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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29671

PLC Training in First Year Electrical Engineering Program

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Abstract

Programmable Logic Controllers (PLCs) have had a profound impact on industry and society at large. PLCs are an integral part of a wide variety of control systems, ranging from industrial manufacturing to amusement park rides and filmmaking. Programming languages like ladder logic allow technicians and engineers without formal programming experience to build and debug complex automation systems much faster than if they needed to physically build arrays of relays and logic elements.

While many engineering programs have already implemented PLC courses in their curricula, instruction remains lacking in many others. Since engineering students with some PLC training may have better career opportunities than those who do not, this may represent an area for improvement for some programs.

Introduction to Projects and Tools is a freshman level course offered to electrical engineering students at [XXX University]. This one-credit laboratory course serves to provide students with hands-on experience with a variety of projects such as the implementation of 555 timers, basic logic circuits, and measurements of electrical quantities.

A two-week PLC module was developed and implemented in the Introduction to Projects and Tools course in the Fall 2019 semester. Students were introduced to ladder logic programming and were required to design PLC programs for performing specific assigned tasks. Student feedback and comments were collected through a survey at the end of the semester to investigate the impact of the module on student learning. This study includes a description of the module and the results of the survey. The results indicated that students found the module both exciting and an excellent learning opportunity.

Introduction

PLCs are used to implement complex industrial controls. PLCs take inputs from sources like sensors or switches and generate outputs like command signals for actuators. PLCs are configurable, reliable, and have been the backbone of many industrial processes such as Manufacturing Production Lines, Chemical & Petrochemical, Energy & Utilities, Pulp & Paper, Oil & Gas, Water and Wastewater Treatment, Pharmaceutical, Food, Tobacco, & Beverage, Automotive, and more [1].

The PLC market has shown consistent growth over the last 50 years, and growth is going to continue with an expected compound annual growth rate of 3.7% between the forecast period of 2019 to 2024 [2]. In fact, automated PLC systems are projected to reduce average machine downtime from 20% to almost 4% [3].

PLC programming is a part of engineering technology programs at many universities, and are commonly taught by experienced industry people or implemented as a module in industrial control [4], fluid power [5], manufacturing automation [1], and Applied Process Control Engineering [6] courses. Many PLCs manufacturers/providers also offer examples and practice to be used in PLC curriculum [7]. A discussion of whether PLC should be taught by the PLC manufacturing or should be a formal course as part of a university or college curriculum can be found in [8].

Due to the popularity of PLCs in industrial controls, engineering students are often expected to have some knowledge of PLC programming with ladder diagrams. Ladder logic diagrams, based on two-wire relay control logic, are the common language of PLC programming. A ladder logic program consists of multiple 'rungs', each of which specifies an output requirement. When a ladder logic program is executed, the rungs are executed sequentially, looping back to the top rung once each rung has been processed until the process is interrupted or a solution is reached.

The visual style of ladder logic makes maintenance of PLC-based control systems easy due to its resemblance to relay control hardware, allowing engineers and technicians to understand and modify control systems without needing sophisticated coding experience. Virtual PLC programming workbenches called Integrated Virtual Learning Systems for PLCs, or Virtual PLCs for short, have been introduced to aid in PLC education [9]. These Virtual PLCs employ animations, simulations, intelligent tutoring systems, and games, and are cost-effective tools to teach PLC programming [10].

Due to the recommendation of our department advisory board and industry partners, it was determined that there was a need for PLC training in an electrical and computer engineering curriculum at the XXXX university. A two-week pilot module was implemented for freshman electrical and computer engineering students in the Fall 2019 semester. The module was added to a broader introductory course named Introduction to Projects and Tools.

As Introduction to Projects and Tools is one of the first engineering classes students are exposed to, students enter the course with little to no knowledge of PLC programming, with many students even having no prior exposure to text-based programming. The PLC module was covered over two weeks of the Fall 2019 semester and included 1.5 hours of lecture and 2.5 hours of hands-on lab projects. At the end of the course, students were given a survey to assess learning outcomes. This paper will describe the pilot PLC module and discuss the results of the student survey.

Introduction to Projects and Tools

Introduction to Projects and Tools is a one-credit laboratory course taken by freshman electrical and computer engineering students. The course provides hands-on experience with multiple electrical engineering projects such as the implementation of 555 timers, digital gates, AC/DC measurements, and more. The objective of the course is to introduce students to basic electrical engineering tools and equipment such as power supplies, breadboards, function generators, and soldering stations, and to help students understand the main steps involved in completing engineering projects.

