Design and Implementation of an automation trainining panel with PLC and HMI applied to a filling system using servomotors for the power electronics laboratory.

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Abstract

The current Project consists on the implementation of an automation training panel for the electronics and automation engineering students at ESPOL University, with the purpose to provide a didactic tool so that the power electronics laboratory's students could develop any other applications using the equipment and electrical machinery currently available at the laboratory. Also, an auger filling system, consisting of a small conveyor belt and a hopper, was automated as a demonstrative application for the panel.

This training panel was designed to have a HMI and a PLC with its digital inputs and outputs wired to terminals on its front face. The same digital inputs on the front face, are represented as two position switches in case it is needed to simulate an external signal, and the digital outputs have pilot lights that work as state indicators. The same principle was applied to the PLC's analog inputs and outputs, using a variable DC voltage power source to simulate an external signal if desired.

The actuators of the filling system were two AC servomotors with their respective AC drives. The control of the devices was made through a PROFIBUS link between the PLC and the drives.

Keywords*: SIEMENS, HMI, PLC, EMERSON, UNIDRIVE SP, PROFIBUS, TIA PORTAL, CTSOFT, S7-1200, KTP-600, AC DRIVES, AC SERVOMOTORS, AUGER FILLING SYSTEM, GSD FILE, PPO4 WORD, FIEC, ESPOL.*

1. Introduction.

This Project was designed with the main purpose of providing a tool that allowed students to implement other applications unifying and expanding the knowledge they got from previous power electronics and automation courses using the variety of electrical machinery, starters and drives available at the power electronics laboratory, which are used in the local industrial environment in real industrial applications. In a few words, our goal was to implement a PLC and HMI programing panel, keeping in mind the didactic aspect of it during the design stage, with the ability to communicate the PLC with other devices, for example an actuator, through a PROFIBUS network.

Because it was our intention to provide a tool that allowed students to develop applications using the devices on the laboratory, it was decided that the approach for the control of these devices should be done using data communications. Although the majority of soft starters and VSD's have signal terminals which can be used with the physical inputs and outputs of the PLC to offer some degree of control over an electric motor, it is when we use some kind of data transfer protocol between the controller and the actuators that in some way those physical limitations are eliminated and the user has a wider range of control options.

It is necessary that the electronics and industrial automation engineering students at ESPOL get in touch with a well-known and widespread industrial automation programming environment. On this particular case, we used a PLC and HMI manufactured by SIEMENS and its programming software, TIA PORTAL V12.

With the automation of an auger filling system, implemented by the CAMPRO laboratory at ESPOL, we wanted to provide a demonstrative application for the training panel using the UNIDRIVE SP and the UNIMOTOR FM servomotors, available at the power electronics laboratory as actuators controlling the speed of a belt conveyor, which will transport empty containers up to a certain position under a hopper which has the auger inside, and the number of revolutions the auger will turn to dose a certain volume of product into the container. All this process will be controlled by the S7-1200 PLC through a graphic interface on the KTP-600, both mounted on the training panel.

On the local industrial environment these types of filling systems are mainly used on the pharmaceutical and food industries and the products to dose are generally powders, grains and cereals. Because of physical limitations inside the laboratory, the system was reduced to only the filling stage, therefore the number of variables for the PLC to control were also reduced since a complete industrial filling system consists of several stages like sterilization, labeling and a product feeding system to the hopper.

