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Design of Laboratory for Practical Teaching of Industry 4.0 Technologies Applicable in Colombian Energy Sector

Diseño de laboratorio para enseñanza de tecnologías de Industria 4.0 aplicables al sector energético colombiano.

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Resumen

La industria 4.0 ha permitido una transformación global de las distintas cadenas de producción e impactado diversos sectores sociales. Sin embargo, uno de los grandes retos generados para su adopción, es la falta de personal capacitado que cuente con las competencias suficientes para el manejo de tecnologías, generando así una necesidad que se puede abordar a través de estrategias de enseñanza en centros de formación superior. Por lo tanto, en este artículo se muestra como desde el laboratorio de Gestión de la Demanda Eléctrica de la Universidad Nacional de Colombia – Sede Manizales, se construyeron dos tableros con tecnologías de la industria 4.0 y se desarrollaron prácticas de laboratorio permitiendo a estudiantes de las carreras de ingeniería eléctrica y electrónica, obtener conocimiento en tecnologías como el internet de las cosas, la computación en la nube y el análisis de datos, con un enfoque hacia su aplicación en el sector energético colombiano.

Palabras clave: Análisis de datos, Analizador de redes, Calidad de la energía, Computación en la nube, Enseñanza, Industria 4.0, Internet de las cosas, Prácticas de laboratorio, Protocolos de comunicación, Router Industrial.

Abstract

The advent of Industry 4.0 has brought about a global transformation in various production chains, significantly impacting different sectors of society. However, one of the major challenges hindering its widespread adoption is the

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lack of adequately trained personnel equipped with the necessary skills to navigate advanced technologies. This has created a pressing need that can be addressed through teaching strategies implemented in higher education institutions. In this article, we present a case study conducted at the Laboratorio de Gestión de la Demanda Eléctrica of the Universidad Nacional de Colombia – Sede Manizales. Two panels incorporating Industry 4.0 technologies were constructed, and laboratory practices were developed to provide students in electrical and electronic engineering programs with knowledge in key areas such as the Internet of Things, Cloud Computing, and Data Analytics, with a specific focus on their application within the Colombian energy sector.

Keywords: Cloud computing, Communication protocols, Data analysis, Industrial router, Industry 4.0, Internet of Things (IoT), Laboratory practices, Power analyzer, Power quality, Teaching.

1. Introduction

The fourth industrial revolution or Industry 4.0 is a movement that has had a significant impact on the way goods and services are produced using information and communication technologies (ICT) [1], [2]. However, one of the challenges generated globally by the integration of Industry 4.0 is the need for trained personnel to handle the various technologies it encompasses [3], [4], including measurement equipment connected through the Internet of Things (IoT) [1], [5], the use of cloud computing [6], [7], and the analysis of information based on big data, etc. [2], [8]–[12]

The training of personnel for technology management has been primarily addressed by various higher education institutions, as they are centers of education and knowledge generation and thus should take the lead in generating programs that incentivize and develop professionals capable of technology management [13]–[15]. Consequently, international experiences worldwide have set objectives to allocate resources for the development of teaching strategies in Industry 4.0 technologies, where one of the identified strategies is the utilization of virtual practices. These practices allow students or professionals to access real platforms and setups remotely operated [16], [17], thereby enabling the acquisition of knowledge and competencies necessary for proposing projects that impact companies or productive sectors in various ways [4], [18].

Industry 4.0 also finds applications in the electrical sector, with Demand-Side Management (DSM) being one illustrative example. DSM aims to enhance and optimize the electrical system from the user's perspective. This is achieved through the integration of energy efficiency schemes, the utilization of dynamic pricing for different consumption patterns, and real-time control of distributed energy resources. The integration of measurement technologies at strategic points within the system, such as key processes or subprocesses within a production line, is essential for monitoring and assessing the network's condition. Furthermore, when combined with Industry 4.0 technologies like the IoT, cloud computing, and data analysis, these capabilities enable DSM processes and empower end-users to participate in these improvements by providing them with information, enabling them to understand and analyze it, and thereby adding value to their electrical systems [19].

Considering the above information, this article presents the implementation of a practical board utilizing measurement technologies and cloud connectivity, developed at the Laboratorio de Gestión de la Demanda Eléctrica (GESDELEC) of the Universidad Nacional de Colombia. The objective is to enable students in fields such as electrical and electronic engineering to acquire knowledge in the utilization of specific Industry 4.0 technologies, with a focus on their application in the end-user level of the electricity sector. These technologies include the Internet of Things, cloud computing, and data analysis as an integral component of Big Data. The article highlights the establishment of laboratories that leverage this practice board, facilitating the practical learning experience for students.

This article is structured as follows: Section 2 presents the methodology used for the development of the practice boards. In Section 3, the obtained results are presented, including the final practice board, the proposed laboratory practices, and the conducted socialization and practice sessions. Finally, Section 4 contains the conclusions derived from this work.

2. Methodology

The methodology employed in this study was Design Thinking, a methodology developed by the Stanford Design School and IDEO, which provides tools for the development of innovative ideas aimed at solving problems for a target audience [20]–[22]. This methodology consists of five main stages, which are detailed as follows:

1. Empathize: In this phase, the objective is to understand the needs of the target audience to whom the proposal is directed.

2. Define: In this phase, the goal is to identify the problem that needs to be solved and will bring value to the target audience.
3. Ideate: In this phase, the aim is to propose or suggest different ways to solve the identified problem.
4. Prototype: In this phase, the objective is to create or develop preliminary versions of the ideas, making the solution tangible and more visible.
5. Test: In this stage, the goal is to observe the functionality of the solution and, together with the target audience, identify areas for improvement, potential flaws in the solution, or possible shortcomings.