Students are introduced to a variety of engineering projects and tools through several projects, each organized into a module covered over the course of one to three weeks. The instructor chooses these projects from a list of eight developed modules, which are described as follows:

Module 1: Students are introduced to Ohm's law, series and parallel networks of resistors, and work with lab equipment. Digital multi-meters and laboratory power supplies are used to verify students' calculations.

Module 2: Students explore the properties of Light Emitting Diodes (LEDs) and sinusoidal wavefunctions in an AC circuit using oscilloscopes and function generators.

Module 3: Students build synchronous and asynchronous 555 timers, adjusting timing parameters through the choice of capacitors and resistors.

Module 4: Students are introduced to basic digital logic such as AND/NAND/OR/XOR gates, and binary-to-decimal conversion.

Module 5: Students are introduced to MATLAB programming and use MATLAB to generate discrete sinusoids for musical notes.

Module 6: Students are introduced to three-phase electrical power systems.

Module 7: Students are introduced to PLCs and ladder logic, as described in this paper.

Module 8: This module is always included in the course as a final project. Students prototype an electronic kit on a breadboard before implementing it on a printed circuit board (PCB).

PLC Module

In response to student interest and calls from industry partners, a PLC training module was added to the class Introduction to Projects and Tools as the first step to including PLC training in the broader electrical and computer engineering curriculum. The objectives of the module were to introduce students to PLC programming and wiring. The module consisted of one example involving the control of a mixing tank and two hands-on projects completed over the course of two weeks.

The mixing tank example included two inlet valves for the intake of two separate liquids, two level switches for detecting high and low fluid levels, an outlet valve, and a mixer with a motor, as shown in Figure 1.

The behavior of the tank system is as follows: when the PLC detects a low fluid level, the outlet valve is closed, and the inlet valves let their respective fluids in. Once a high fluid level is detected, the inlet valves are closed, and the motor is run for a set time to mix the fluids.

When the time is up, the outlet valve is opened until the PLC detects a low fluid level and the cycle is started again. Students were walked through each step of creating a ladder diagram for the control of the tank, culminating in a complete ladder diagram similar to the one shown in Figure 2.

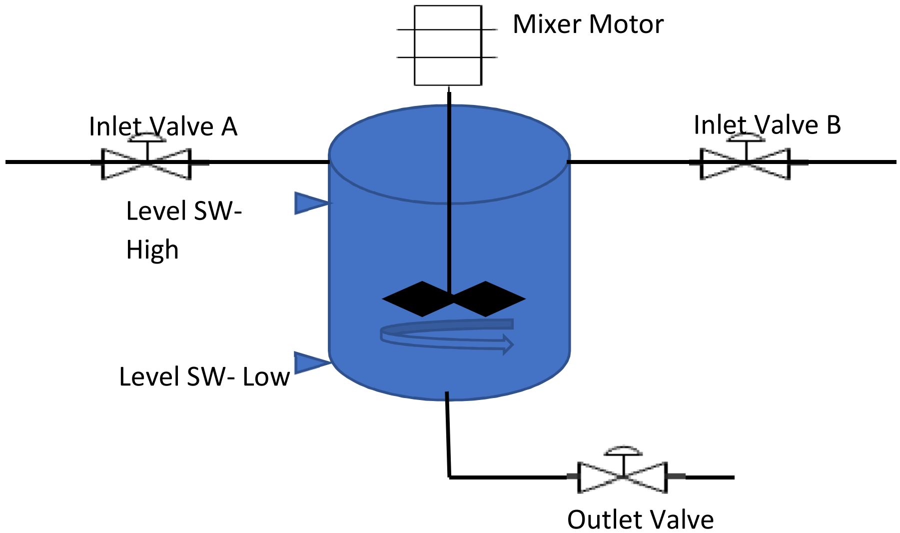

Figure 1. A diagram of the mixing system implemented in the first project of the PLC module.

