SCADA systems in crude oil refining process

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ABSTRACT

This document presents the realization of a SCADA system on a thread for crude oil refining, where the main objective is to remotely control and supervise each stage of the process from start to finish and that in turn it has programmed alarms capable of indicating the personnel in charge when an inconvenience occurs. In the oil industry, it is vitally important to be aware of oil refining, since any change in this procedure can result in obtaining a poor quality product, which generates waste of time and money. Since each of these processes have defined characteristics and standards such as the temperatures or the reaction time of the liquid that must be established so that there are no changes in the final result of the product. This is done thanks to two controls implemented on the heating and reaction process on which a PID controller and a state feedback controller are applied, respectively. And on which the temperature values of each of these must always be visible in the user interfaces, whether local or remote, that allows the personnel in charge to observe that none of these exceed the limits or generate unforeseen errors despite the alarms. installed in the system and that both the reactor motor (inverter) and the pump (servomotor) are operating correctly.

INTRODUCTION

Crude oil refining involves a series of physical and chemical processes to which crude oil is subjected, the products obtained from them have different yields since they depend on the origin of the crude oil; To adjust these yields to the consumption pattern, some of the fractions are subjected to various conversion processes. These conversion processes are applied in order to obtain lighter products, through molecular rearrangements, whose commercial value is higher. These processes can be of three types: distillation processes, disintegration processes and purification processes. [1]

For this application, a SCADA system is made that controls and supervises different oil refining processes, but it is worth defining each of the points that participate in the entire process and its function:

SCADA systems provide supervision software and control through multiple programmable logic controllers. These systems are designed to be used over long distances such as water or extensive electrical networks. Due to the long distances, these systems allow a process to be visualized and controlled in real time by means of a monitoring station.[2]

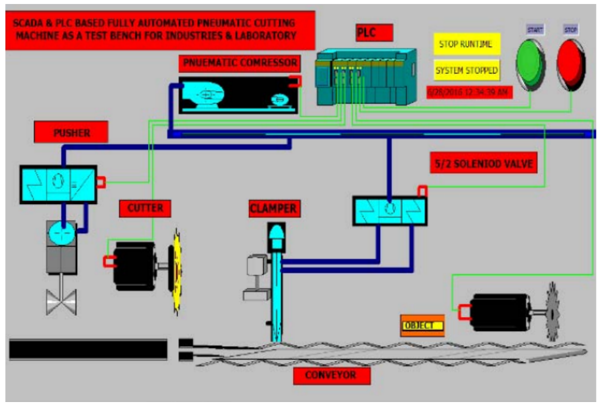


Figure 1: Example of a SCADA system.[3]

The frequency variator regulates the speed of electric motors so that the electricity of the motor adjusts to the real demand of the application. An inverter is an industrial controller that sits between the power supply and the motor. Mains power passes through the drive and regulates the power before it reaches the motor, then adjusts the frequency and voltage based on procedure requirements.[4]

Figure 2: Micromaster SIEMENS drives[5]

Servomotors with their corresponding driver are drive devices for precision control of speed, torque and position. These replace pneumatic and hydraulic drives (except in high-torque applications) and are the best performing alternative to drives via frequency converters, since they do not provide position control and are ineffective at low speeds.[6]]

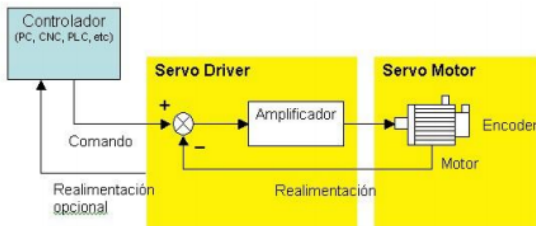


Figure 3: Servomotor with driver [6]

OBJECTIVE

Design and implement a SCADA system that allows the control and supervision of 3 workstations locally and remotely, simulating a crude oil refining thread with preheating and reaction systems for this using controllers PID and feedback of state variables.

MATERIALS

*PLC S7-1500
*Ethernet cables
*Micromaster 440 Siemens
*Siemens Motor 1LA7 070 2YA60
*TIA Portal V13
*MATLAB R2017a
*PT100 Siemens
*YASKAWA Sigma II
servomotor *HMI KTP600 Basic Color PN
*Relay
*Analog components (Capacitors, resistors, operational amplifiers)

PROCEDURE

To carry out this application, the process to be carried out must be clear, that is why it is separated in all the key points, as well as the real components that are represented:

- Furnace = Thermal plant.
- Mixer = Three-phase motor using the speed variator.

- Reactor = Circuit made by analog computers.
- Centrifugal pump = Servomotor.