Figure 1 illustrates the five stages that comprise the Design Thinking process.

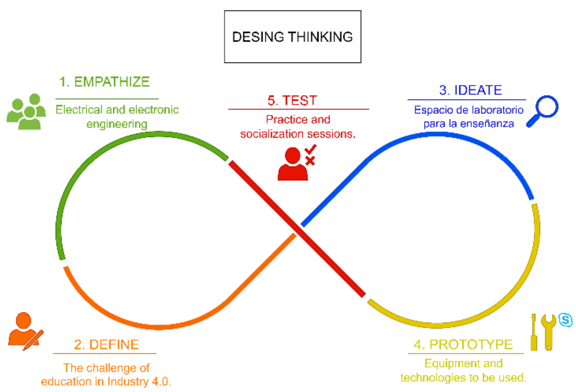

Figure 1. Design Thinking methodology. Source: own work.

This figure illustrates how the methodology can be used cyclically, where each stage generates feedback to improve the final proposed product. The following describes the development undertaken for each stage of the methodology:

In the first stage, Empathize, the need to establish teaching processes for Industry 4.0 was identified. The target audience consisted of electrical and electronic engineering students, aligning with the focus of the GESDELEC laboratory and this article, which is centered around its application in the electrical sector.

In the Define stage, the primary objective was to define the teaching and training processes in Industry 4.0 technologies within the laboratory. It was considered important to have both on-site and remote laboratories through a cloud-based platform, considering international experiences [16], [17].

During the Ideate stage, it was proposed that the GESDELEC laboratory should have a dedicated space for conducting practical exercises using a board equipped with technologies that enable the integration of electrical system measurement. This would involve the use of equipment such as a power analyzer or meter, data collection devices like Gateways, PLCs, or an Industrial Router, which would also transmit information to the cloud. The goal was to enable decentralized analysis and management, thus facilitating the development of laboratory exercises where students can gain knowledge in Industry 4.0 technologies, with a specific focus on their application in the electrical sector.

In the Prototyping stage, the Conceptual Engineering approach was employed, which is a stage defined in Engineering Design found in the Manual de Referencia de Tarifas en Ingeniería (ACIEM) [23]. Conceptual Engineering involves defining the client's needs, project objectives, operating principles, and key equipment and system characteristics. In the case of projects involving communications, a network topology is established at this stage, although detailed plans may not yet be available. However, this stage allowed for the initial proposal of the possible equipment to be used and the communication topology, as depicted in Figure 2.

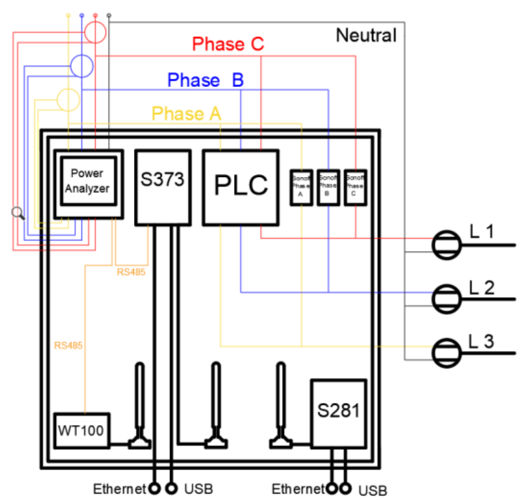

Figure 2. Initial Panel Layout. Source: own work.

The topology illustrated in Figure 3 enabled the achievement of the initial objectives set for the board, the integration of desired technologies, and the inclusion of foundational equipment. Subsequently, a provisional board was assembled with some equipment and the requisite connections to facilitate measurement processes, data acquisition, and cloud-based information transmission, as observed in Figure 3.

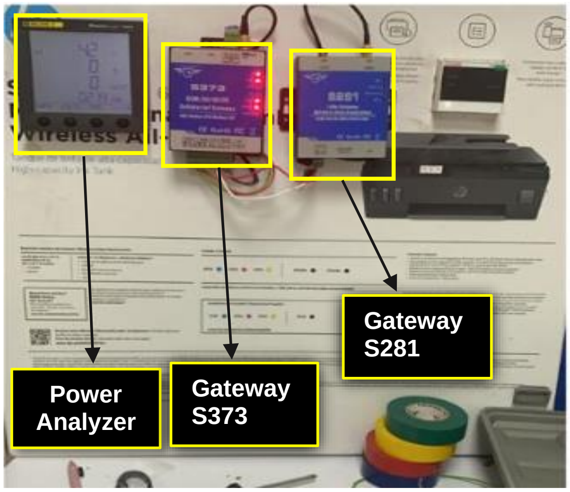

Figure 3. First prototype of the mounted electrical panel for testing. Source: own work.

The equipment used and depicted in Figure 3 are detailed below:

- A Schneider PM800 three-phase power analyzer with ports for RS485 and Ethernet connections, allowing the use of protocols such as Modbus RTU and TCP.
- A King Pigeon S373 Gateway compatible with Modbus RTU and Modbus TCP, capable of sending data to a custom cloud platform called KPIIOT. This device can transmit data through a SIM card or an Ethernet connection.
- A second King Pigeon Gateway, the S281, which includes a WT100 auxiliary node with RS485 connectivity. Both the node and the Gateway support LoRa communication protocol. The connection involves linking the WT100 node to the power analyzer via RS485, and then connecting the WT100 node to the S281 Gateway using LoRa communication protocol. The S281 Gateway receives the information and sends the data to the KPIIOT cloud platform through a SIM card or an Ethernet network connection.