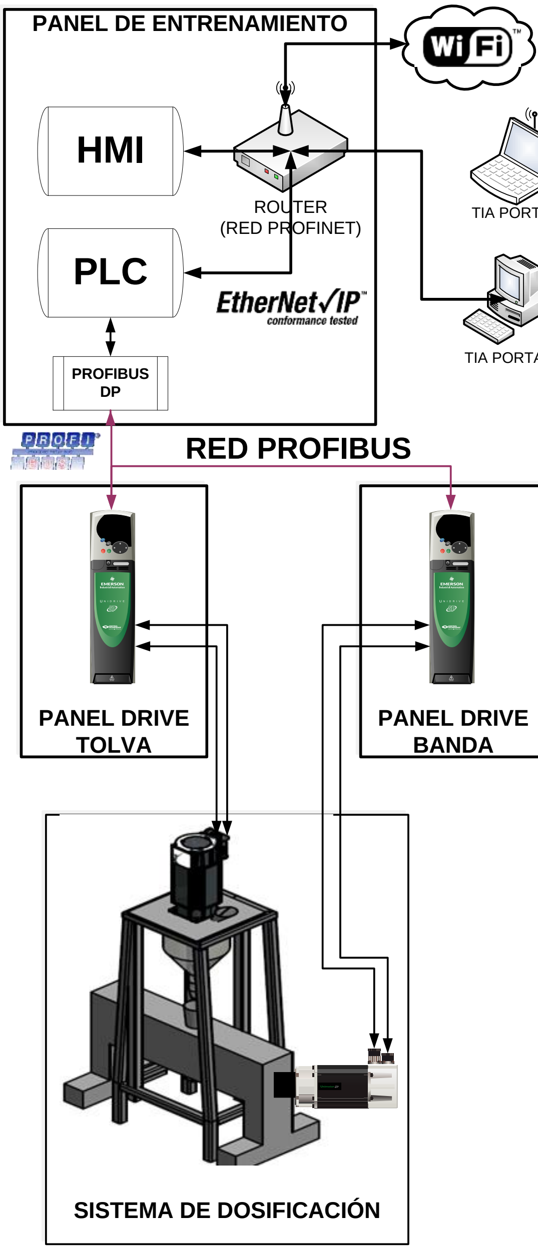

Figure 1. Project block diagram[1].

2. Panel Design

The panel was designed according to previous dimensions used on other projects in the laboratory, 1.5m hide by 0.75m wide. By convenience it was decided to divide the front face of the panel in two halves. The upper lid holds the KTP-600 HMI, two digital voltmeters to visualize the value of the signal from the 10 VDC variable voltage source on the interior, and the potentiometer knobs to modify the voltage. Two digital voltmeters are used to visualize the value of the PLC's analog voltage outputs, Pilot lights as indicators were used for the main power, PLC, and HMI, four 2-position switches to choose whether to use as an analog input the variable voltage source or an external signal and to choose to use as an analog output the voltage signal from the PLC's analog module, and four more on/off switches for the 2 analog inputs, and the 2 analog outputs.

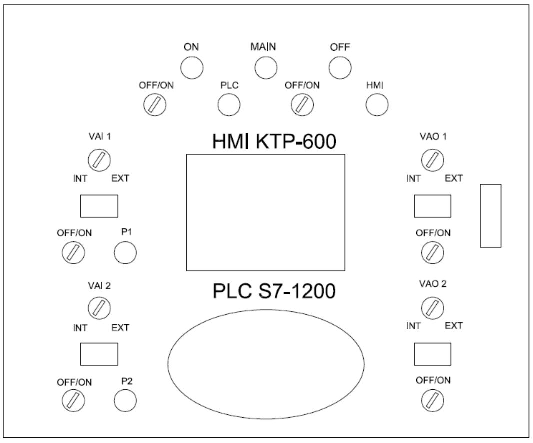

Figure 2. Design of top panel cover training[1].

The lower lid of the panel's front face has 14 2-position switches which in conjunction with relays and a 24 VDC source, simulate digital signals on the input terminals of the PLC. Under each switch for the digital inputs, there's also a terminal for external digital inputs, using the 24VDC output also on the front face of the panel, these external signals can come from other devices such as limit switches or a photoelectric sensor's output relay.

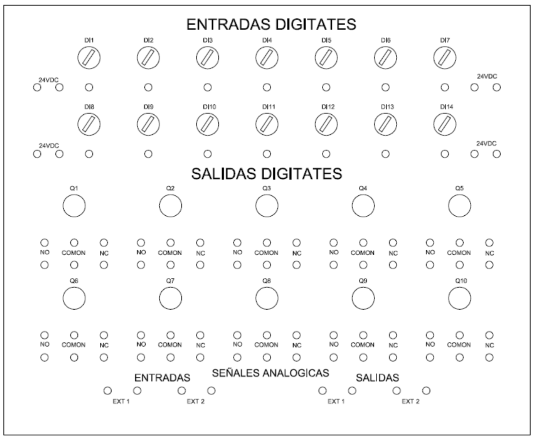

Figure 3. Design of lower panel cover training[1].

On the bottom we find terminals for 2 external analog inputs and for 2 analog outputs as well, these terminals are directly wired to the PLC's analog module.

There's 10 pilot lights that work as indicators for each of the PLC's digital outputs, and also, under each indicator, there are 3 terminals for the respective

COMMON, NO and NC relay contacts for each digital output, this way the training panel can be used to control external devices through digital signals without compromising the integrity of the PLC terminals.

