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Article

Expansion and improvement of modular workstation for advanced PLC analysis and operation

Expansión y mejora de estación de trabajo modular para análisis y manejo avanzado de PLCs

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Abstract

This work provides continuity to the development of a modular workstation for the advanced operation of the programmable logic controller (PLC), through incorporation of the functions of master-slave communication, proportional-integral-derivative (PID) controller and high-speed counters (HSC); and its use as a support element for teaching process of related topics. The operation of the workstation constituted from the integration of a speed control system in a three-phase alternating current motor is analyzed; whose test parameters are entered from a graphical interface executed through a touch screen. Such application was implemented through a communication network between controllers; in addition, it uses a variable frequency drive (VFD) and an encoder as power and perception elements, respectively. The performance observed during the tests carried out confirms an adequate follow-up of assigned parameters, by reaching and settling real response of system in these. While, with regard to the use of the developed modular workstation as a teaching tool for analysis of advanced automation solutions, its relevance is confirmed.

Objectives	Methodology	Contributions
Expand the functionality of an existing modular workstation for advanced PLC operation. Use the modular workstation as support in the teaching-learning process.	✓ Identify the functionality of existing electrical panels and the functions and devices to be incorporated. ✓ Establish the redistribution of electrical panels and carry out the physical modification process. ✓ Integrate an industrial control system for the application of the added functions.	Enable and have an improved modular workstation for advanced PLC analysis and operation. Introduce the participant to the current trends and scope of automation and industrial control systems.

Programmable logic controller, PLC advanced functions, modular PLC workstation

Resumen

El presente trabajo brinda continuidad al desarrollo de una estación modular de trabajo para el manejo avanzado del controlador lógico programable, a través de la incorporación de las funciones de comunicación maestro-esclavo, controlador proporcional integral derivativo (PID) y contadores de alta velocidad; y su utilización como elemento de apoyo al proceso de enseñanza de tópicos relacionados. Se analiza la operatividad de la estación conformada a partir de la integración de un sistema de control de velocidad en un motor de corriente alterna trifásica, cuyos parámetros son ingresados desde una interfaz gráfica ejecutada a través de una pantalla táctil. Tal aplicación fue implementada a través de una red de comunicación entre controladores; además, de emplear un variador de frecuencia y un encoder como elementos de potencia y de percepción, respectivamente. El desempeño observado durante las pruebas ejercidas constata un adecuado seguimiento de los parámetros asignados, al establecerse en éstos la respuesta real del sistema. Mientras que, en lo que respecta al uso de la estación modular de trabajo desarrollada, como herramienta didáctica para el análisis de soluciones avanzadas de automatización, se confirma su pertinencia.

Objetivos	Metodología	Contribuciones
Ampliar la funcionalidad de una estación modular de trabajo para el manejo avanzado de PLCs existente. Utilizar la estación modular como apoyo en el proceso de enseñanza-aprendizaje.	✓ Identificar la funcionalidad de los tableros eléctricos existentes y las funciones y dispositivos a incorporar. ✓ Establecer la redistribución de los tableros eléctricos y ejercer el proceso de modificación física. ✓ Integrar un sistema de control industrial para la aplicación de las funciones agregadas.	Habilitar y disponer de una estación modular mejorada para el análisis y manejo avanzado de PLCs. Encarar al participante con las tendencias y los alcances actuales de la automatización y los sistemas de control industrial.

Controlador lógico programable, funciones avanzadas del PLC, estación modular de trabajo con PLC

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Introduction

Mechatronics Engineering synergistically integrates knowledge from the areas of mechanics, electronics, computing and control, for automation of processes and optimization of the use of resources, based on design, planning and construction of instruments and tools. In this way, a mechatronics professional must have an analytical, critical and creative capacity, oriented to design, implementation and innovation of automated systems; in addition to integrating, operating and maintaining them (Aquino Robles, Corona Ramírez, & Trujillo, 2013; Bolton, 2017; Baque Castro, Marcillo Parrales, Cedeño Ferrín, & Gutiérrez García, 2022). Companies receiving Mechatronics Engineers will generally require, in addition to the aforementioned skills, other added values, depending on functions to be performed (Breaz, Bologa, & Racz, 2014; Benavides Bastidas, Mosquera Terán, Peluffo Ordóñez, & Terán Pineda, 2017).