Finally, for the testing phase, tests were conducted in the laboratory with postgraduate students in electrical engineering. These tests involved measuring basic loads, connecting the Gateways using the supported communication protocols, and establishing a connection with the KPIIOT cloud platform. This stage provided valuable feedback to improve the proposed prototype and enhance the design of the electrical panel. To accomplish this, the remaining two stages of engineering design, namely basic engineering, and detailed engineering, were carried out. These stages are detailed below:

In the basic engineering stage, the objective is to characterize each of the main project components, gather information, determine equipment placement, implement protections, and provide an overall project description. In this regard, for this stage, the use of a power analyzer for electrical system measurements, an Industrial Router, a Gateway, and a PLC for data collection and transmission to the cloud were defined. The types of loads to be measured with the power analyzer were specified, and the placement of the panels within the laboratory was determined. Additionally, a communication architecture was proposed for the defined equipment, as depicted in Figure 4.

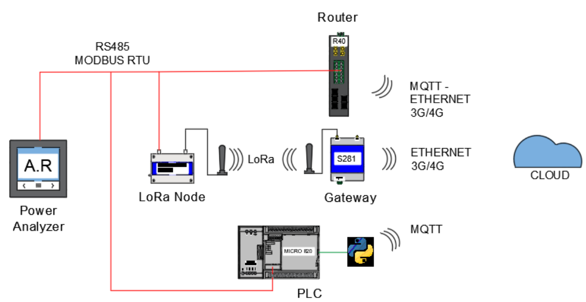

Figure 4. Communication architecture. Source: own work.

This figure was used to define the communication between the power analyzer and each of the data collection equipment. It is worth noting that there were additional alternatives for equipment and protocols, including the use of a S373 Gateway, which was replaced by an Industrial Router due to its different functionalities and configuration options. Additionally, the use of Modbus TCP over Ethernet was considered, but this alternative was discarded due to the functionalities of the selected power analyzer.

For the detailed engineering stage, the basic equipment specifications, electrical diagrams, quantities of materials, work plans, as well as installation, maintenance, and operation manuals for the system were defined. The main developments in this stage included creating the single-line diagram of the electrical panel, as shown in Figure 5. Additionally, the connection scheme, depicted in Figure 6, was established, along with a list of required equipment and materials for the panel assembly.

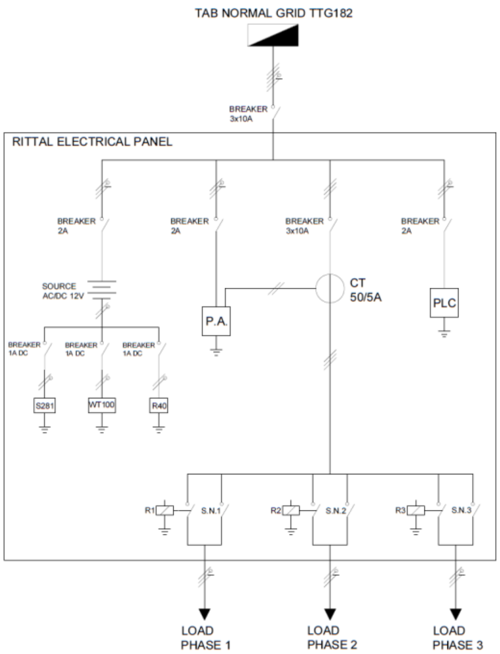

Figure 5. Single-line diagram of the electrical panel. Source: own work.

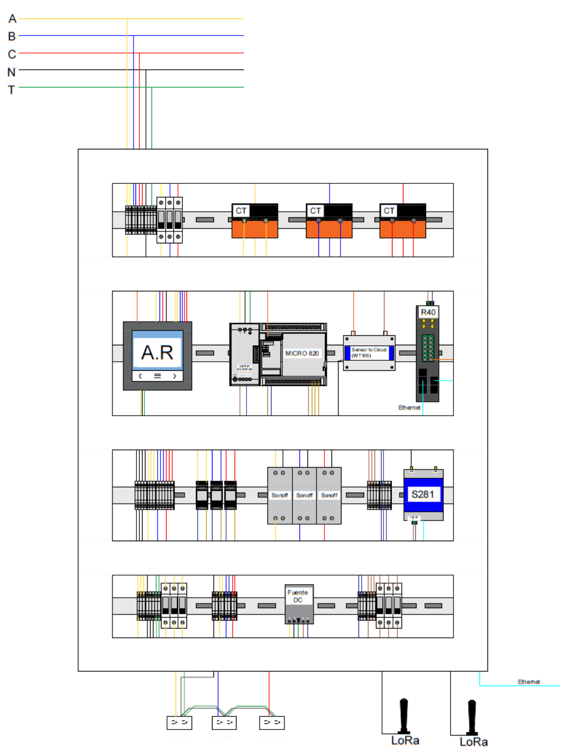

Figure 6. Connection scheme of the electrical panel. Source: own work.

These figures allowed for establishing the distribution of equipment in the electrical panel, determining the conductor sizes, specifying the necessary protections, setting up the communications to interconnect the equipment with both the power analyzer and the cloud for interaction with the remote laboratory platform. Additionally, it helped define additional necessary elements such as terminal blocks, bridges, and mounting bases for equipment on the rail.

The use of the Design Thinking methodology, supported by the stages of engineering design, facilitated the proposal of a panel with the necessary equipment for conducting laboratory practices.