Figure 4. Operating panel.

On the inside we find a double 10 VDC at 1Amp variable power source, a 24 VDC at 2.5 Amps power source for the 10 relays' coils, an ETHERNET router through which a PROFINET link is created for the communication between the KTP-600 HMI on the front face of the panel, and the S7-1200 PLC on the interior, the S7-1200 SIEMENS PLC with the 1214C CPU has 14 digital inputs, 10 digital outputs, two 0-10V analog inputs and a PROFINET RJ45 port. For the extra analog inputs, it was necessary the SM 1232 module for the S7-1200 with two 0-10V analog inputs.

The CM1243-5 PROFIBUS DP communications module for the S7-1200 was also included, this will allow the data communications between the PLC as a network master and other PROFIBUS enabled devices like the UNIDRIVE SP in the power electronics laboratory. The CM1243-5 provides the PLC the capacity to control up to 32 PROFIBUS slaves.

For further information about the wiring and the electrical diagrams for the implementation of this project we recommend to follow the link below in the references section[1].

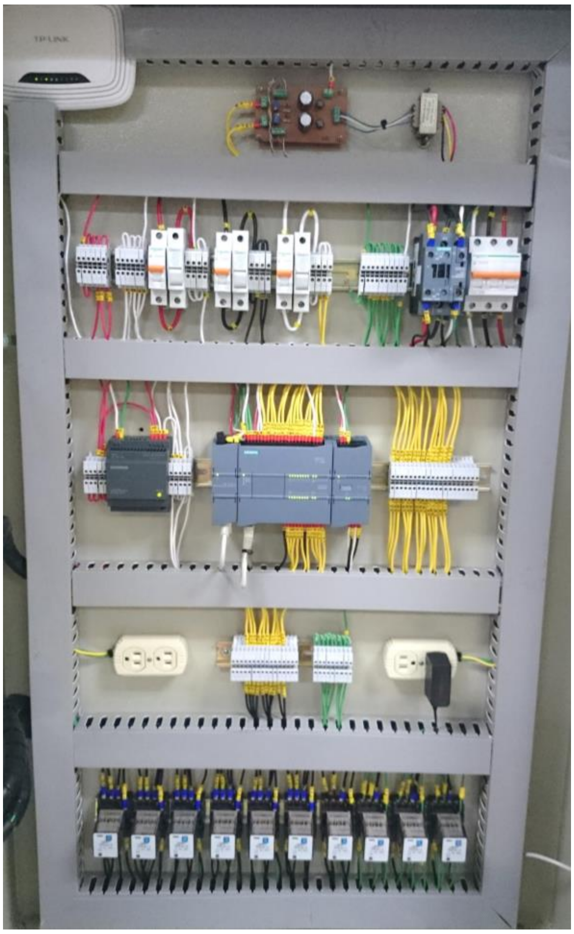

Figure 5. Training panel interior.

3. Auger filling system.

As it was already mentioned, as a demonstrative application for the training panel, it was decided to automate an auger filling system using the S7-1200 PLC on the panel to control the AC drives that "feed" 2 servomotors. The shaft of the first servo will be coupled to a chain transmission system that'll make the belt conveyor move. The second servomotor's shaft will be directly coupled to an auger inside a hopper that will also contain the product the system is intended to dose. The principle behind this filling system, is that between each of the auger's "teeth" exists a fixed amount of "space" or volume which in this case will be occupied by a powder or a granular material (e.g. a cereal like rice or quinoa), as the auger rotates that fixed volume of material will descend from the top part of the hopper all the way down through the auger and falling by gravity through a hole at the bottom inside a plastic container under the hopper, in other words the dosage of the material will be volumetric and the amount of dosed product depends on the number of revolutions the shaft of the second servomotor rotates.

