ISSN: 2594 - 2905

DEVELOPMENT OF A DIDACTIC PROTOTYPE FOR MANEUVERING A DOUBLE-BUS SUBSTATION WITH TRANSFER BUS BAR

DEVELOPMENT OF A DIDACTIC PROTOTYPE FOR MANEUVERING A DOUBLE-BUS SUBSTATION WITH TRANSFER BUS BAR

Ruiz Ramírez José Efraín[1], Santana Camilo José Alfonso[2] , López Chávez Enrique[3] , Ríos Tapia Martín[4]

https://doi.org/10.61117/ipsumtec.v8i2.382

[1] National Technological Institute of Mexico/Zacatepec Technological Institute,jose.rr@zacatepec.tecnm.mx , https://orcid.org/0009-0003-2039-0923.
[2] National Technological Institute of Mexico/Zacatepec Technological Institute,jose.sc@zacatepec.tecnm.mx , https://orcid.org/0009-0000-9864-6026.
[3] National Technological Institute of Mexico/Zacatepec Technological Institute,enrique.lc@zacatepec.tecnm.mx , https://orcid.org/0009-0009-2112-6140.
[4] National Technological Institute of Mexico/Zacatepec Technological Institute,L20090823@zacatepec.tecnm.mx , https://orcid.org/0009-0009-9929-0661.

Summary -- This project involves the development of an educational prototype for performing maneuvers in electrical substations, in a double busbar configuration with a transfer busbar. The prototype consists of two main elements: the first component is the graphical user interface, better known as GUI (Graphical User Interface), developed in the LabVIEW programming environment; The second is the physical model, which consists of relay modules and the PIC16F877A microcontroller, which controls the opening and closing of the relays and interacts with the GUI via wireless asynchronous serial communication through the HC-05 module.

The prototype seeks to reinforce the knowledge of students in the electrical substations course of the Electromechanical Engineering Educational Program and other related programs that include this subject in their curriculum.

The GUI includes on/off buttons for switches and disconnectors (blades), as well as indicator lights and a double-bar diagram with a transfer bar. The end result is the creation of a graphical user interface, a physical prototype that incorporates technology by automating maneuvers, allowing students taking the Electrical Substations course to continuously practice connection and disconnection operations in accordance with the criteria, thereby consolidating meaningful learning.

Keywords: Electrical Substations, GUI, Double Bar, LabVIEW, Microcontroller, Switches, Disconnectors, Maneuvers, Prototype.

Abstract -- The present project covers the development of a didactic prototype to perform maneuvers in electrical substations, in double bus configuration with transfer bus. The prototype is integrated by two main elements, the first component is the graphical user interface, better known as GUI (Graphical User Interface), developed in the LabVIEW programming environment, the second is the physical model, which is formed by relay modules, the PIC16F877A microcontroller, which controls the opening and closing of the relays, and interacts with the GUI through wireless asynchronous serial communication, through the HC-05 module.

The prototype seeks to reinforce the knowledge of students in the electrical substations course of the Electromechanical Engineering Educational Program and other related plans that include this subject in their syllabus.

In the development of the GUI, on/off buttons for switches and disconnectors (blades) are included, as well as indicator lights and a double bar diagram with transfer bar. The final result is the creation of a graphical user interface, a physical prototype that contemplates the technological part by automating the maneuvers that allows students taking the subject of Electrical Substations to continuously exercise the operations of connection and disconnection, according to the criteria, consolidating a significant learning process.

Key words – Electrical substations, GUI, Double busbar, LabVIEW, Microcontroller, Switches, Disconnectors, Maneuvers, Prototype.

INTRODUCTION

An electrical power system is the set of devices that converts energy from a primary form

Electricity is transported from its point of generation and distributed to end consumers. The intermediate facilities responsible for carrying electricity and maintaining transmission parameters are electrical substations [1].

Electrical substations are classified in different ways: according to function, location, mobility, type of insulation, voltage level, and transformation [3].

The configurations or arrangements of electrical substations consist of a set of equipment used to control the flow of energy and ensure the safety of the system by means of automatic protection devices [2].

protection devices [2]. The configuration depends on certain criteria to facilitate the transmission and distribution of electrical energy [4]:

Reliability: The ability of a substation to supply power for a given period of time, under the condition that at least one component of the substation is out of service [4].

Flexibility: The property of the substation to adapt to different conditions that may arise, especially due to operational changes in the system and, in addition, due to contingencies and/or maintenance [4].