3. Results

The implementation of the methodology allowed for the construction of the two panels currently available in the GESDELEC laboratory. This provided the necessary resources for the design and development of laboratory practices, through which students could acquire knowledge about the use of Industry 4.0 technologies in the energy sector. Consequently, this chapter includes the following sections: Section 3.1 addresses the construction of the panels, Section 3.2 presents the proposed laboratory practices, Section 3.3 highlights the sessions of socialization and practical exercises conducted in the laboratory, and finally, Section 3.4 showcases some preliminary applications identified from the laboratory sessions.

3.1. Electrical panel for practices

The GESDELEC laboratory is integrated into the Remote Laboratories project, which is a project launched by the Laboratory Directorate of the Universidad Nacional de Colombia – Sede Manizales. The objective of this project is to have a cloud-based platform through which educational institutions can access different automated setups and control them remotely for the development of practical exercises. This transition allows for a shift from simulated environments to real-world practices where processes and phenomena are authentic but operated and controlled remotely through the platform.

Thanks to the Remote Laboratories project and the feedback obtained from testing the Design Thinking methodology supported by the engineering design stages mentioned earlier, the initially proposed prototype was improved. As a result, the construction of two panels was proposed, enabling the development of hybrid practices (both in-person and remote). Both panels feature the same measurement, data acquisition, and data transmission equipment, which are detailed in Table 1.

Table 1. Parts and equipment of the electrical panel. Source: own work.

Part	Description	Reference
Power supply and protections	The board operates in a four-wire three-phase system supplied from the laboratory's Main Distribution Panel at 220VAC. For the electronics and equipment requiring DC power, a 12V power supply was used. Both the equipment and the board have a series of protections and switches in place to safeguard the circuits, internal devices, and individuals handling the board.	
Power measurement	As mentioned in previous chapters, a CIRCUTOR brand power analyzer, specifically the CVM B100 model, was used. This analyzer features an RS485 connection port and measures all loads connected to the system for the purpose of conducting practical experiments. The board includes a semi-direct measurement setup, for which three current transformers (CTs) with a transformation ratio of 50/5A are employed to obtain current signals. Voltage signals are directly acquired from each of the phases using terminal blocks.	 
Data adquisition	For this part, an Industrial Router from King Pigeon with the reference R40 was used. This router is compatible with both Modbus RTU and TCP protocols and additionally supports MQTT communication protocol. Both the WT100 node and the S281 Gateway were installed for the integration of the LoRa communication protocol into the experiments. Finally, an Allen Bradley PLC with the Micro 820 reference was installed. It connects through RS485 and is compatible with Modbus RTU. It also serves the function of remotely activating and deactivating loads through its digital outputs, a relay coil system, and a Python program through which commands can be sent to it from the remote laboratory platform.	   
Load control devices	For this section, considering applications in both automation and home automation, as well as in the remote laboratory project, two types of load control systems were chosen. The first is a relay system activated by the PLC, and, on the other hand, SONOFF smart switches were used. These switches connect to a WiFi network, and through a mobile application, they can be controlled and activated from anywhere.	 

Loads	In this section, three power outlets and three main loads were installed. Incandescent light bulbs were used to simulate a purely resistive network or circuit, LED light bulbs to demonstrate their behavior and the capacitive reactive power in the system, and finally, a single-phase motor was incorporated to observe the behavior of an inductive load. However, due to the use of standard power outlets, it is possible to employ any other type of load as needed.	
Communications	In this section, the necessary wiring is provided for the RS485 connection between the power analyzer and the Industrial Router, Gateway, and PLC. Additionally, antennas are included for the transmission of information, and Ethernet cabling is used for connecting equipment to the internet.	

In Figure 7, Figure 8, Figure 9 and Figure 10 the equipment assembly process in the double bottom, the installation of the panels in the designated laboratory space, one of the panels fully equipped, and both panels installed and operational in the laboratory can be observed.

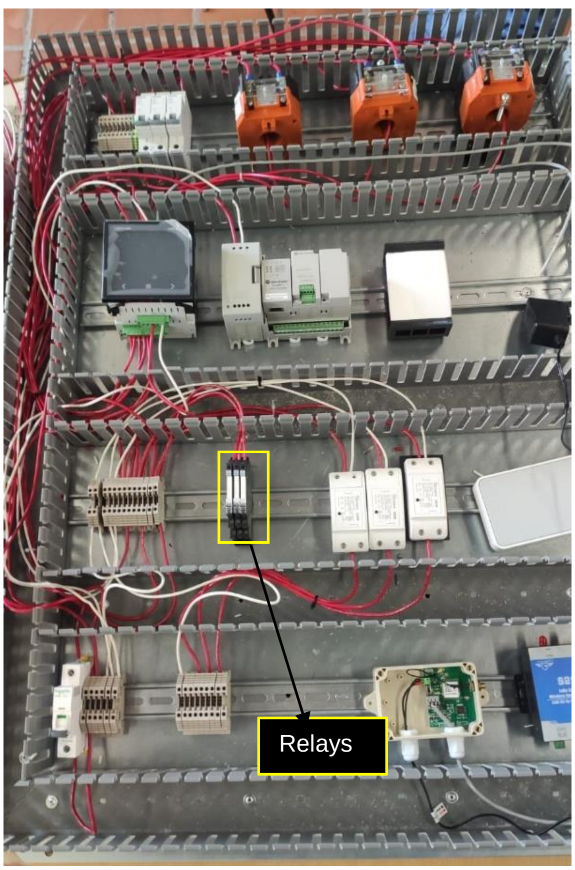

Figure 7. Initial assembly of the double bottom of the panel. Source: own work.

This figure shows the assembly process of the panel, where different spatial distributions and equipment were tested. Some components, such as the block relays shown in the image, had to be replaced with coil relays.