A highly sought-after skill in the industrial environment for Mechatronics Engineer is the operation of programmable logic controller (PLC). This is an industrial computer for process automation, which allows the implements to which it is adapted to effectively develop the functions of each system that constitutes them. This device has been vital for incorporation of automation in industrial systems. Its main function is the management of control systems, basis of automation; some of which will be closed-loop (Ephrem & Mohammad, 2016; Kelemen & Sinčák, 2020; Channi, Kumar, & Dhingra, 2024).

However, despite the recent advances promoted by introduction of Industry 4.0 paradigm and hyperconnection of devices, PLC has competitive characteristics that have allowed it to remain the industrial controller par excellence. Even so, recent industrial developments have made increasingly more demanding to take advantage of advanced functions that PLC may have, which allow operations to be carried out in real time, based on a reduced reaction period (Aquino Robles, Corona Ramírez, & Fernández Nava, 2019; Langmann & Stiller, 2019; Sehr et al., 2021).

Among the advanced functions that a PLC can have, it can be mentioned: handling of analog inputs and outputs, use of PID (proportional-integral-derivative) controller instruction, management tasks through HMI – SCADA (Human-Machine Interface – Supervisory Control & Data Acquisition) systems and interaction with other control devices, or regulation of actuators, through different communication protocols, to form industrial networks. To the extent that functions described are adequately applied in process management, the permissible level of automation will be established (Baniyounis & Alshabi, 2015; Mhetraskar, Namekar, Holmukhe, & Tamke, 2020; Hermans, 2023).

Background and purpose of the intervention

Due to the low availability of industrial equipment required for development of advanced automation practices, as part of training of Mechatronics Engineers graduated from Technological University of Northern Aguascalientes, the convenience of implementing a series of electrical panels, made up of the minimum components, dictated by topics of subject Advanced Logic Control, has been analyzed for some time. It is worth mentioning that this subject concentrates a large part of contents related to the current trend of industrial automation; it being vital for the future professional to have a previous and significant contact with related devices, which at some point will have to be manipulated.

Thus, the purpose of this intervention was to expand the functionality of an existing modular PLC workstation, made up of two electrical test panels, or modules, integrated from Allen Bradley components. Housed inside the first panel were a PLC Micrologix 1500, an analog input and output module 1769-IF4XOF2, an Ethernet module 1761-NET-ENI, and an operator's interface PanelView Plus 600. The second panel housed a variable frequency drive (VFD) PowerFlex 40. Both panels were fitted with easy-to-connect terminals, in order to save as much time as possible in their operation; given that, originally, there was only one workstation, which was used to provide service to at least two groups, whose population fluctuates between 20 and 30 students.

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With the intention of promote a radical improvement in function of existing panels, it was agreed that they could be modified, either to adapt other devices or to provide a different organization to those that were already in place. In general, it was intended that, after this intervention, panels could be used to develop a greater number of educational applications; in addition, to generate a more significant impact on training of the participant. Innovation would focus on strengthening programming capabilities of available PLCs, to emphasis them on automatic process control, through use of PID instruction and high-speed counters (HSC); in addition, to incorporate some other controller to implement a hierarchical communication architecture between them.

Given the functions available in modular PLC workstation, after its modification, a series of practical exercises were proposed that could be developed with it, and that were then used, initially, for practical evaluation of subject Advanced Logic Control. Among the proposals assumed, one in particular was analyzed, which required the use of all the existing software and hardware elements, and which also served as a reference to establish the respective setting process. It was determined that the implementation of a closed-loop system for speed control on shaft of a three-phase motor would fulfill the given purpose; which is documented in this work, to account for adaptations made to the original modular PLC workstation.

Control system preparation

In an industrial control system, the structure of which is shown in Figure 1, automatic controller compares the value obtained at the output of process to be controlled, with the reference input, to determine error signal between them. In relation to deviation detected and by applying a relevant control action, the same controller will set control signal so that detected error be reduced to a very low value or zero.