Safety: Property that prevents damage to equipment or injury to personnel when a substation operates under normal or abnormal conditions [4]

Modularity: Versatility of an installation to modify its configuration when required by needs or the system [4]

Installation costs: Number of switches per input/output (circuit), number of disconnectors per circuit, and necessary measurement, control, and protection equipment [3].

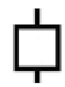
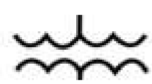
Operation and maneuvering: possibilities for interconnection between circuits [3].

Busbar diagram of an electrical substation.
In substations, busbars or buses are the physical connection between the elements that make up the system. It is important to consider the economic balance when selecting the type of configuration and its application. In context, the busbar diagrams or arrangements of a substation are as follows [5]:

1. Single busbar.
2. Split single busbar.
3. Single busbar with bypass.
4. Busbar set with transfer.
5. Double busbar.
6. Double bar set with bypass.
7. Double bar set with transfer bar.
8. Ring.
9. Switch and half.

To understand the busbar diagram, Table 1 identifies the basic elements [5]:

Table 1. *Basic elements in bar diagrams*

Element	Description
	**Disconnector (blades)**. This is a switching device without cutting power that can open or close circuits when they are unloaded. They are used to visibly ensure the cutting of the circuits.
	**Power switch**. These are switching devices with an arc extinguishing procedure and, therefore, with breaking capacity cutting power.
	**Busbars**. These are known as the set of electrical conductors used as a common connection for the different circuits that make up a substation.
	**Grounding blades**. These are used as elements to safely and securely ground busbars, branch circuits, capacitors, and any other equipment that has been previously disconnected from the power supply network.
	**Power** transformer**.** An electrical device that allows the voltage of an alternating current electrical circuit while maintaining the power.

Source: *López Chávez, (2025*).

This document is only applicable to the double-bar configuration with transfer bar and explains the synergy between the physical prototype for opening and closing power switches and disconnectors, which are emulated by relay modules and controlled by a microcontroller [12] and a virtual reality simulation, using a graphical user interface developed using LabVIEW software [6,11].

One of the areas that has particularly benefited from virtual reality simulations is electrical power systems. Virtual reality allows for the acquisition of theoretical and practical knowledge of elements such as transformers or complete infrastructures such as electrical substations [9].

Simulation systems are capable of addressing two of the major limitations of current learning in the field of electrical power systems: cost and safety. With particular emphasis on safety, in most cases, the nature of electrical components and the large amount of energy flowing through them

ISSN: 2594 - 2905

makes it impossible to directly visualize their operation or behavior [10].
In 2014, González Sancho Eladio [5] proposed an electrical substation simulator, developed in the LabVIEW programming environment. This simulator handles all busbar configurations, but the disadvantage is that it has no physical interaction, which would allow for a greater understanding of the maneuvers in busbar diagrams.
Similarly, in 2016, Jiménez [7] proposed a simple busbar teaching module with transfer to visualize electrical variables using a SCADA system, controlled by a PLC (Programmable Logic Controller) and an interface in LabVIEW.

In 2019, Xue [8], for example, proposed modules consisting of three modes of operation: visualization of machines and components, in order to learn their names and characteristics; the development of routine practices, such as linear maintenance procedures; and consideration of necessary actions in the event of a malfunction or risky situation, referring to the handling of adverse situations [2].

DEVELOPMENT
Design and simulation for prototype implementation The busbar layout proposed for this project is a double busbar with transfer busbar, which can be seen in the single-line diagram in Figure 1. The disconnectors (knives) use the nomenclature 89-1, where the number 89 identifies the element, followed by a hyphen, and the next digit is the number assigned to the equipment. Power switches are identified in the same way, but with the number 52.

