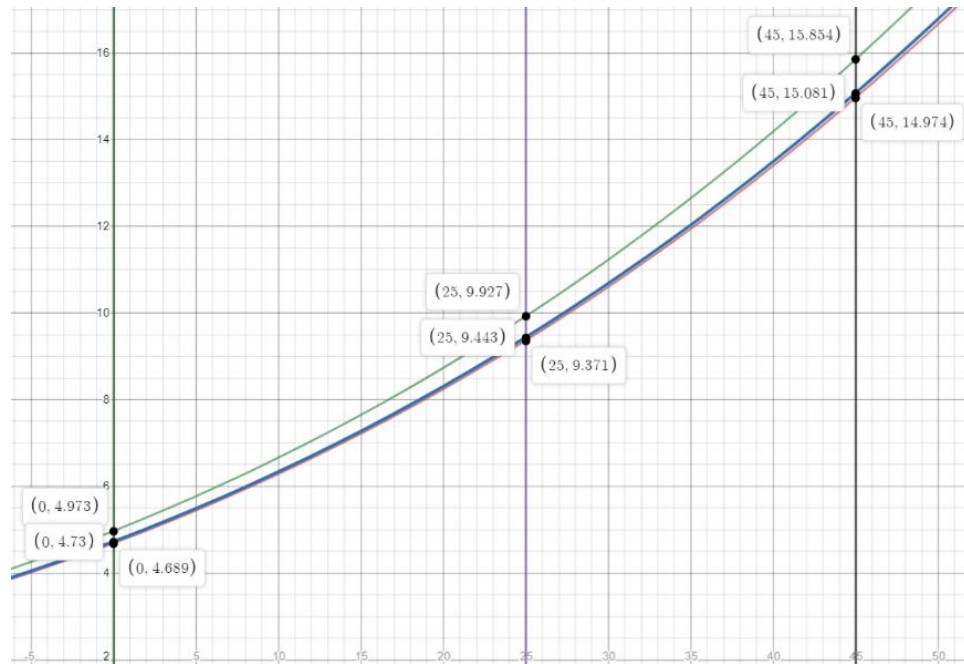
Figure 3.29 Propane vapour pressure equations

In the previous graph are represented all three mentioned equations. The real vapour pressure will follow the behaviour described by the blue graph, therefore, in order to be in liquid state, it will always be necessary to work in pressure-temperature points above the blue graph. To achieve this, in the old program a safety pressure was added to the calculated value, so that the red graph would rise linearly above the blue graph.

In the new program, the Antoine's equation has been modified (As shown in the **Figure** *3.30*) by adding an exponential value to ensure the calculated pressure is always higher than the vapour pressure described by the blue graph.
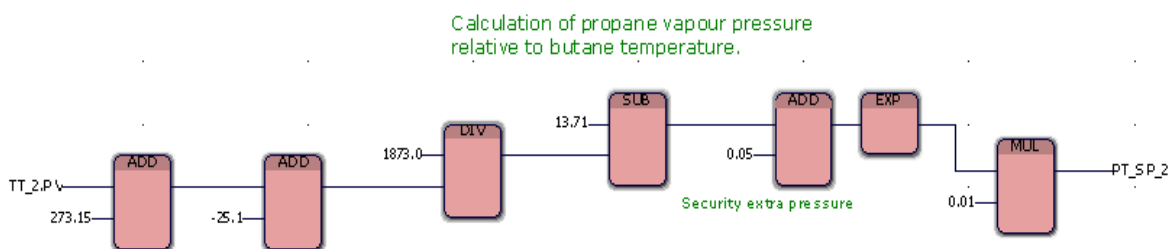
Figure 3.30 PLC Program content. Worksheet: PID_1 (Source: ControlEdge Builder)

To work with the HWPID block we will use an auxiliary copy of the pressure sensor analog input. With the HWAI2PV block (Left blue FB in **Figure** *3.31*), we will assign the ANALOG_TYPE variable, from PT_1 or PT_2 data structure, to the PT_1_AUX and PT_2_AUX variables respectively. Once the variable is copied, the data from the data structure is copied from PT_x to PT_x_AUX.
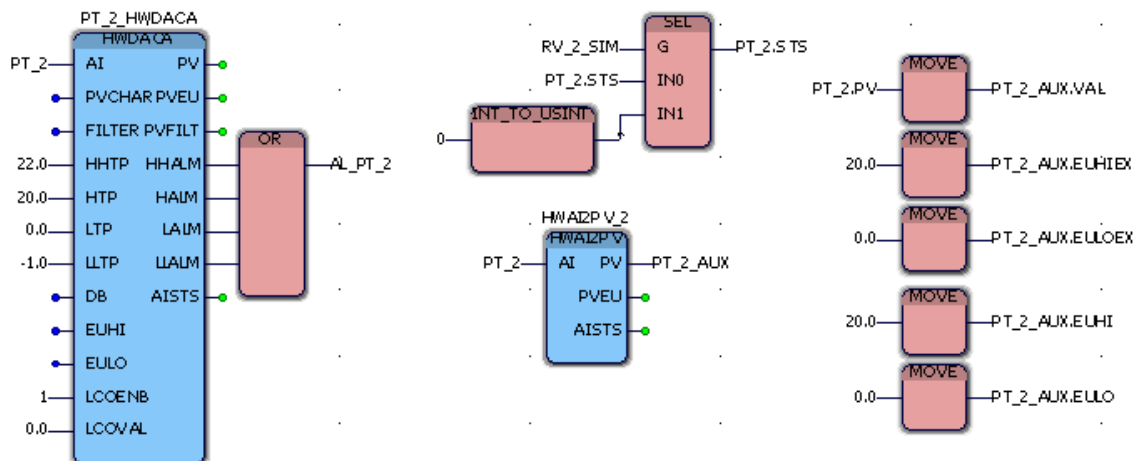
Figure 3.31 PLC Program content. Worksheet: Analog_IN_2 (Source: ControlEdge Builder)

An additional PID_2_TIMEOUT alarm has been configured, to those already predermined in HWPID. This alarm is activated when the value of the analog output variable, OPRC_1 or OPRC_2, is more than 5% away from PRV_1_AUX or PRV_2_AUX, for over 30s (This time is adjustable). PRV_1_AUX and PRV_2_AUX are an analog variable copy of the automatic regulating valve position input, this auxiliary copy is used to simulate the analog input function.
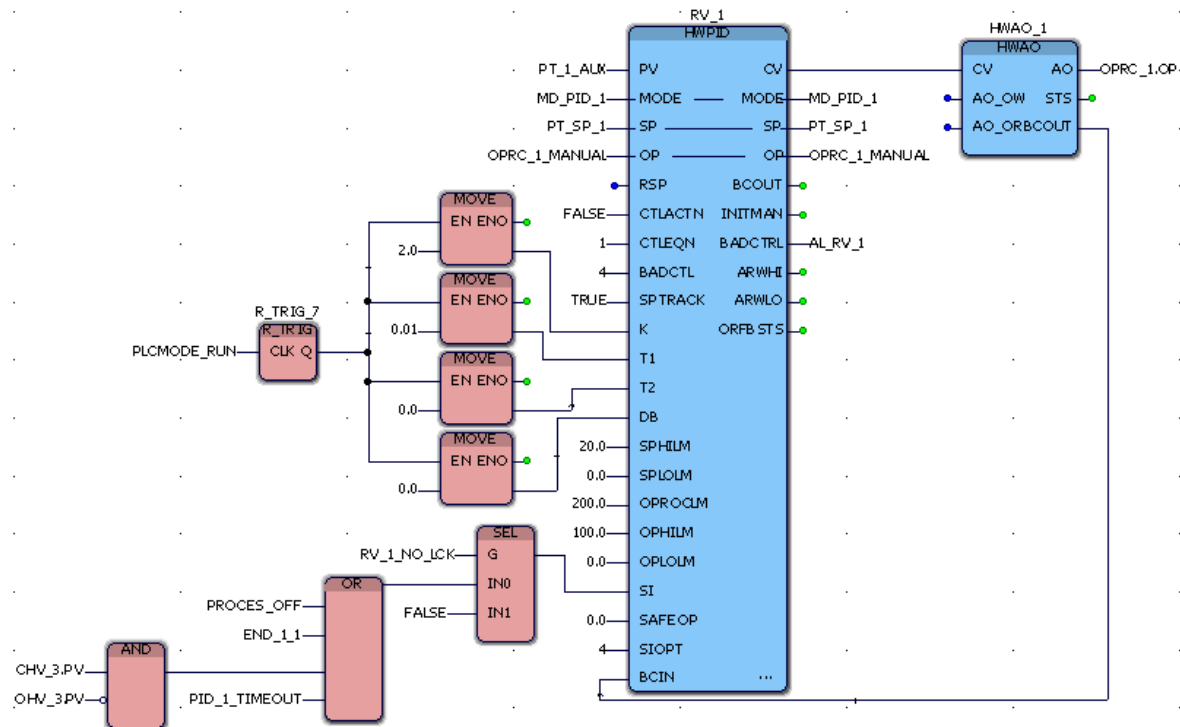
Figure 3.32 PLC Program content. Worksheet: PID_1 (Source: ControlEdge Builder)

HWPID is also from the new ControlEdge PLC library and is configured to have special integration into Experion HS. It is normally used together with an analog output management block, HWAO. The function of the FBs inputs and outputs is described below:

- **PV:** The process variable is connected, in this case the auxiliary copy of the pressure sensor analog input.
- **MODE:** Work mode selection. Manual, the process command is written manually or by logic, Automatic, the set point is written manually or by logic, Cascade, the set point is determined by another primary HWPID.
- **SP:** PID system set point for automatic mode.
- **OP:** PID system order process for manual mode.
- **RSP**: PID system set point for cascade mode.
- **CTLACTN:** Input to determine the operating direction of the PID system on the OP output. For this application the forward acting is used (CTLACTN=0), for a positive error between the PV and the SP, the output OP will increase its value; for a negative error, OP will reduce its value.
- **CTLEQN:** Choice of PID equation to use. For this program the PID equation B (CTLEQN=1) is used, the proportional and integral terms act on the PV-SP error and the derivative term acts on the PV changes. This equation is used to avoid spikes generated by the derivative action due to fast SP changes.
- **BDCTL:** Action selection when bad control alarm is activated. For this program in case of alarm, OP will be changed to its security value (BADCTL=4).
- **SPTRACK:** For manual mode, configure whether the SP tracks PV or not. For this program, this option is activated.
- **K, T1, T2 and DB:** Parameters of the PID equation. These parameters are tuned in the plant start-up, for simulations and demonstrations; the same values tuned in the previous program will be used. There is no derivative action or deadband, it is recommended for temperature-pressure PID control only use the proportional and derivative action.
- **SPHLIM and SPLOM:** Upper and lower limits respectively of the SP variable. In this case, the limits are the same as those given by the instrumentation, between 0 and 20 bars of pressure.
- **OPROCLM:** Configuration of the maximum output change rate in %/min.
- **OPHILM and OPLOLM:** Upper and lower limits respectively of the output variable OP. The automatic regulating valves are controlled with an analogue signal scaled between 0% and 100%.
- **SI:** Activation of PID interlocks. The automatic regulating valves stop when the process ends after the automatic bottom valves of the source tanks close, to avoid having remaining product in the piping system. They also interlock in case of position sensors failure of the final

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automatic unload valve. Like other devices, it is possible to deactivate the interlocks, in this case with the variables RV_1_NO_LCK and RV_2_NO_LCK.

- **SIOPT:** When interlocked, HWPID acts according to the action determined in the SIOPT input, in this case the same as in the BADCTL input. If SI is activated, the OP will change to its safety position (SIOPT=4).

- **SAFEOP:** OP safety position assignment for BADCTL and SIOPT. In this program the safety position is closed, 0.0%.

- **BCIN and BCOUT:** Input and output of the HWPID and HWAO blocks respectively that connect the PID system feedback.

- **CV and AO:** CV is the OP output in Analog_Type data type of the HWPID that is connected to the HWAO CV input. AO is the output OP in REAL data type; it is connected directly to the analog output OPRC_1 or OPRC_2.

- **BADCTRL:** General failure activation in the PID control, this output is used as a general internal alarm of the automatic regulating valves.

During plant start-up, the two PIDs will be tuned using the Ziegler-Nichols tuning method. This method allows the PID to be empirically tuned, without needing to know the equations of the plant or the controlled system.