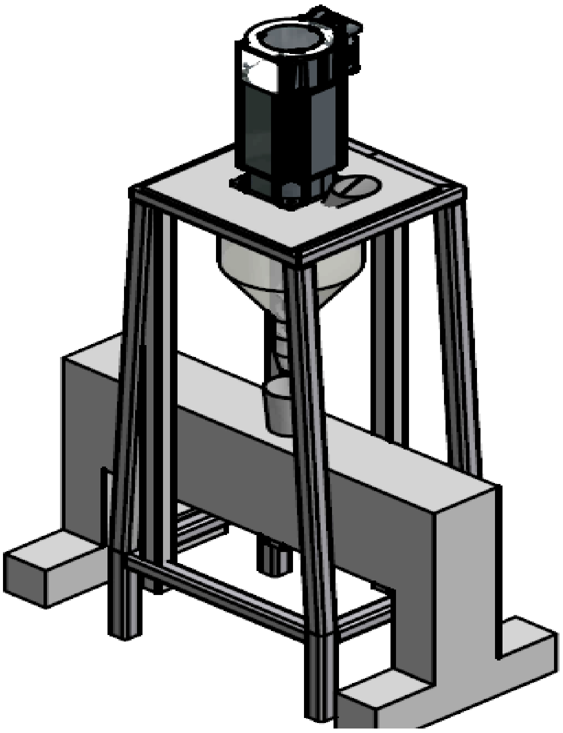

Figure 6. Auger filling system design.

The whole system's routine will be to transport an empty container from one end of the conveyor to a specific position detected by a photoelectric sensor, when the sensor detects the container the PLC will command the servomotor to stop so that the container will be under the hopper, after this, the PLC will command the second servo to rotate a certain amount of revolutions so a certain volume of the product inside the hopper will fall inside the container, once the PLC detects the servo has rotated the commanded number of revolutions, it will command the first servo to start moving the conveyor belt until the photoelectric sensor detects a new container and the process repeats.

Figure 1 shows a block diagram of the whole system. First we can see the communications between devices inside the training panel, the PLC communicates with the HMI display through the router, and since it's a wireless router, students can establish a connection to the PLC directly from a laptop that has installed TIA PORTAL V13 and program the HMI and the PLC. The S7-1200 communicates through its CM1243-5 PROFIBUS DP module to the communications module on both of the UNIDRIVEs, once the link is stablished the PLC can read or modify data from the drives parameters that show operation values as speed, axis position, output voltage and control the servomotors different operation modes. As it's shown, the servo coupled to the belt conveyor will run on a speed control, that means that the PLC modifying the speed value on the speed reference parameter, will change the velocity at which the containers are transported, and by changing the value of the bits on the drive's Control Word parameter, it will command the UNIDRIVE SP when to stop o start the rotation of the servo's shaft. The second servo, the one coupled by the shaft to the auger inside the hopper, will run on a revolutions control, the PLC once it detects and empty container under the hopper and after stopping the conveyor, will command the respective UNIDRIVE SP to rotate the servo's shaft the amount of revolutions the operator of the system specified through the graphic interface on the KTP-600.

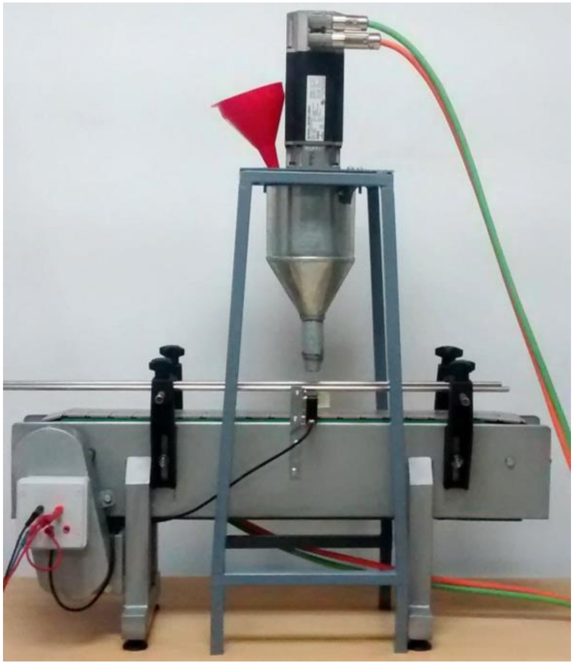

Figure 7. Belt conveyor, hopper, photoelectric sensor and servomotor of the auger filling system.

4. Communications setup.

It is simple to establish a PROFINET link between the KTP-600 and the S7-1200 using a router, the first thing to do is to setup the network configuration of the router using a computer to access its internal software, then an IP address and a subnet mask must be assigned for the router; the subnet mask must be the same for the 3 devices (router, PLC, HMI). The steps to achieve this may vary depending on the router´s manufacturer. A wireless TP-Link router was used for our project.