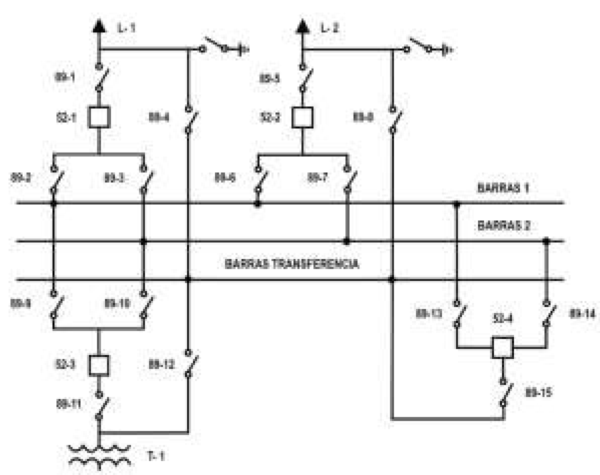


Figure 1. *Double bar with transfer bar*
Source*: Santana Camilo, (2025).*

This layout adds greater flexibility (double busbar layout) because, although it is possible to connect to either of the two busbars via their bar selector switches, it is also possible to isolate the main switches for maintenance using the transfer circuit.

The main advantages of a double busbar scheme with transfer busbar are:

- Either busbar can be isolated for maintenance without interrupting service to the connected circuits.
- Greater flexibility with two operating bars.
- A circuit can be easily transferred from one busbar to another using the busbar disconnect switch and the busbar selector disconnectors.
- A main switch can be isolated by the transfer busbar and the transfer switch, thus allowing for maintainability.

The power and control circuit of the double busbar scheme with transfer busbar (see Figure 2) was simulated in the CADE_SIMU software, which is used to make electrical control diagrams (electrical control simulator) and allows simulations of virtually any circuit. In addition, it allows problems that occur to be solved, since it presents the faults that occur during the execution of the simulation.

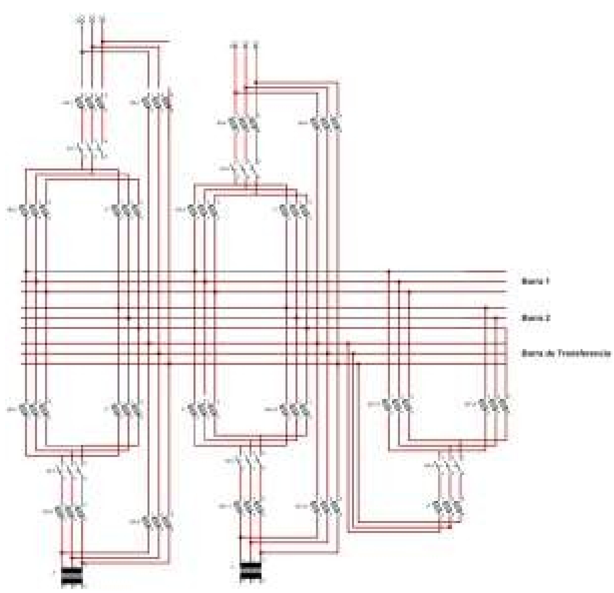


Figure 2. *Circuit simulation.*
Source*: Santana Camilo, (2025).*

Once the circuit simulation has been completed to ensure that it is functioning correctly and that there are no short-circuit faults, the electronic and electrical components are physically connected using five relay modules, each containing 16 relays. Therefore, a total of 80 relays are used.

The circuit is divided into two parts: the power circuit, which connects the three-phase power supply to the loads by switching power switches and disconnectors on and off; and the control circuit, which switches pilot lights on and off corresponding to the switching on and off of the above-mentioned elements, as well as a buzzer that is activated when sequences of maneuvers are performed. The control circuit is used to turn pilot lights on and off, which correspond to the connection and disconnection of the above-mentioned elements, as well as a buzzer, which is activated when incorrect sequences of opening and closing of the switches and blades are performed. All of the above is installed on a wooden board with a metal structure (see Figure 3 and Figure 4).

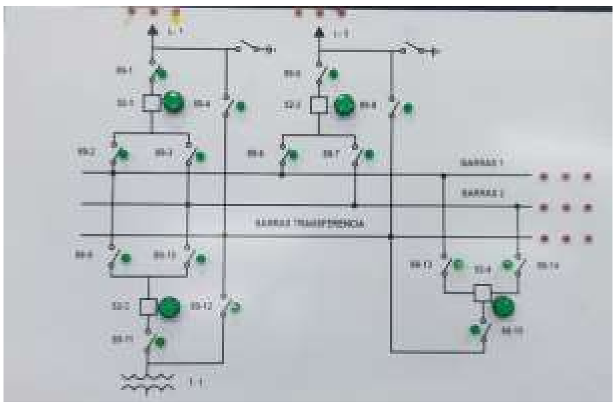


Figure 3. *Front panel of the prototype.*
Source*: Ríos Tapia, (2025).*

Figure 4. *Rear panel of the prototype.*
Source*: Ríos Tapia, (2025).*

Software development and graphical user interface

The PIC16F877A microcontroller, programmed in BASIC language, is used to control the opening and closing of relays that emulate power switches and disconnectors (blades). The operation is performed from a graphical user interface (GUI) using virtual buttons, which send commands to the microcontroller via an HC-05 Bluetooth module.