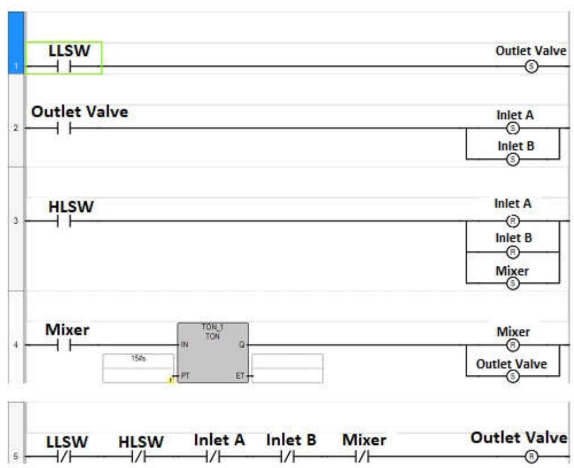

Figure 2. ladder diagram representing the logic described above

For the first hands-on project, students developed a system for flashing several lights in order. The students were given a ladder diagram that switches between two lights and were tasked with modifying it to cycle through four lights in counterclockwise order.

For the second hands-on project of the module, students developed ladder logic for a two-way traffic light and wired the outputs of a PLC to external LEDs. The traffic lights were required to exhibit traditional traffic light behavior: a traffic light would remain green for six seconds, turn yellow for two seconds, then turn red as the other light repeated the same cycle.

A wiring diagram for the two-way traffic light system is shown in Figure 3. A more advanced version of this project has been developed by Pina and Hsieh [11]. Students were given a breadboard, six LEDs (two sets of green, yellow, and red), six current limiting resistors, and an Allen-Bradley Micro 820 trainer, which is shown in Figure 4. This trainer includes one PLC, one Training Module with 6 discrete inputs, 6 discrete outputs, one analog input, one analog output, power switch, programming cable, power supply, and ethernet cable**.**

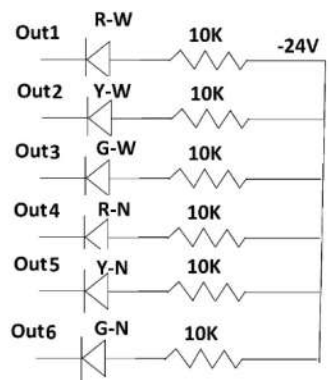

Figure 3. A wiring diagram for the PLC module's third project, a two-way traffic light system. R,Y,G represent Red, Yellow, Green and W,N represent west-east and North-South sides

Figure 4. An Allen-Bradley Micro 820 trainer used for the final project of the PLC module.

The software used for ladder logic programming in the PLC module was Connected Components Workbench (CCW) from Allen-Bradley [12]. This software is free of charge for educational purposes, and provides device configuration, controller programming, and integration with a Human-Machine Interface (HMI) editor. CCW is available in a variety of localizations, including

English, Spanish, French, Italian, Portuguese, and Simplified Chinese. The standard edition comes with programming software for Rockwell Automation Micro Control System, including a demo version of Micro800 Simulator. Students found the software easy to work with, barring some communication glitches when communicating via the Ethernet port over a local network. Version 10 of the software was the most consistent, despite higher versions being available. Figure 5 shows the version selection page in CCW.

Student Perceptions for the Course and PLC Module

Student opinions were collected with an electronic survey. Out of 56 students from two sections of Introduction to Projects and Tools, 42 responded to the survey. The survey questions are as follows:

1. Rate from 1-5 your agreement with the following statements (learned a lot from PLC module, the PLC module was fun and exciting, PLC lab was practical and has many applications)
2. Did the PLC hand out have enough information to get you started? (Yes, No, other)
3. Was the PLC prelab lecture helpful? (Yes, No, Partially)
4. What do you think of Mixer example in prelab? (Very helpful to understand PLC Somewhat helpful, I did not understand the mixer, Wish there were more examples like mixer, Other (please specify)
5. Which of the following projects did you like the most? (Light flasher in the first week, Traffic light, Both, None)
6. Which of these labs you like the most? (PLC, Digital lab (AND, OR, BDC), Function Generator and Oscilloscope,555 timer)
7. Comment box

Responses to the survey are shown in Figures 6-a through 6-f.