The first method proposed by Ziegler and Nichols will be used, it is the most widely used and ideal method for systems that do not present behavioural curves with overshoots. For this method, the system must be adapted temporarily, in **Figure** *3.33* the system is observed in normal state, to apply the method the SP value will be written manually and the SP logic calculated in **Figure** *3.30* will be ignored.
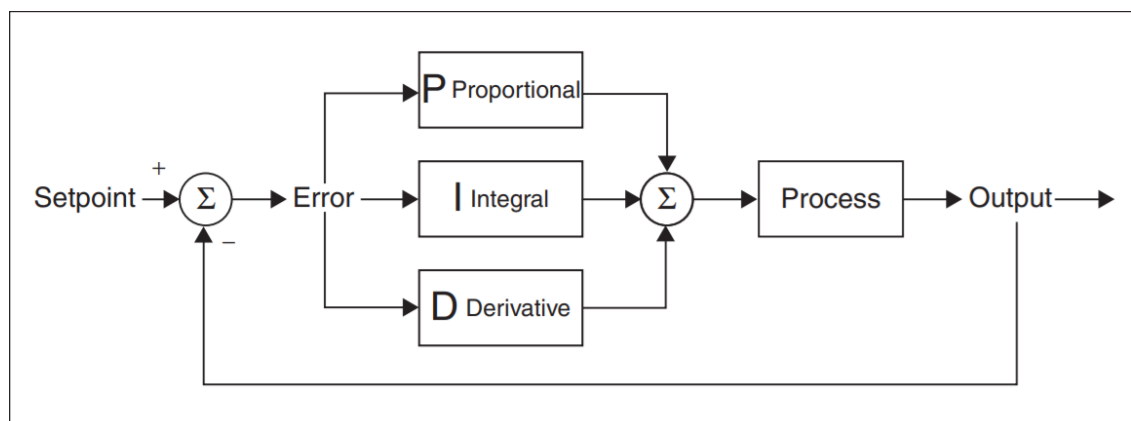
Figure 3.33 Closed-loop PID control system

The PID control response graph must be displayed to obtain the time measurements L and T shown in **Figure *3.34***. To get this data, a tangent line must be drawn at the inflection point of the PV process variable curve and the cut-off points with the 0 value and the desired SP value must be marked.
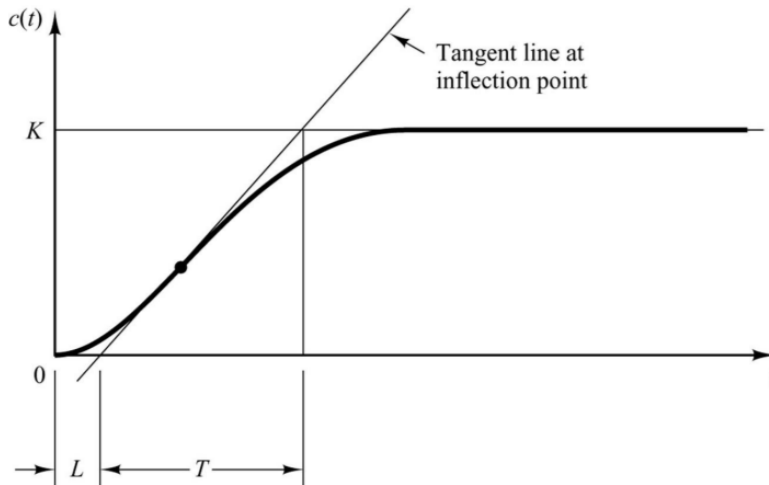
Figure 3.34 Example of system response to a step input

Once these two data have been obtained, a setting proposal can be calculated for the parameters of the PID control system. Following **Table *4***, we can calculate the parameters Kp, Ti (in seconds) and Td (in seconds) and apply them to the PID block configuration with the inputs K, T1 and T2 mentioned previously.

Table 4 Ziegler–Nichols PID parameters based on first method.

Type of Controller	K_p	T_i	T_d
P	$\dfrac{T}{L}$	∞	0
PI	$0.9\dfrac{T}{L}$	$\dfrac{L}{0.3}$	0
PID	$1.2\dfrac{T}{L}$	$2L$	$0.5L$

(Jenkins 2012).

3.2.6.   Simulation system programming

A process simulation system has been developed to check the correct operation of the automation and the control interface. The simulation is divided into two parts: the devices simulation and the thermodynamic process behavior simulation.

SIM_START and SIM_STOP variables can control the activation of the device simulation. SIM_RUN activates all device simulation variables: HV_1_SIM, P_2_SIM, RV_1_SIM, etc.

Devices simulation variables replace digital and analog inputs that inform about device operation. These are replaced by the given setpoint value, so there will never be a mismatch between the command and the execution of the device.
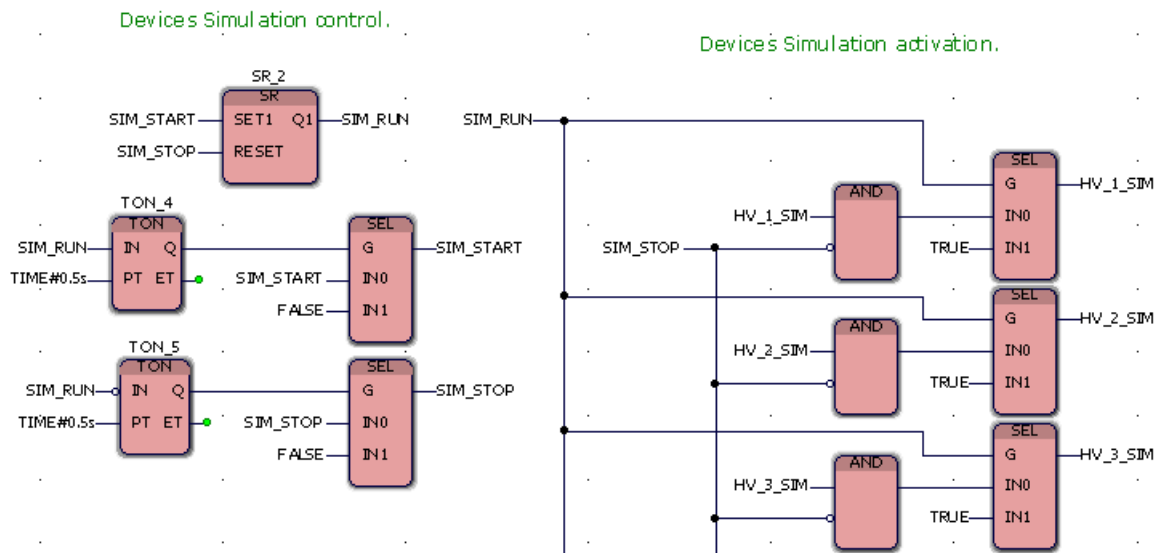
Figure 3.35 PLC Program content. Worksheet: Simulation_Devices (Source: ControlEdge Builder)

An example can be seen in **Figure *3.27*** where the ZSF input, if the simulation is active is the same as the XYF output. This is also used, for example for RV_2, the position check variable, PRV_2_AUX, in simulation mode is the same as the command calculated by the PID system; therefore, the PID_2_TIMEOUT alarm will never be activated.

The simulation of the thermodynamic behaviour of the process has been programmed as much as possible like the real behaviour of the physical variables of the process. For some thermodynamic behaviours, an equation has been approximated due to the difficulty of simulating the real behaviour. This second part of the simulation is used to visualize the tests and to make a demonstration of the operation; it is not a job of detailing the thermodynamic process.

The following examples are the simulation of the thermodynamic behaviour of butane, the simulation of butane or propane is directly activated on the control interface with the variables SIM_BUT and SIM_PROP.

When starting the butane simulation, if the system devices are closed and under the conditions described in *Figure 3.36*, an ambient pressure of 1 bar is simulated. When the process is paused, even if the devices are closed, the pressure value is maintained because the pipes have not been emptied. When the automatic bottom valve of the source tank is opened, the pressure becomes 2 bar, as shown in the **Figure** *3.37*. It is assumed that gases are stored in the tank at a higher pressure than atmospheric pressure.
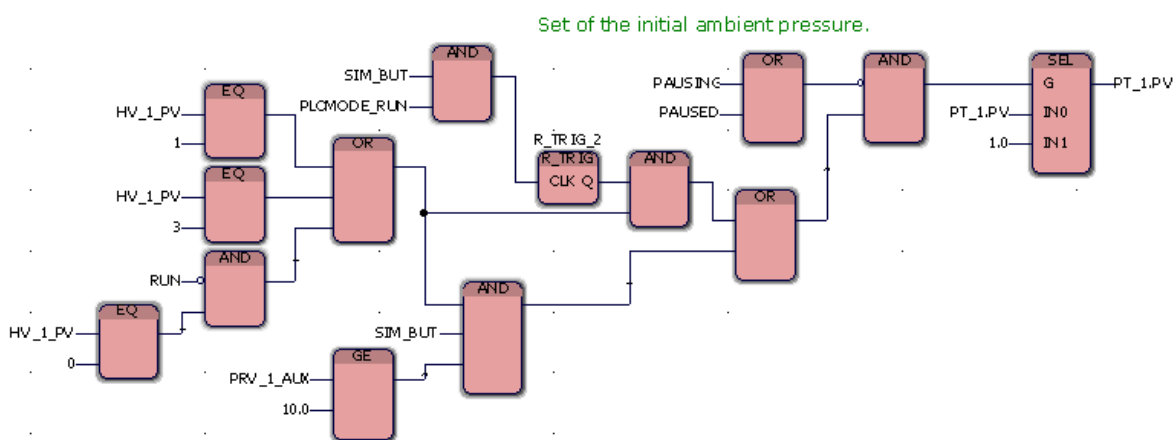
Figure 3.36 PLC Program content. Worksheet: Simulation_BUTANE (Source: ControlEdge Builder)
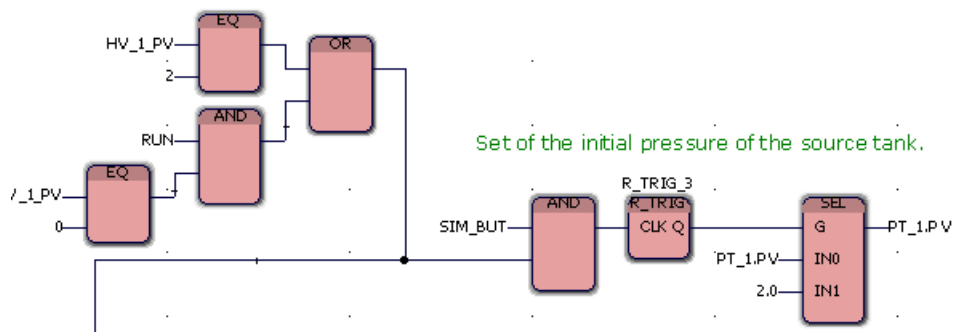
Figure 3.37 PLC Program content. Worksheet: Simulation_BUTANE (Source: ControlEdge Builder)

The most difficult variable to simulate is temperature, as a lot of events influence its value. The temperature will be simplified, the ambient temperature will be 25°C and when the process is running and the pressure is regulated, when it increases the temperature will also increase linearly. The simulated behaviour of the butane temperature is detailed below, in the **Figure** *3.38* you can see the programming of this simulation.

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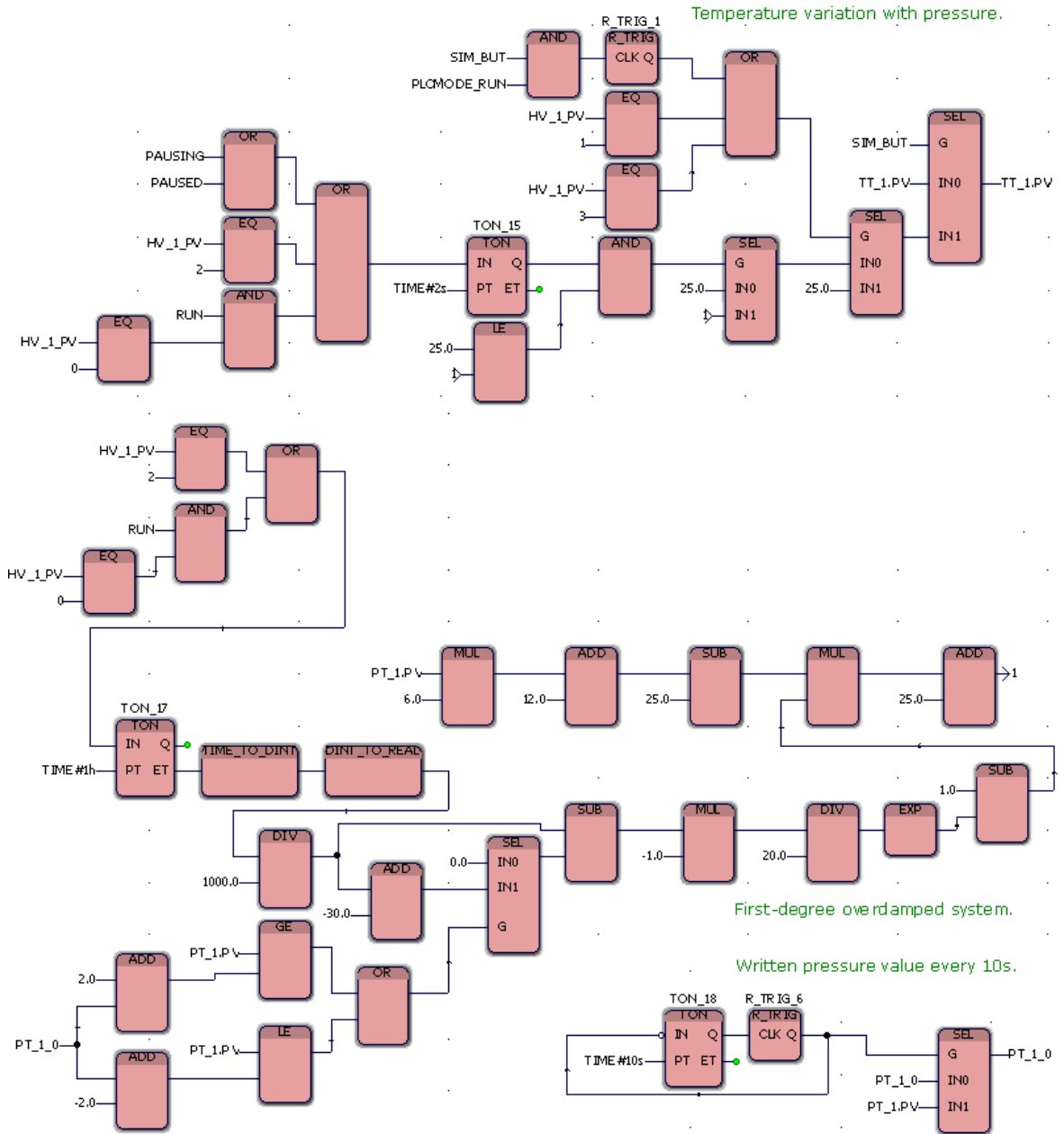BARCELONATECH
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Figure 3.38 PLC Program content. Worksheet: Simulation_BUTANE (Source: ControlEdge Builder)

If simulation is active and the bottom valve is closed, the ambient temperature is determined at 25°C. To simulate the variation of the temperature with the pressure, a linear equation is created and to simulate a more real behaviour an over-damped response is applied.

$$TT\_1 = Temp(p) \cdot (1 - e^{\frac{-t}{\tau}})$$

Equation 3.7

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In order to make the above equation with the available code blocks, a TON is used as a timer to simulate the t variable. Time constant (τ) is determined in 20s, in practice 99% of the maximum value is reached in a time $t_{PVmax} = 5\tau$, therefore it will reach the setpoint in 100s.