Communication and Data Transfer

- The connection between the computer and the PIC16F877A is established via asynchronous serial communication.
- The wireless link is achieved with the HC-05 Bluetooth module, allowing data transmission to activate/deactivate the switches in the physical prototype.
- The flowchart describing the operation of the program is shown in Figure 5.

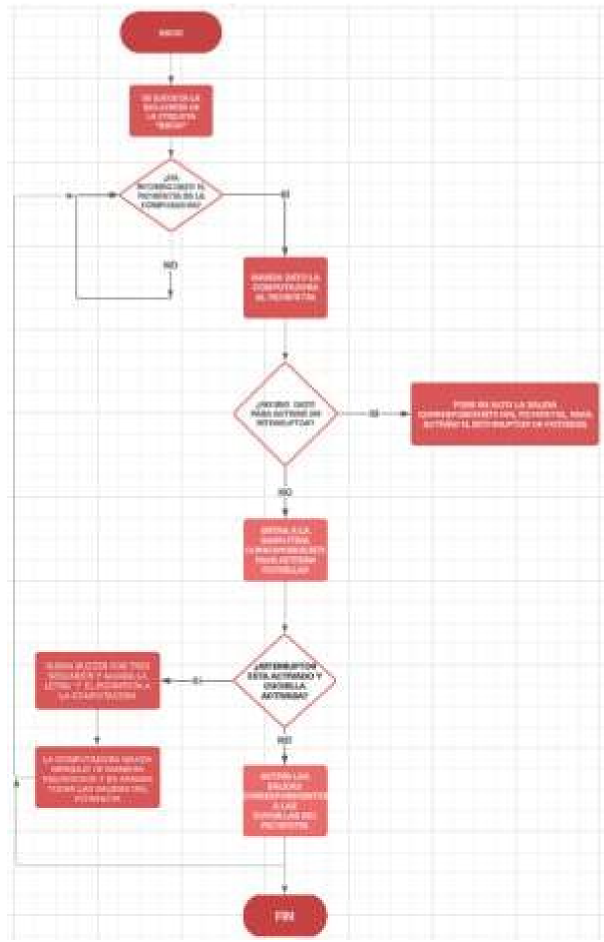


Figure 5. *PIC16F877A microcontroller program flowchart.* **Source***: Ruiz Ramírez, (2025).*

Communication with the GUI using LabVIEW

The graphical user interface (GUI) is developed in LabVIEW, a graphical programming environment based on the visual language "G." This language uses a data flow approach, where programming is done by connecting visual objects in a diagram, rather than writing traditional code.

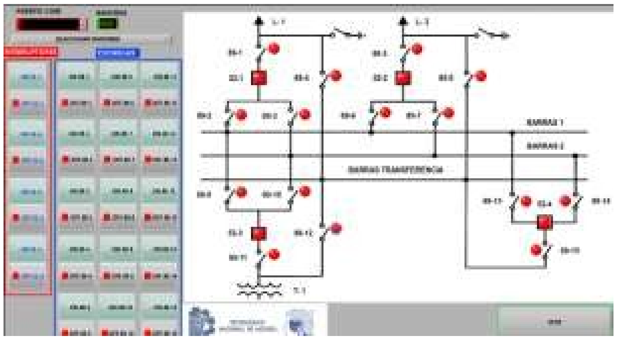
LabVIEW structure

1. Front panel (Figure 6 (a)):

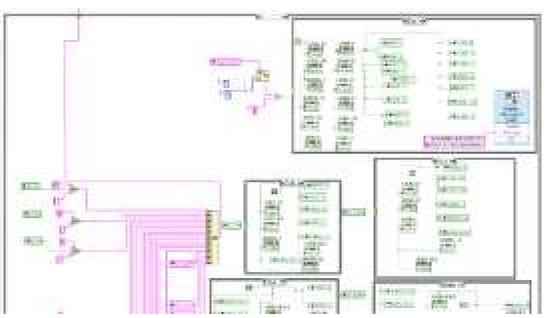
- Contains the visual elements (buttons, indicators, graphics) for user interaction.