Box 1

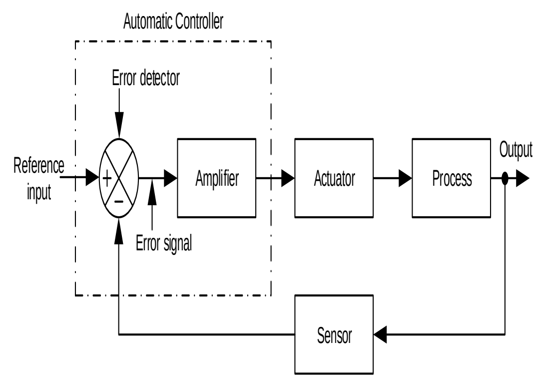

Figure 1
Block diagram of an industrial control system
Source: Ogata, 2010

Error signal usually has a very low power level, so controller amplifies it. Controller output is conducted to actuator, so that the latter produces a signal that, in turn, is routed to process to be controlled, in order to influence output signal in it to be controlled to approach the given reference signal. For its part, sensor interprets the process output signal, so that it can be compared with the reference signal (Ogata, 2010).

For purposes of control system to be implemented, a three-phase motor powered at 220 VAC (voltage of alternating-current) was used as an actuator, which provides a nominal speed of 1800 revolutions per minute (RPM); while sensor to be used would be a quadrature encoder, which provides 600 pulses per revolution. Encoder was adapted to the rear portion of motor shaft, from a mechanical coupling made with polylactic acid (PLA) filament, using 3D printing, and an aluminium base, as shown in Figure 2.

Box 2

Figure 2
Motor used and encoder adapted to its shaft
Source [Own elaboration, 2024]

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In turn, the use of a PLC for acquisition of speed data emitted by encoder was determined; therefore, to make an adequate interpretation of them, the respective programming was developed in RSLogix 500 software. Given the frequency of pulses generated, it was necessary to enable their reading from high-speed counters, which were set as programmable limit switches (PLS) in the digital input terminals of PLC, to which encoder was connected. Figure 3 shows the window for setting high-speed counters in RSLogix 500 software.

Box 3

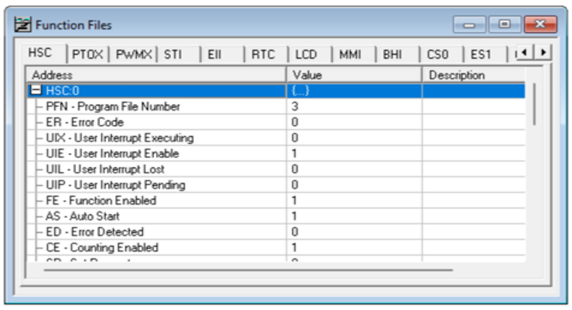

Figure 3
High-speed counters setting in RSLogix 500 software.
Source [Own elaboration, 2024]

PID Instruction Configuration

In order to be used, PID instruction requires the association of specific addresses to the parameters: PID File, Process Variable and Control Variable, which are shown in Figure 4. PID File stores data necessary for execution of the instruction itself, with a length of 23 characters; so, it must be entered as an integer file address. Also, it is recommended to use a unique data file for PID File, so that accidental reuse of program addresses can be avoided. In PID File, given setpoint can be configured or deleted, preferred operating mode (time, manual/automatic and control) can be imposed, or enabled output can be limited.

Box 4

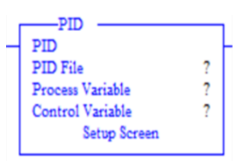

Figure 4
PID instruction in RSLogix 500 software.
Source [Own elaboration, 2024]

Process Variable stores the control system reference value or setpoint, which can come from a register containing reading obtained from an analog input terminal, or another associated with it, once processed. Finally, Control Variable records the value emitted by PID instruction itself or control signal, after processing system reference. It is worth mentioning that PID instruction does not allow floating-point values in any of its parameters, but rather these must be represented in integer format, between 0 and 16383, which corresponds to values between 0 and 100% of both process variable and control variable, as appropriate. The window for setting PID instruction in RSLogix 500 software is shown in Figure 5.

