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Protective Relay Lab Development

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Protective Relay Lab Development

Abstract

In an effort to expand The University of Maine's Electrical Engineering Technology program a protective relay lab is being developed. The lab is using donated Schweitzer Engineering Labs, Inc. (SELINC) microprocessor based protective relays. The equipment is being setup to mimic real world conditions. Further, a CMC 356 relay testing tool from Omicron USA is being used to validate operation of the relays and expose students to state of the art test equipment. The relay lab will be used as a basis for a course specific to protective relays and system design. This paper will describe the efforts put forth by faculty and students to develop the lab. It will describe some of the lab procedures. Finally, it will provide the reader with some information to develop their own relay lab.

Figure 1 – Typical Relay Lab Station

Introduction

The electric power generation and delivery industry has undergone a considerable transformation due to the introduction of microprocessor based relays. Historically, utilities required large number of electro-mechanical relays and control switches to monitor and control their systems. In addition, utilities developed protection and control schemes based on the use of electro-mechanical relays. The microprocessor based relays have gained universal acceptance by utilities. Extensive testing and evaluation of the relays has shown that these devices are reliable and do not experience drifting typical of the old mechanical-style relays. In addition, racks and rack of old relays could be replaced with a single microprocessor based relay. Finally, the microprocessor based relays provided enhanced communications allowing remote control and status indication of substations. Due to the numerous advantages of microprocessor relays, utilities have transitioned to new systems and designs.

As mentioned, protective relays have evolved from single function electro-mechanical devices to multi-function microprocessor based devices. This evolution has resulted in much greater control and protection capabilities but far more complicated devices to set up and configure. In addition, these microprocessor based devices provide opportunities for users to customize the relays by adding additional control, protection, and metering features not inherently built into the relays. Further, the relays provide communication capability greatly enhancing information exchange while reducing the need for hard wiring. In fact, the International Electrotechnical Commission (IEC) has developed IEC 61850 [3] to provide manufacturers, utilities, and system integrators guidelines and protocols to automate electrical energy transmission and distribution stations.

Due to the complexity of the protective relay designs and the importance of a highly available and reliable electric energy delivery systems, significant testing is required of these designs. Sophisticated relay test systems have been developed to ensure that the proper relay settings are used and that the relays actuate within the prescribed times based on input signals. An example is an overcurrent condition. A protective relay should not operate until the overcurrent exceeds a minimum value (pickup level) for a specified period of time (timeout). Periodic testing to ensure proper relay operation [4] is mandated of utilities by North American Electric Reliability Council (NERC). These test equipment are evolving to complex microprocessor devices that require programming to verify and automate testing. As a result, operators of the test equipment must be highly trained and knowledgeable of the relays and test equipment.

Microprocessor based protective relays provide engineering technology and applied engineering programs an opportunity to expose students to real world applications involving power system analysis and design, Boolean algebra programming, and hardware design and specification. Further, students need to be able to understand the testing methodologies required for verifying proper relay operation.

The University of Maine's Electrical Engineering Technology (EET) program recognized the need to prepare students to be able to select, configure, program, install, and test these microprocessor based relays. The EET program obtained some Schweitzer Engineering Laboratories (SEL) microprocessor based relays to provide a platform for relay programming. In addition, the EET program obtained and Omicron CMC 356 relay test and commissioning tool to verify proper relay programming and calibration.

Relay Configuration

The relays obtained by the EET program are SEL 300 series relays. These relays provide multi-function protection. In addition, the relays provide areas to customize relay operation. These relays use Boolean algebra to permit programming. Further, the relays have analog and digital I/O, push buttons, and LEDs to allow external interfacing with the relays.

Multi-function protection generally consists of monitoring currents and voltages to determine if out of tolerance conditions exists. For example, a utility would configure a relay to provide instantaneous or time overcurrent protection. It is necessary to monitor to the current so the relay must be equipped with inputs necessary to accurately convert the analog current signals to digital signals. The SEL relays used have a nominal 5amp current rating but can monitor up to 100amps. The relays also have inputs to monitor voltage (potential). This is also required to detect over and undervoltage conditions that may damage equipment. The SEL relays used have a nominal 200V rating but can be configured to identify another rated voltage.

The SEL relays also have discrete I/O. A typical required input may be the state (open or closed) of the device that energizes or deenergizes the circuits (often referred to as a circuit breaker). A typical output is a tripping signal to open the circuit breaker. There are additional discrete I/O that can be configured for other conditions as the application warrants.

These relays also have pushbuttons and LEDs to permit local operation and control. The front panels of the LEDs have pushbuttons that can be configured to issue open or close commands to the circuit breakers or other functions as required. Further, LEDs can provide state indication of the circuit breaker without requiring operators to physically verify the breaker position. The LEDs are essential if a local display device is not supplied or available.