In addition, to soften temperature response to abrupt pressure changes, a system has been programmed. If there are changes of more than 2 bar in a period of 10s, 30s will be subtracted from the elapsed time, so the effect of the over-damped response is more accurate.

This temperature with an over-damped response will only write the analog input if its value is greater than the ambient temperature. It is made to avoid the red graph of **Figure 3.39** and simulate a more realistic temperature behaviour.
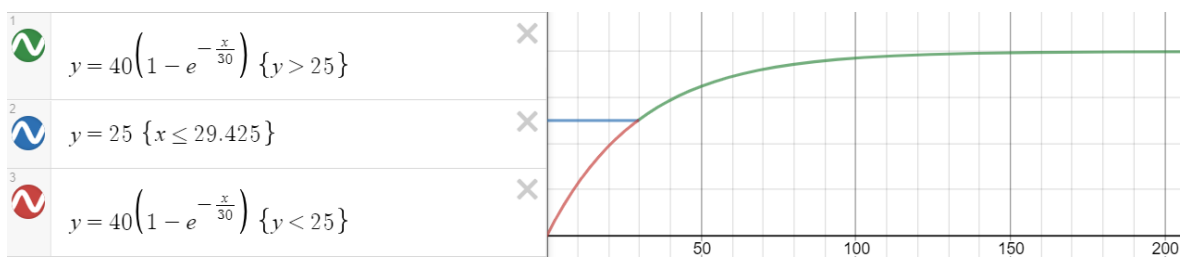
Figure 3.39 Example of temperature simulation behaviour, for a calculated value of 40 °C.

Equation 3.8 and **Equation 3.8**Equation **3.8** **Equation 3.9** are created to simulate the behaviour of temperature variation with pressure for butane and propane, approximate a direct linear behaviour between temperature and pressure. These equations have been adjusted to allow the PIDs to find an equilibrium position in simulation, that resembles a real equilibrium position.

$$T_{butane}(°C) = 6 \cdot p_{butane}(bar) + 12 \qquad\qquad T_{propane}(°C) = 2 \cdot p_{propane}(bar) + 12$$

<div style="display:flex; justify-content:space-between;">

Equation 3.8
Equation 3.9

</div>

In the **Figure 3.40** and **Figure 3.41**, you can see the combined behaviour of the pressure SP calculation and the simulation of the temperature variation with pressure. While simulating, the PID should find

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the same equilibrium point as the two points marked in each graph (for butane and propane respectively).
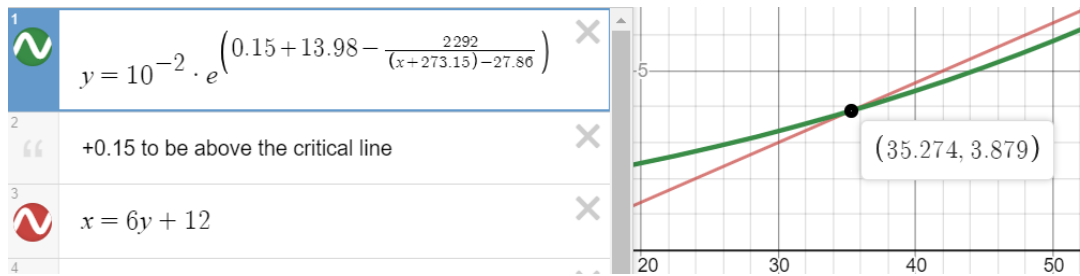

Figure 3.40 Butane pressure-temperature equilibrium point graph for PID control.
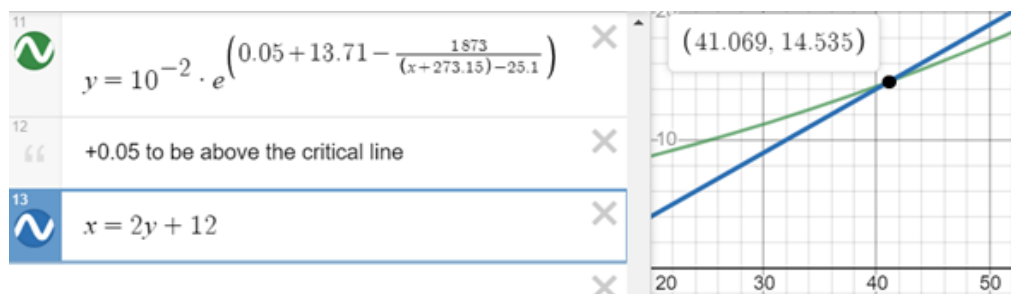

Figure 3.41 Propane pressure-temperature equilibrium point graph for PID control.

To simulate the behaviour of the volumetric flow through the pipes, an over-damped response has also been used, which is present in the operation of most hydraulic pumps.
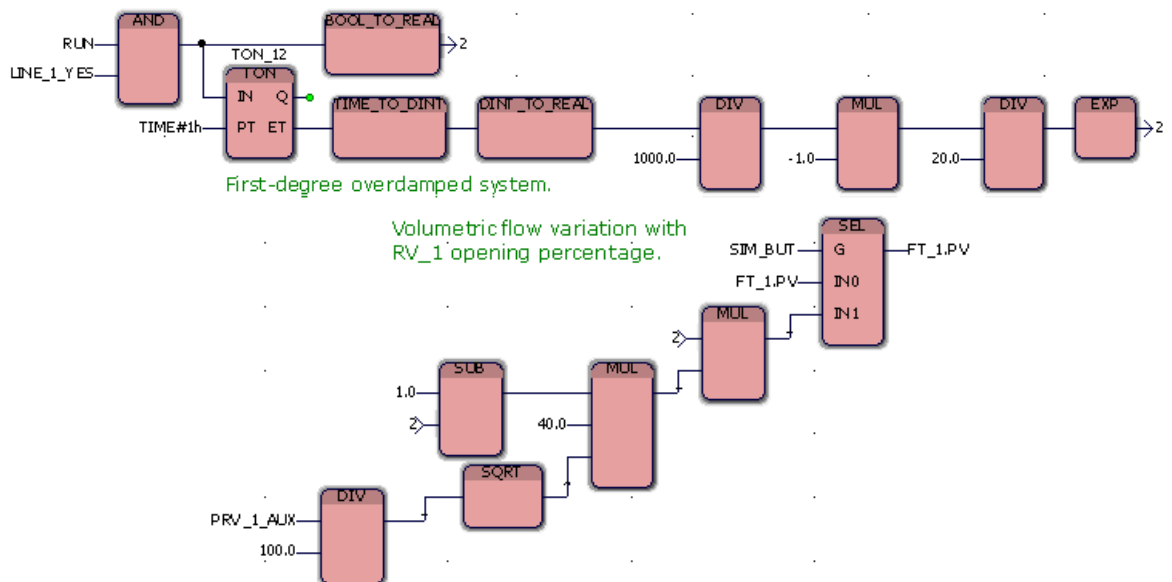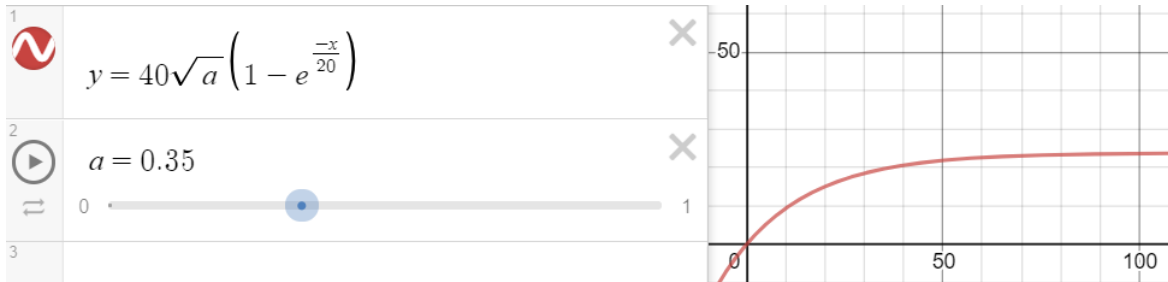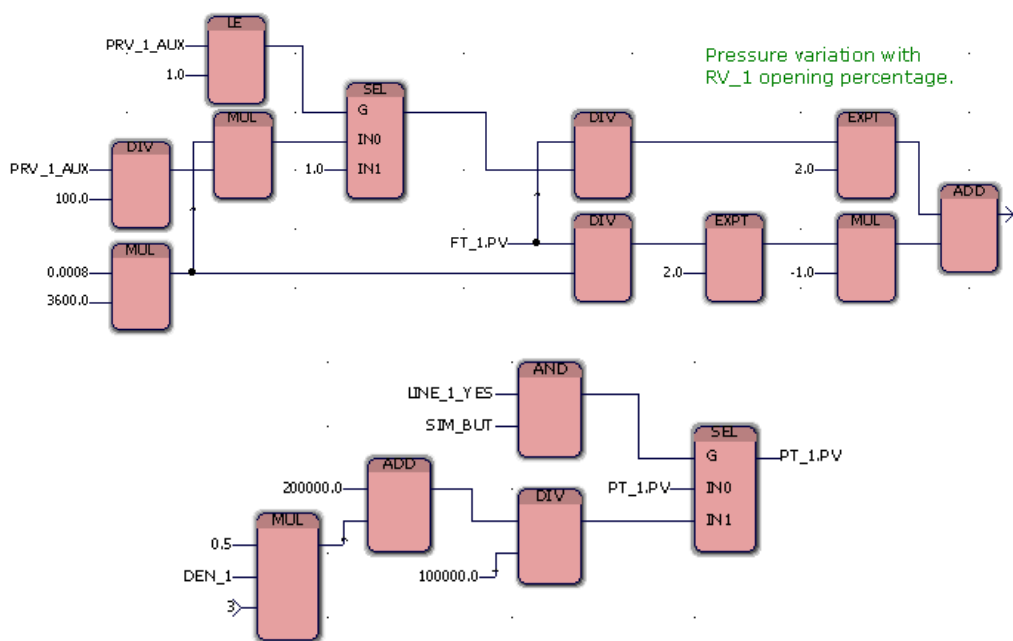

Figure 3.42 PLC Program content. Worksheet: Simulation_BUTANE (Source: ControlEdge Builder)

The automatic regulating valve in this process regulates the pressure of butane and propane, but also affects the fluid flow, so this effect is simulated. Assuming the maximum flow rate offered by the centrifugal pump is $40m^3/h$, the square root of the opening percentage of the regulating valve is multiplied. This calculation is an approximation to make the simulation of the volumetric flow behaviour more real.

Figure 3.43 Over-damped response for centrifugal pump volumetric flow with 35% opening of the automatic regulating valve.

Figure 3.44 PLC Program content. Worksheet: Simulation_BUTANE (Source: ControlEdge Builder)

When the SIM_BUT or SIM_PROP is active and the corresponding unload line is open, the pressure is determined following **Equation *2.13***. For the equation the density variables according to the temperature variation (DEN_1 and DEN_2) and the simulated volumetric flow variable (FT_1 and FT_2) will be used. The pipe section has been approximated, as there is not enough information avaliable about the plant architecture.

- Butane pipe: Section = $0.0008\ m^3$. Radius $\cong 3.2\ cm$.

- Propane pipe: Section = $0.0003 \ m^3$. Radius $\cong 2 \ cm$.