2. Block diagram (Figure 6 (b)):

- Houses the program logic, represented by interconnected icons that define the data flow.



(a)



(b)

Figure 6. *(a) Front panel (b) block diagram.*
Source*: Ruiz Ramírez, (2025).*

The interface developed consists of two sections of buttons, the first section is designed to control the four power switches of the aforementioned diagram.

Distribution and functionality of switches
Total number of buttons: 8 (two for each switch).

Functionality:

- 1 button to turn the switch ON.

- 1 button to close (OFF) the switch.

This arrangement is illustrated in Figure 7.

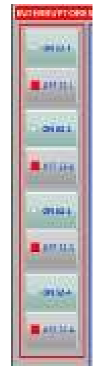


Figure 7. *Switch button section.*
Source*: Ruiz Ramírez, (2025).*

The second section of the interface includes 30 buttons, used to control the opening and closing of the system's 15 disconnectors (blades).

Distribution and Functionality of Disconnectors

- Total number of blades: 15 (double busbar + transfer bar).

Buttons per blade: 2 (1 for opening, 1 for closing). See Figure 8.

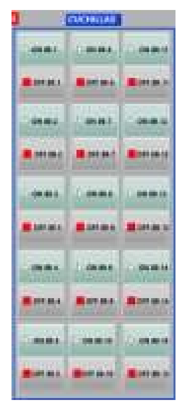


Figure 8. *Switch buttons section.*
Source*: Ruiz Ramírez, (2025).*

On the other hand, the interface has a drop-down menu for the user to select the required maneuver. There are a total of 9 maneuvers, three of which are disabled, as some specific maneuvers must be performed as a first step (see Figure 9).

IPSUMTEC
ISSN: 2594 - 2905

Figure 9. *Available maneuvers.*
Source: *Ruiz Ramírez, (2025).*

To configure communication between the microcontroller and the interface, select the virtual COM port assigned to the Bluetooth module and the data transmission speed (baud rate), which should be 9600 (see Figure 10).

Figure 10. *COM port and transmission speed selection.*
Source*: Ruiz Ramírez, (2025).*

The complete GUI control panel is shown in Figure 11.

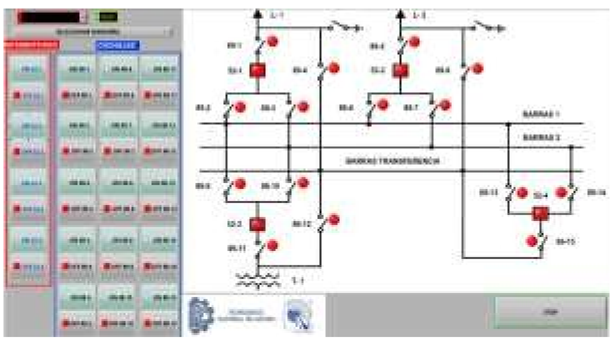


Figure 11. *Complete front panel of the interface.*
Source*: Ruiz Ramírez, (2025).*

To facilitate the use of the system (GUI) on any computer without prior software requirements, a standalone executable package (.exe) is created that includes:

- The application developed in LabVIEW.
- The necessary drivers for serial communication.
- Components for Bluetooth interface

To install the program, run the file called "install" and follow the instructions of the installation wizard. The system is then ready to communicate with the PIC16F877A via Bluetooth (see Figure 12).

Figure 12. *Program installer.*
Source*: Ruiz Ramírez, (2025).*

DISCUSSION AND ANALYSIS OF RESULTS
This section shows the results obtained in the operation and functioning of the prototype.

Before starting the tests, it is essential to follow the correct connection sequence:

1. Initial connection:

    - First close the disconnectors (blades) corresponding to the selected maneuver Technical note: Disconnectors cannot operate under load

    - Then close the power switches
Reason: These devices have electric arc extinguishing mechanisms, therefore they can operate under load.

2. Disconnection procedure:

    - First, open the power switches.

    - Then open the disconnect switches.

The first maneuver performed with the complete prototype is "CONNECT AND DISCONNECT L1 TO BUS 1" (see Figure 13).

Figure 13. *Selected maneuver.*
Source*: Ruiz Ramírez, (2025).*

Initial configuration:
Two banks of lamps were installed in a star configuration:

ISSN: 2594 - 2905

- First bench: Connected to the output of Bar 1.
- Second bank: Connected to the output of Line 1.