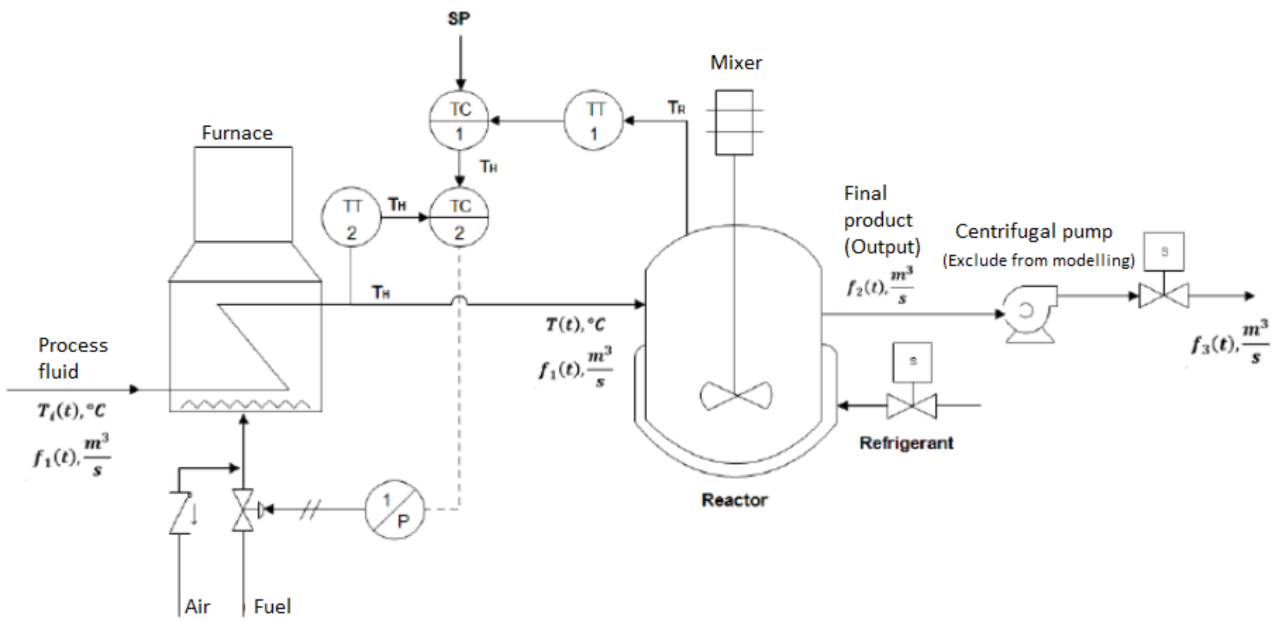
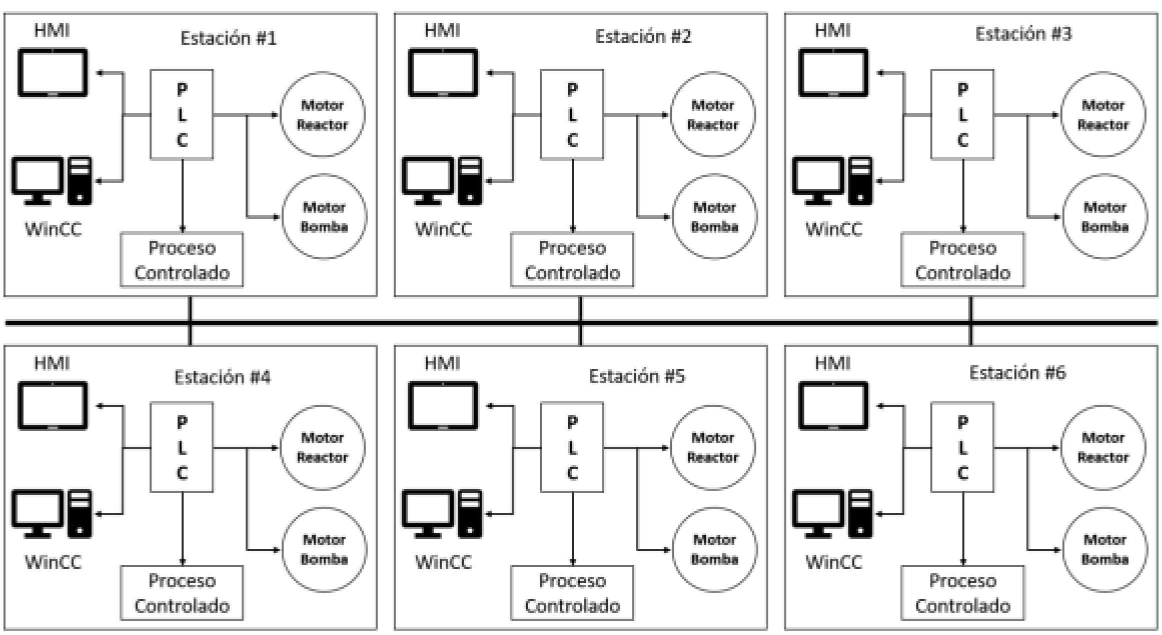


Figure 4: Oil refining thread scheme

The main objective of this laboratory is to control and supervise 6 different processes through SCADA systems using PROFIBUS communication where each station can control another and supervise either locally (HMI) or remotely (WinCC).)



- **Local**

Remote supervision is performed using the KTP600 Basic Color HMIs available in the automation laboratory. The main image with which the user is, from which he can select the workstation to control and monitor.

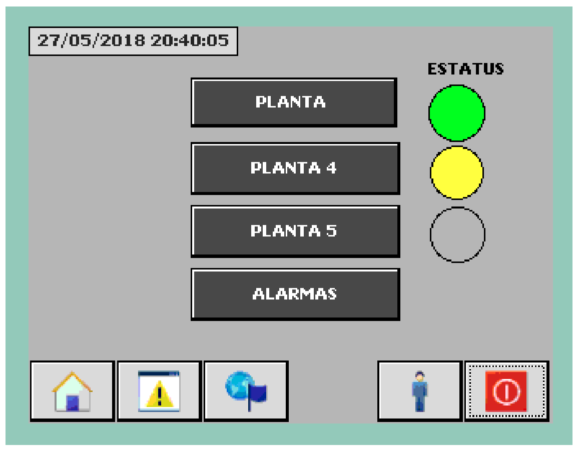


Figure 5: HMI main image

This is the main image where the plants that can be connected are located and also have the alarms of the entire system.

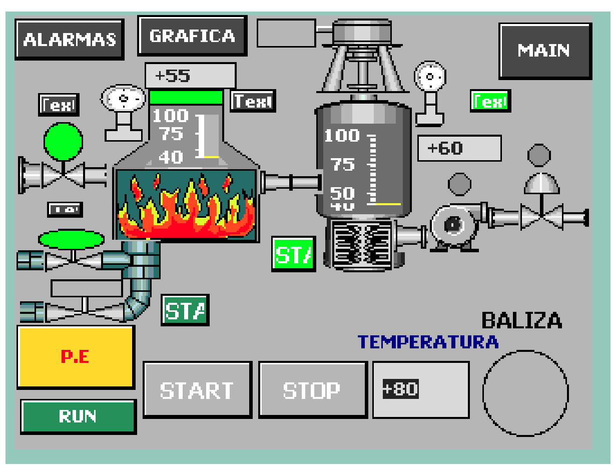


Figure 6: Diagnosis image of the HMI Phase 1 process

Description of the plant HMI Screen

In each plant we find each plant sensor where we find the air valve for combustion, the fluid to be refined, the pressure of the reactor furnace, the furnace temperature sensors and from the reactor the agitation pump the system outlet valve and the system outlet pump the system can start if everything is ready for the fluid to enter the process.