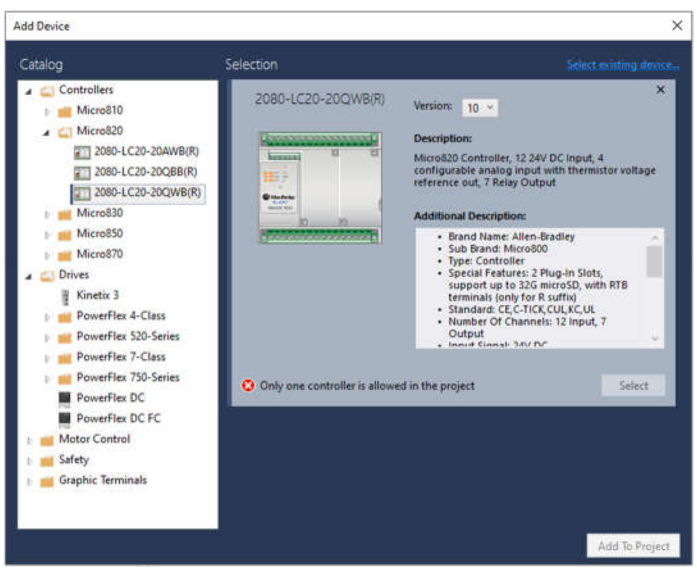

Figure 5. Version selection in CCW.

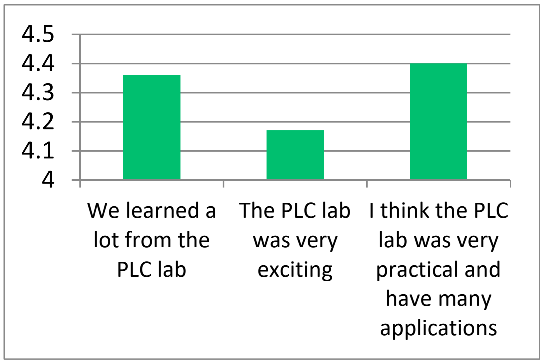

Figure 6-a. Rate from 1-5 your agreement with the following statements. Vertical axis represents weighted average

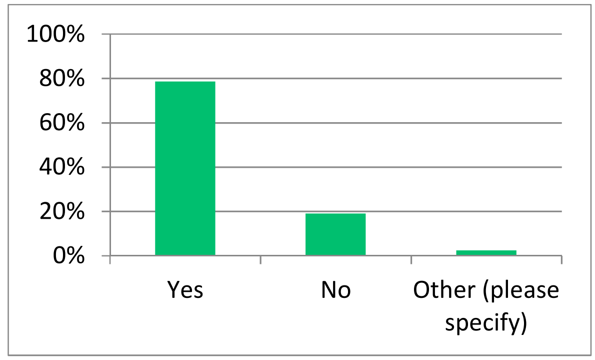

Figure 6-b. Did the PLC hand out has enough information to get you started? Percentage of respondent

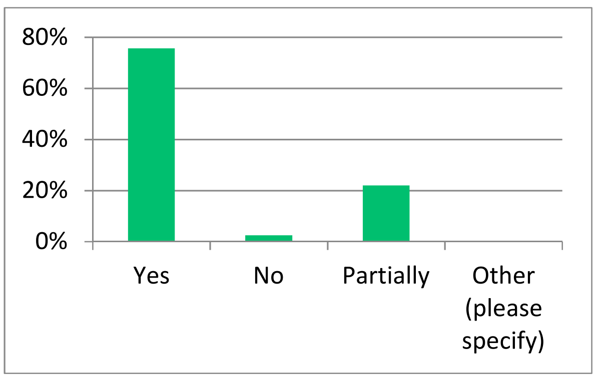

Figure 6-c. Was the PLC prelab lecture helpful?

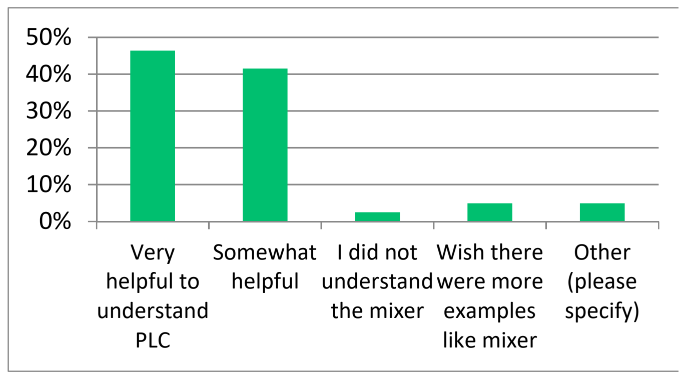

Figure 6-d. What do you think of Mixer example in prelab?