Box 5

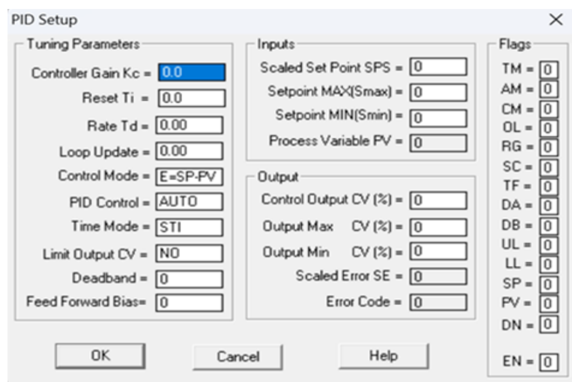

Figure 5
PID instruction parameters in RSLogix 500 software.
Source: Own elaboration, 2024

Proposed communication architecture between devices

As part of control system to be implemented, integration of a communication architecture was contemplated that would establish a hierarchical relationship between two PLCs: a master terminal unit (MTU) controller and a remote terminal unit (RTU) controller, which would be located in different electrical test panels, or modules. Likewise, an operator's interface would be incorporated, to manage the operation of the entire modular PLC workstation. Figure 6 presents proposed distribution for components of the control system to be implemented.

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Box 6

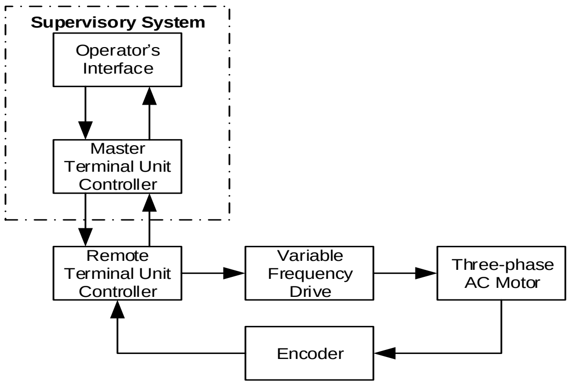

Figure 6
Original architecture of the proposed speed control system.
Source: Own elaboration, 2024

Originally, it was considered that direct control function would entirely executed by remote terminal unit controller; in whose programming, the emission of control signal that would lead to regulating speed reached on motor shaft, by means of the VFD used, as well as the interpretation of signal associated with such variable, acquired from encoder adapted to the motor shaft itself, would be ensured. Therefore, PID instruction would also be included in the programming of remote controller.

Control commands, or references, would be entered from operator's interface, and would also be guided to remote terminal unit controller through master terminal unit controller. Consecutively, information regarding speed reached on motor shaft would also be presented in operator's interface itself, after having been acquired by the same master controller from remote controller. In this way, both operator's interface and master controller would conform a supervisory system for direct control exercised on the motor.

Adapting the communication architecture to existing devices

For physical integration of the planned communication architecture, it was agreed to use both operator's interface PanelView Plus 600, as well as two Allen Bradley PLCs, as master terminal unit and remote terminal unit controllers, respectively.

Also, in order to speed up interaction between devices described, it was proposed to use Ethernet/IP protocol, which is supported by all of them; in addition, to establish a physical connection between them through a switch.

Ideally, two PLCs to be integrated were supposed to be of the same model, with PLCs Micrologix 1400 being initially chosen; however, only one of these was available. Instead, a PLC Micrologix 1500 was chosen, to which a 1761-NET-ENI module was adapted to ensure its access to an Ethernet network. Under the new device organization, PLC Micrologix 1400 would act as master terminal unit controller; while PLC Micrologix 1500 would be remote terminal unit controller; consequently, analog input and output module 1769-IF4XOF2 would also be adapted to the latter, to carry out action of VFD incorporated. It is worth mentioning that configuration assigned to PLC Micrologix 1500 corresponded entirely to that adopted in the first available electrical panel.

On the other hand, arrangement of high-speed digital inputs on PLC Micrologix 1400 and not on PLC Micrologix 1500, influenced to the designation of the first one to acquire data from encoder. Therefore, to improve the organization of devices and their connections, in the last network proposal to be implemented, it was decided to replace PLC Micrologix 1500 in the first existing electrical panel with PLC Micrologix 1400. This decision led to the creation of another electrical panel to house PLC Micrologix 1500 and the associated Ethernet and analog input and output modules, which is shown in Figure 7. In this way, the final proposal for distribution of components of control system to be implemented was integrated, which is shown in Figure 8.