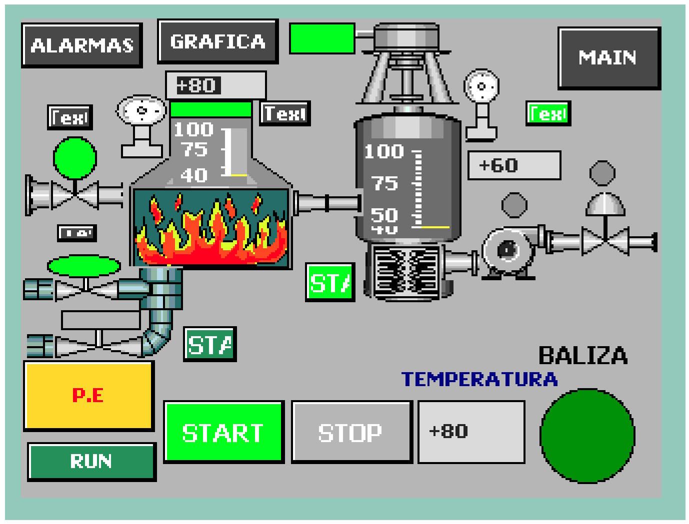


Figure 7: Diagnostic image of the HMI Phase 2 process

When the furnace temperature reaches the desired temperature for its refining process, the agitation pump is turned on until the reactor reaches its desired temperature.

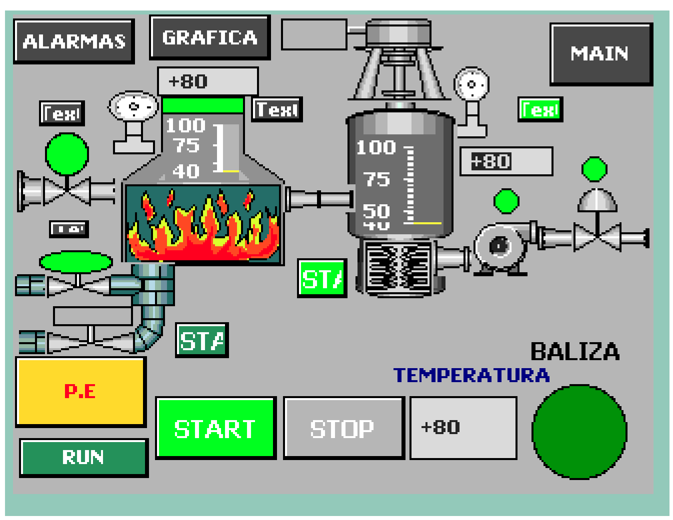


Figure 8: Diagnostic image of the HMI Phase 3 process

When the desired temperature is reached in the reactor we can know that the fluid is ready for the system outlet, so we turn off the agitation pump and turn on the system outlet pump with its valve to stop the flow of fluid.

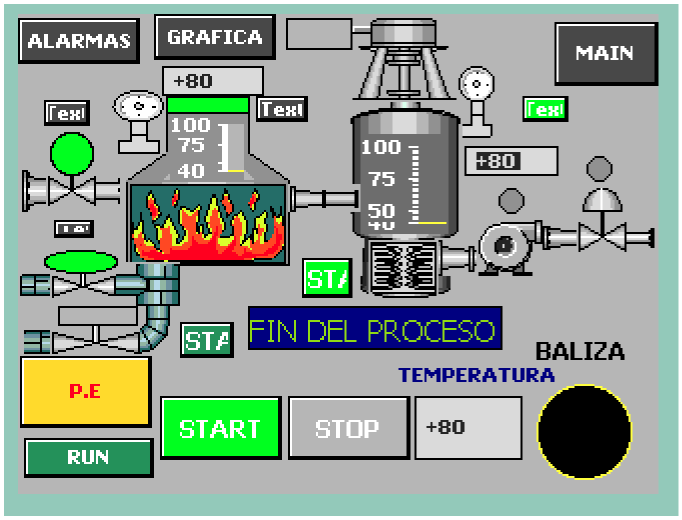


Figure 9: Diagnostic image of the HMI Phase 4 process

We have an end of process signal so that the operator knows that it has finished and that he is ready to change the temperature if he wishes for the next process.

ALARMS

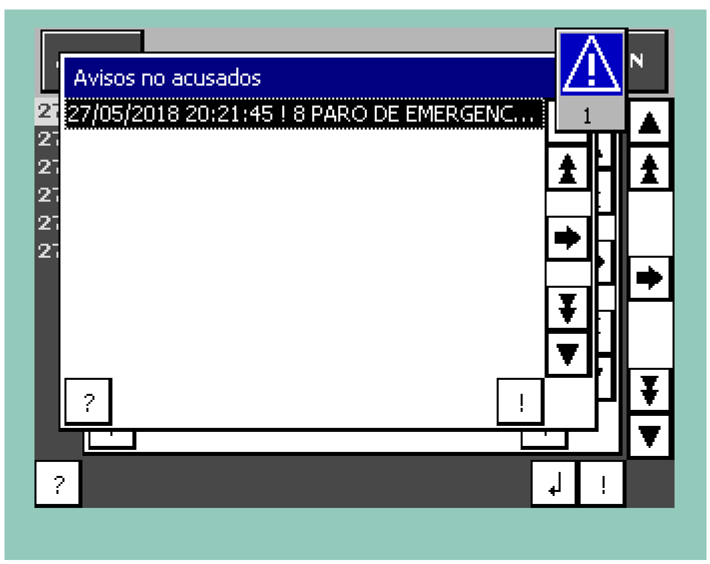


Figure 10: HMI Emergency STOP warning image

There is an error alarm that tells us that the emergency stop is activated, which no matter what screen we are in, we can see it immediately.

Figure 11: HMI alarm warning image

We have some emerging alerts regarding the system sensors and refiner operation; We also have the cycle end alert that we can see from anywhere in the plants from any HMI or Scada.