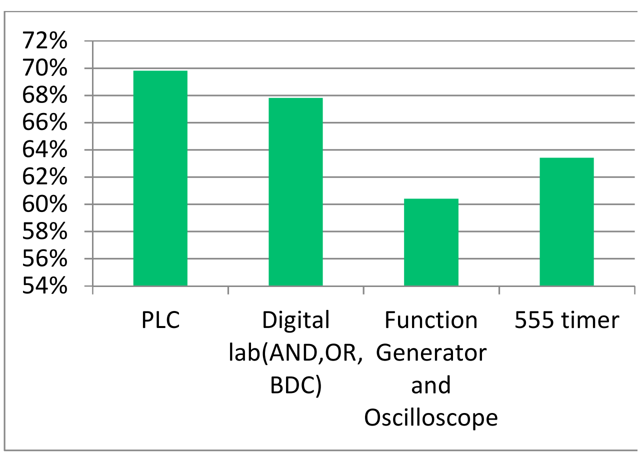

Figure 6-e. Which of the following projects did you like the most?

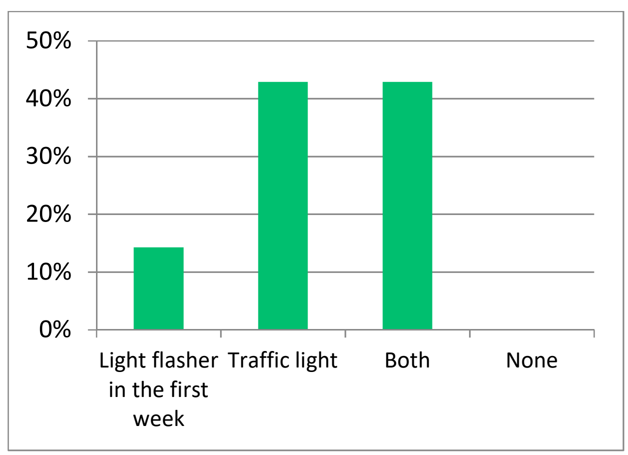

Figure 6-f. Which of the following projects did you like the most?

Comments: Some students left a comment in the comment box. Most comments were complimentary of the course, with the PLC module being singled out as particularly praiseworthy. Only one student gave a negative comment, saying they wished that handouts given for the PLC module included more explanation.

Results and Discussion

As described above, a PLC module was designed and implemented in a one-credit laboratory-based coursed named Introduction to Projects and Tools after a call for PLC training from the department industry partners and academic advisory boards. The course included 3-4 learning modules, each lasting 2-3 weeks. The new PLC module consisted of two lab hours per week over the course of two weeks. In a survey conducted after the course was complete, students indicated that they learned a lot about how to control PLCs, as well as PLC applications, as can be seen in Figure 6-a.

A handout explaining the basic principles of PLC systems and ladder logic diagrams was written and distributed among students. Most students indicated that the handout had enough information for them to get started (Figure 6-b). In addition to the hands-on learning sessions, there was an hour lecture demonstrating how a PLC could be used to control an industrial mixer. Since the students had no PLC experience or background, they found the lecture and the mixer example very helpful (Figures 6-c and 6-d). Among the other modules included in the course such as projects related to 555 timers, digital circuits, and AC/DC measurements, the PLC module was rated the highest by students (Figure 6-e).

In addition to the one-hour lecture period, the module consisted of two hands-on projects: a light flasher (LED chaser) and a pair of two-way traffic lights. For the light flasher project, students were asked to design a ladder logic program to turn on four lights (blue, green, yellow, red as indicated in figure 5) for 2 seconds sequentially. For the light flasher project, students were given a handout with instructions on how to make 2 lights flash sequentially, and students were required to extend the functionality to 4 lights. This project did not include any wiring. The second project, two-way traffic lights, included wiring the outputs of the PLC to two sets of green, yellow, and red LEDs. The students completed this with no guidance. Most students indicated that both projects were interesting (Figure 6-f).

Overall, the module was a success and met its objectives. We believe that a PLC course should cover three aspects: applications, ladder logic, and hardware. Students must be able to understand an industrial control problem and be capable of translating a solution into useable logic on applicable hardware. The projects themselves were designed to teach students PLC applications by offering simplified versions of problems that are seen in industry. Each hands-on projects in the module involved students designing their own ladder logic, and lastly, wiring is the hardware aspect of PLC training. We believe that these three aspects were covered by the module. However, many advanced topics such as complicated “instruction blocks” or PID controls using PLCs were left out due to the time constraints or the lack of technical background of freshman students. Also, the module did not cover input signals. A full PLC course can be placed into an engineering curriculum to address the advanced topics. While we are planning a new full course on PLCs, we will continue placing the PLC module into the Introduction to Projects and Tools course.

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