TEACHING PLC IN AUTOMATION
--A Case Study

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Abstract

Programmable logic controllers, PLCs, have become the industry standard, replacing the hard-wired electromechanical devices, in controlling process machines and driving the equipment of manufacturing. Varying in size and sophistication, these electronic devices are now produced by over 50 manufacturers. In our 2 and 4 credit-hours courses for manufacturing and electronic engineering technology students, relay circuits, fundamentals of sensors, and electrical controls are explained first. Then, the PLCs, from hardware structures, installation, wiring, to ladder logic programming are elucidated. Experience in teaching two different groups of students with different academic background and preparation are presented. Approaches taken in each class are discussed.

Introduction

Manufacturing systems were controlled by electromechanical devices, such as relays, solenoid valves, and actuators, before the digital electronics came on the scene. Nearly all controllers were permanently hard-wired, making changes difficult and expensive. Programmable logic controllers, PLCs, have dramatically altered this picture since their initial applications in 1960s. Because of their functionality and versatility, PLCs are playing ever-popular and critical roles in modern manufacturing systems.

Missouri Western State College is a public, state supported institution providing a blend of traditional liberal arts and sciences and career-oriented degree programs. Professional education programs such as teacher education, nursing, engineering technology, and business have played an important role at Missouri Western for many years and have come to be seen as an area of strength for Missouri Western throughout the northwest Missouri region. The college has chosen to retain its open access policy while continuing its commitment to pursue academic excellence and quality teaching.
Missouri Western State College has long had career-oriented education as a primary part of its mission and function. It has a solid undergraduate program in engineering technology accredited by the Technology Accreditation Commission of the Accreditation Board for Engineering and Technology (ABET). It valuably serves both its students and the employers of the City of St. Joseph, the northern fringes of the Kansas City metropolitan area, and its five-county regional service area by providing highly skilled engineering technologists and technicians to help the region grow and prosper. It wishes to continue to serve the people of Missouri in this way.

Manufacturing Engineering Technology (MET) is the profession in which the understanding of a broad range of technologies is necessary to apply and control manufacturing processes. It includes methods of production of industrial commodities and consumer products. The manufacturing professional must be able to plan, design and implement the facilities, tools, machines, and the sequence of operations for producing high quality products at competitive prices.

Manufacturing Engineering Technology is a highly interdisciplinary field, requiring elements from other areas of engineering technology, along with an in-depth knowledge of materials and manufacturing processes. The manufacturing professional must possess excellent technical and communication skills, knowledge of computers, electronics, materials, and information technology.

Graduates with Associate of Applied Science in Manufacturing Engineering Technology will be able to fill a wide variety of positions. Specifically, career opportunities exist in manufacturing engineering of facilities, machinery and tool design, process and quality engineering, computer-aided design and computer-aided manufacturing (CAD/CAM), robotics and industrial automation, computer-integrated manufacturing (CIM), technical sales, plant engineering, production and supervision of management processes, and productivity improvement. Graduates have a strong, broad foundation that enables them to perform well in any field which requires the application of manufacturing principles. The graduates will grow as new technologies develop and at the same time will be sensitive to the impact of technology on society. Manufacturing engineers get involved in the production of a variety of industrial and consumer goods and develop the expertise to see them through the completion.1

The four-year Electronics Engineering Technology (EET) program is a broad-based technical program. It has strong foundations in mathematics, computers, basic and engineering sciences, and has an excellent blend of theory and practice of electrical/electronics engineering principles. The curriculum is designed to train students in the fundamentals of electronics applications via hands-on experimentation in a variety of laboratory settings. Career opportunities for the graduates include positions in computer maintenance/repair, design/testing, instrumentation, telephone companies and other companies that use electronic or manufacture electronic equipment.

The students of the two programs come from diverse backgrounds with significant difference in academic and industrial experiences and different career
objectives. It is the purpose of this study to share our experience and approach in teaching the two different groups of students.

Lectures

In the lecture part of the classes, we cover the hardware components, wiring diagrams, ladder logic, and basic programming of a PLC including timers, counters and control instructions. During the teaching, we found that students have difficulty in accepting two basic concepts:

- Distinguishing between field devices, which are actual hardware, and their representation in software. It is relatively easy for EET students to follow relay logic schematics and visualize how closing a switch energizes a relay which in turn activates an output. However, it is difficult for them to look at a ladder logic diagram and realize how closing “real” switch affects the logic inside the PLC microprocessor, how software timers affect the output etc.

- Understanding the interface between the field devices and the PLC. Ladder logic diagrams are intentionally written like relay logic diagrams. A repeated question, especially among EET students, is what is the current in the PLC and how it is related to the load current.

It is easier to explain how field device signals are converted to PLC signals to an EET class since they have knowledge of digital logic and microprocessor operations.

