

Lab Exercise for INST231 course – introduction

Your team's task is to wire the basic controls for two power circuit breakers at a substation, which includes a networked PLC as a "remote terminal unit" (RTU) we will tie into our power grid's networked SCADA system during the next course (INST232). You will also prototype a circuit breaker control program for this PLC first on paper and then on your personal PLC trainer, based on a "philosophy" document describing the program's intended operation. You will be assigned to a total of two circuit breakers at one or more substations in the DMC lab room. Two substations presently exist, the north (Nooksack) station and the south (Stevens) substation. Each substation will receive power from three different generating stations, and will connect to the other substation through a single transmission line.

All documentation will be provided to you, to ensure consistency between all circuit breaker controls. Any modifications you make in the wiring will be edited in the final diagram version by your instructor.

Objective completion table:

Performance objective	Grading	1	2	3	4	Team
Breaker functional test and inspection	mastery	–	–	–	–	
Breaker installed on substation rack	mastery	–	–	–	–	
Breaker control cable terminated on TB1	mastery	–	–	–	–	
Explain PLC control philosophy document	mastery	–	–	–	–	
Prototype PLC program (<i>before programming!</i>)	mastery	–	–	–	–	
Circuit design challenge (PLC driving relay)	mastery					– – – –
Lab question: Wiring connections	proportional					– – – –
Lab question: Commissioning	proportional					– – – –
Lab question: Mental math	proportional					– – – –
Lab question: Diagnostics	proportional					– – – –

The only "proportional" scoring in this activity are the lab questions, which are answered by each student individually. A listing of potential lab questions are shown at the end of this worksheet question. The lab questions are intended to guide your labwork as much as they are intended to measure your comprehension, and as such the instructor may ask these questions of your team day by day, rather than all at once (on a single day).

It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what's already been done, what's left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!

Lab Exercise – wiring standards

Wiring for this lab exercise (INST231) consists of building all circuit breakers and then terminating the cables for those circuit breakers at their respective end-points within the substation cabinet. The rest of the wiring will be completed during the next course (INST232), including wiring to the substation PLC.

Each circuit breaker is equipped with two multi-conductor cables: one for routing current transformer (CT) signals from the breaker's CTs to a "test switch" located down near the floor of the substation cabinet, and another for routing control and status signals between the circuit breaker and various switches in the control cabinet (as well as the PLC). These two cables should be kept separate from each other as much as possible, to avoid any potential for "cross-talk" interference between them. Short jumper wires should be connected between the odd-numbered terminal pairs on the CT test switches as shown in red on the CT wiring diagram.

Wire duct arranged adjacent to the main terminal block (TB1) inside each substation cabinet serves to neatly route the control cable conductors. The sheath of each cable needs to be stripped off at some point before the cable's individual twisted-pair conductors enter the wire duct and then terminate at the proper terminals. The wire pairs themselves must be kept long enough to easily reach past the terminals they are intended to connect to (one foot extra reach is a good rule to follow), just in case any mistakes are made and a bit more cable length is needed.

Wire-tie anchors will be located inside the ducts to allow the conductors to be bound together for neatness. All wires entering a terminal block will be terminated with a *ferrule*. All wires connecting to a device screw will be terminated by either a *fork terminal* or a *ring terminal*. These compression-style ferrules and terminals bind all the loose wire strands together and makes for more reliable electrical connections. Where a wiring diagram shows a wire "daisy-chained" between different terminals, these wires will be inserted into a common compression-style ferrule or terminal.

Each of the circuit breaker cables contain unused conductor pairs, which must be left the same length as all the used pairs in that cable. These unused wire pairs will serve as "spares" in case any of the regular wire pairs happen to fail open or shorted. Place a tight wrap of tape around the tips of all these unused pairs, and lay them inside the wire duct for future use.

Professional fit and finish is important for this project, because it will not be disassembled as is the case with so many of our other projects. This project will become a permanent fixture of the Instrumentation lab, with future graduating classes using it to learn PLC programming and power system operation. Those students taking the elective INST233 ("Protective Relays") course this summer will use what you have built.

Lab Exercise – programming the system

Like wiring a control system, programming one is best done with thoughtful planning rather than a “design-as-you-build” approach. Each team will work with the instructor to develop a “prototype” PLC program, usually on a whiteboard or on paper. *Having multiple teams prototype their programs on whiteboards within the same classroom works well to foster peer review of programming, where teams analyze and critique other teams’ programming solutions!* Your prototype program should completely address the following points:

- Identify all inputs to the PLC, including tagnames
- Identify all signal outputs from the PLC, including tagnames
- Identify all major program functions (i.e. *What must this program do?*)
- Identify all internal variables necessary for these functions, giving each one a sensible tagname
- Identify all system variables necessary for these functions (e.g. real-time clock/calendar variables)

The importance of identifying and naming all relevant variables is paramount to “clean” programming. This is especially true when an HMI (Human-Machine Interface) is to be connected to the PLC, and all relevant variables must be named there as well.

After developing a “paper” prototype program, you will work with your team to write a functional PLC program in your own personal PLC, de-bugging it there with switches and lamps in place to simulate input signals and output signals, respectively. Even if your personal PLC is a different model (or manufacture) than the project PLC, this is a very helpful exercise. Furthermore, it allows you to continue program development outside of school when you do not have access to the project PLC. A recommended procedure for writing your first version of the program is as follows:

- Establish communications between PLC and personal computer (PC)
- Connect all I/O cards (modules) to the PLC and get them recognized by the processor
- Assign tagnames to all relevant variables, beginning with I/O points
- Enter a simplified version of the program, running to check for “bugs”
- Diagnose any program problems
- Add complexity to the program (e.g. additional features) and run to check for “bugs”
- Repeat last two steps as often as necessary
- Add comments to each and every line of the program, explaining how it functions

Your team’s PLC program should be well-documented, clean, and as simple as possible. All members of the team should have a hand in designing the program, and everyone *must* thoroughly understand how it works. The final program contain identical ladder-logic “code” for each circuit breaker, which means all teams must eventually come to a consensus on the final program structure.

Programming the project PLC will be done in the next course (INST232). Since this particular project uses just one PLC processor per substation, controlling multiple circuit breakers with that one PLC, I recommend each team write their final program as a “subroutine” within the main PLC program. This divides the PLC program into distinct sections, one for each circuit breaker. Since each PLC will have one combination I/O card per circuit breaker, each circuit breaker will have clearly delineated I/O points in the PLC’s memory. This means it would be advantageous to write your test program in your own PLC using subroutines as well, to become accustomed to the concept.

Common mistakes:

- Waiting too long after writing the program code to insert comments. This is best done immediately, while everything makes sense and is fresh in your memory!
- Insufficient commenting – only makes sense to the person who did the programming
- Students working on portions of the program in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!