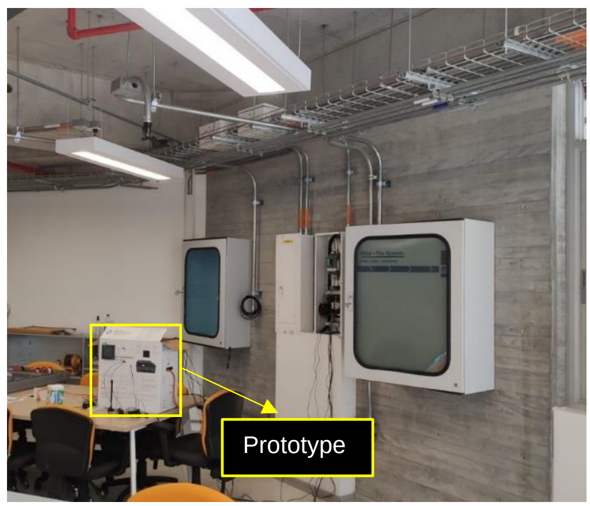

Figure 8. Panels mounted on the laboratory wall. Source: own work.

This figure displays the placement of the panels within the GESDELEC laboratory, positioned on either side of the standard and regulated electrical network distribution panels. The three-phase power supply originates from the standard distribution panel and is routed to the practice panels through EMT conduits. It's worth noting that the figure also includes the initial prototype for reference.

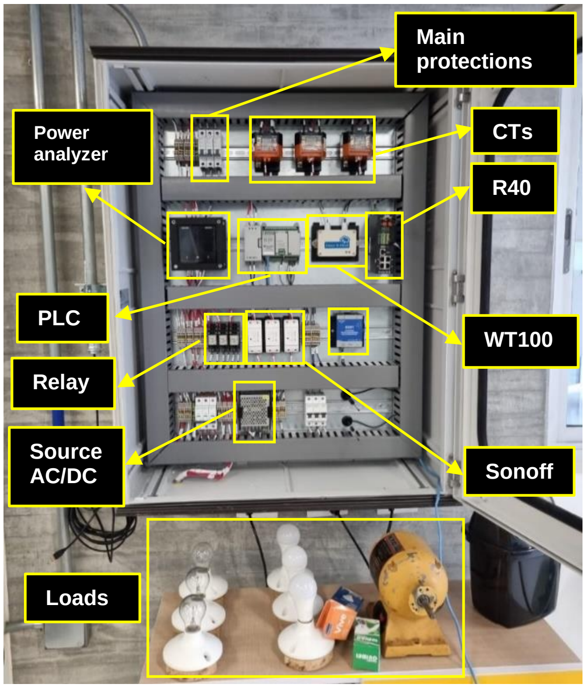

Figure 9. Double bottom mounted in the panel with all the equipment. Source: own work.

This figure displays the final layout of the practice electrical panel, showing the placement of each equipment and the loads used for measurements.

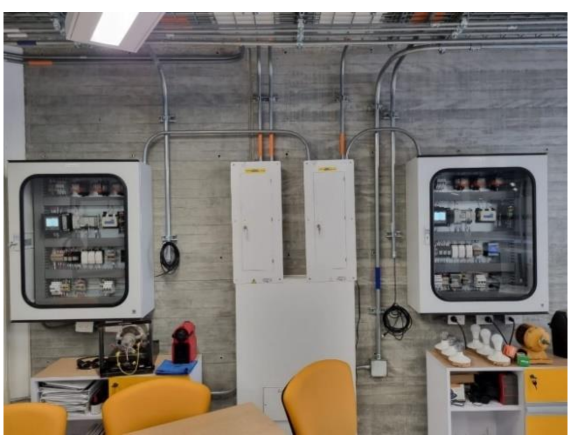

Figure 10. Finalized and operational panels. Source: own work.

This Figure Shows the Two Operational Panels Mounted in the Laboratory, Both Panels Having the Same Equipment and Layout.

3.2. Laboratory Practices

In addition to the development and assembly of the panels, various laboratory practices were also designed. It is worth noting that a significant portion of the practices in the GESDELEC laboratory were intended to be carried out in a hybrid manner, where students can learn how to operate and configure the equipment both in-person and remotely through the laboratory platform. However, currently, more practices can be conducted in-person than remotely, but it is expected that these numbers will equalize in the medium term.

These laboratory practices were designed to be carried out sequentially, starting with the fundamental basis of measurement, progressing to the integration of IoT through the use of the Industrial Router, Gateway, and PLC, followed by cloud computing processes using the SaraCloud platform, and a portable power analyzer that captures real-time data from a substation at the Universidad Nacional de Colombia - Sede Manizales. Finally, a practice is conducted to analyze the collected information from this substation. The aim is for students to not only learn about the operation of technologies and equipment but also develop critical thinking skills to identify the advantages and disadvantages of these technologies and their potential applications in electrical systems. The seven proposed laboratory practices are detailed below:

3.2.1. Connection and Configuration of a Power Analyzer

This practical exercise aims to provide students with a comprehensive understanding of sizing and selecting measurement equipment, as per the guidelines stipulated by Colombian regulatory bodies, such as CREG 038 of 2014 [24], and in accordance with the standards established by the energy company, exemplified by EPM RA8-030 [25]. Furthermore, students will be introduced to the intricate process of establishing the connection and configuring a power analyzer for precise measurements across diverse load types. The primary objectives of this exercise encompass:

- Mastery in the selection and identification of appropriate measurement techniques, aligned with the regulatory protocols mandated by the energy company.
- Proficiency in the meticulous sizing and selection of current transformers to cater to specific measurement applications.
- Differentiation between an energy meter and a power analyzer, discerning their respective functionalities and operational disparities.