The final key component of the SEL relays is the communications ports of the relays. These relays use EIA-485 serial ports for communication. The serial ports allow DNP3.0 communication protocols to allow remote communications.

In all cases of relay configuration, the relay must be set to enable and relay words must be assigned to identify what is being flagged. This is done by setting the relay utilizing AcSELerator Quickset. The Quickset software allows the user to configure the relay using an efficient method that is easily explained to students.

Relay Installation

The relays have numerous I/O which must be interfaced. It is impractical to have students wire directly to the relay I/O and repeated connections may damage the relay terminals. Rather, the I/O were wired to terminal blocks which provide easy access to permit wiring changes. This is also consistent with how the utility industry functions. That is, all I/O are wired to terminal blocks and field wiring is terminated onto the terminal blocks. Some of the terminal blocks include switches to permit replicating field conditions. Wiring diagrams are developed which shows the I/O and the associated terminal blocks. This also provides a schematic to facilitate future wiring modifications.

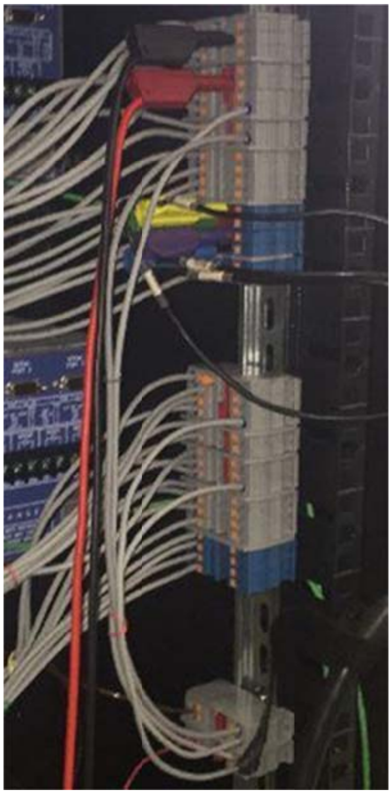

Figure 2 – Terminal Block Configuration

Some of the I/O utilize contacts that have no supplied voltage (dry contact) whereas other contacts use a voltage to enable external devices (wet contact). The relays used by the EET program have both types of contacts so a separate dc supply was procured to provide the enabling voltage. This power supply is rated for 125Vdc which is a typical voltage utilities utilize in their substations.

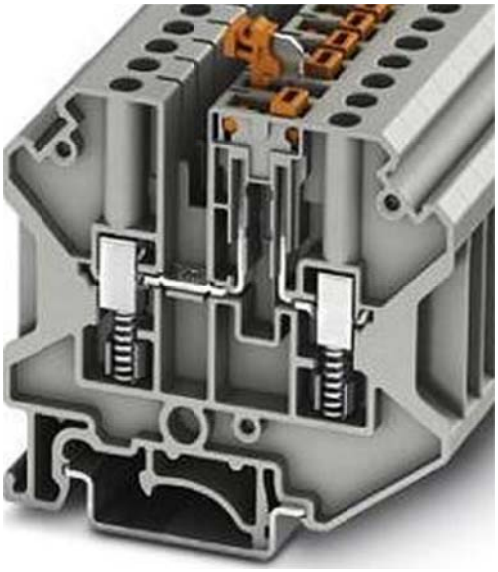

Figure 3 – Switching Type Terminal Block

Communications

At this point in the lab development, relay communications are very basic and primarily consist of relay front panel access to serial ports. Future plans are to incorporate Ethernet access for remote access to the relays. In addition, IEC 61850 will be incorporated into the lab. IEC 61850 is a standard that governs substation automation. It is unique in that it can be used to allow software control and operation within the relay. Utilities have been hesitant to use software for any control to this point.

Relay Testing and Verification

To ensure that the relay functions as programmed and configured, it is necessary to test the relay. The EET program was able to obtain an Omicron CMC 356 relay test and commissioning tool. The CMC 356 is a device capable of producing balanced, three phase voltages and currents as well as various discrete I/O. The CMC 356 is equipped with two independent three phase current outputs. This permits testing of three phase differential relays which require the six separate current signals.

The CMC 356 is customizable via software programming. The CMC 356 can be programmed thru the front panel or thru a PC connect via USB to provide calibrated analog test signals which can be used to verify the relay is set correctly and calibrated. The CMC 356 also has I/O to provide permissives or monitor change of relay state. This is particularly useful when verifying overcurrent curves. Multiple overcurrent curves are available within the relays to provide proper equipment protection. These curves are current versus time and have an inverse characteristic. That is, the higher the current the sooner the relay should issue a trip command. The curves have a characteristic from inverse to extremely inverse. The CMC 356 also has these curves programmed which allows the user to select a curve and a point on the curve and the test unit verifies that the relay operates within a specified time around the selected point.

