Development of a Laboratory Course in Industrial Power and Control for Electrical Engineers

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Abstract

As the need for more complex electrical control systems grows, qualified individuals to design and maintain these systems become essential. Consequently, industrial sectors such MEP (Mechanical, Electrical, and Plumbing), have experienced rapid growth and increased investments worldwide in automation which further means that the jobs in this sector are also expected to proliferate. To address this, the electrical engineering program at Cal Poly State University has been developing a new laboratory course that utilizes the recently donated Programmable Automation Controllers from Schneider Electric. The course aims to introduce students to industrial power control and automation, and to provide them with the hands-on training in implementing most commonly used hardware and software for control, monitoring, and automation of electrical systems. This paper presents the development of the course, the associated learning outcomes, and the lab experiments that have been designed for the course. Results from the first offering of the course in Spring 2023 will be discussed, along with lessons learned, challenges, and plans for future improvements of the course.

Keywords

Student projects, industrial automation lab, laboratory development.

Introduction

Automation is a vital part of modern society, allowing supply to meet demand in various industries. It is the method or system of controlling a process using electronic devices to keep human intervention to a minimum[1]. Automation was first introduced in the early ages with the inventions of the watermill and windmill to lessen human labor involvement[2]. Later, the concept was introduced along with electricity into the manufacturing industry in the early-to-mid 20th century[3]. Over time, automation extended into the aeronautical, nautical, cellular industries, among others. To support this, various new instrumentations such as sensors, recorders, and displays were utilized. To flexibly control different machines and make use of these new devices, modular control units known as Programmable Logic Controllers (PLCs) were developed.

Programmable Logic Controllers (PLC) has become a revolutionary invention that continues to impact the world significantly and to be a valuable tool in automation. This is demonstrated by the growing PLC industry whose global market value is expected to increase roughly $2-3 billion in the next 4-5 years[4,5]. One of the main driving forces behind this increase is the desire to decrease machine downtime which PLCs can assist in. Another is the desire to increase automation in factories, especially in the automotive industry to ramp up production to meet growing demand. Various industries including electric utility companies also have a need for more complex control solutions which the PLCs could facilitate with their processing power, greater memory size and functionality[4]. However, despite the increasing use of PLCs in electrical systems and PLCs being a large part of many career paths in electrical engineering, the electrical engineering program at Cal Poly State University did not have any course that focuses on the topic. To address this issue, a new course focusing on PLCs has recently been developed. The development of a new PLC laboratory for the course was made possible by the recent generous donation from Schneider Electric, which is one of the major manufacturers of PLCs.

The Course

The new course is designated as EE435, Industrial Power Control and Automation. It is a 1-unit electrical engineering laboratory course held once a week in the newly established PLC lab. The course is also a technical elective course that requires students to satisfy the prerequisite electric machines and control system courses before they can enroll in the course. The lab contains six workstations as shown in Figure 1. These workstations are equipped with the donated Schneider Electric Modicon M580 PLCs as well as the Magelis human-machine interface (HMI) systems and various attachment modules.