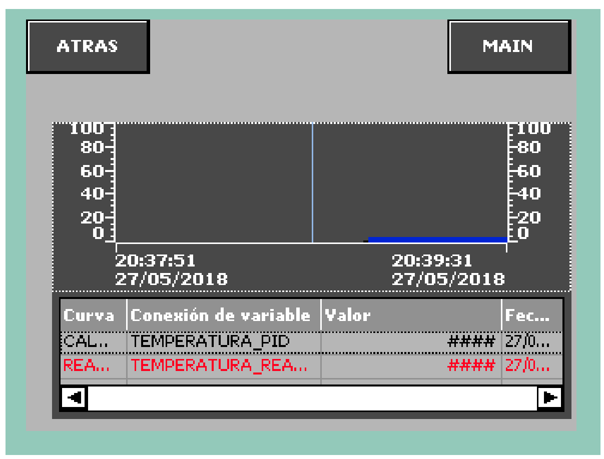


Figure 12: HMI temperature graph

There is a real-time history of the two temperatures of each plant, which implies control in the operations of each cycle and the fuel costs in each plant for the refining of the desired fluid.

- **Remote supervision (WinCC)**

The PC station is responsible for supervising and controlling the process through the computer, this is linked to a PLC through a subnet, which must be the same as configured in the PLC communication module, so that the process can be controlled from a remote site through the WinCC program.

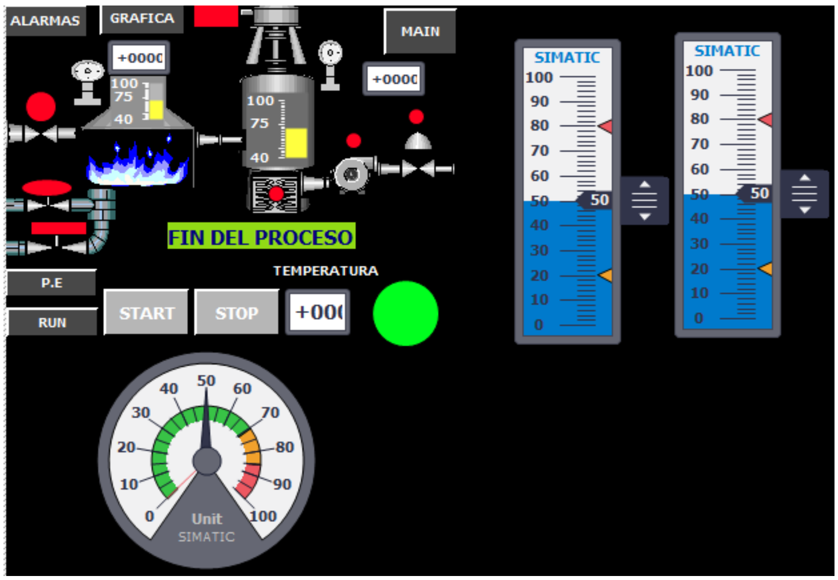


Figure 13: Process screen, PC station in WinCC

In WinCC we can have more space for the process we can have clearer gauges of the furnace and reactor temperatures with a gauge at the bottom of the temperature at which we need to be the plant

- **Analog inputs**

For this application, 2 analog inputs are configured that will be the voltage of the voltage divider that allows the measurement of the PT100 and the output of the reactor circuit.

- **Outputs**

Two analogue outputs are configured for this application, which will be: 1) The control signal output of the servosystem that enters the reactor circuit and 2) The reference voltage, which is the signal that activates the servomotor when it is required.

- **Reactor**

In the modeling of the reactor, different physical and characteristic factors enter into it, in the case consulted it is an industrial reactor, however, since this is a smaller-scale application, factors such as the size of the reactor and the temperature must be adjusted which it will work. These constants are presented in table **1** :

Variable	Valor	Descripción	Unidades
F	0.2	Flujo volumétrico	m^3/s
r	0.8	Radio del reactor	m
h	1.5	Altura del reactor	*m*
Cp	2.2	Coeficiente de presión	*KJ/Kg*
p	800	Densidad del crudo	Kg/m^3
K	2.2	Constante cinética	-
Cin	5	Conc de alimentación	$Kmol/m^3$
TH	275	Temp inicial reactante	*K*
Tc	300	Temp del refrigerante	*K*

Table 1: Reactor constants.

After having these constants, 3 variables are defined: 1) $A = \pi * r^2$ which will be the area of the reactor, 2) $V = A * h$ which will be the volume of the reactor, and finally 3) $k1 = A * 0.05$ which is 5% of the reactor area that is not used. And replacing these variables and constants in the matrices of figure X would solve the model by state variables. [7]

$$A = \begin{bmatrix} -\left(\frac{F}{V}\right) - K & -K \\ \frac{K}{p * Cp} & \frac{-\left(\frac{F}{V}\right) - k1}{p * Cp * V} \end{bmatrix}$$

$$B = \begin{bmatrix} 0 \\ \frac{F}{V} \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 1 \end{bmatrix}$$

$$D = 0$$

Figure 14: Matrices that form the state space model of the reactor.

Then using Matlab's ss2tf function that allows converting a state space model to a transfer function, it will then be as follows.

```
         0.2709
----------------------
s^2 + 2.255 s + 0.2734
```

In order to simulate the transfer function of the reactor on analog computers, it was necessary to look for a circuit that complied with a similar second-order response and for this, the implementation of a second-order band-pass filter was found based on [8], that to reach the transfer function, the values of resistors and capacitors are varied according to the adjustment of the proportional gain of the system and its characteristic open-loop establishment times.

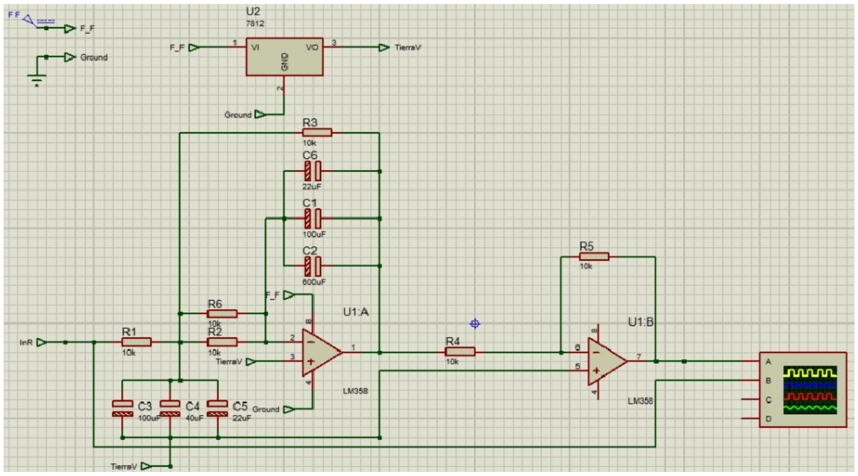


Figure 15: Analog circuit that simulates the reactor.