Equation *3.10* and **Equation** *3.11* are plotted in **Figure** *3.45* (red and green graph respectively). In order to achieve high pressures it is necessary to have a regulating valve opening lower than 30%. The equilibrium points of the PID control have also been indicated, as in **Figure** *3.40* and **Figure** *3.41*, it can be appreciated that even having a smaller pipe section, to liquefy propane a smaller opening than propane will be needed.

$$y = \frac{\left(2 \cdot 10^5 + \frac{1}{2} \cdot 573 \cdot \left(\left(\frac{40\sqrt{\frac{x}{100}}}{3600 \cdot 0.0008 \cdot \frac{x}{100}} \right)2 - \left(\frac{40\sqrt{\frac{x}{100}}}{3600 \cdot 0.0008} \right)2 \right) \right)}{10^5}$$

Equation 3.10 Butane pressure (y) variation with regulating valve position (x), measured volumetric flow and butane density.

$$y = \frac{\left(2 \cdot 10^5 + \frac{1}{2} \cdot 493 \cdot \left(\left(\frac{40\sqrt{\frac{x}{100}}}{3600 \cdot 0.0003 \cdot \frac{x}{100}} \right)2 - \left(\frac{40\sqrt{\frac{x}{100}}}{3600 \cdot 0.0003} \right)2 \right) \right)}{10^5}$$

Equation 3.11 Propane pressure (y) variation with regulating valve position (x), measured volumetric flow and propane density.
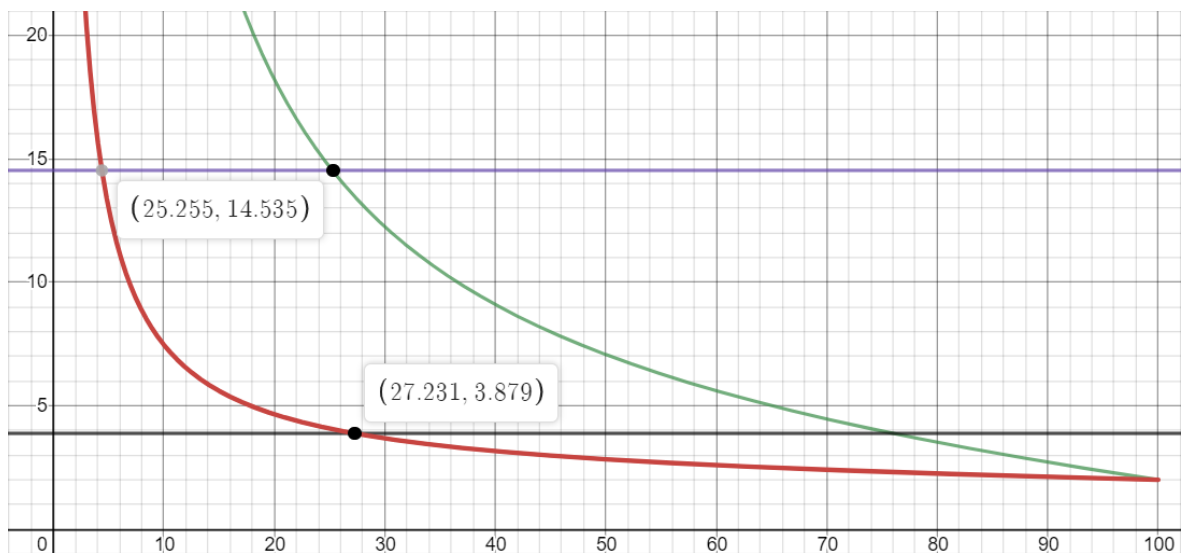

Figure 3.45 Butane and propane pressure graph with the variation of the regulating valve position.

The activation of the system simulations can be controlled from the SCADA displays, and the simulation test results will be detailed in section 3.4.

3.3. SCADA system configuration

The Experion HS SCADA system is built in two parts: First, all desired displays are designed using HMIWeb Display Builder tool, where you can configure the appearance and animation of the objects and figures. The second part consists in the PLC information integration to work with Experion HS, the program points will be configured using Quick Builder tool.

The entire creation procedure of the SCADA control environment with Experion HS will be detailed below.

3.3.1. Displays design

As previously mentioned, this project displays will be designed based on the standard ISA 101, in addition, compared to the previous SCADA system, it has been decided to re-organize and increase the displayed information to obtain greater efficacy in the remote control of the process.

Different file types can be created in HMIWeb Display Builder: Display, Popup, Shape Sequence and Dynamic Shape. In this program only Displays, Popups and dynamic shapes are used.

Dynamic shapes are a great tool that in previous SCADA system was not available, dynamic shapes allow you to create objects that can be linked to a group of SCADA points and to be referenced as many times as you want in the displays. Next, the dynamic shapes used in this project will be described, as well as their configuration and operation.

- **Two_states valve:**

  For this process automation, three automatic valves with two states (closed and opened) are used. A dynamic shape is created for them to avoid having to repeat the same procedure three times.
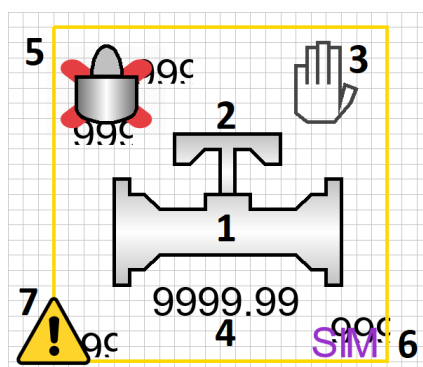

Figure 3.46 Two-state valve Dynamic Shape design (Source: HMIWeb Display Builder)

Starting from the main figure of the dynamic shape, object number 1 will show the PV status and object number 2 the OP of the valve linked to the object. Object number 1, is animated according to the value of the valve PV status variable (3.2.4), so it will have 4 possible colours: Light grey for the transition state, black for the closed state, white for the open state and dark grey for the bad state. Object number 2 will only have 2 states: Black for the close order and white for the open order.

Object number 4 is an alphanumeric object that will show the name of the linked valve. Object number 3 will be visible if the operating mode of the valve is manual, otherwise nothing will be shown.

Object number 5 animates the status of the valve interlock and there are three options: The valve is locked and the padlock is shown, the valve is not locked and no figure is shown or if the valve interlock is deactivated, a padlock with a red cross above will be visible.

Lastly, objects 6 and 7 are used to visualize whether the valve is in simulation mode or has an activated alarm, respectively. If there are no alarms activated or you are not in simulation mode, they are not displayed.

- **Regulating Valve:**
  Similar to the previous one, a new dynamic shape is created to refer to the two automatic regulating valves of the system.
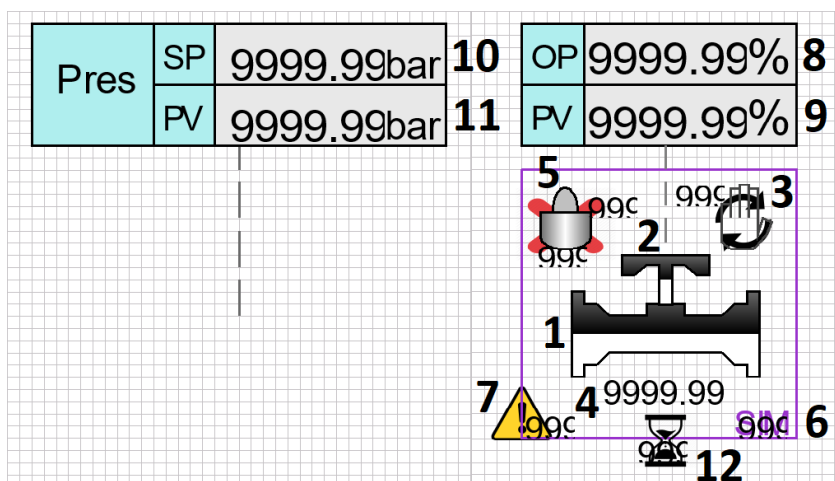

Figure 3.47 *Regulating valve Dynamic Shape design (Source: HMIWeb Display Builder)*

Objects 4, 5, 6 and 7 have exactly the same functionality as the previous two-states valve. The object number 3, now has three possible operating modes, for the cascade mode another object will be shown, the other two modes will work like the previous dynamic shape. Object number 12 is the PID_TIMEOUT indicator that is shown when the valve variable is activated.

For the regulating valve, objects 1 and 2 are animated according to the opening percentage (PV) or opening order (OP), for more visual information the percentage is indicated in the objects colour; black is 0% and white is 100%.

The alphanumeric objects 8, 9, 10 and 11 indicate the analog values of the PID: opening order of the regulating valve, position of the regulating valve, PID pressure setpoint and pressure signal measured in the plant.

- **Two_states pump:**
  The dynamic shape used for pumps has almost the same functioning as that used for automatic valves.
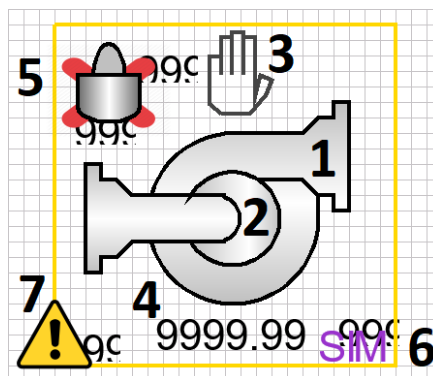
Figure 3.48 Two-state pump Dynamic Shape design (Source: HMIWeb Display Builder)

The only difference of this dynamic shape is the number of device PV states, object number 1 has only 2 states: Black for pump stopped and white for pump running.

Once the dynamic shapes used in this project are presented, they will be used as an example to explain the procedure of animation and configuration of a dynamic shape.

Each dynamic shape created in HMIWeb Display Builder has a configuration window where a virtual point must be created in order to link it with the desired SCADA point. A program point or SCADA point is the element used to reference an external variable in the SCADA system. Normally SCADA software licenses are licensed by number of points, therefore, it is important to optimize the point use.

Each created object can be linked to a point, for example, to make the dynamic shape of the automatic valves animate object 1 of **Figure *3.46***, object 1 must be linked to the created fictitious point (Tag) and to the parameter you want to read (PV).

Figure *3.49* shows the configuration window of data link of an object, in this case because it is a dynamic shape, in the 'Point' section you have to put the virtual point created. For variables that you want to write, activate or modify in the SCADA display, 'Data entrey allowed' box should be activated.
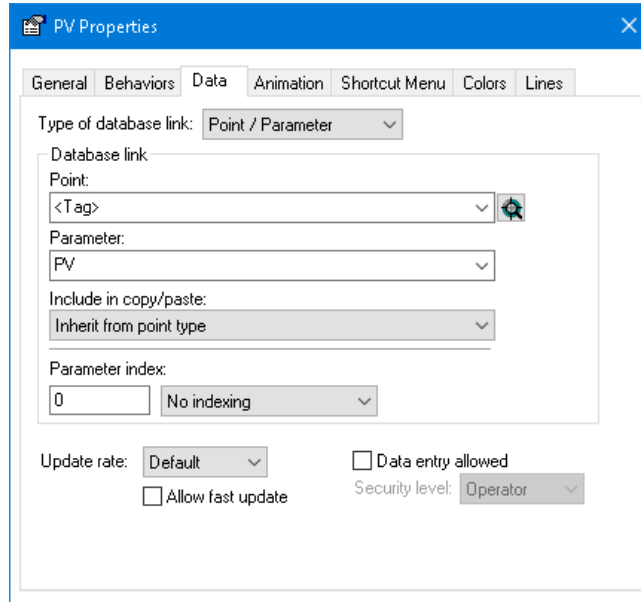

Figure 3.49 Link configuration between an object and a point (Source: HMIWeb Display Builder)

Figure *3.50* shows the animation configuration window, in this example is the animation of the automatic valve and the four states defined previously. In this window you can also configure the animation to fill the figure with a color according to an analogical variable, as it is done in the regulating valves.
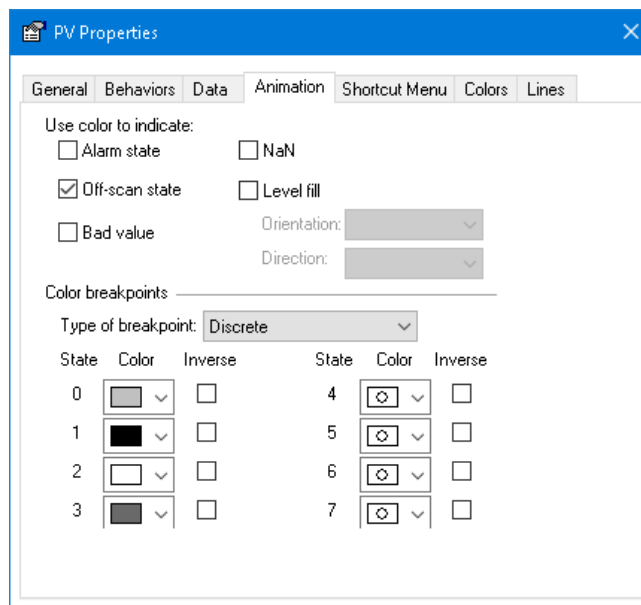

**Figure 3.50** Object Animation Configuration (Source: HMIWeb Display Builder)

For other types of object animation you must do it manually from the scripts in VisualBasic[1] . Each created object has its own script for additional configurations if required.