Operating sequence (connection):
Activation of disconnect switches:

- Close switch 89-1
- Close switch 89-2
- Close switch 52-1 (last stage of the sequence).

Complete procedure:

1. The maneuver begins by verifying the status of all devices in the open position.
2. The sequence is executed in the established order to ensure system safety.
3. Each step is performed with verification intervals (it is checked that the relay in the prototype has been activated (closed), which can be observed and confirmed if the corresponding pilot light is on).

Activation of Switch 89-1
Graphical User Interface (GUI):

- A virtual line lights up in the diagram.
- A virtual LED changes state (Figure 14).

Physical Prototype:

- The indicator light on switch 89-1 turns on (Figure 15).

Repetitive Process for Disconnector 89-2 and Switch 52.1.

The same behavior is replicated during the activation of:

- Disconnector 89-2 → Visual confirmation on GUI and prototype.
- Switch 52.1 → Graphic and physical feedback.

Final System Status
Once the sequence is complete:

- Line 1 remains connected to Bus 1 (Figure 16).

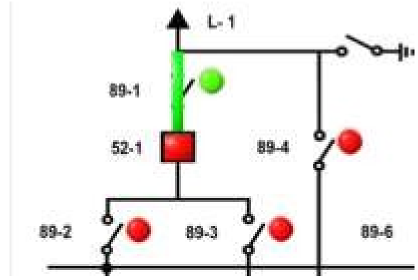


Figure 14. *Disconnector 89-1 closed at the interface.*
Source*: Ruiz Ramírez, (2025).*

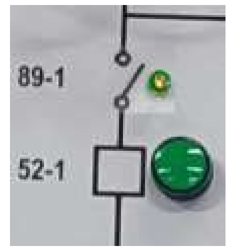


Figure 15. *Disconnector 89-1 closed in the prototype.*
Source*: Ruiz Ramírez, (2025).*

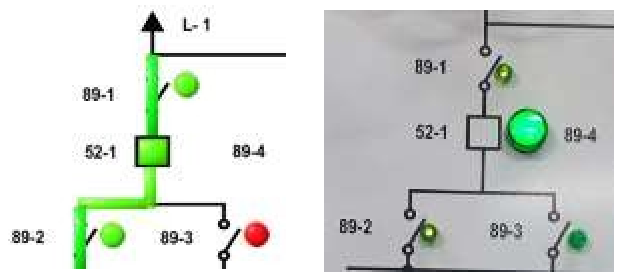


Figure 16. *Complete maneuver in prototype and interface.*
Source: *Ruiz Ramírez, (2025).*

In order for line 1 to be energized, transformer 1 must be connected to busbar 1, which is the next maneuver to be performed: "CONNECT AND DISCONNECT T1 TO BUSBAR 1" (see Figure 17).

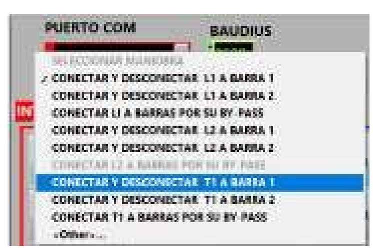


Figure 17. *Connecting transformer 1 to busbar.*
Source*: Ruiz Ramírez, (2025).*

Operating sequence:

- Operate disconnector 89-9 (close).
- Operate switch 89-11 (close).
- Operate switch 52-3 (close).

Status indicators:

On the GUI:

- Connection lines change to green.
- Virtual LEDs activate. On

the physical prototype:

- Green pilot lights turn on (Figure 18)

Power verification:

1. Bus 1 and Line 1 are energized.
2. The connected lamps connected to the corresponding line should turn on (Figure 19)

Operational validation:

The change of color to green on all indicators confirms:

- Successful connection of the disconnect switches.
- Correct energization of the circuit.
- Proper operation of the protections

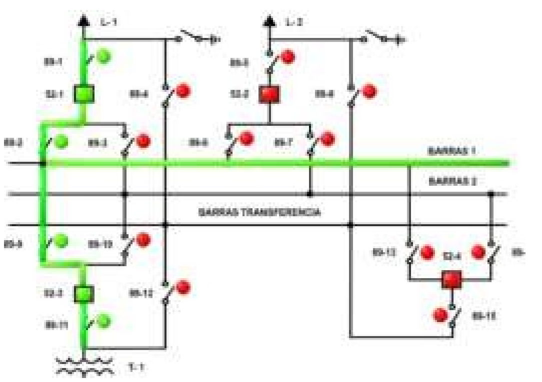


Figure 18. *Line 1 and busbar 1 energized at the interface.*
Source*: Ruiz Ramírez, (2025).*

Figure 19. *Line 1 and bar 1 energized in the physical prototype.*
Source: *Ruiz Ramírez, (2025).*

System Disconnection Procedure

1. De-energize Line 1.

Operating sequence (reverse order of connection):

- Open switch 52-1 (main protection).
- Open switch 89-2.
- Open switch 89-1.