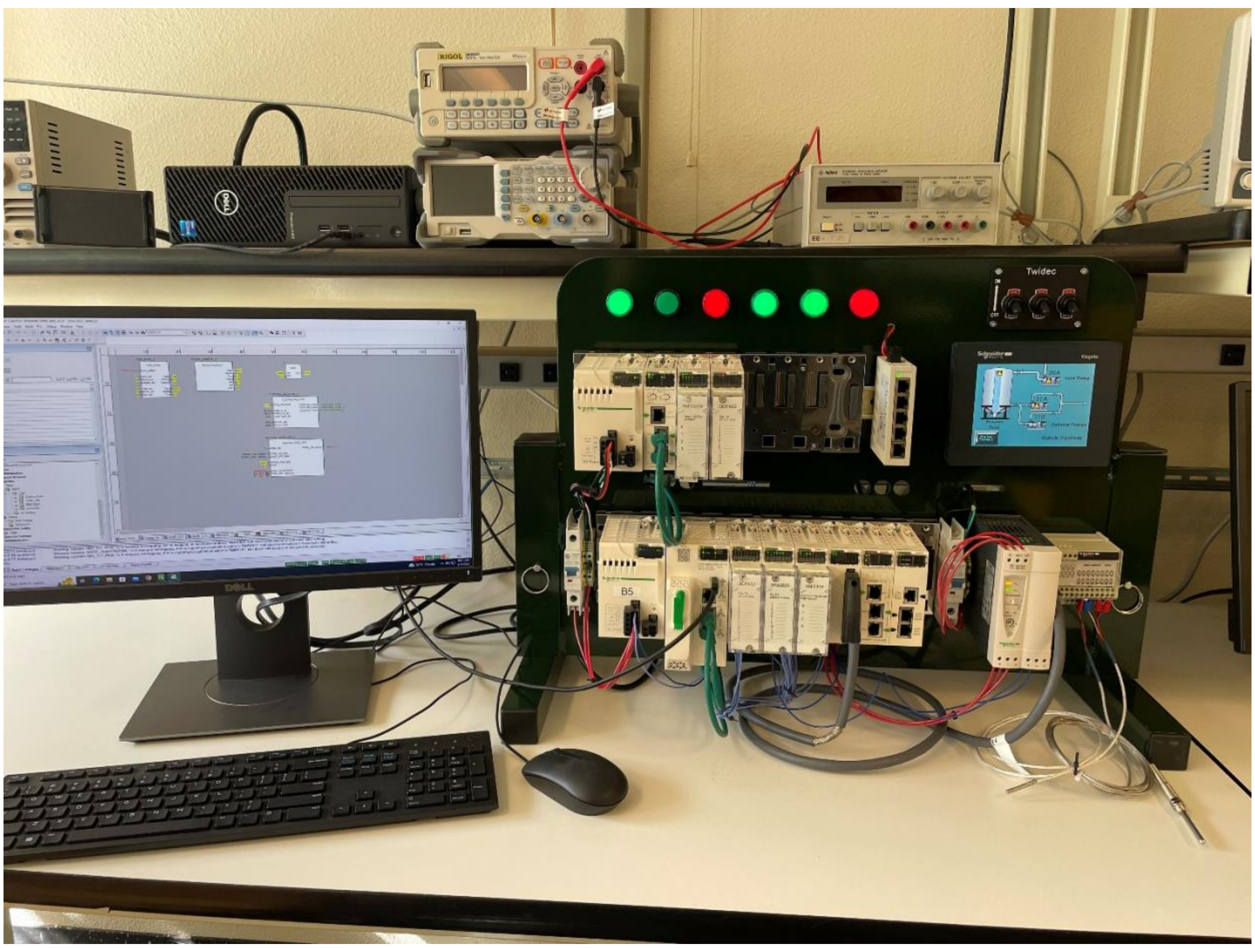

Figure 1. PLC lab workstations

One of the goals was to develop a programmable automation controller course that would expose students to a wide range of current technologies in automation used in industries today.

We interviewed automation controls engineers at electric utilities and water/wastewater facilities for what technologies they would want engineering graduates to be trained in industrial automation. They emphasized process control programming (PID), Object Oriented Programming utilizing custom Function Block development, cybersecurity, and industry standard communication protocols to intelligent electronic devices (PLCs, VFDs, meters).

The course aims to introduce students to the various concepts in automation and process control, to become familiar with the programming and operation of PLCs. The laboratory experiments encompass electrical engineering applications which differentiates this course with PLC courses in other engineering programs. The 2022-2026 Cal Poly course catalog has the following description for the new EE435:

"Introduction to programmable automation controllers including custom developed functions, electrical hardware interfaces, communications networking to intelligent electronic devices, and machine operator interface terminals. Applications of industrial power control and automation systems including protection equipment, motor controllers, renewable energy, and sensors. 1 laboratory." [6]

The learning outcomes of the course are established such that upon completion of the course, students will be able to:

- Apply safety procedures to lab work
- Define uses and functions of input and output devices, logic devices, relays, and motors
- Design and build a system utilizing input and output devices, logic devices, relays, and motors
- Establish a Real-Time Modbus TCP and EtherNet/IP protocol communication setup using explicit messaging and Device Type Manager (DTM) technology to devices (PLCs, VFDs, meters, Intelligent Electronic Devices).
- Construct a system with a centralized PLC and connected devices using IEC 61131-3 programming languages such as Ladder Diagram (LD), Sequential Function Charts (SFC), Function Block Diagram (FBD), and Structured Text (ST)
- Design a system utilizing PLC to monitor, control, and coordinate industrial power equipment, sensors, and intelligent electronic devices
- Formulate a PID controller for controlling VFDs and industrial power equipment and meeting steady-state and stability requirements
- Design a Human Machine Interface to perform communication and control of PLC connected equipment and devices

Laboratory Experiments

Developing laboratory experiments for EE435 posed various challenges, such as the need to present complex concepts in a digestible manner for students. Achieving this involved incorporating components that enforce the understanding of the concepts into an introductory format. At present, a total of 8 laboratory experiments have been developed. Each laboratory experiment is a short project incorporating one or more aspects of PLCs. Students form groups of three to complete each experiment in three hours. Prelab assignments and laboratory are used to assess student understanding of the material and lab experiment. With this format, the course can cover a wide variety of topics while relating them all with the application of PLCs. Below is the list of the laboratory experiments that have been designed and developed for the course.

Lab 1: LED Lighting System

Students develop an LED lighting hardware simulator using the Modicon M580 PAC to learn how to configure I/O and remote I/O modules, demonstrate the use of digital, analog current/voltage modules (range/resolution, sensor devices) and scale I/O variable assignments in conjunction with ambient light and occupancy sensors to control brightness of LED light.

Lab 2: Fan Cooling System

Students develop a Fan Cooling System by implementing variable data types, using ladder logic and/or Functional Block Diagram to create section/tasks to program motor start/stop circuit. The controller will monitor temperature sensors to automatically determine the number of fans (up to 3) being operated and their speed to achieve the most energy efficient system.