Figure *3.51* shows a fragment of the script of the dynamic shape 'Two-state valve', which is used to make visible or not an object, in this example the object Alarm. All the objects that have been animated in the displays of this project are based on the previous examples of animation: colour change, gradual colour change or visibility change.

```
sub inline_AL1_onupdate(elem)

    dim varAl

    set varAl = elem.parentElement.parentElement.Objects("Alarm")

    if (elem.value = 1) then
      varAl.style.visibility = "visible"
    else
      varAl.style.visibility = "hidden"
    end if

end sub
```

Figure 3.51 Object Animation Script (Source: HMIWeb Display Builder)

When dynamic shapes have already been designed, they must be added to a display and be assigned to one point, in order to link correctly the objects of the dynamic shape with the parameter of the indicated point. In **Figure** *3.52*, the dynamic shape inserted in the display, named HV_1, is assigned point HV_1 to the virtual point Tag.
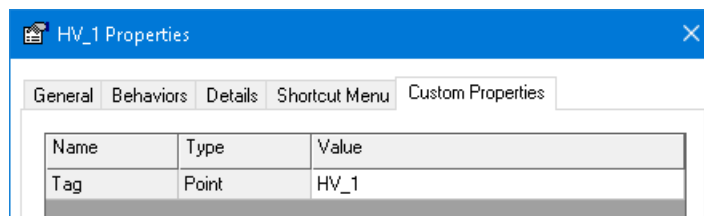
Figure 3.52 Point-dynamic shape link configuration window (Source: HMIWeb Display Builder)

The dynamic shapes that have been presented are added to a display or popup, in this project the information visualization has been compressed and optimized to work with a single general display. **Figure** *3.53* shows the 'Main' display, which has been numbered in order to reference the different objects in the text.

---

[1] Visual Basic (VB) is an event-driven programming language, developed by Alan Cooper for Microsoft. This programming language is a BASIC dialect, with relevant additions. Its first version was presented in 1991, with the intention of simplifying programming using a development environment (Wikipedia - Visual Basic 2019).
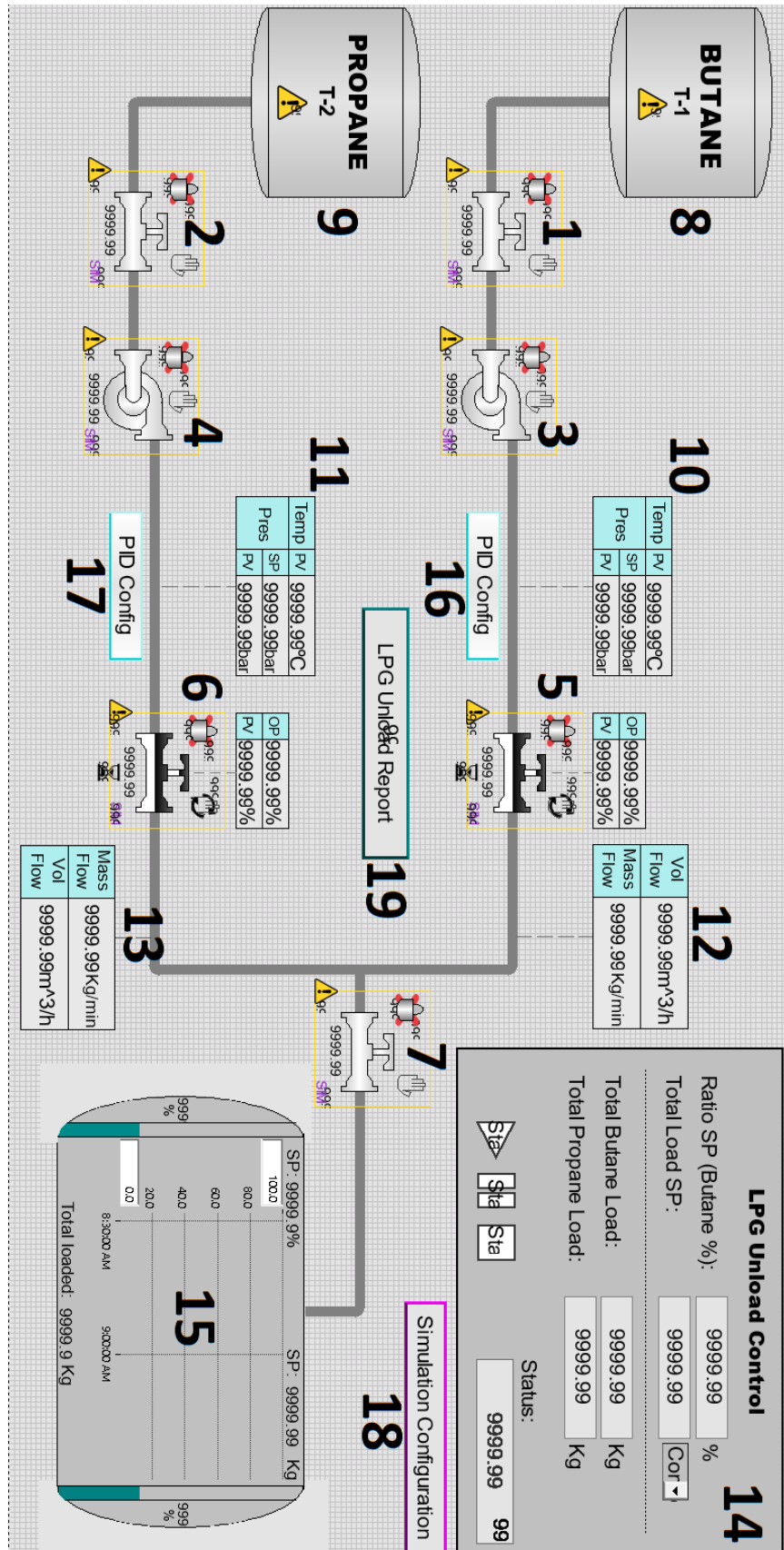
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Figure 3.53 Main display design (Source: HMIWeb Display Builder)

- **Figures 1, 2, 3, 4, 5, 6 and 7:**

  Dynamic shapes inserted in the general display will show the status and characteristics of a device. Dynamic shapes that are associated to device points have exclusive features that facilitate the monitoring and control of these.

- **Figure 8 and 9:**

  These two figures symbolize the source tanks of butane and propane respectively. The alarm indicator is only visible if the digital input for low tank pressure is activated, it can be clicked to activate a popup that indicates the problem.

- **Figure 10 and 11:**

  They are the temperature indicators of butane and propane respectively. Clicking twice on them will access to the automatic detail screen of Experion HS (section 3.3.3).

- **Figure 12 and 13:**

  These are the flow indicators for butane and propane respectively. They can be displayed in two measure units: m^3 / h, which are used by the flow meter, and kg / min, which provide information that is easier to understand for users.

- **Figure 14:**

  This rectangle offers all the information corresponding to the configuration of the unload you want to make. Unlike the previous SCADA system, this unload configuration is on the same display as the other objects.

  The butane percentage that is needed and the desired LPG value can be written, also select if this last value will be in kilograms or litres. Once the above data has been introduced, the total amount needed of each product is shown in kilograms.

  From this set of figures, you can control the START, PAUSE and STOP_O buttons.
  These can only be clicked in the allowed states, defined in section 3.2.3, if they are unavailable to be clicked, the color of the button is changed, and if clicked, a 'Control Fail' alarm will be triggered.

  Lastly, there is an alphanumeric object that shows the state of the process. **Figure 3.54** shows an example of this figure while actively unloading.
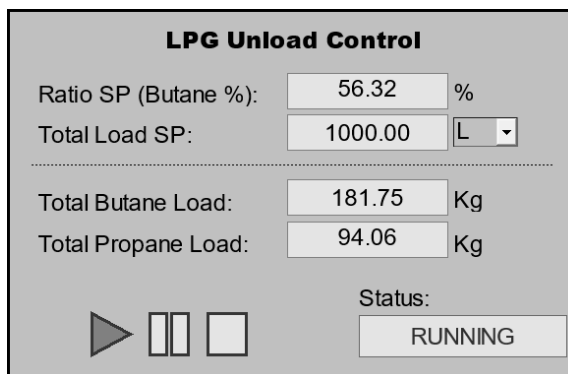
Figure 3.54 Unload configuration box while active unload (Source: Experion HS)

- **Figure 15:**

This tank represents the exit tank where the product is unloaded; its design is based on the new minimalist trend of the ISA 101, where the graph and indicators are inside the tank to optimize the display space.

The SP unload data are at the top (in % and kg); on each side there are two indicators, one alphanumeric and one graphic. They are used to display the value of the variables MC_P and M_P (Left and Right respectively), which as explained above, represent the butane percentage of the current unload quantity and the percentage of unload completed.

In the central part we can see the graph that shows the unloads course. It is a scalable graph on both axis and with three live signals at the same time, historic values can also be viewed. **Figure 3.55** shows an example of the figure while unloading, with the red indicator instantaneous values can be consulted. Lastly, the lower part shows an alphanumeric indicator of the total quantity of product unloaded, MC_3.
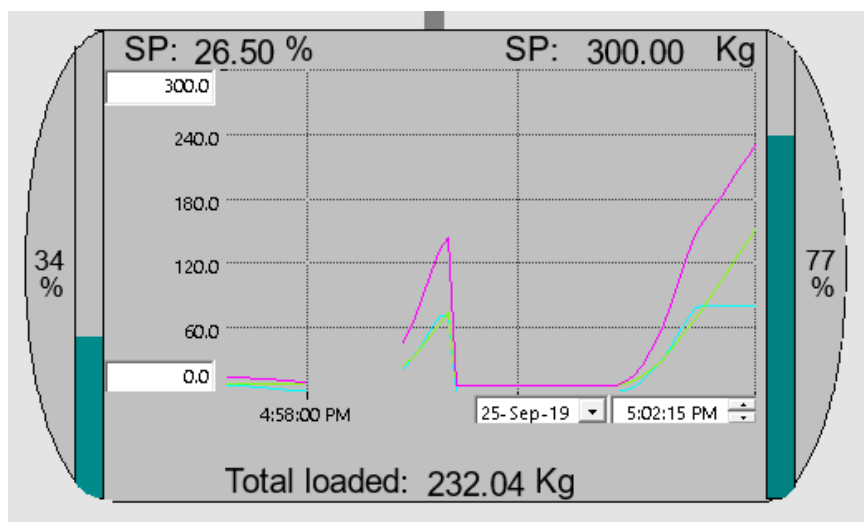

Figure 3.55 Unload Tank behaviour while active unload (Source: Experion HS)

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- **Figure 16 and 17:**

  These two 'PID Config' buttons are used to have direct access to the automatic PID configuration screen of Experion HS. In the detail screen you can visualize the graph of the PID process variables and modify their parameters, they will be specified in section 3.3.3.
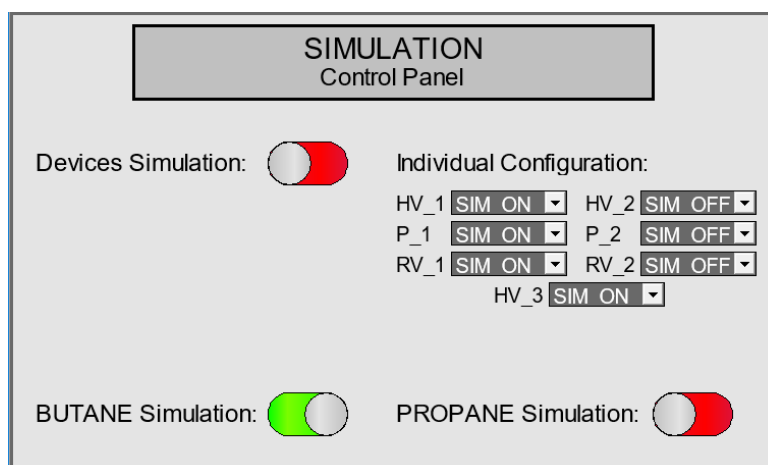
- **Figure 18:**

  This button is configured to open a popup in a specific position when clicked, this is another action that can be configured in any object within HMIWeb Display Builder.
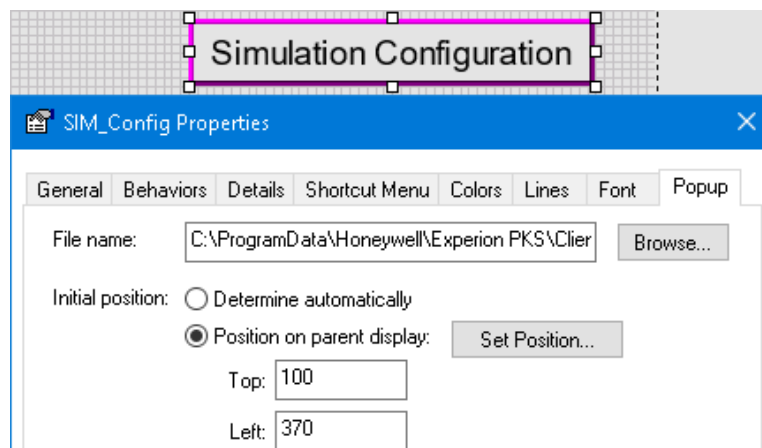
Figure 3.56 Popup button configuration (Source: HMIWeb Display Builder)

This popup is used to activate or deactivate the desired simulations. As shown in the **Figure 3.57**, we can activate the simulations of each device individually or all together, as well as the butane and propane simulations.