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Box 7

Figure 7
Electrical panel for PLC Micrologix 1500.
Source: Own elaboration, 2024

Box 8

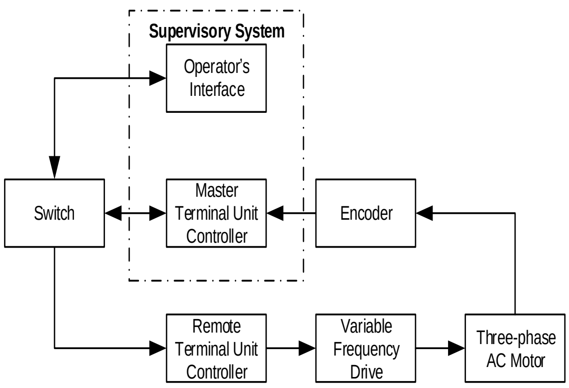

Figure 8
Final architecture of the proposed speed control system.
Source: Own elaboration, 2024

The application of Ethernet/IP protocol in hierarchical architecture shown in the figure above requires a Producer/Consumer dialogue mode between component devices. Producer role is assumed by the highest-ranking device, that is, the one around which communication structure itself is established; for purposes of system analyzed, this would correspond to master terminal unit controller (PLC Micrologix 1400); while remote terminal unit controller (PLC Micrologix 1500) would be considered as Consumer, as it responds to Producer's requests.

Programming of controllers and operator's interface

Dialogue setting between both PLCs used was integrated into the corresponding programming code, developed in RSLogix software. Mainly two types of instructions were incorporated: one for messaging, to manage sending of data from Producer to Consumer, and another for routing, which would allow the constant updating of exchanged information. And, since PLC Micrologix 1400 would also acquire speed data recorded in motor, also in the corresponding programming, it would be assumed that such information would be sent to PLC Micrologix 1500, as a feedback signal in the corresponding control system. The programming developed for both controllers is shown in flow charts in figure 9.

Box 9

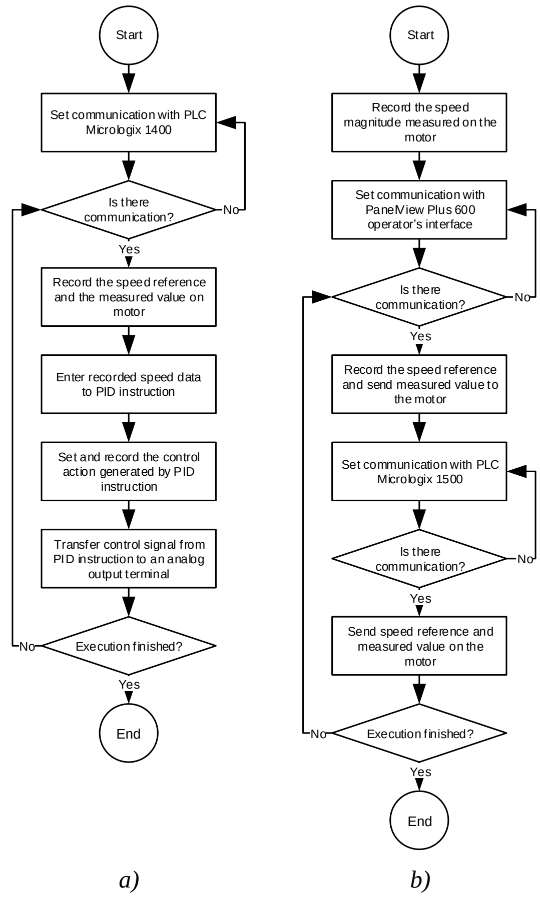

Figure 9
Programming flowchart for: a) PLC Micrologix 1500 and b) PLC Micrologix 1400.
Source: Own elaboration, 2024

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On the other hand, graphical interface was also developed to manage the operation of control system, from operator's interface PanelView Plus 600, using Factory Talk software. Through this interface, control setpoints, or references, could be admitted, as well as magnitude of the actual motor speed, or feedback, could be displayed. In the case of main screen design, interaction between the different modules used was taken as a reference, as shown in figure 10. Operator's interface also assumes the role of Consumer in the network integrated.