- **Feedback control by state variables**

Having the transfer function in continuous-time, it must be discretized so that a digital control can be carried out, the matrices G and H are obtained to carry out the servo system with an observer.

$$G = \begin{bmatrix} -0.0178 & -0.0378 \\ 0.1384 & 0.2942 \end{bmatrix} \quad H = \begin{bmatrix} -0.1779 \\ 1.3837 \end{bmatrix}$$

To find the desired polynomial, a damping coefficient “zita” of 1 and a settling time of 300 seconds are defined.

```
Zd =
z^3 - 1.687*z^2 + 0.7522*z - 0.03352
```

After this, the feedback control constants, integral constant, and observer constants are obtained.

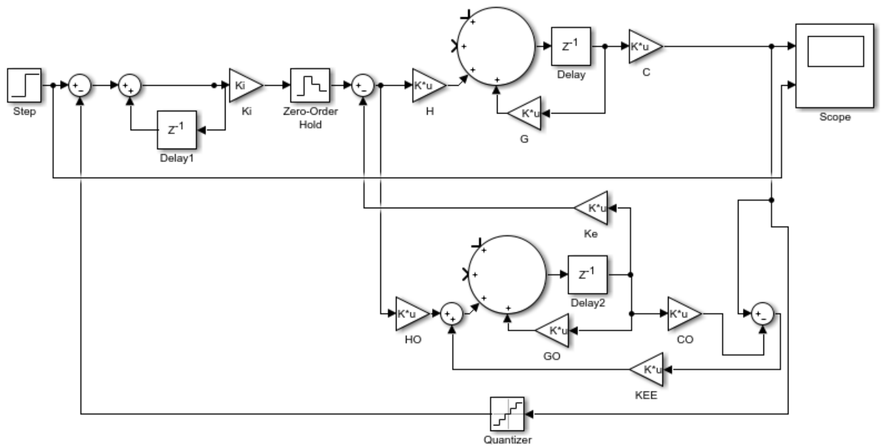


Figure 16: Servosystem with discrete observer

Y the response of the system with the controller implemented is shown in figure x, where the system stabilizes in approximately 300 seconds and with an overdamped response.

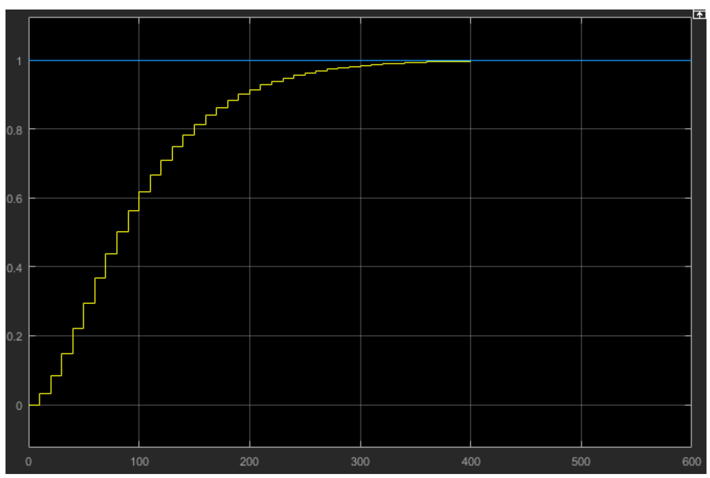


Figure 17: Reactor response with controller implemented.

- **Communication**

Ethernet communication is used for communication between the workstations, communication between the programmable logic controller and the drive uses the PROFIBUS standard, which is already internally wired in the devices available in the laboratory, and communication with the screens HMI uses the PROFINET standard, where the individual IP addresses for the 3 workstations and also for the PC station are configured in the TIA Portal program.

- **Thermal modeling**

For the realization of the thermal plant, an oven or muffle prototype is made using MDF wood on the outside and aluminum and expanded polystyrene are used as thermal insulation on the inside. In this, an element capable of raising the internal temperature of the plant must be implemented and that the intensity of heat it produces can be controlled, so for this element it is decided to opt for an incandescent lamp capable of heating the aluminum and the temperature inside the muffle. Inside the oven there is also the Siemens PT100 temperature sensor that will measure the temperature inside. To measure the temperature, it is necessary to make a voltage divider that allows reading the change in voltage over the variation of the RTD, since this is a resistor that changes its resistance according to the temperature at which it is found. The connection must be made as follows.

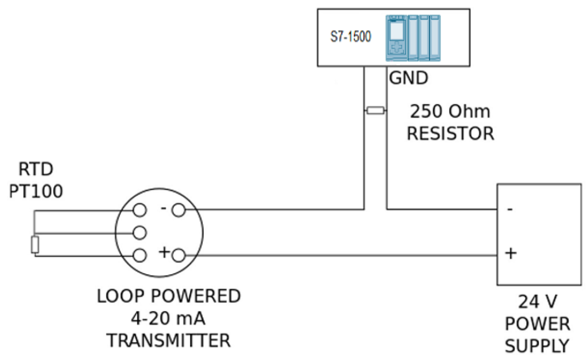


Figure 18: Voltage divider connection for PT100 voltage reading. [9]

The voltage measurement is carried out with an analog input of the PLC, configured to a voltage range that the user wants, either from a range between 0 to 10V or from 1 to 5V.

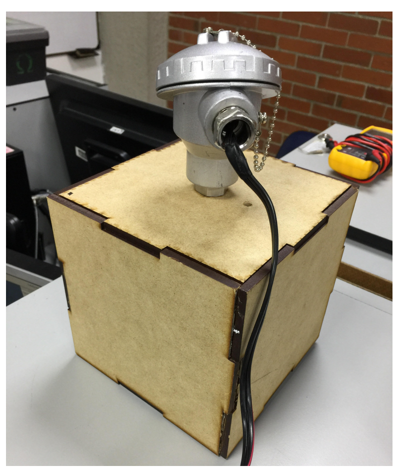


Figure 19: Implemented thermal plant with Siemens PT100

To obtain the model of the thermal plant, the light bulb is powered to heat the inside of the muffle where the temperature is being measured using a thermocouple with a Fluke multimeter and measuring the voltage in the divider of voltage as output and the voltage on the light bulb as the input for the system.