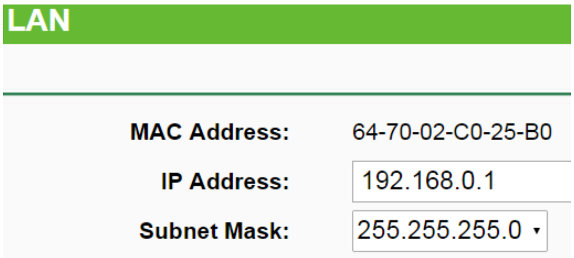

Figure 8. ETHERNET configuration of the router.

Then an IP address must be assigned to the KTP-600 on its PROFINET configuration menu, for this case the IP assigned was 192.168.0.3 and the subnet mask 255.255.255.0. After the PROFINET setup on the HMI has been done, it is necessary to make the same configuration to the HMI block on the TIA PORTAL

V12 project where we've put the blocks for all the hardware we intend the PLC to recognize and to exchange information with. For the HMI KTP-600 the configuration must be as shown on figure 7.

Figure 9. PROFINET configuration for HMI[1].

For the PLC S7-1200 block, the PROFINET configurations is as follows:

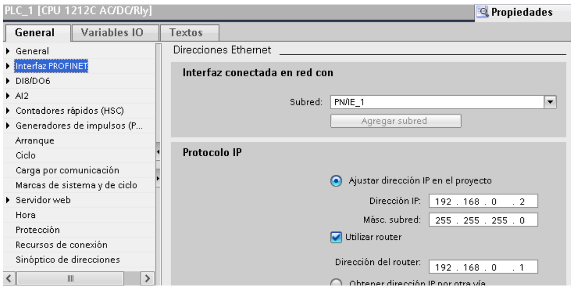

Figure 10. PROFINET configuration PLC[1].

With this setup, the PLC will be able to recognize the HMI and transfer data from it, also, once this setup is made, it is possible to program the PLC and design the HMI's SCADA for the system using TIA PORTAL and then upload it to the devices using a computer connected to the same PROFINET network through the router.

To setup a PROFIBUS link between the S7-1200 and both UNIDRIVE SP, first on TIA PORTAL's network view, the GSD blocks for the UNIDRIVE SP must be added, this block contains all of the drive's PROFIBUS characteristics and the ".gsd" file must be downloaded from the manufacturer's website and installed on the TIA PORTAL libraries, this way the PLC is able to exchange information with drives from different manufacturers via PROFIBUS.

Figure 11. PROFINET and PROFIBUS networks established[1].

After the PROFIBUS network has been has been set up, each of the devices linked to it must have a PROFIBUS address and since the S7-1200 will work as a network master, the PROFIBUS address must be assigned as "1" in the CM 1243-5 properties window, then all of the devices that will operate as network slaves, sending information and being controlled by the PROFIBUS master, will have to be assigned to an address number, for this case the UNIDRIVE commanding the servo that's coupled to the auger was assigned the address number 2 and the one commanding the servo on the belt conveyor was assigned as the number 3. The same procedure must be performed on both of the UNIDRIVE's PROFIBUS configuration parameters either manually or using the CTSoft, software tool for Emerson industrial devices.

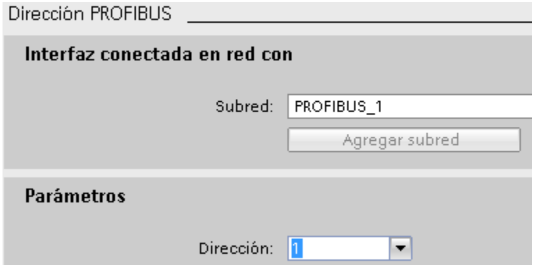

Figure 12. PROFIBUS configuration of the network's master[1].

The UNIDRIVE SP is enabled to be part of a PROFIBUS network and to operate as a network slave when the SM PROFIBUS-DP module is fitted on any of the 3 expansion slots in it. Depending on the slot the module is fitted, the menu number where the PROFIBUS's configuration parameters are can vary from 15 to 17. So, with the communications module installed, the same PROFIBUS node addresses assigned on TIA PORTAL must be assigned on the respective drive. The PROFIBUS communications module actually makes available 10 input and 10 output communications channels for the drive to exchange information with the network master through the PROFIBUS BUS cable. The 10 input and 10 output channels are allowed to use up to 16, 32-bits, data words or 32, 16-bits, data words to assign to each of the communications channels depending whether you are using a channel to exchange information in a cyclic or non-cyclic way with another device in the network. This is because when using one (input or output) channel for a cyclic data transference, it's only possible to assign a single parameter which could be one word of 16-bits or 32-bits in size, but for non-cyclic communications there's only one channel available which depending on the selected non-cyclic transference type (e.g. CT single word or PPO4 word) could be one or four, 16-bits, words in size. The fundamental difference between a cyclic and non-cyclic data exchange for the UNIDRIVE SP, is that cyclic transferences occur periodically and data values are updated constantly between devices on the PROFIBUS network and only one parameter per channel is allowed, while with a non-cyclic data transference a single channel can have access to all UNIDRIVE's parameters, the exchange of information only occurs when the master of the network commands it and there is a format to follow to make a reading or writing petition so that the slaves send or receive info from the master.