Box 10

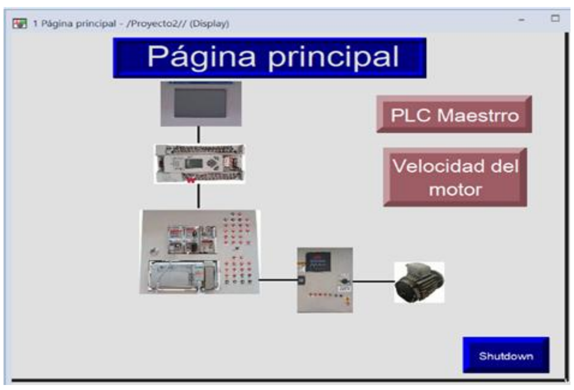

Figure 10
Main screen of control system graphical interface.
Source: Own elaboration, 2024

Two alternate screens were also developed. From the first alternate screen, a specific speed value would be applied to the motor used, through PLC Micrologix 1500, by means of a start and stop automation, which would use a different button for execution of each function. The second alternate screen would display speed magnitude measured on motor shaft, in revolutions per minute (RPM), acquired by PLC Micrologix 1400. For navigation through graphical interface, it was decided that from main screen it would be possible to access both alternate screens or to turn off the system; while from the first alternate screen it would be possible to go to main screen, or to the other alternate screen, and from the latter only main screen could be accessed.

Operation of the communication network and the modular workstation

After completing the development of programming codes for devices to be used, these would be downloaded to the respective PLC and operator's interface.

Subsequently, the interaction between both controllers would be established, based on integration of a peer-to-peer network. Operator's interface PanelView Plus 600 would be added to this communication architecture, to manage the operation of control system. Initial performance tests focused on ensuring the proper functioning of device network, through the associated graphical interface, thereby validating both the correct operation of each node, as well as the establishment of communication between them, as shown in figure 11.

Box 11

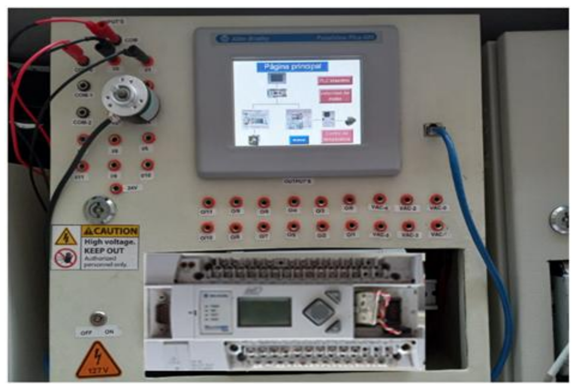

Figure 11
Communication between operator's interface and device network
Source: Own elaboration, 2024

For performance tests of the complete modular PLC workstation, connection was made between PLC Micrologix 1500 terminals and VFD PowerFlex 40, which would regulate the operation of motor. In this case, control signal generated by PID instruction programmed in PLC would be destined to an analog output terminal. Variable voltage magnitude generated by terminal used would be the reference for motor speed adjustment by the VFD used. Figure 12 shows the use of each electrical panel of modular workstation, modified or configured, in the development of operation tests of the proposed control system.

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Box 12

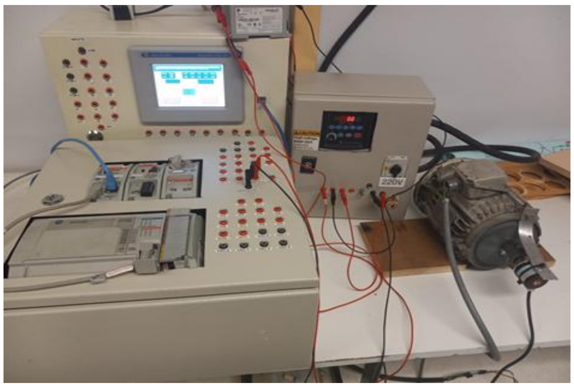

Figure 12
Test development with the complete modular PLC workstation.
Source: Own elaboration, 2024

As part of tests carried out, motor activation would be executed from the developed graphical interface, while magnitude of the actual speed reached on motor shaft could be monitored; both data would be entered as parameters to PID instruction, while the respective output signal would be destined to VFD, in order to regulate the speed of motor shaft to the desired value. It is worth mentioning that operating tests carried out determined the expected behaviour both in each device involved, as well as in the interaction between them, as part of modular PLC workstation.