Subsequently, using the Matlab <ident> complement, the input and output data of the system are introduced, where the type of transfer function to be obtained is selected, which in this case will be a second-order function.

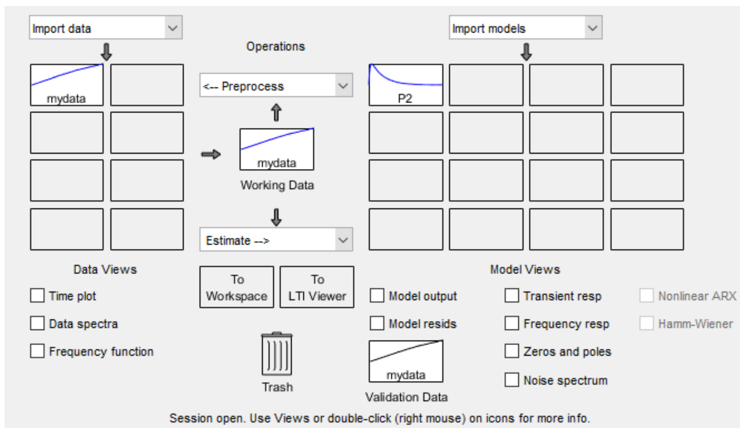


Figure 20: Matlab ident plugin interface

This plugin outputs the proportional constant of the system and also the 2 characteristic times of the response in open loop.

```
Process model with transfer function:
                 Kp
  G(s) = -----------------
         (1+Tp1*s)(1+Tp2*s)

         Kp = 0.14217
        Tp1 = 56.549
        Tp2 = 4.8693
```

When performing the characterization, a similarity percentage is obtained between the real response and the response with the transfer function obtained using ident.

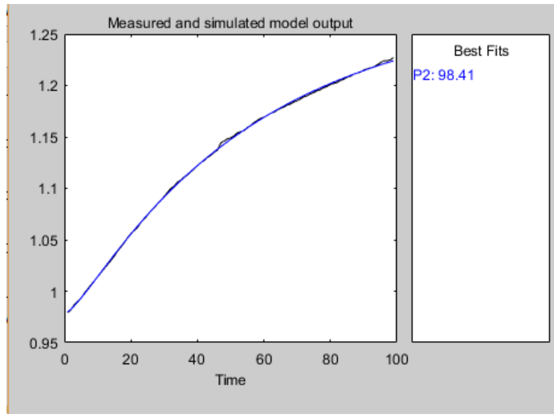


Figure 21: Percent similarity of real and characterized transfer function.

And finally, the transfer function is shown below:

$$\frac{0.0005162}{s^2 + 0.223\ s + 0.003631}$$

- **PID control**

block is inserted PID_Compact , which allows characterizing and controlling the plant that is connected to the analog input defined in the TIA Portal and the PLC . [10]

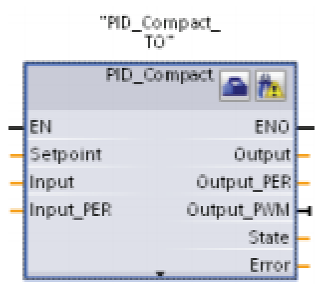


Figure 22: PID Compact Block

When characterizing the system, the minimum and maximum point of the plant output signal is defined first in degrees centigrade, and in turn the value of the voltage is taken in bits at the time of reading through the PLC input.

Figure **23** shows the graph of the commissioning system, where you can see the reference or setpoint (cyan color, in degrees, the point you want to reach), the scaled input signal (green color, the normalized point which you want to reach), and finally the red output, which is the PWM signal that controls the relay that turns on the light bulb to raise the temperature of the oven. Where the reference is 50ºC as an intermediate point of the characterization.

