Microgrid Protection Student Laboratory

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Abstract

To better prepare students for careers in the electric power industry, specifically in the discipline of power system protection, the Electrical Engineering Department at Cal Poly San Luis Obispo proposed an initiative calling for the creation of new laboratory curriculum that uses microprocessor-based relays to give students hands-on experience in the application of protection theory. This report describes the creation of a system that meets this need by providing a laboratory-scale power system that demonstrates the use of common protective relays and protection schemes. This system provides a platform for laboratory coursework using protective relays for transmission line, transformer, and induction motor protection. Within this laboratory system, one of the primary goals of the project was the integration of the SEL-311L Line Protection Relay and the SEL-710 Motor Protection Relay as part of the overall protection scheme.

Development of the project was completed successfully, producing a protection scheme that protects power transmission equipment and the induction motor in both radial and bidirectional systems. The system clears all desired fault types and abnormal operating conditions with primary protection elements for each piece of equipment, as well as time-coordinated backup protection system-wide. The completed protection system is selective, removing only the minimum amount of power equipment necessary to clear fault conditions. It is also secure, in that normal operation does not result in unnecessary trips, and reliable, in that all fault conditions are cleared even when primary protection devices do not operate. The SEL-311L and SEL-710 relays were

implemented successfully, and used to demonstrate more complex and advanced protection methods than simple overcurrent elements, such as permissive overreach transfer trips and motor thermal modeling.

Acknowledgements

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The Cal Poly Electrical Engineering Department and the Cal Poly Electric Power Institute provided continuous and generous support throughout the project, ranging from IT services to on-site SEL training courses and off-site technical seminars.

Schweitzer Engineering Laboratories graciously donated the protective relays and other SEL equipment used in this project.

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"Power flows to the one who knows how."

Megatron

Background

Power system protection is important to providers and customers alike. Providers aim to utilize the full potential of power system protection theory to implement protection schemes that are selective, secure, and reliable. Protection schemes that are selective ensure the minimum amount of equipment is removed from a power system while isolating the faulted components. Protective schemes that are secure ensure that protective equipment does not trip under normal operating conditions. Protective schemes that are reliable ensure that components are protected by more than one relay so that in the event of a primary relay failure, components within the power system are still protected though backup relays.

The power systems within this project contain the following components which require protective relays: transformers, simulated transmission lines, and induction motors. All relays used within this project were developed by Schweitzer Engineering Laboratories (SEL). Transformers utilize the SEL-387 and SEL-587 relays to protect them. Transmission lines use the SEL-311L relays for their protection. And finally, the induction motor is protected by the SEL-710 relay. These relays are coordinated within this project to maximize the selectivity, security, and reliability of the complete protection scheme.

Chapter 1: Introduction

The Microgrid Protection Student Laboratory (MPSL) is a laboratory-scale power system designed to provide Cal Poly students with hands-on experience in power system analysis and protection using microprocessor-based relays. The MPSL provides a platform for laboratory coursework in the fundamentals of fault protection, relay settings, and relay coordination. Students apply these fundamentals of protection theory to detect faults in transformers, transmission lines, and induction motors in radial and bidirectional systems using microprocessor relays and other devices produced by Schweitzer Engineering Laboratories, Inc.

The MPSL focuses on microprocessor-based relays in order to prepare students for an electric power industry that is experiencing a rapid shift towards automation and intelligent protection schemes where advanced multifunction protection and metering devices are quickly becoming the norm. In light of this shift, the MPSL gives students the opportunity to become familiar with the capabilities of these intelligent electronic devices through exercises in relay programming and logic, event reporting and analysis, fault detection and clearing, relay-operated circuit breakers, and communication-based protection schemes, all in the context of modern microprocessor relays.

The MPSL also provides a convenient platform for laboratory experiments suitable for existing courses such as EE 444, as well as a new laboratory section for EE 518. The project also lays the foundation of future work in the development of the Cal Poly Microgrid.

Chapter 2: Customer Needs, Requirements, and Specifications

2.1 Customer Needs Assessment

This project is designed to meet the needs of Cal Poly's electrical engineering department in utilizing protective relaying equipment donated by Schweitzer Engineering Laboratories, Inc. (SEL) to introduce new laboratory coursework in the power system protection curriculum. This project will give students hands-on experience in the application of protection fundamentals with microprocessor-based relays through additional laboratory experiments in existing power systems courses (EE 444), new laboratory components in graduate lecture courses (EE 518), expansion of the system in future senior projects, and provide the basis for further work in developing the planned Cal Poly Microgrid.