Fig 1. Example circuit for I/O modules
We use Fig 1 to explain that when current flows in the input circuit, it will transmit a signal of “1” to the microprocessor via an opto-isolator, while absence of current will transmit a signal of “0” to the microprocessors. Based on these signals the PLC microprocessor can calculate which output will be activated using software to implement the ladder logic diagram including timers and counters. Once the calculation is complete, the PLC provides a low voltage signal, which uses triacs or other switching devices, to energize the output. 2 Similar approach was tried in a MET class. We found that the students did not have the required background to understand the theory, therefore, we decided not to mention this example in subsequent MET classes.

Fig 2 is used to explain the interface between the field devices and the ladder logic program. This figure indicates how the state (ON or OFF) of an input field device is identified (addressed) in a ladder logic program. The addressing process is independent of the specific types of PLC used or how it is used by the program to determine which output will be activated. 2 This approach is effective for students with only limited knowledge of electronics and was used successfully in both EET and MET classes.

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**Fig 2. Interface between field devices and the PLC**
Laboratory Experiments

Our lab uses SLC5/04 mounted on a board. Toggle and push button switches act as input field devices and lights act as output field devices. The switches and lights can be connected to any desired input or output port of the PLC using jumper wires. The lab assignments have been selected to reinforce the theory taught and they are built on the topics covered in class.

![Diagram](image)

(a) Input Module  (b) Output Module

Fig. 3. Field wiring for DC input and output modules

We first explain to the students how to connect the field wiring for the input and output modules (Fig. 3) and demonstrate how to use a PC to write ladder logic program and download it to the PLC. Then assignments are distributed, which are intended to familiarize students with the different ways of how control logic is described and how it can be implemented in programming as well as how it can be executed by the PLC. Some of the examples we use are:
- Sensors that are used to monitor the pressure and temperature of a chemical process in which an alarm must be activated when either the pressure or the temperature is excessive.

- Control logic described by logical gates\(^3\) (Fig. 4) (This is for EET students only).

![Logic Gates Diagram]

**Fig. 4. Control Logic described by Logic Gates**

- Relay logic schematics\(^3\) (Fig. 5).

In the assignments, we explain how to use the status indicator lights on the input and output modules to verify that the inputs are connected correctly, and how to use the processor to determine the correct outputs that should be activated.\(^4\) After these assignments are completed, additional projects are assigned to allow students to gain experience in developing programs for specific applications. One example is to design an enunciator flasher in which two internal timers form an oscillator which generates timed pulse output with a specified duration. The program is required to be able to turn ON and OFF a sequence of lights with specified delay between them. The programming is difficult to some extent, nevertheless, students are motivated when they can actually see the results of their work.
Fig. 5. Relay logic schematics

Once students gained some confidence in their ability to use PLC, they are asked to implement a process similar to the one in Fig. 6. For some students, it may be easier to write the program to implement this process than to verify it. The program is verified in such a way that all sensors are implemented by toggle or push button switches and all output devices by lights. Students have to simulate a sensor reading by turning a switch on or off and imagine that an output field device, such as a solenoid, is activated when a light comes on. It is usually easier for MET students to visualize this process since most of them work in the local industry and seen various processes in operation.
Fig. 6. A process for PLC control

An easy way to visualize how a PLC controlled process works is illustrated in Fig. 6. We provide students with a stepper motor and ask them to develop the program. The program will cause the stepper motor to move a specified number of steps or to rotate at a specified speed in certain directions and it will implement the process: when the water reaches a certain level, the pump is stopped; and it is restarted when the water drops below a specified level. In the experiment, the water pump is started manually to fill a tank. Sensors are used to demonstrate their functions in automation.

Conclusions

Students taking the PLC courses come from diverse academic backgrounds with tremendous differences in preparation. Ignoring the individual differences within each group, MET students tend to have more industrial experience but less electric and electronic knowledge, while EET students have more programming and hardware experience but less in understanding of manufacturing concepts. Therefore, there are commons things that we can share in both courses such as the pedagogy of explaining the
relay circuits, fundamentals of sensors, and electrical controls. To achieve optimal results, however, different approaches have to be taken towards elucidating the PLC hardware, installation, wiring and the writing of ladder logic programming. It is our experience that EET students may have difficulty in visualizing how real industrial processes work, however, once understood, they are able to write complicated ladder logic programs. Most MET students have some industrial experiences, it is easier for them to visualize how an actual industrial process works from the simulation of the switches and lights in the lab. Considering the facts that MET students are less prepared in electronics and two-hours shorter in class time, it is highly effective to start the MET class from very simple concepts, then to gradually advance the students to complex programming. At the same time, wiring of the system as well as verifying of PLC operations should be emphasized.

References