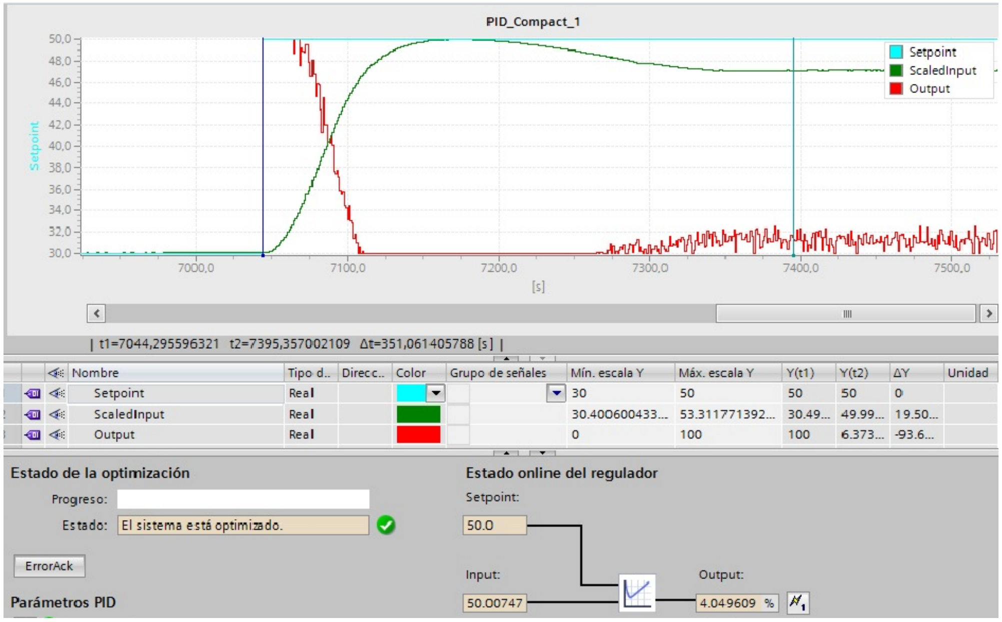


Figure 23: Optimization for an intermediate value of the setpoint

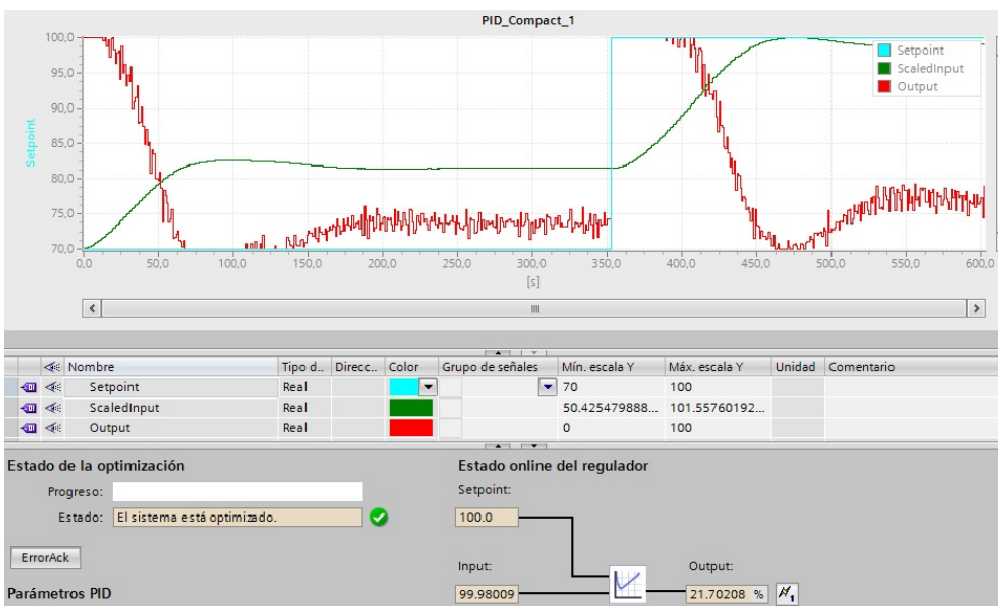


Figure 24: Optimization for the maximum value of the setpoint

- **Variable speed**

drive The frequency drive, as mentioned above, controls the percentage of the phase coming from the electrical network that enters the motor, from this In this way it becomes a controller for the motor, it communicates through PROFIBUS to the PLC and thus be able to control the three-phase motor.

Figure 25: Micromaster 440 SIEMENS Inverter [11]

All the parameters related to the motor, communication and electrical characteristics are entered here. These parameters and their respective function are found in table 1:

Parameter	Value	Description
P10	30	Factory
setting P970	1	Reset values
P3	3	Expert user
P4	0	All parameters
P918	# = 55	Card address
P10	1	Start-up
P100	1	American system 60Hz
P304	220	Motor voltage [V]
P305	1.9	Motor current [A]
P307	0.5	Motor power [HP]
P310	60	Motor frequency [Hz]
P311	1590	Rated speed [RPM]

Parameter	Value	Description
P700	6	PROFIBUS connection
P1000	6	PROFIBUS connection
P1080	0	Minimum frequency [Hz]
P1082	60	Maximum frequency [Hz]
P1120	5	Time at max speed [sec]
P1121	2	Time deceleration [sec]
P2040	#	Monitoring time
P3900	x	Load configuration

Table 2: Micromaster 440 drive

parameters Parameters (words) are sent to the drive from the TIA Portal so that it changes the percentage of the fa frequency I know that it reaches the motor, which is directly proportional to the speed exerted by it.

- **Servomotor**

For the servomotor, a speed control is performed at the moment in which the centrifugal pump is activated, for this an analog voltage is sent to the servomotor through the V-REF input of the driver, the voltage is sent through the PLC with the in order to rotate the servomotor at a certain speed, since in parameter Pn300 of the servomotor the speed can be configured by means of the voltage configured in this parameter. This parameter is set from 0 to 1200 which indicates that the motor will rotate at full speed (3000 rpm) at 12V clockwise and -12V counterclockwise at full speed. For this practice, it is decided to set it to 1000 since the output voltage at this point in the process will be 5V and the speed at which the shaft rotates will be 1500rpm.

Figure 26: YASKAWA Sigma II servomotor

At the end of this document there is an annex with the GRAFCET.

ANALYSIS OF RESULTS

When performing the fine optimization of the plant, the software calculates and displays the resulting values of the control, such as the values of the proportional, integral and derivative gains that are necessary characteristics to carry out a PID controller.

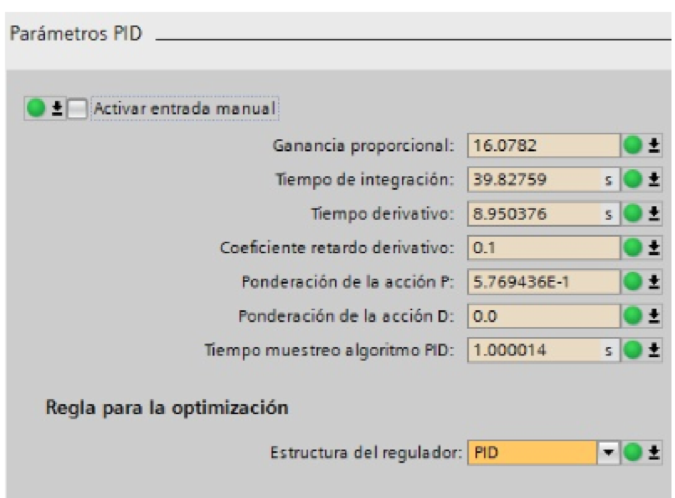


Figure 27: Parameters of the PID controller for the muffle. [10]

Control of the thermal plant is successfully obtained thanks to the PID_Compact incorporated in the PLC.

CONCLUSIONS

In the refining processes, the control of the variables in real time is of the utmost importance, for that an optimal system of precise supervision must be developed, for this case the WinCC software is capable of communicating the required information in the desired way. In the control of the oil plant and even simulating this system, a control model is required, preferably without offset error and capable of having a fast response time.