Figure 4 – CMC 356 Front Panel

In addition to the ability to produce analog curves, the CMC 356 can be used to test programmed logic. For example, the CMC 356 can change an output state to indicate a breaker failure initiate command. The relay is wired to monitor this output and is programmed to issue a trip or block close command to multiple outputs. The CMC 356 can be configured to monitor these relay outputs to verify that the time intervals specified within the logic, as well as the logic is accurate.

Future plans for the CMC 356 include testing the relays configuration regarding IEC 61850. At the time of the writing of this report, the CMC 356 is the only device capable of testing IEC 61850. Future lab development will incorporate IEC 61850 programming and testing.

Learning Outcomes

The relay lab provides numerous educational opportunities to students. A few of these are listed below.

- Relay Programming: Students are required to develop logic diagrams to implement a specific design. The students use Boolean algebra to program the relays to mimic operation represented in the logic diagrams.
- Relay Testing: A key portion of substation protection is to field verify that the relays are properly configured, wired, and programmed. Students are exposed to the field verification process by utilizing the CMC 356 to test the relays. They develop their own test plans to verify proper functionality
- Power Systems Analysis: The entire purpose of protective relaying is to remove equipment from service when a fault occurs but to maximize system reliability by taking the least amount of equipment out of service. Students are given real world models of utility systems and then perform calculations to determine appropriate settings. These settings are then entered into the relay and tested.
- Wiring and Schematic Diagram Development: Students are required to develop documentation to show how their relays are configured. The diagrams are essential for proper setup and testing of the relays.

Experiments

Several labs were developed to allow students to demonstrate the learning outcomes. These labs are intended to develop confidence and expertise with the equipment.

Lab 1

The introductory lab teaches students how to interface with the relays using AcSELerator Quickset and the relay front panel. Students are expected to have the software properly installed on their laptops and download the relay configuration. Further, students determine the relay firmware version using the front panel buttons and display.

Lab 2

Students proceed to learning how to use the Omicron CMC 356. The CMC 356 has two methods for unit control. The most straightforward method uses the CMC 356 front panel. The front panel provides multiple menus and a touch screen to adjust the outputs. The more powerful, but more difficult to master, method uses Omicron's Test Universe. Test Universe allows the user to generate multiple states and to sequence the states to verify relay operation. If the test set is configured to monitor breaker status, the test set can indicate pass / fail for tests requiring timing verification. Students are taught both methods and develop simple tests. In addition, students connect the test set to the relays and verify proper connections.

Lab 3

In this lab, students are taught how to implement basic logic functions in the relay. The SEL relays use Boolean logic so the SEL operators for each logic function are discussed. Students implement a simple tripping and closing scheme using Boolean logic.

Lab 4

Students begin to configure the relays so that they actuate trips. This lab integrates material covered in a power systems analysis course. They are given a basic system that experiences a fault. Students select an overcurrent curve to provide proper system protection. This includes the specification of a tap and time dial. This lab is a simple introduction to coordination of overcurrent elements.

Figure 5 – Overcurrent Testing

Lab 5

This lab integrates additional relay coordination by including a directional element. A directional element provides a much greater level of coordination. Students develop coordination utilizing additional inputs. The added inputs provide polarizing quantities so that the relay can determine actual direction.

Lab 6

The final lab developed includes testing of the settings students developed. This requires also verifying the directional element. Students will develop multiple test points and verify proper operation.

Industry Support and Feedback

The utility industry has been extremely supportive of the relay lab. They have provided funds to purchase various equipment to expand the lab. Further, industry personnel have been used to teach additional items that is normally not covered. This gives students an opportunity to see how their designs can be incorporated into utility systems.

The major benefit to industry is that students are equipped with the skills necessary to be immediately productive in the utility and consulting industries. They have a great deal of familiarity and exposure to the typical activities associated with substation design and automation. Industry personnel have indicated that our students are well prepared and effective.

Future Lab Plans

Additional devices will be added to the lab to enhance student learning. One element will be the addition of a distance relay. The distance relay measures both voltage and current to determine circuit impedance. If the impedance is too low, the relay initiates a trip. Additional topics include load encroachment to account for heavy circuit loading.

Added labs will also include communications. There is an additional course being developed that will focus on relay communications and the lab will be an integral part of that course.

Finally, additional equipment manufacturers will be incorporated into the lab. It is important for students to understand some of the challenges of integrating various manufacturers into a system.

Conclusion

This paper described the relay lab developed at the University of Maine. It describes the numerous learning opportunities associated with protective relay specification, design, and testing. It identified the steps necessary to develop a lab including support equipment. Finally, it discusses future plans to expand the lab and lab capabilities.

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