- Aptitude in the meticulous configuration and seamless commissioning of a power analyzer to facilitate accurate measurements within complex electrical systems.

3.2.2. Modbus RTU Communication Protocol through R40 Router (Hybrid)

This laboratory practice aims to provide students with an initial introduction to IoT by connecting the Industrial Router to the Power Analyzer via an RS485 network. The practice focuses on configuring the RS485 network and utilizing the Modbus RTU protocol to establish communication between the devices and extract information from the Power Analyzer. The objectives of this practice are as follows:

- Gain a basic understanding of the Modbus RTU communication protocol and its connection using RS485.
- Collect measured data from the practice panel through the Power Analyzer and the Industrial Router R40, using the Modbus RTU protocol.
- Demonstrate the various applications that can be achieved with measurement equipment and data acquisition devices in electrical systems.

This practice can be conducted in a hybrid manner, where for remote practice, the remote laboratory platform is utilized to remotely activate and deactivate loads, as well as read parameters. The configuration of the RS485 network and Modbus RTU is performed using a PC located within the laboratory, and the student can access it using FortiClient or Anydesk to configure the Industrial Router.

3.2.3. Modbus RTU Communication Protocol through a PLC (Hybrid)

In this practice, the energy analyzer and the PLC are connected via an RS485 network. The main objective is to familiarize the student with the PLC configuration using the manufacturer's software. This allows for the activation and deactivation of loads, as well as the configuration of the Modbus RTU block to extract data from the energy analyzer. This practice involves integrating another device into the IoT system. The objectives of this practice are:

- Learn how to configure a PLC for relay control using its digital outputs.
- Set up the Modbus RTU protocol over an RS485 network to extract information from an electrical network.
- Demonstrate the functionality of the Modbus RTU communication protocol through the PLC.

This practice can be performed in a hybrid manner, where for remote practice, the student can only activate and deactivate loads through the laboratory platform. Additionally, they can view the registers obtained by the PLC. In this case, the register is not labeled with the corresponding variable name, allowing the student to identify each data point using the energy analyzer's register table.

3.2.4. LoRa Communication Protocol

This practice was designed to introduce the functionalities and concepts of the LoRa wireless communication protocol. The general idea is for students to establish a wireless connection between the LoRa node WT100 and the Gateway S281, and to connect the Gateway to the KPIIOT cloud platform. In this case, the LoRa node will be connected to the analyzer through an RS485 network to extract data, which will then be wirelessly transmitted to the Gateway S281. The Gateway will further transmit the information to the cloud, providing students with an initial understanding of cloud computing. The objectives of this practice are:

- Gain comprehensive knowledge and understanding of the LoRa communication protocol.
- Learn about the operation and advantages of wireless communication protocols.
- Demonstrate the functionality of the LoRa Gateway with the KPIIOT platform.

3.2.5. MQTT Communication Protocol through the R40 Router (Hybrid)

This practice aims to provide students with an introduction to one of the most common protocols for sending information to the cloud, namely MQTT. MQTT is widely supported by cloud platforms such as AWS, Google Cloud, Azure, etc. The objective is for students to configure the Industrial Router to extract data from the analyzer using Modbus RTU and subsequently configure the MQTT protocol to publish the information to a free cloud service. By using Python code, students can subscribe to and read the published information. The objectives of this practice are:

- Understand the operational principles of the MQTT communication protocol.
- Establish an initial connection to a cloud platform using MQTT.

- Highlight the advantages and potential applications of the MQTT communication protocol.

This practice can be conducted in a hybrid manner, where remote practice development is facilitated through the remote laboratory platform. Students can activate and deactivate loads, as well as read parameters using the platform. Configuration of Modbus RTU and MQTT is performed using a PC located within the laboratory, with access granted through FortiClient or Anydesk remote access software.

3.2.6. Creation of Dashboards for Electric Variable Visualization on the SaraCloud Platform

This practice was designed to familiarize students with accessing, using, and configuring a real cloud-based platform called SaraCloud. Through this platform, students can create dashboards with tables, graphs, and widgets to visualize the information collected by the portable power analyzer. The objectives of this practice are:

- Gain an understanding and contextualization of the functionality of a cloud-based platform for information visualization.
- Familiarize students with the features and tools available on cloud platforms for customizing data visualization through dashboards.
- Identify potential applications of remote measurements in electrical systems.

3.2.7. Data Analysis of an Electrical Panel through the SaraCloud Platform

This practice aims to teach students how to perform basic analysis on the information collected by the portable power analyzer and identify deficiencies and potential improvements in the electrical system based on regulations such as CREG 108 of 1977, CREG 015 of 2018, or CREG 199 of 2019 [26]–[28]. The objectives of this practice are:

- Demonstrate the behavior of an electrical system through the visualization of information on a dashboard.
- Perform a basic analysis of the information collected from an electrical system.
- Learn to identify potential areas for improvement in an electrical network based on the analysis of the information.

For the development of remote practices, the University of National Colombia - Manizales Campus has its own Remote Laboratories portal. This platform, currently in development, will be accessible to students through their institutional email accounts. In Figure 11, you can see the platform's home interface, which features a laboratory menu. Upon entering, students will find a list of available practices. Additionally, the platform provides the option to view the logged-in user's email and a logout button.