Conclusions

Despite the technological advances promoted by the Industry 4.0 paradigm, the PLC continues to be the controller par excellence used to constitute automated systems. However, it can be said that a basic understanding of PLC operation is not enough for future professionals in areas such as Mechatronics Engineering to be able to face the challenges posed by the current scope of automation. For example, at this time, automated systems do not operate as isolated entities, but rather, on the contrary, they form a vast distributed organization that ensures the operation of increasingly complex production processes. Therefore, it is vital to delve deeper into the study of the advanced functions that a PLC has.

In this case, the following were analyzed: the PID instruction, high-speed counters and hierarchical communication systems.

On the other hand, the configuration of the PID instruction in a PLC not only marks the incursion into the application of industrial automatic controllers, but also provides an idea of their operation in a device that, at an educational level, is not usually used for this purpose. Likewise, the existence of high-speed counters could potentially be unknown, until both the need to acquire signals at high frequencies and the fact that only some PLCs have them are determined. Finally, the establishment of communication between PLCs, based on a hierarchy, constitutes the principle for the integration of huge distributed systems, which in operational reality incorporate a wide variety of levels.

In this way, the modular PLC workstation exposed, and whose functionality has been extended from the intervention documented in this work, is outlined as a tool that will allow, even on a small scale, to involve the student of Mechatronics Engineering of the Technological University of Northern Aguascalientes in the current trends and scope of automation, with application in industrial control systems. This is a reality that is frequently misunderstood and little sought after, within the classroom, even in technological education institutions; in which, the minimum equipment required for the development of practices may not be available.

The update has enabled a means to be put into operation through which not only can each incorporated device be experimented with, but also, through the programming and functionality of each formulated application, the advanced functions available can be analyzed in greater depth. On this occasion, it is a pleasure to exhibit a sample of what can be integrated through the use of the advanced functions of the PLC, in combination with the capabilities of other devices, such as an industrial control system. Thus, the commitment after this intervention will be to continue improving the existing modular PLC workstation, evaluate the options for its application as support material in related subjects and analyze the possibility of integrating some others, to provide greater attention to the students.

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Conflict of interest

The authors declare no interest conflict. They have no known competing financial interests or personal relationships that could have appeared to influence the article reported in this document.

Authors' Contribution

The contribution of each researcher in each of the points developed in this research, was defined based on:

Rodríguez-Franco, Martín Eduardo: Contributed to the project idea, research and experimentation methods, devices acquisition, physical devices redistribution planning into electrical panels and the writing of the article.

Jara-Ruiz, Ricardo: Contributed to the project idea, research and experimentation methods, physical devices redistribution planning into electrical panels and the configuration of controllers in software.

Zacarías-Rodriguez, Luis Gerardo: Contributed to the physical redistribution and electrical connection of devices into electrical panels, the development of graphical interface and the workstation operation tests.

López-Álvarez, Yadira Fabiola: Contributed to the project idea, literature research, technical information reviewing and scientific supervision of the writing of the article.

Availability of data and materials

The devices and equipment used were acquired by the researchers for the purposes of the exposed application and the programs and graphical interfaces developed by themselves.

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Abbreviations

HSC	High-speed counters
HMI	Human-machine interface
MTU	Master terminal unit
PLA	Polylactic acid
PLS	Programmable limit switch
PLC	Programmable logic controller
PID	Proportional-Integral-Derivative
RPM	Revolutions per minute
RTU	Remote terminal unit
SCADA	Supervisory control & data acquisition
VFD	Variable frequency drive
VAC	Voltage of alternating-current

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Basics

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Supports

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