2.2 Requirements and Specifications

This project encompasses the first two phases of a concurrent master's thesis project, the Protective Relaying Student Laboratory (PRSL), which dictates the requirements and specifications shown in Table 2.1 and 2.2 [1].

This project is the implementation of protective relaying for the power system topologies shown in Figures 2.1-2.3. Phase I of the project is the development of a protection scheme using microprocessor-based relays and circuit breakers for the radial system shown in Fig. 2.1, and the similar radial system shown in Fig. 2.2. Phase II of the project is the protective coordination scheme for the power system topology shown in Fig. 2.3, which is the combination of the Phase I topologies into a bidirectional system with two sources feeding a shared load bus.

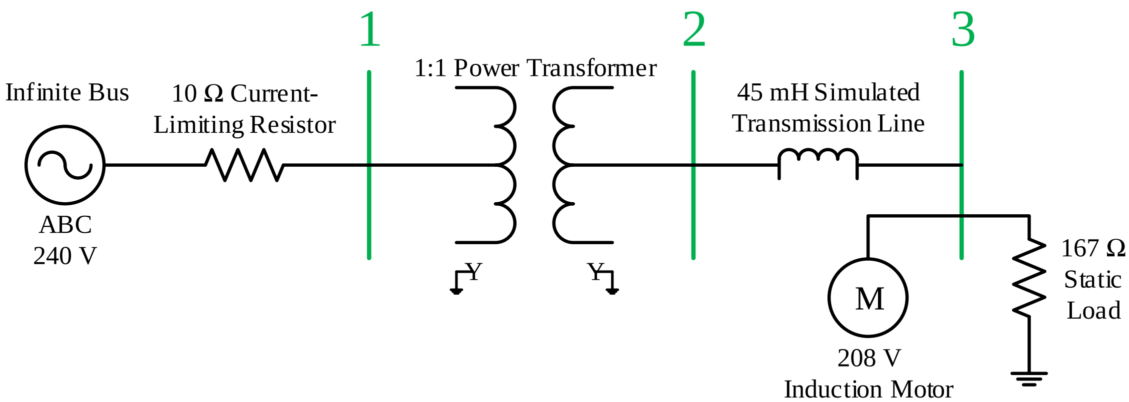

Figure 2.1: Phase I Radial System 1 Single Line Diagram

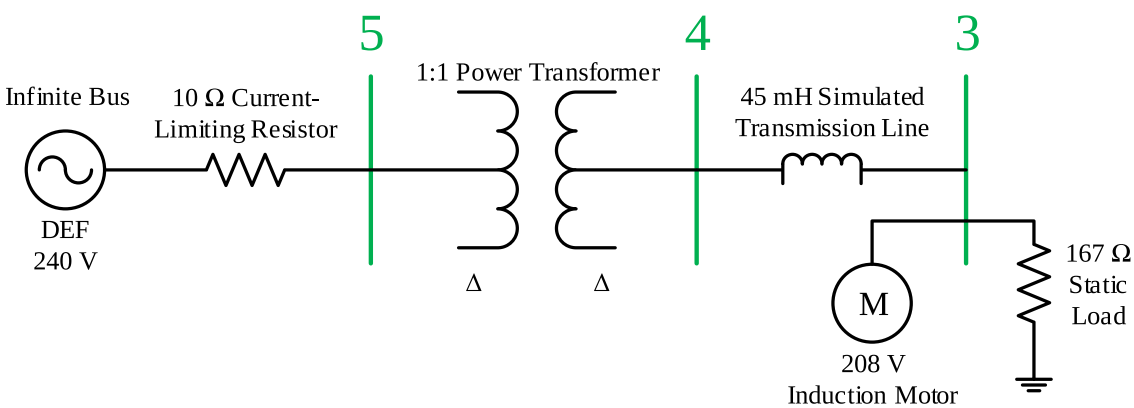

Figure 2.2: Phase I Radial System 2 Single Line Diagram

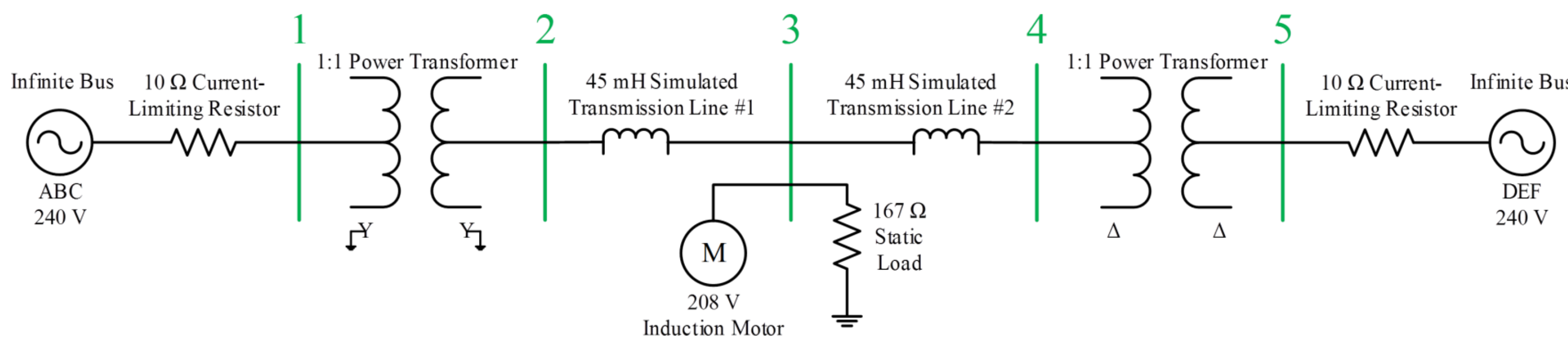

Figure 2.3: Phase II Bidirectional System Single Line Diagram

The focus of this project is to provide students experience in the application of power system protection theory, which is “the science, skill, and art of applying and setting relays or fuses, or both, to provide maximum sensitivity to faults and undesirable conditions, but to avoid their operation under all permissible or tolerable conditions” [2].

Table 2.1 describes the fault protection requirements that apply across all system topologies. Requirements 1-5 are driven by the need in the electric power industry to quickly identify clear faults to avoid equipment damage, personnel hazards, and further service interruption. In addition, accurate record keeping of fault events allows the opportunity for fault analysis, which is used to determine causes and prevent or mitigate reoccurrences in the future. In the real world, primary protective devices may not operate correctly for a variety of reasons, and Requirement 6 reflects the need for backup protection to ensure that a fault is cleared by other devices should the primary device fail. Protection equipment should not operate under normal operating conditions, leading to Requirement 7.