Parameter	Description	Default	Memory
17.00	**Parameter 0**	0	**0**
17.01	Solutions Module ID	403	**403**
17.02	Solutions Module software version	0,00	**3,02**
17.03	**Fieldbus Node Address**	126	**3**
17.04	**Fieldbus Baud Rate**	0	**3**
17.05	**Mode**	4	**216**
17.06	Fieldbus diagnostic	0	**554**
17.07	**Trip delay time**	200	**200**
17.08	**Little endianism select**	0	**0**
17.09	**Register control**	0	**0**
17.10	**'I' data register 0**	1040	**6151**
17.11	**'I' data register 1**	201	**1040**
17.12	**'I' data register 2**	0	**809**
17.13	**'I' data register 3**	0	**502**
17.14	**'I' data register 4**	0	**401**

Figure 13. PROFIBUS configuration and parameters of the UNIDRIVE SP[1].

The figure, shows the PROFIBUS configuration menu for the UNIDRIVE of the servo coupled to the belt conveyor. In parameter 17.03 we assign the address number for this drive inside the PROFIBUS network, in parameter 17.05 you specify the type of communication to use (e.g. cyclic, CT single word, PPO4 or mixed) and the amount of data words to be available for the 10 input and output channels. By default, the SM PROFIBUS DP module assigns to each cyclic channel 32 bits of space which is the maximum size a parameter can be, smaller parameters (16, 8 or 1 bit size) only use the most significant bits of that space.

From parameters 17.10 to 17.19 we have access to the 10 input communication channels and from 17.20 to 17.29 the output channels. When non-cyclic communication is implement, the first input and output channels are reserved and the rest available for parameter assignation. For our purposes, it was needed to control from the PLC the servomotor's speed, start and stop. So parameter 6.42 and 1.18 were assigned to 17.21 and 17.22 respectively. Parameter 6.42 corresponds to the drive's Control Word, a 16 bit word where the start and stop commands can be given; parameter 1.18 corresponds to the speed reference in RPM, modifying this 16 bit word will be change the servomotor's shaft speed.

For more information regarding the UNIDRIVE's PROFIBUS characteristics and the SM PROFIBUS DP module, refer to the "Advanced User Guide for the SM PROFIBUS DP module" for the UNIDRIVE SP found on controltechniques.com.

5. PLC programming and design windows on HMI.

The S7-1200 programming was done in the Siemens's TIA PORTAL software, programming was made into several blocks and also the program's main block was divided into segments according to the role of the code.

Segmento 1:	INICIO DEL PROGRAMA CON BOBINAS PARA EL SISTEMA
Segmento 2:	PANTALLA DRIVE DISPENSADOR
Segmento 3:	PANTALLA DRIVE BANDA TRANSPORTADORA
Segmento 4:	PPO4 WORD A PARÁMETRO 13.20 ESCRIBIR # DE VUELTAS AUTO/MANUAL
Segmento 5:	GIRO DEL TORNILLO SIN FIN
Segmento 6:	CONTROL DE LA BANDA MODO AUTOMÁTICO
Segmento 7:	BLOQUES DE FUNCIÓN EN MODO AUTOMÁTICO
Segmento 8:	BLOQUES DE FUNCIÓN EN MODO MANUAL
Segmento 9:	MODO MANUAL
Segmento 10:	MODO DOSIFICADORA

Figure 14. Segments of programming block Main[1].

The PLC that controls the servomotors, uses the Control Words of the two UNIDRIVE SP, This is a 16-bit word, and its functions are explained in more detail in the graduation project's file [1]. For example the following image shows how to write W#16#0180 on %QW114 and %QW74, corresponding to both servos control words, causing disabling of the drives.