Figure 3.57 Simulation configuration popup (Source: Experion HS)

- **Figure 19:**

  The last figure of the display is also like the previous one, a button that activates a popup. This button is only shown if the unload is completed correctly, when it is activated it overlaps the PLAY, PAUSE and STOP buttons, blocking their action (The real position of figure 19 is above the unloading control buttons, but in **Figure** *3.53* it is placed in a different position in order to be able to visualize all the figures).

  This popup displays the unload report information: The final amount of LPG unloaded, the final percentage of butane in LPG and the time the unloading took. When the operator considers that the information is valid, there is a button at the bottom to finish the unload process and return to the IDLE state to unload again.

Figure 3.58 End Unload Report popup (Source: Experion HS)

3.3.2.   Experion HS integration

To work with Experion HS, displays are designed in the HMIWeb Display Builder tool and stored in a specific directory. This directory must be added in the Experion HS configuration in order to be able to view the required displays.

To display the values processed by the PLC ControlEdge in Experion HS, the external variables points of the PLC program must be integrated. With the correct configuration of the communications detailed in section 3.1.5, it will be possible to integrate the points through the Quick Builder tool, which acts as a link between ControlEdge Builder and Experion HS.

To integrate the points in Quick Builder you must first configure a communications channel, selecting the PLC you want to integrate and configuring its main parameters. Once the basic configuration has been completed, the integration can begin.

Figure 3.59 PLC integration configuration (Source: Quick Builder)

Once the PLC to be integrated has been chosen, the first step is generate the desired points. From a long list of available points to integrate (both external variables, such as FB from the Honeywell library or PLC predefined variables) you must choose those that interest you, normally all those variables chosen as external variables and FBs will be integrated. If there are already points generated, it is possible to select only those that have been modified, added or deleted.

In this project all points related to external variables and 7 FBs data structures are generated, one for each device. The configuration for the different types of points used in this project is shown below.

The points of Bool type variables are the most basic used in this program, by default, a Bool type point has configured the name and an internal address generated automatically in Quick Builder.

Figure *3.60* is the Main configuration window of the point; each Bool point has seven configuration windows where you can edit different characteristics of the point. A Bool variable that you simply want to use to animate an object, such as the one in **Figure** *3.60*, does not require any extra configuration. It is important to check that the scan time is different from zero and have a valid PV parameter address.
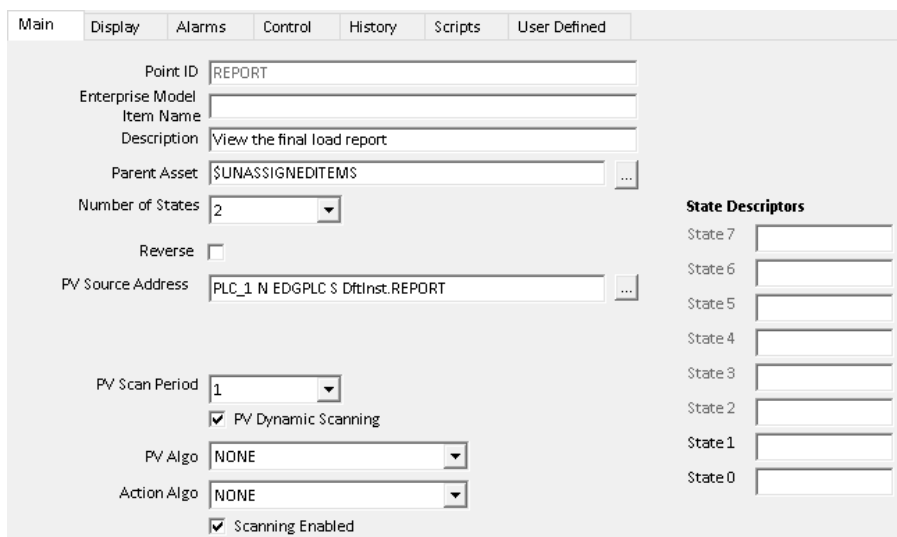

Figure 3.60 REPORT Point, Main window configuration (Source: Quick Builder)

For example, if you want to visualize the state of a Bool variable, like the simulation variables, it is important to describe the states in the lower right part, in order to better interpret the active state.

The variables, which you want to act and change the value, must be configured to allow writing, for this you must assign an address to the OP parameter of the point (normally the same auto-generated PV address is used) and configure its scan period and the parameter states, as shown in **Figure** *3.61*.
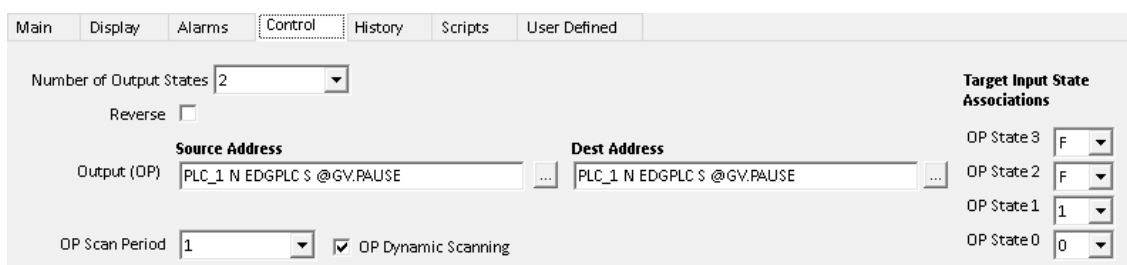

Figure 3.61 PAUSE Point, Control window configuration (Source: Quick Builder)

Lastly, if the point is wanted to be used as a system alarm, it is important that you have a clear definition of the point and the required state alarm activated. You can also set the priority of the alarm, delays in appearance or disappearance, among others.

The analog variable points have few differences with the Bool variable points, the additional highlight configurations are: Modification of the measurement units, maximum and minimum range of the variable and configuration of Set Point control direction and possibility of historicizing the values. You can also activate predefined alarms such as those shown in la **Figure *3.62***.

Figure 3.62 TT_1 Point, Alarms window configuration (Source: Quick Builder)

A great integration feature between Experion HS and ControlEdge Builder is the integration of device blocks from the new Honeywell library. The different device control FBs have a special point configuration that gives many possibilities. To present the features of the device configuration, the integration of the automatic regulating butane valve will be used as an example.

A point of a device can be understood as a group of points, the main value is the PV, which is configured as the other points in the Main window. The detail displays created automatically by Experion HS, are very useful to control the devices, therefore, in the Display window you can assign the displays that will be activated when you click 1 or 2 times on the object.

PV parameter alarms can be configured as in **Figure *3.62***, in addition FB's own internal alarms can be included in the alarm system. For RV_1's specific case, 3 more variables can be configured in the control window: Set Point, Order Process and Mode. If these 3 control variables have a read and write address, the regulating valve can be controlled from Experion HS, with the default Experion HS displays.

Apart from the 3 control variables that can be configured in the points of FB blocks, there is also the possibility of defining 4 auxiliary variables, in the case of RV_1 these 4 auxiliary variables are predefined as the 4 PID control parameters: Proportional constant, Integral time, derivative time and deadband. This feature is very useful because they help to have the most concentrated and organized information.

Like the PID system control parameters, real-time graphics of the 3 PID control parameters SP, OP and PV are automatically configured. With this graph we will obtain a diagnosis of the behavior of the PID system in each one of the regulating valves.

Lastly, as a common feature for all points (although it is mainly used in device points) is the option to add user-defined variables. As can be seen in **Figure** *3.63*, 7 extra variables have been created in RV_1 point. These variables are linked to a device point in order to be referenced in the dynamic shapes created for each type of device.

Figure 3.63 RV_1 Point, User Defined window configuration (Source: Quick Builder)

Each point created in Quick Builder can be linked to objects, indicators, buttons or dynamic shapes in HMIWeb Display Builder. To reference created variables, such as those in the previous example, you have to consider that besides linking to the point, you also have to choose the parameter you need.
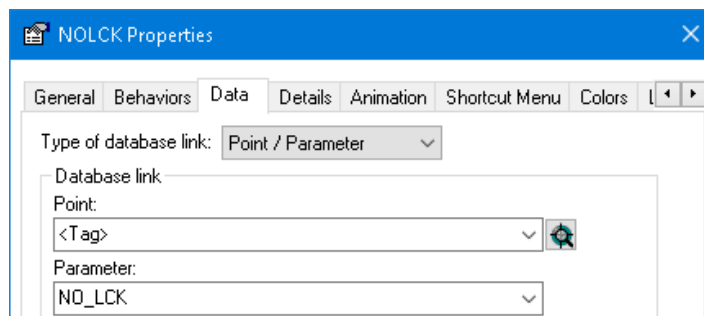
Figure 3.64 Dynamic Shape data link configuration (Source: HMIWeb Display Builder)

After presenting the whole procedure and possibilities of point integration with Experion HS, a list of advantages over other older software from Honeywell or the competition can be made:

- Fast and automatic integration. You only have to do the previous configuration of the PLC in Quick Builder and all the points can be generated and used.

- The default configuration of the points reduces the integration time of the project, you only have to configure points that you want to add extra functionality.

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- Possibility of collecting several variables in a single point. The default configuration of the device points already contains at least four variables, apart you can link all that are needed.

- Decrease in points. Thanks to the above feature, the number of points used can be greatly reduced, for example, for the automatic butane-regulating valve, with a single point RV_1, 15 variables are included. In other softwares it is not possible to group variables in a single point.

- License cost reduction. As previously mentioned, number of points used licenses most SCADA software. The possibility of reducing all the points used by a device to a single point generates a license price reduction.

3.3.3.   Experion HS default displays

As already mentioned, one of the best features of Experion HS is its pre-designed displays that integrate perfectly when used in conjunction with ControlEdge Builder. This section will present the different default displays used in this application and their features.

Experion HS contains a predefined alarm system, all generated points have basic default alarms configured, but as explained above, additional alarms can be added.

Experion HS alarms can be classified in several ways.

- By relevance: Low priority, High priority and Urgent priority.
- By status: Recently unshelved, shelved, suppressed and unacknowledged
- By location in the defined plant sectors (not applicable in this project).

All alarms that have been activated remain visible until their display is confirmed by activating the 'Acknowledge Alarm' option.

In **Figure *3.65*** we can see an example of 3 different alarms activated:

- **Alarm 1:** The first alarm in the list is an alarm generated automatically, in the Source column we can see to what point it belongs and in Condition column the type of alarm. In this case it is a control failure of the START button, operator tries to write the value 1 (Trip Value) but the value remains at 0 (Live Value).
- **Alarm 2:** This alarm is generated manually; it is activated when the state of the variable ALHV_1 is 1. We can see in the column Description the reason of the activation of the alarm.

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- **Alarm 3:** The last alarm is also generated automatically for points coming from analog inputs or outputs. The system creates alarms when the maximum or minimum values configured in the I/O modules are exceeded.

Figure 3.65 Experion HS Alarms system example (Source: Experion HS)

Another type of predefined Honeywell screens are the point detail screens, in **Figure *3.66*** we can see an example of the analog point detail screen of TT_2. As we can see in the upper part, we have windows like the ones we saw in Quick Builder. As mentioned before, if you have access to a user with permission you can change point settings.

It is recommended to activate the option to visualize the PV history of analog points, so we get real-time graphs of PV values and you can access historical data, all from within the detail screen of the point. You can also see the left column that offers information about more control variables linked to this point (SP, OP or MD), in this case there are no additional control variables linked.
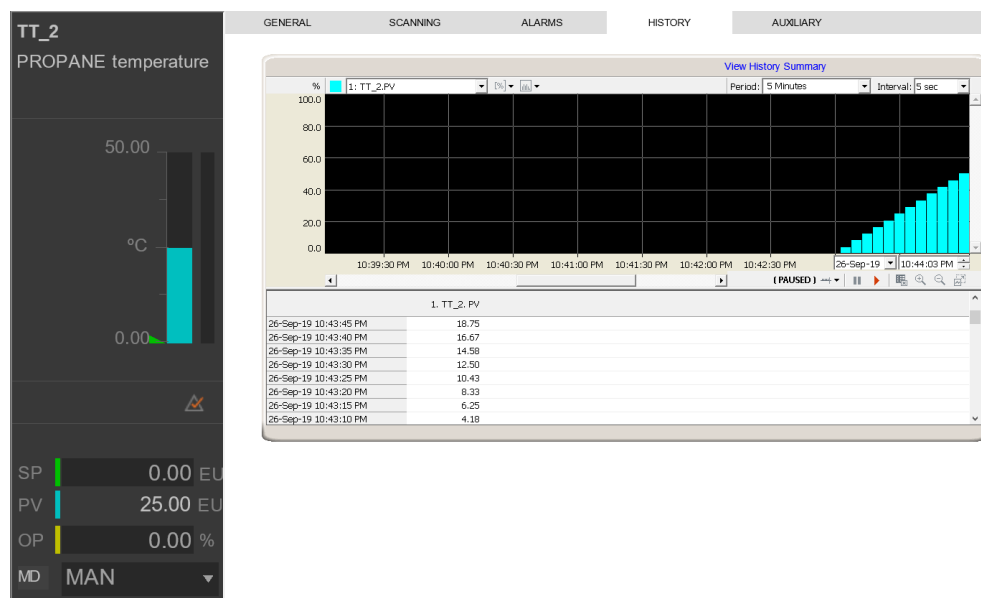
Figure 3.66 TT_2 detail display (Source: Experion HS)

The left column of the detail screen can also be displayed on the faceplates. These are a predefined type of popup special for device points, used for faster access to the device controls. In the case of **Figure *3.67***, the floating popup on the general display, allows to visualize and act on the main control parameters.