Status check:

- Line 1 is completely de-energized.
- The connected lamps are turned off.
- Bus 1 remains energized.

2. Disconnection of Transformer 1

Safe procedure:

- Open switch 52-3.
- Opening of switch 89-11.
- Opening of switch 89-9.

Technical notes:

- The reverse sequence ensures operational safety.
- Each step must be visually confirmed on the GUI and physical prototype.
- Strict order prevents electric arcs and surges.

Final states:

- Transformer 1 completely isolated.
- Busbar 1 remains energized (ready for upcoming operations).
- Entire system in safe condition.

Prevention of Incorrect System Operations Technical basis:

Power switches are designed to operate under load, while disconnectors (knives) should only be operated under open circuit conditions. An incorrect sequence (activating switches first and then disconnectors) would result in:

- Dangerous electric arc.
- Physical damage to the equipment.
- Operational risk

Prototype protection system:

Automatic detection:

ISSN: 2594 - 2905

- The GUI and physical system continuously monitor the sequence of operation

Actions in case of error:

- Audible alarm activated (buzzer for 3 seconds).
- Visual message on GUI: "Incorrect maneuver - Repeat procedure" (Figure 20).
- Automatic disconnection of of all active devices.

Safe restart:

- The system resets to its initial condition.
- Allows the maneuver to be restarted correctly

Key system features:

- Immediate response to sequence errors.
- Comprehensive equipment protection.

The following is an example of an incorrect switching sequence for connecting switches and disconnectors:

1. Connect switch 52-1
2. Connect switch 89-1
3. Connect switch 89-2

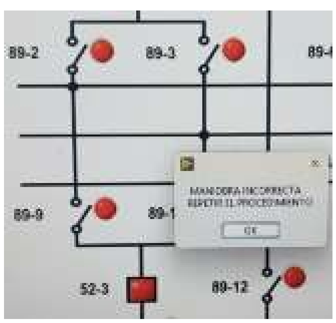


Figure 20. *Incorrect operation alarm message.*
Source: *Ruiz Ramírez, (2025).*

CONCLUSIONS

Effectiveness of the implemented solution:

The integrated system (GUI + physical prototype) demonstrates optimal performance by: Perfectly synchronizing virtual and physical operations, responding appropriately to the following maneuvers:

- Connection/disconnection of switches and disconnectors.
- Energizing/de-energizing: Busbars 1 and 2, output lines L-1 and L-2

Safety mechanisms:
Automatic detection of incorrect sequences, with an alert system consisting of: Audible alarm (buzzer), visual error message, and preventive system lockout.

Educational value:
The prototype is an effective teaching tool for understanding busbar diagrams in substations, learning the correct operating protocols for power switches and disconnectors, and visualizing the consequences of incorrect maneuvers.

Academic implementation:
As shown in Figure 20, the equipment is being used successfully by electromechanical engineering students in the Electrical Substations course to reinforce theoretical and practical learning.

Additional benefits:

- Reduces risks in learning real-world operations.
- Allows for the safe repetition of maneuvers.
- Facilitates understanding of energy flows.

Unlike the simulator proposed by González Sancho Eladio [5], this prototype incorporates a synergy between the simulation of maneuvers in the busbar diagram and the physical part, which allows observation of how both the busbars and the connected loads are energized and de-energized, thus facilitating a better understanding of the procedures performed.

For its part, the system developed by Jiménez [7] consists of a simple bar teaching module with transfer, which also integrates simulation with the physical part. However, its bar layout is the least commonly used in electrical substations. In addition, Jiménez uses a PLC system for automation, which is more expensive than a microcontroller.