Lab 3: Tank Level Controller

Students develop a hardware simulation of water tank level monitoring and tank fill controller system. Students also create a 2-pump tank fill logic, discrete level monitoring of alternating pump control, flow rate using variable frequency speed control, and PID control for analog level monitoring of the tank.

Lab 4: Recloser and Circuit Breaker Controller

Students develop a recloser and circuit breaker system for protection from fault current. Students also create M580 custom Function Blocks that implement electrical gain, circuit monitoring/alarming logic, and make use of input/output pins, and internal & external variables. The recloser will trip the breaker and go through at least 2 cycles of fault checking and breaker tripping before it goes into a lock mode.

Lab 5: Energy Storage Monitoring and Communication System

Students utilize the M580's communication protocols (Serial and Ethernet) and modules as well as Function Blocks and implementing generic Modbus TCP DTM (Device Type Managers) to monitor and connect/disconnect the energy storage device and other Intelligent Electronic Devices (relays, meters, etc.). Students also create communication logic in Function Block Diagram and write data across networked M580 systems.

Lab 6: Human Machine Interface (HMI) for Microgrid System

Students simulate a microgrid system with multiple energy sources and loads by utilizing and configuring the HMI module. HMI touch screen programming is used for setpoints and monitoring system status. Students implement several functions including remote I/O diagnostic and status, diagnostic functional blocks, and HMI alarm event viewer/time stamp screen.

Lab 7: Cybersecurity in Industrial Automation

Students configure security options in the M580, to learn Cybersecurity concerns and attacks in Industrial Automation. The lab reviews standards, PLC network architectures, device configuration (switches, routers, IPSEC, IP addressing, Syslog server) as well as networked SCADA systems and IEDs.

Lab 8: Variable Frequency Motor Drive

Students program the M580 with Ethernet communications to a Variable Frequency Drive (VFD) system. Students also create a control process for the VFD using Modbus TCP Function Blocks and DTMs to program logic for start, stop, forward, reverse and creating a VFD speed reference profile.

Lessons Learned

The course was first offered in Spring 2023 with enrollment of 16 students grouped into 6 teams. Each week group memberships were randomized to allow the students to get to know one another and to increase chances of encountering peers with diverse backgrounds and interests.

In terms of the laboratory experiments, we learned that some of the experiments were quite extensive for students to finish within the three-hour lab time. This was expected since this course was offered for the first time, and so we were still gauging how much time students would need to complete for every software and hardware components they had to do in each experiment. As students progressed through the first few weeks of the course, they became more acquainted and more comfortable working with the PLC and its associated software and hardware components. Therefore, majority of the groups were able to finish the experiment in time in most of the later experiments. Additional issue that caused some groups not to be able to complete the tasks relates to troubleshooting software glitches and hardware problems which unfortunately would occur especially with new laboratory software and hardware setups.

Results from student evaluations of the course indicate that the course was effective in meeting the course objectives. Average numerical scores for both the instructor and the course are 4.86/5.0 and 4.71/5.0, respectively as shown in Figure 2. Additional verbal comments from students further indicate that they enjoyed the hands-on experience and that they believe the course prepared them for industry. Students also conveyed that more structured laboratory manuals would help improve the course and that some experiments could be shortened to gain better understanding of the concepts instead of rushing through to complete the experiment.

SUMMARY EVALUATION

NUM	QUESTION	AVERAGE
3.1)	Overall, this instructor was educationally effective.	4.86
3.2)	Overall, this course was educationally effective.	4.71

Figure 2. Course evaluation results from Spring 2023

Other recommendations for future improvement include designing and assembling electronics behind the model box before developing the lab manual to ensure a seamless integration of theory and application. Moreover, employing a proactive measure like constructing a mind map aids in visualizing and aligning the lab's goals, facilitating a coherent and focused development process. These measures will collectively contribute to the overall improvement and effectiveness of learning the materials in the course. Lastly, to enhance the quality of the course materials, we could include a test group of students to read and perform the lab manual, providing valuable feedback to refine the content.

For the faculty teaching the course without prior experience with PLC, the course would require significant time commitment to become familiar with the PLC software and to learn how to operate the PLC and its components. To prepare for teaching the course, several faculty members attended on-site PLC seminars by inviting an engineer from Schneider Electric. Additionally, the engineer provided the full support by developing and coteaching the course with two other faculty members.

Besides refinements to improve the recently developed laboratory experiments, additional experiments are currently being planned to expand the course due to upcoming transition from quarter to semester system. Additional hardware modules are being developed and lab equipment are also being added to extend the capability of the lab and to enhance the course content.

Conclusion

A new laboratory course that addresses the lack of industrial power control and automation content in the electrical engineering program at Cal Poly has been presented in this paper. Several hardware laboratory experiments utilizing the recently donated PLCs and other hardware modules from Schneider Electric were developed for the course. The course was offered for the first time in Spring 2023 and it was well received based on the enrolment and positive results and comments from the end of quarter course evaluation. Improvements based on the feedback are currently on-going to enhance student’s learning for future offering of the course. More laboratory equipment and experiments are also being added to prepare for the transition to semester system which will start in Fall 2025.

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