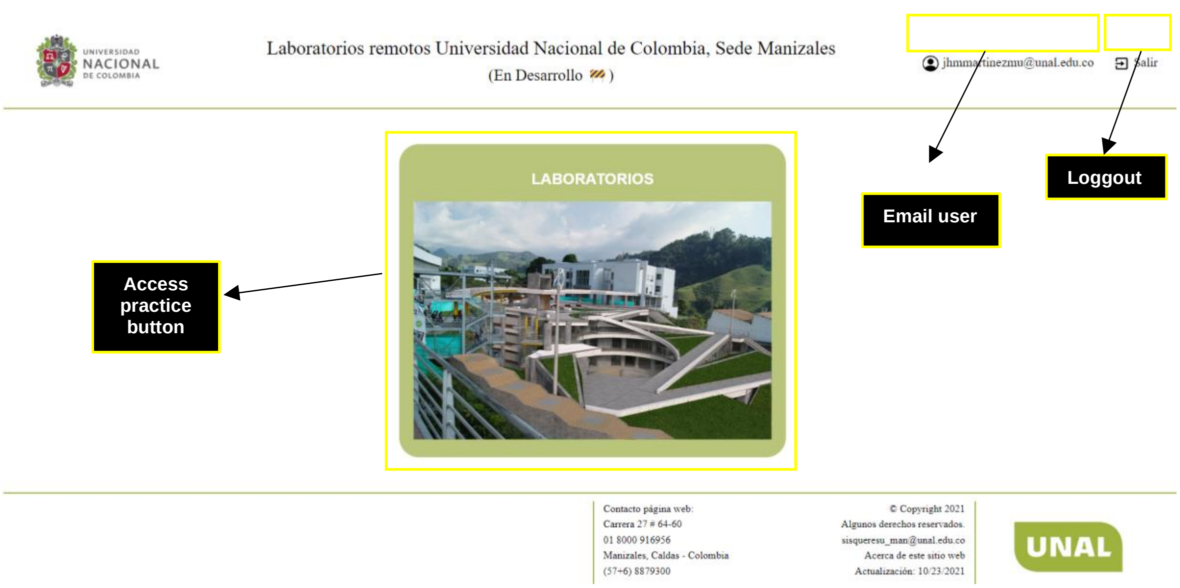

Figure 11. Start interface of the remote laboratories' platform. Source: own work.

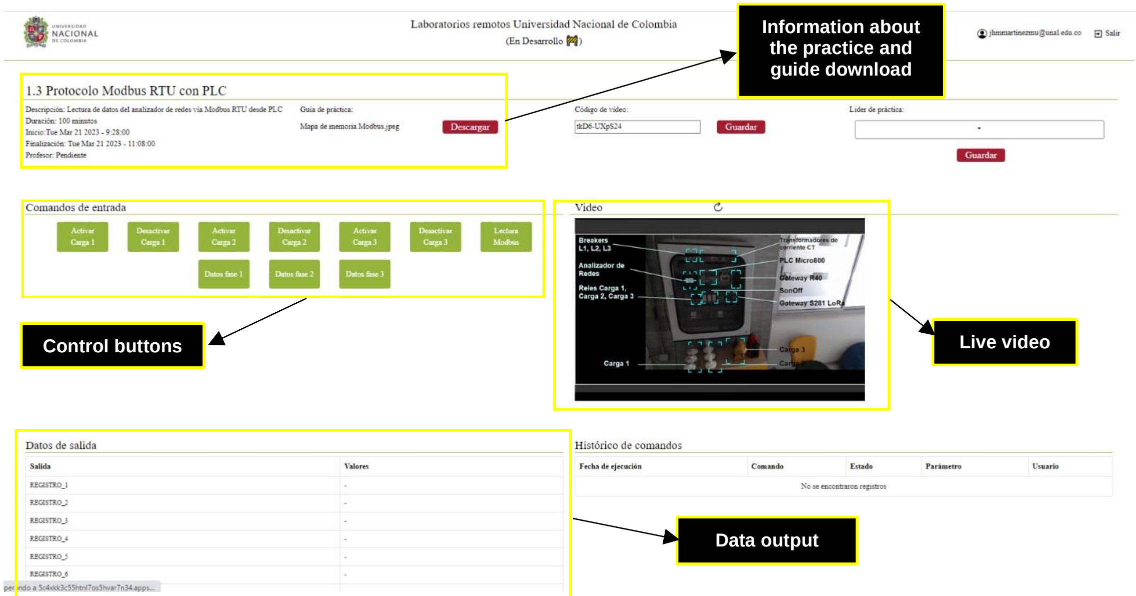

Figure 12. Remote Laboratory Practice Interface. Source: own work.

Once inside, students will have access to different tools, such as a section to download the guide, a section where buttons and actions for manipulating the electrical panel are located, an output section where data provided by the panel will be displayed. These data are measured by the power analyzer and delivered to the platform through the PLC or the Industrial Router. Finally, there is a video streaming section where students can observe in real-time what is happening in the setup. Figure 12 provides a clearer view of the interface of a remote practice in the GESDELEC laboratory.

3.3. Teaching Processes within the Laboratory

Following the installation and commissioning of the laboratory panels, various sessions of socialization and practical work have been conducted with students from the Environmental Energy and Education Policy (E3P) research group, as well as students from electrical and electronic engineering courses. These sessions have provided an opportunity to refine the teaching processes and laboratory practices.

The socialization sessions were conducted as descriptive laboratory sessions where only the equipment on the board was presented to the students, as depicted in Figure 13, which shows the socialization sessions with students inside the laboratory. These sessions were carried out with students from the E3P research group and served to identify potential laboratory practices that could be conducted and enhance the explanation of the technologies present on the board.