Table 2.2, below, shows the specifications and requirements specific to the operation and protection of an induction motor in the system. In addition to faults, the protection scheme for the motor must consider other abnormal conditions that jeopardize the safe operation of the machine, including undervoltage, locked rotor, and thermal overload.

TABLE 1.1: FAULT PROTECTION REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	**Engineering Specifications**	**Justification**
0-0	Isolate faults in a primary zone of protection within 1 s of fault inception.	Prompt termination of fault conditions avoids harming people and equipment. A protective device should operate quickly in its primary zone of protection, where it must respond before more distant protective devices react [2].
0	Coordinate secondary protection for every point in the circuit between source buses.	A minimum number of protective devices should respond to a fault condition. Backup protection helps ensure fault termination.
0	Do not operate fault protection features in response to nominal induction motor operation.	Fault protection should never interrupt nominal circuit operation [2]. Negative-sequence and residual overcurrent protection detect faults in both low- and high-magnitude currents.
0-0	Maintain chronological records of fault trip conditions using a synchronized IRIG-B timing signal.	Knowing when abnormal system conditions occurred provides clues to their causes and effects within the system. Distributing a synchronized IRIG-B timing signal ensures accurate time stamping of events.
Marketing Requirements Detect, isolate, and record bolted single-line-to-ground faults downstream of source buses. Detect, isolate, and record bolted double-line-to-ground faults downstream of source buses. Detect, isolate, and record bolted triple-line-to-ground faults downstream of source buses. Detect, isolate, and record bolted three-phase faults downstream of source buses. Detect, isolate, and record bolted line-to-line faults downstream of source buses. Coordinate primary and secondary zones of protection. Initiate protection measures only during faults, never nominal load conditions.		