Figure 21. *Equipment used in practice.*
Source: *Ruiz Ramírez, (2025).*

IPSUMTEC
ISSN: 2594 - 2905

ACKNOWLEDGMENTS
To the Zacatepec campus of the National Technological Institute of Mexico, Department of Metal Mechanics, for providing the facilities to work and conduct tests in the Electrical and Electronic Engineering Laboratory.

BIBLIOGRAPHY
[1] MATULIC, Iván. Introduction to Electrical Systems from Power. RevActaNova [internet], June 2003. [accessed on March 27, 2025]. Vol. 2, No. 2, 2003. 208-215, Available at: http://www.scielo.org.bo/scielo.php?script=sci_arttext&pid=S1683-07892003000100005&lng=es&nrm=iso
[2] Jorge Lozano González, Luis Francisco Vázquez Calvillo, Leticia Neira Tovar (2021). Virtual reality simulation systems for electrical substation training – an overview. Educational Tracks [Internet]. Jul 2012 [accessed March 20, 2025]. 468-487p Available at: https://pistaseducativas.celaya.tecnm.mx/index.php/pistas/article/view/2730.
[3] Jesús Trashorras Montecelos. Electrical Substations. 1st edition. Spain: Paraninfo. 2015. 387p.
[4] Yanza Zamora, A. J. Development of a training system for electrical substation operation, aimed at substation operators at CELEC EP - TRANSELECTRIC, using the LabVIEW programming environment [online thesis]. Ecuador: National Polytechnic School; 2021 [accessed March 20 of 2025]. Available at: http://bibdigital.epn.edu.ec/handle/15000/21396
[5] González Sancho, Eladio. Electrical substation simulator 2.0. [thesis online]. Valladolid: University of Valladolid; 2014 [accessed February 10, 2025]. Available at: http://uvadoc.uva.es/handle/10324/12995.
[6] Lajara Vizcaino, José Rafael, and Pelegrí Sebastiá, José. Graphic Programming Environment. 3rd Edition. Spain: Marcombo. 2017. 537p.
[7] Jiménez Espinosa Juan Pablo. Design and construction of the operation of a single-busbar substation teaching module with transfer for the visualization of electrical variables using the Scada system in the electromechanics laboratory of the Technical University of Cotopaxi, 2014. [online thesis]. Ecuador: Technical University of Cotopaxi; 2016 [accessed January 21, 2025]. Available at: http://repositorio.utc.edu.ec/handle/27000/2976
[8] Xue, Z., Gao, W., Li, X., Wu, W., Research on Operation, Repair and Simulation Training Method of Electrical Equipment in Substation Based on Virtual Reality Technology. Journal of Physics: Conference Series 1345, 62035, 2019.
[9] Ayala García, A., Galván Bobadilla, I., Arroyo Figueroa, G., Pérez Ramírez, M., Muñoz Roman, J., Virtual reality training system for maintenance and operation of high-voltage overhead power lines. Virtual Reality [internet], January 2016. 20(1), 27–40, available at:
[10] P. N. A. Barata, M. R. Filho, and M. V. A. Nunes, "Consolidating Learning in Power Systems: Virtual Reality Applied to the Study of the Operation of Electric Power Transformers," in IEEE Transactions on Education, [internet], Nov. 2015, vol. 58, no. 4, pp. 255-261, available at: https://ieeexplore.ieee.org/document/7027870
[11] Bruce Mihura. LabView for data acquisition. Pearson Education. 1st edition. United States of America: Prentice Hall. 2001. 460p.
[12] Les Johnson. Proton PIC BASIC Compiler.

Contribution Role Table

Role	Author(s)
Conceptualization	<equal> José Efraín Ruiz Ramírez, <equal> José Alfonso Santana Camilo
Data curation	Enrique López Chávez
Methodology	José Efraín Ruiz Ramírez
Administration of the project	José Efraín Ruiz Ramírez
Resources	<equal> José Efraín Ruiz Ramírez, <equal> Martín Ríos Tapia
Software	<equal> José Efraín Ruiz Ramírez, <equal> José Alfonso Santana Camilo
Supervision	<same> José Efraín Ruiz Ramírez, <same> Enrique López Chávez
Validation	José Efraín Ruiz Ramírez, Enrique López Chávez, José Alfonso Santana Camilo, Martín Ríos Tapia
Display	<equal> José Efraín Ruiz Ramírez, <equal> Martín Ríos Tapia
Writing	<same> José Efraín Ruiz Ramírez, <same> Enrique López Chávez, <same> José Alfonso Santana Camilo