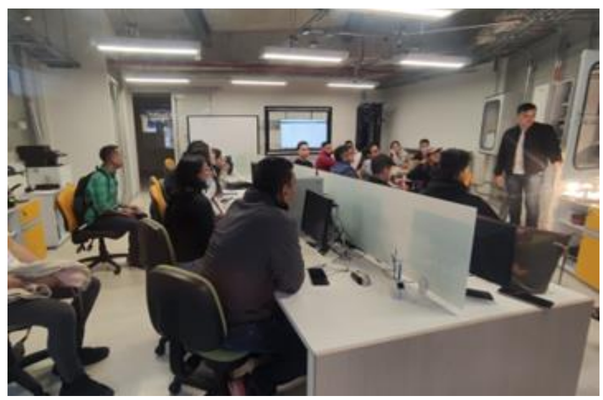

Figure 13. Laboratory Orientation Session. Source: own work.

Regarding the practical sessions, the goal was to actively involve students, as depicted in **¡Error! No se encuentra el origen de la referencia.**, enabling them to manipulate and control the various components integrated into the board. These sessions were conducted with undergraduate students from courses such as Machines I, Machines II, and Special Academic Practice, as well as with master’s students from courses like Smart Grids and Microgrids.

As the sessions were sequential, starting from configuring measurement equipment, then proceeding to interconnecting IoT devices with the cloud, and concluding with data analysis, students were able to collaborate effectively and understand that measurement processes involve multiple layers. As shown in the figure, students divided their work, with some responsible for measuring and configuring equipment on the board, while others were tasked with analyzing the information from the cloud on their computers.

Additionally, through the analysis of the reports submitted by students and the feedback process, the objectives, activities, and calculations in the guide were validated and refined.

Figure 14. Laboratory practice sessions. Source: own work.

3.4. Learning objectives

Based on the Criteria for Accrediting Engineering Programs released by ABET in 2020 [29], various learning objectives have been considered within the laboratory. As the laboratory is designed for research, outreach, and teaching activities, it aims to contribute to the development of different skills for students or faculty members using the laboratory space and the boards presented in this article. Therefore, below are some of the learning objectives that are intended to be developed or promoted through the practical sessions:

Table 2 Learning objectives considered within the practice sessions.

ITEM	DESCRIPTION
1	Develop practical skills in the configuration, operation, and startup of measurement devices and technologies such as IoT
2	Assist in identifying, formulating, and solving electrical engineering problems using tools and analysis
3	Foster communication skills
4	Promote teamwork skills
5	Enhance the ability to recognize ethical and professional responsibilities
6	Strengthen the capacity for data analysis and interpretation by understanding basic concepts of electrical systems
7	Assist in forming engineering judgment based on standards and regulations
8	Encourage the ability to acquire and apply new knowledge through independent work

3.5. Identified Applications through Laboratory Sessions

The processes of socialization and teaching through laboratory practices have allowed the identification of various applications that can be achieved with Industry 4.0 technologies in the energy sector at the end-user level. The versatility of the equipment enables the establishment of reliable and measurable systems that can be continuously monitored to identify areas for improvement. In this regard, the following are some of the applications identified during the laboratory sessions:

1. Advanced metering systems.
2. Energy digitalization.
3. Real-time monitoring of electrical variables.
4. Remote and decentralized variable tracking.
5. Easy access to information.
6. Quick and easy data analysis through dashboards.
7. Power quality analysis.
8. Network status diagnosis.
9. Identification of improvement points to enhance and optimize energy consumption.
10. Monitoring of results in the implementation of energy efficiency strategies.
11. Generation of alarms based on data.
12. Identification of faults, deficiencies, or vulnerabilities in the power grid.
13. Remote control of actuators.
14. Predictive maintenance.

These are just a few applications, and it is expected that more will be identified as additional laboratory sessions are conducted.

4. Conclusions

The work carried out allowed the development of 2 fully functional electrical panels through the design thinking methodology supported by engineering design. Following a step-by-step process, a structured approach was taken starting from identifying the needs, brainstorming ideas, preliminary design, and prototyping. Through feedback and refinement, the initial prototype was improved to achieve the final panel model currently available in the laboratory.

The selected equipment for the final electrical panel provides a range of technologies and communication protocols for teaching purposes within the laboratory. This is evident in the number of proposed practices that cover various modules, including applications using both wired and wireless communication, such as the equipment compatible with the LoRa protocol. Additionally, due to the modularity of the panels and available space, additional equipment with different protocols or technologies can be integrated.

The laboratory practice sessions with students allowed the utility and functionality of the panels to be demonstrated. It also validated the proposed guides and provided valuable feedback to strengthen the teaching processes within the laboratory. This feedback helped identify and address any errors or weaknesses in the guides and laboratory sessions.

4.1. Future Work and Recommendations

As future work, there are four main areas to consider:

1. Explore additional Industry 4.0 technologies and equipment that can be integrated into the laboratory. This could involve incorporating new communication protocols or directly integrating other technologies such as augmented reality, simulation, or cybersecurity.
2. Utilize the feedback obtained during the practice sessions with students to refine the teaching process within the laboratory. This feedback can be invaluable for identifying areas of improvement and enhancing the overall learning experience.
3. Integrate other cloud platforms with free access and data analytics software to complement the teaching processes within the laboratory. This can expand the capabilities and possibilities for data analysis and visualization, enhancing the educational value of the laboratory.
4. Explore further applications of the integrated technologies in the panel that can have direct benefits within the energy sector. By identifying and implementing additional applications, the laboratory can address specific industry needs and provide a more comprehensive learning experience.

These future endeavors will contribute to the continuous improvement and expansion of the laboratory, ensuring its relevance and effectiveness in educating students and exploring innovative solutions for the energy sector.

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