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Faceplates also provide information about if there is an active related alarm and the possibility to mark them as acknowledge. The faceplates are activated by clicking once on the object that animates the PV parameter, in points that are not devices, by default they do not have faceplate available.
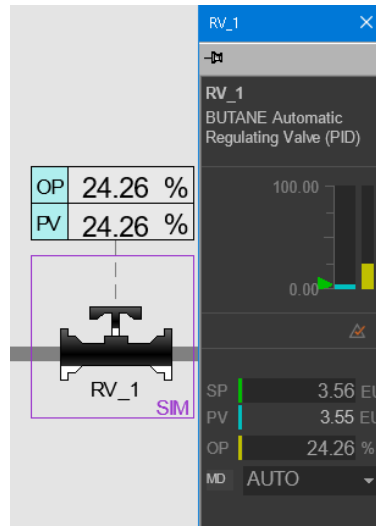
Figure 3.67 RV_1 faceplate in live unload (Source: Experion HS)

Lastly, the last distinguished feature of Experion HS's automatic displays is the automatic generation of a PID control graph. This tool allows you to view SP, PV and OP parameters in real-time, as well as edit PID control parameter values. In this auxiliary graph you can also access historical values of the PID control.
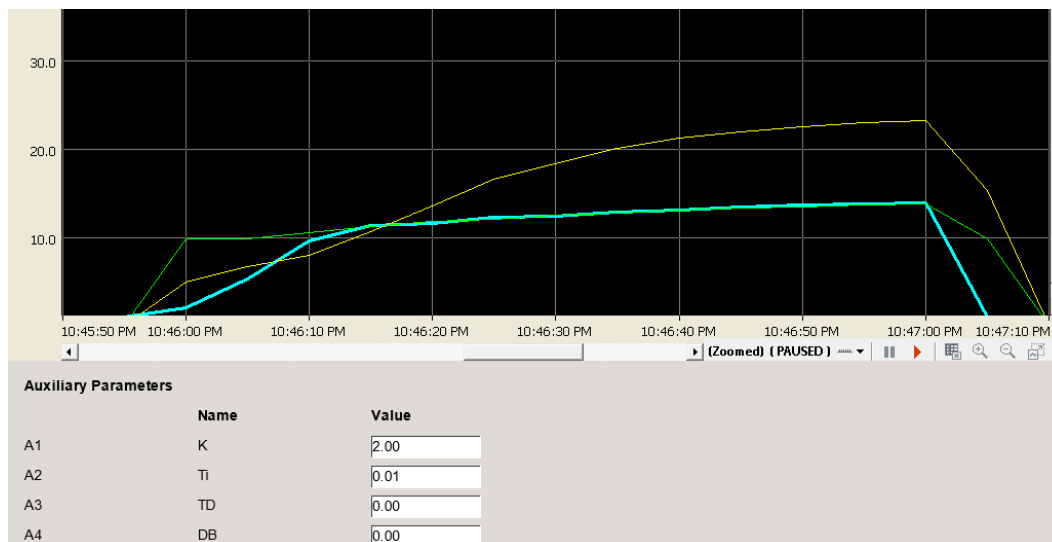
Figure 3.68 RV_2 PID behaviour graph in Auxiliary detail display (Source: Experion HS)

Overall, these default displays offer a high level process control and accessibility, with automatic integration in most cases.

3.4.   Simulation Results

The simulation system has been used to test and improve the automation system of the LPG synthesis and unload process. In the last development month, different types of unloads have been simulated in order to improve and adjust the automatisms. **Figure** *3.69* shows a graph of the absolute errors of unload parameters for 100 unloading simulations and the trends that characterize their behaviour

For 100 simulations, the following data have been collected: Setpoint of percentage of butane, setpoint of quantity to unload, final percentage of butane and final quantity unloaded. With the use of **Equation** *3.12* and **Equation** *3.13*, the absolute error between setpoint and process value has been determined and the graph of **Figure** *3.69* has been generated.

$$Percentage_{OP} - Percentage_{PV} = E_{abs\_Percentage} = \% \, Abs\_error$$

Equation 3.12

$$LPG\_Quant_{OP} - LPG\_Quant_{PV} = E_{abs\_LPG\_Quant} = Kg \, Abs\_error$$

Equation 3.13

As can be seen in the trend lines, the latest unloads have minimized the error to under 1% on average. The green trend-line should only be considered since data number 46, the previous unloads were only butane or propane (Percentage 100% or 0%) and the program logic fixes the process value with the same value as the SP, therefore, there is no error.
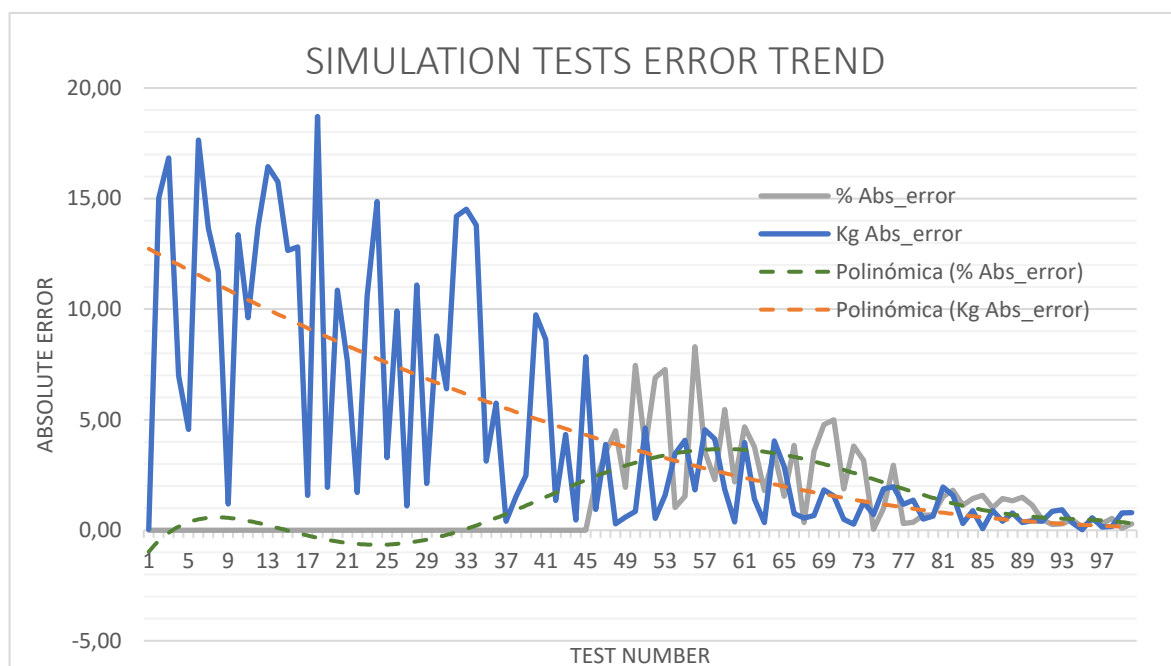
Figure 3.69 Simulation Test Error Trend

Thanks to the development of a complex simulation system, it has been possible to detect all possible errors in the process automation during the development of the project, in order to improve the system to its optimum operation.
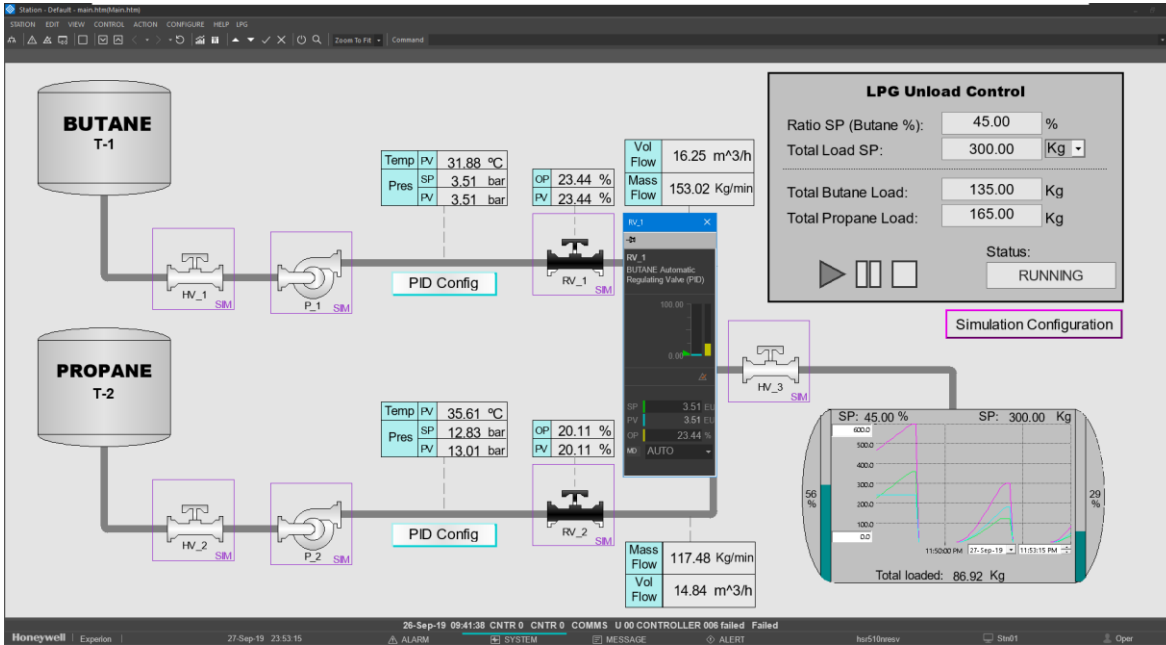
Figure 3.70 Main display while unloading simulation (Source: Experion HS)

Figure 3.71 PID behaviour graph while unloading simulation (Source: Experion HS)

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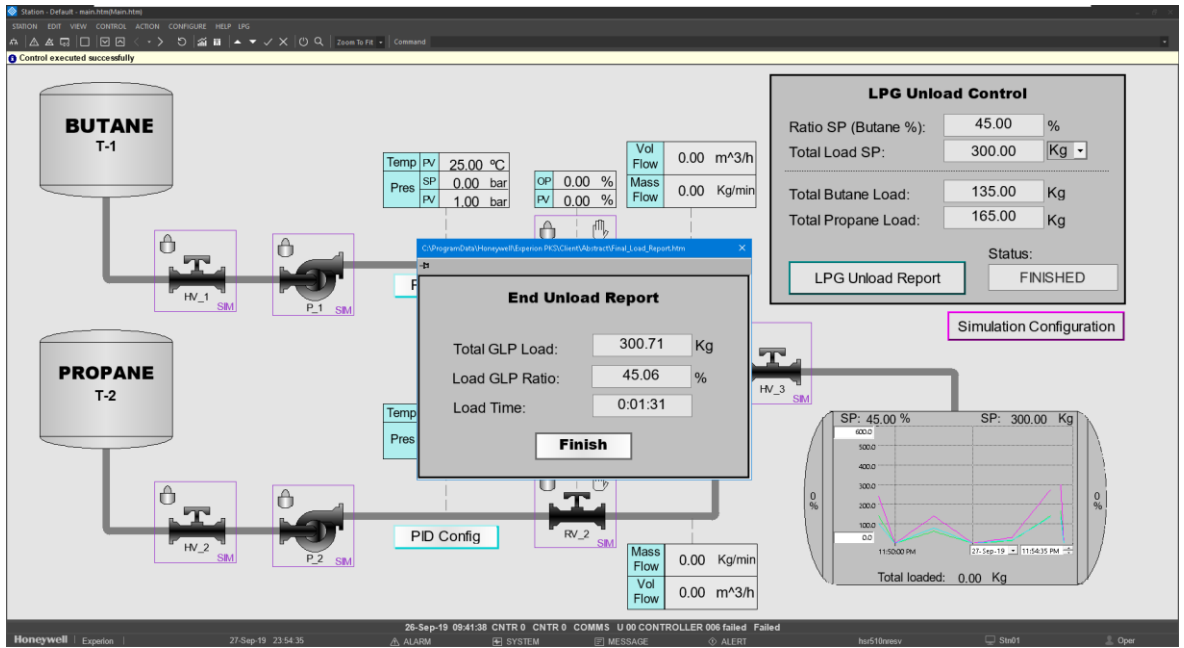
Figure 3.72 Main display at the end of an unloading simulation (Source: Experion HS)

3.5. Regulations

In this project, for certain parts development, norms and standards have been used to standardize programming and design and to facilitate the interpretation and communication of automatic control systems.

3.5.1. PLC program

As previously mentioned, programming in ControlEdge Builder is based on the IEC 61131-3 standard. This standard, created by the common effort of 7 multinationals of the sector, intends to standardize programming languages in industrial automation and communication between control devices and other systems.