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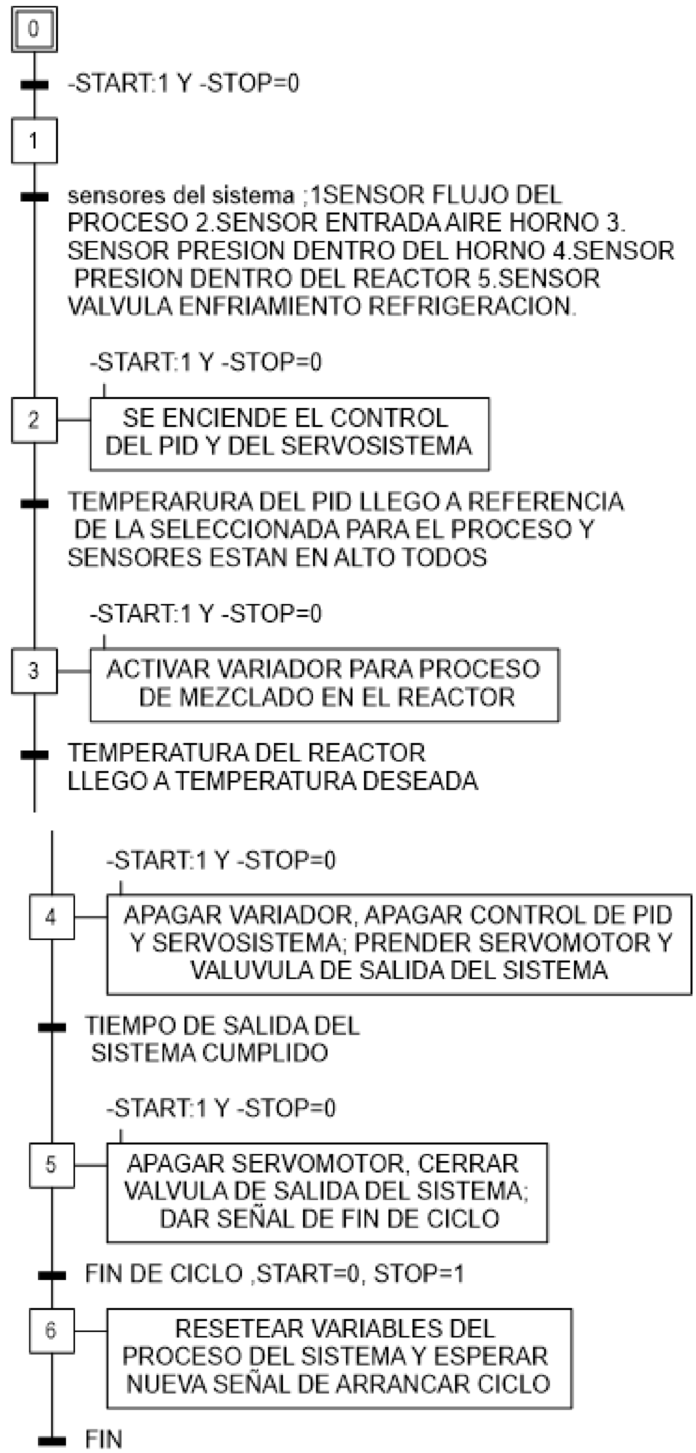
ANNEX

- **GRAFCET**

LEVEL 1


0
-START:1 Y -STOP=0
1
sensores del sistema ;1SENSOR FLUJO DEL PROCESO 2.SENSOR ENTRADA AIRE HORNO 3. SENSOR PRESION DENTRO DEL HORNO 4.SENSOR PRESION DENTRO DEL REACTOR 5.SENSOR VALVULA ENFRIAMIENTO REFRIGERACION.
-START:1 Y -STOP=0
2
SE ENCIENDE EL CONTROL DEL PID Y DEL SERVOSISTEMA
TEMPERARURA DEL PID LLEGO A REFERENCIA DE LA SELECCIONADA PARA EL PROCESO Y SENSORES ESTAN EN ALTO TODOS
-START:1 Y -STOP=0
3
ACTIVAR VARIADOR PARA PROCESO DE MEZCLADO EN EL REACTOR
TEMPERATURA DEL REACTOR LLEGO A TEMPERATURA DESEADA
-START:1 Y -STOP=0
4
APAGAR VARIADOR, APAGAR CONTROL DE PID Y SERVOSISTEMA; PRENDER SERVOMOTOR Y VALUVULA DE SALIDA DEL SISTEMA
TIEMPO DE SALIDA DEL SISTEMA CUMPLIDO
-START:1 Y -STOP=0
5
APAGAR SERVOMOTOR, CERRAR VALVULA DE SALIDA DEL SISTEMA; DAR SEÑAL DE FIN DE CICLO
FIN DE CICLO ,START=0, STOP=1
6
RESETEAR VARIABLES DEL PROCESO DEL SISTEMA Y ESPERAR NUEVA SEÑAL DE ARRANCAR CICLO
FIN

LEVEL 2

I_D	
I0.0	PARADA DE EMERGENCIA
I0.1	START
I0.2	STOP
I0.3	SENSOR FLUJO DEL PROCESO
I0.4	SENSOR ENTRADA AIRE HORNO
I0.5	SENSOR NIVEL DENTRO DEL HORNO
I0.6	SENSOR NIVEL DENTRO DEL REACTOR
I0.7	SENSOR VALVULA ENFRIAMIENTO REFR

Q_D	
Q0.0	SEÑAL DE CONTROL TEMPERATURA VALVULA DE COMBUSTIBLE (T_C_HORNO)
Q0.1	VALVULA BOMBA SALIDA SISTEMA
Q0.2	SEÑAL DE ACTIVACION DE VARIADOR
Q0.3	VALVULA REFRIGERANTE
Q0.4	VALVULA BOMBA CENTRIFUGA
Q0.5	VALIZA VERDE
Q0.6	VALIZA AMARILLA
Q0.7	VALIZA ROJA

I_A		
IA0	IW2	TH(PT100)
IA1	IW4	TR(SALIDA INTEGRADO)
IA2	IW6	
IA3	IW8	

Q_A		
QA0	QW2	SEÑAL DE CONTROL REACTOR
QA1	QW4	BOMBA CENTRIFUGA (SERVOMOTOR)