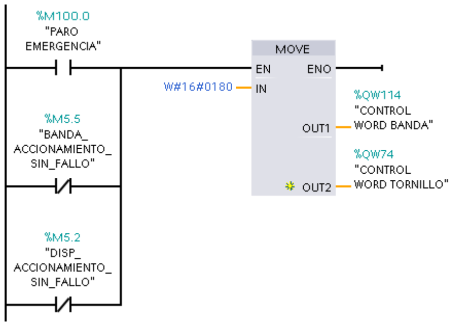

Figure 15. Emergency and failure stop`s block[1].

In the "MODO AUTOMATICO" screen HMI , the operator presses the START button , the parameters 1.18 "Precision Reference Coarse " where is written speed and 6.42 "Control Word " is changed, the bit of gear is engaged . When the sensor detects a bowl Run bit is cleared, the band stops. Once the signal has finished the filling process is received, the Run bit is reactivated and the band returns to advance. If while in automatic mode STOP is pressed, this is set to 0 the motor speed.

The PLC does also access the Status Word of the drives. It reads bits 0, 1, 7, corresponding to "Drive in perfect condition" , "Drive On" and " Load Reached" respectively and these parameters are associated with a PLC's internal variable so their values can be used for other purposes like monitoring the state of the drives and according to it, perform an action .

For filling, the PLC reads the parameter 3.28 that indicates the current number of revolutions already made. This value is added to the number of revolutions to rotate, previously determined by the user through the HMI, and the result becomes used to modify the parameter 13.20, the servomotor shaft begins to rotate a number of revolutions equal to the difference between the new value 13.20 and the previous value and when finished, automatically stops at the end.

From the PLC option to change non cyclic data, for example the parameter 13.20 of the UNIDRIVE SP, the hopper using the data type PPO4, there are 4 words of 16 bits to read or modify any parameter of the drive is programmed. The first word 16#700D corresponds to the ID TASK = 7 and the menu parameter 13. The second 16#1400 indicates hexadecimal parameter 20 to menu 13 and the other two words would the data to change that parameter [9].

The development of the windows on the HMI to be used for the control and monitoring of the filling was also made entirely on TIA PORTA. Their design was thought for the system to have 3 modes of operation: automatic mode of production, manual production mode, dosing mode and maintenance modes.

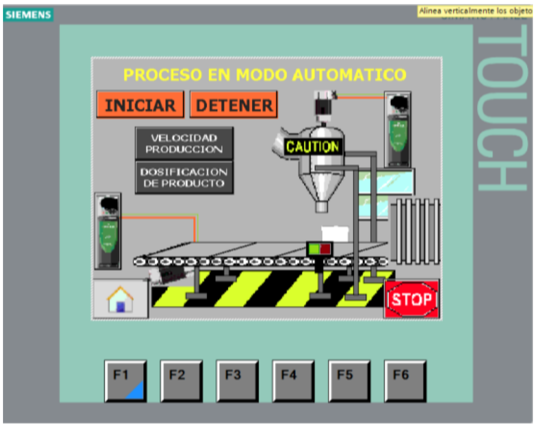

Figure 16. System's SCADA[1].

7. Conclusions.

1. We were able to design and implemented a panel that provides the possibility to create a graphic user interface that works in conjunction with a PLC, giving access through terminal on its front face, to the inputs and outputs both digital and analog of the S7-1200 so it works as a learning tool to program automated systems and as a controlling tool for the AC drives in the laboratory with the possibility of implementing more complex applications.

2. It is more efficient to control an industrial drive by PROFIBUS communication, instead of a control made via digital or analog inputs and outputs of a PLC, since the wiring is significantly decreased and the range of control is not limited by the PLC's hardware.

3. Implementing a volumetric dosing system using a PLC, AC servomotors, AC drives and using a PROFIBUS network is a viable project and its main benefit is the significant reduction of wiring, the control range that the PLC has over the motors and the drive's parameters.

4. Human-machine interfaces have enabled us to provide user control of the filling system without having to access a computer to change the process variables in real time.

8. Acknowledgements.

This project that was developed for 6 months with support from the Escuela Superior Politécnica del Litoral by their economic investment for this project.

We want to thank MSC. Damian Larco for being our mentor and guide in this project, Everyone at CONDIMAQSA Company SA and CAMPRO laboratory at ESPOL, who collaborated with the design and construction of the dosing system and specially our families for their unconditional support.

Figure 17. Complete Project.

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