IEC 61131-3 can be divided into two different parts:
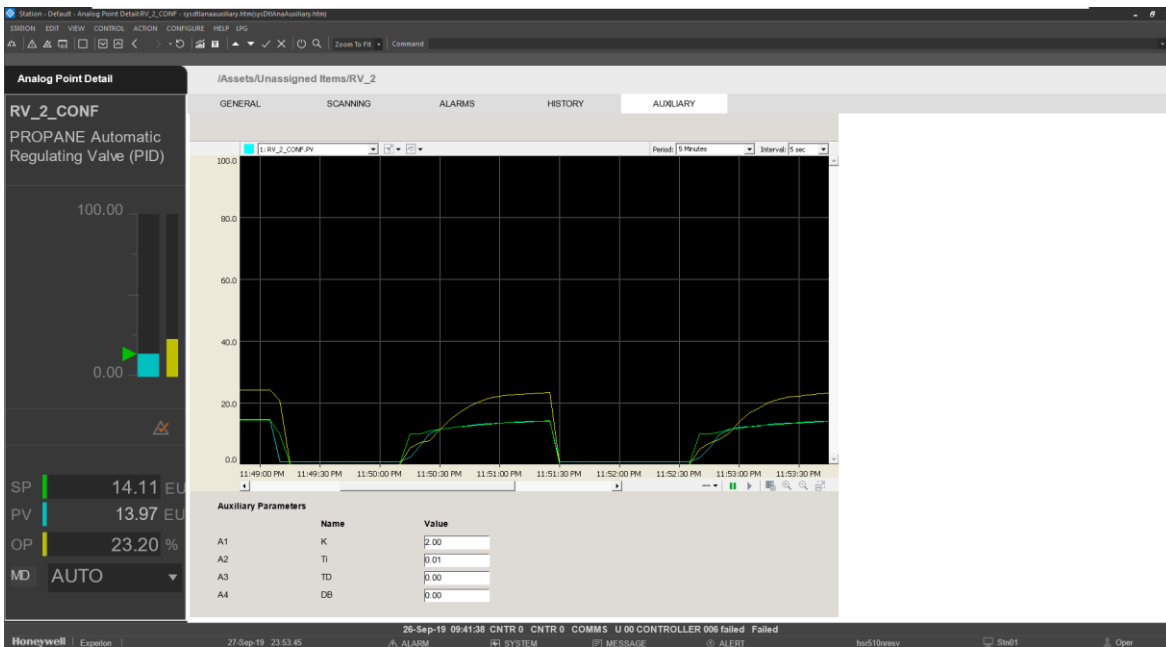
- Common elements: Standardization of general use variables, tasks, resources, internal organization of the program, functional blocks (FU and FB) and sequences, among others.
- 5 types of standard programming languages are defined:
    - Literal: Instruction List (IL) and Structured Text (ST).
    - Graphic: Diagram Ladder (LD), Sequential Function CHART (SFC) Function Block Diagram (FBD).

(IEC 61131-3 2008, 1-2).

This last type of defined language (FBD) is the one used in ControlEdge Builder.

3.5.2. SCADA design

As detailed in section 3.1.4, the design of the SCADA has been based on ISA 101. This standard HMI display design for SCADA systems is oriented to continuous processes, where it is not necessary to highlight with bright colours a normal behaviour such as switching a valve on or off, bright colours are used for extraordinary situations such as alarms and emergencies.

Another great proposal that will mark the path of future SCADA systems is the optimization of space and the management of information to be shown. ISA 101 recommends a increased usage of dynamic indicators that offer temporary information in substitution of the ones used until now, ne moment in time indicators.

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3.5.3. Codification

The P&ID instrumentation documents and GRAFCET process graphics in this project have been made based on ISA S5.5 and IEC 848 respectively.

ISA S5.5 establishes a graphic system of symbols to visualize plant devices and processes, also a coding for the devices that compose a system and are represented in a P&ID. The following table shows the coding standard:

Table 5 ISA S5.5 Identification letters *(ISA 1985, 41)*

First letter (4)			Succeeding letters (3)		
Measured or initiating variable		**Modifier**	**Readout or passive function**	**Output function**	**Modifier**
A	Analysis (5, 19)		Alarm		
B	Burner, Combustion		User's Choice (1)	User's Choice (1)	User's Choice (1)
C	User's Choice (1)			Control (13)	
D	User's Choice (1)	Differential (4)			
E	Voltage		Sensor (Primary Element)		
F	Flow Rate	Ratio (Fraction) (4)			
G	User's Choice (1)		Glass, Viewing Device (9)		
H	Hand				High (7, 15, 16)
I	Current (Electrical)		Indicate (10)		
J	Power	Scan (7)			
K	Time, Time Schedule	Time Rate of Change (4, 21)		Control Station (22)	
L	Level		Light (11)		Low (7, 15, 16)
M	User's Choice (1)	Momentary (4)			Middle, Intermediate (7, 15)
N	User's Choice (1)		User's Choice (1)	User's Choice (1)	User's Choice (1)
O	User's Choice (1)		Orifice, Restriction		
P	Pressure, Vacuum		Point (Test) Connection		
Q	Quantity	Integrate, Totalize (4)			
R	Radiation		Record (17)		
S	Speed, Frequency	Safety (8)		Switch (13)	
T	Temperature			Transmit (18)	
U	Multivariable (6)		Multifunction (12)	Multifunction (12)	Multifunction (12)
V	Vibration, Mechanical Analysis			Valve, Damper, Louver (13)	
W	Weight, Force		Well		
X	Unclassified (2)	X Axis	Unclassified (2)	Unclassified (2)	Unclassified (2)
Y	Event, State or Presence (20)	Y Axis		Relay, Compute, Convert (13, 14, 18)	
Z	Position Dimension	Z Axis		Driver, Actuator, Unclassified Final Control Element	

IEC 848 presents a standard description of actions associated with stages, applicable to GRAFCETs. The program used to design the GRAFCETs seen in the report, OFT2 Grafcet, is based on this standard. The SFC programming language proposed in IEC 61131-3 is based on this GRAFCETS design standard.

The symbology and coding of devices used in the design of SCADA displays has been based on the standard commonly used in projects developed by the collaborating company.

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Conclusions

The main objective was the renovation and improvement of the process automation system. Despite the absence of physical test evidence, it can be concluded that the proposed control system improve capacity and quality compared to the previous control system. Thanks to the simulations made on, the redesign of the process automation and the extension of calibration variables, it can be forecasted that errors in unloading will be reduced from 10-15 % to a maximum of 2 %.

All the specific and secondary objectives determined at the beginning of the project have been successfully completed. A deep insight in industrial automation has been gained, obtaining knowledge of continuous process programming, PID controls, valves and pumps configuration, FBD programming language, OPC communication between industrial control equipment, among others. A large number of possible improvements to the previous control system were detected and solved in the new control system.

Although it was a risky bet to work with software without other installations or online information, the result has been quite satisfactory. Because of the lack of information, a large part of the work consisted in investigating the functioning of the programming tools of this system: ControlEdge Builder, Experion HS, Quick Builder and HMIWeb Display Builder. In conclusion, it has been a tough task to learn how such a large amount of software works, but at the end, an advanced knowledge of Honeywell control systems has been achieved.

The PLC program has been improved, the main new features that have been developed are:

- Honeywell's native FBs have been used to control the devices.
- Butane unloading has been separated from propane unloading to avoid unnecessary interlocks.
- New tuning variables have been configured for the start-up.
- Automatic control has been redesigned for the new valve system.
- Process status system has been generated to improve process management, among other minor improvements.
- Simulation system has been added.

Lastly, it has been possible to apply the knowledge acquired in different subjects of the degree such as Thermodynamics, digital electronics and automatic regulation, among others. In addition, the development of this bachelor's thesis I have improved my project planning and writing skills.

There are a set of possible improvements that could not be made in time, for example:

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- Integrate the individual simulation control of each device into the autogenerated popup faceplate.
- Generation of a more realistic simulation of temperature variation with pressure.
- Configure plant sectors and user permissions in Experion HS for project part two.

The final own evaluation is very positive, despite the great time and effort dedicated to the project; personally, the project results have been very satisfying.

Budget

This section contains the study on the economic cost of the project, considering the tasks developed by the collaborating company and not the supply and installation of new devices and equipment.

- **Costs of design, approach and study of the legacy system:**
  In order to determine these costs, the time spent on the study of the process to be automated, the system architecture and the software used are considered. In addition, the search for alternatives and improvements proposed in the offers made and the planning and design of the final improvement applied.

Table 6 Costs of design, approach and study of the legacy system

Concept	Time spent (h)	Price per hour (€/h)	Price (€)
Process analysis	20	15,00	300,00
Control system analysis	20	15,00	300,00
Analysis of possible alternatives	15	15,00	225,00
Offers	5	15,00	75,00
Modification planning and design	40	15,00	600,00
Total	100		1.500,00

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- **Cost of PLC programming and SCADA system design:**

    The costs associated with the development of the automation system will then be determined. The price will be itemized in specific tasks of PLC programming with ControlEdge Builder, various configurations, integration of points and SCADA system design with Experion HS.

Table 7 Cost of PLC programming and SCADA system design

Concept	Time spent (h)	Price per hour (€/h)	Price (€)
ControlEdge Builder operation research	30	20,00	600,00
Configuration of I/O and variables	10	20,00	200,00
Process automation programming	50	20,00	1.000,00
Process simulation programming	50	20,00	1.000,00
PLC configuration	15	20,00	300,00
Points Integration	15	20,00	300,00
Display design operation research	25	20,00	500,00
SCADA displays design	50	20,00	1.000,00
SCADA system configuration	10	20,00	200,00
Total	*255*		*5.100,00*

- **Documentation costs:**

    The last section determines the costs of project documentation.

Table 8 Documentation costs

Concept	Time spent (h)	Price per hour (€/h)	Price (€)
Report Writing	150	12,00	1.800,00
Calculations, charts and others.	30	12,00	360,00
Total	*180*		*2.160,00*

Lastly, all the above costs are considered and the final budget for the project realization is obtained.

Table 9 Total cost

Concept	Time spent (h)	Price (€)
Design, approach and study of the legacy system	100	1.500,00
PLC programming and SCADA system design	255	5.100,00
Documentation	180	2.160,00
Total (excl. Tax)	535	8.760,00
Taxes (21%)		1.839,60
Total		1.0599,6

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Environmental impact analysis

Law 21/2013 was published in the Spanish BOE on 11th December 2013. This law stipulates the obligation that any project must present an evaluation and study of the environmental impact generated by the application of the project itself. The law is approved in order to be able to control the environmental impact and reduce it as much as possible (Noticias Jurídicas - Ley21/2013 2013).

Environmental impact is the effect of an event on the environment. The environmental impact of this project can be divided into two parts.

The change in the architecture of the control system has a direct and indirect environmental impact. The acquisition of new devices and pieces, which previously have to be manufactured and supplied, has an indirect impact of the system on the environment. As well as the construction to install the new instrumentation system and the new control devices, all this will suppose a pollution and natural resources use.

The specific manufacturing and installation data of the new devices and systems are not accessible, as they are the competence of the instrumentation company.

Concerning the development of the software, the energy consumed during this can be considered. The Ministry of the Environment establishes at $392 \, g_{CO_2}/kWh$ the CO2 emission in electricity consumption, with this we can calculate an approximate value of CO2 emissions generated during software development.

$$g_{CO_2} = \frac{392 \, g_{CO_2}}{kWh} \cdot P_{\max\_device} \cdot t_{project} = 392 \cdot 0.12 \cdot 535 = 20.166,4 \, g_{CO_2} = 25,17 kg_{CO_2}$$

Equation 0.1

Where g_{CO_2} is the CO2 emission (in grams), $P_{\max\_device}$ is the maximum power of the device used to develop the project and $t_{project}$ is the number of hours of project development.

The modification and optimization of the process automation system will positively affect the environmental impact. Because the system will now be integrated into a global system for the entire plant, in the future unifying the entire plant with this system would greatly reduce potential failures and maintenance costs.

The unload time reduction will cause a smaller use of devices that consume electrical energy. The reduction of unloads error will optimize the use of the products and will avoid possible problems of product leakage or waste due to overfilling tanks or destination containers.

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In this type of process, where highly inflammable products are used, the quality of the piping system, the electrical insulation of the devices and equipment used and the automation system reliability to avoid leaks or higher pressure than required, are very important.

As previously mentioned, no specific information is available on the new actuators and piping system installed in the system, these are detailed in the project report of the instrumentation company. For the PLC selected for the new system, in the following tables we can see the information related to the environmental conditions of ControlEdge PLC.

Table 10 and **Table 11** ControlEdge PLC Environment Conditions

Item	Rated	Transportation & Storage
Ambient Temperature	32 to 140 °F 0 to 60 °C	-40 to 158 °F -40 to 70 °C
Ambient Relative Humidity	10% to 90 % RH non-condensing	5 % to 95 % RH non-condensing
Mechanical shock Acceleration Duration	1 g 30 ms	Not rated
Vibration	0 Hz to 14 Hz— amplitude 2.5 mm (peak-to-peak) 14 Hz to 250 Hz— acceleration 1 g	See below table

The Test condition of random vibration

Frequency (Hz)	PSD (g²/Hz)	RMS (g)	Duration	Direction
10	0.0065			
20	0.0065			
120	0.0002			
121	0.003	0.74	60min/direction	X, Y
200	0.003			
240	0.0015			
340	0.00003			
500	0.00015			
5	0.01	1.07		Z
100	0.01			

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