TABLE 2.2: INDUCTION MOTOR PROTECTION REQUIREMENTS AND SPECIFICATIONS

Marketing Requirements	Engineering Specifications	Justification
0	Terminate power delivery to a three-phase induction motor when it continuously draws more than 2.1 A_{rms} in a bidirectional circuit.	Continuously exceeding the 2.1 A_{rms} current rating of a one-third-horsepower induction motor endangers the machine [3].
0	Isolate an induction motor when its load stops the rotor from turning for 3 s.	Continuously supplying current and voltage to an induction motor with a locked-rotor condition endangers the machine [3].
0	Isolate an induction motor when bus 3 falls below 119 V_{LL} (70% of the induction motor no-load terminal voltage in the radial system).	Ensure steady motor performance by limiting operation to a minimum of 58% of its rated 208 V_{LL} terminal voltage (reflected in motor relay settings). The radial system only supports a load already significantly below the motor's rated voltage.
0-0	Maintain chronological records of motor trip conditions using a synchronized IRIG-B timing signal.	Knowing when abnormal system conditions occurred provides clues to their causes and effects within the system. Distributing a synchronized IRIG-B timing signal ensures accurate time stamping of events.
Marketing Requirements Detect, eliminate, and record induction motor thermal overload conditions. Detect, eliminate, and record induction motor locked-rotor conditions. Detect, eliminate, and record induction motor undervoltage conditions.		

Table 2.3, below, shows the expected project deliverables associated with the project. Quarterly reports provide evidence of progress and opportunities for advisor feedback. Project demonstrations present system functionality for advisor approval. The ABET Senior Project Analysis is required by the Department for student senior project acceptance and institutional accreditation. Final report submission and acceptance represents the completion of the project.

TABLE 3.3: MPSL DELIVERABLES

Delivery Date	**Deliverable Description**
09/30/16	Preliminary Design Review
12/07/16	Fall Quarter Report
01/11/17	Demo: Radial System Coordination
02/16/17	Final Design Review
03/17/17	Winter Quarter Report
04/19/17	ABET Senior Project Analysis
04/27/17	Demo: Bidirectional System Coordination
05/26/17	Senior Project Final Draft Submission

Chapter 3: Protection Equipment and Relay Protective Elements

3.1 Protection Equipment

The MPSL is made possible by the donation of protective relaying equipment and other devices by SEL. This section provides a brief introduction to the devices used in the project. The overall protection schemes utilizing these devices for both phases of the project are found in Chapter 6, while technical discussions of each device and its implementation and performance are found in Chapters 7-10.

3.1.1 SEL-387E: Transformer Protection

The SEL-387E Current Differential and Voltage Protection Relay is designed to protect two- or three-winding power transformers and other multiterminal power equipment, such as generators [4]. The relay provides overcurrent and differential current elements, in addition to under- and overvoltage, frequency, and volts-per-hertz protection. This project uses the inverse time-overcurrent and differential elements of the relay to protect a grounded wye-wye transformer.

3.1.2 SEL-587: Transformer Protection

The SEL-587 Current Differential and Overcurrent Relay is designed to protect two-winding power transformers and other two-terminal power equipment [5]. It is similar to the 387E, but provides fewer capabilities and more limited event recording.

This project uses inverse time-overcurrent and differential elements to protect a delta-delta transformer.

3.1.3 SEL-311L: Transmission Line Protection

The SEL-311L Line Current Differential Relay is designed to protect transmission lines using differential current, distance, and directional overcurrent elements [6]. Phase I of this project uses distance and overcurrent elements to protect a simulated transmission line. Phase II uses the integrated communication features of an SEL-311L for each transmission line to implement a permissive overreaching transfer trip (POTT) scheme for the bidirectional system.

3.1.4 SEL-710: Motor Protection

The SEL-710 Motor Protection Relay is designed to protect and monitor three-phase motors. In addition to overcurrent and ground fault protection, the relay provides thermal, locked-rotor, phase-loss, and voltage-based protection [7]. This project utilizes the phase and residual overcurrent, undervoltage, thermal, and locked-rotor protection features of the relay.

3.1.5 SEL-2032: Communications Processor

The SEL-2032 Communications Processor is designed to collect, store, and distribute data to and from other networked devices for a variety of purposes including SCADA communication and substation integration [8]. This project uses the 2032 to provide a synchronized time signal to connected relays and as a port switch for remote connection to individual relays from a single computer.

3.1.6 SEL-2407: Satellite-Synchronized Clock

The SEL-2047 Satellite-Synchronized Clock is designed to use a GPS satellite time source to generate IRIG-B timing signals to time-synchronize relays and other devices [9]. This project uses the device to synchronize relays for coordination and event analysis.

3.1.7 Laboratory Circuit Breakers

The project uses relay-controlled circuit breakers to safely introduce and clear controlled fault conditions in order to demonstrate relay operation and breaker control. These breakers, shown in Figure 3.1 [10], were designed by a former Cal Poly electrical engineering student for his senior project. Contained in a metal enclosure with a Plexiglas top, the breaker is compatible with Cal Poly’s standard laboratory cables and connectors.

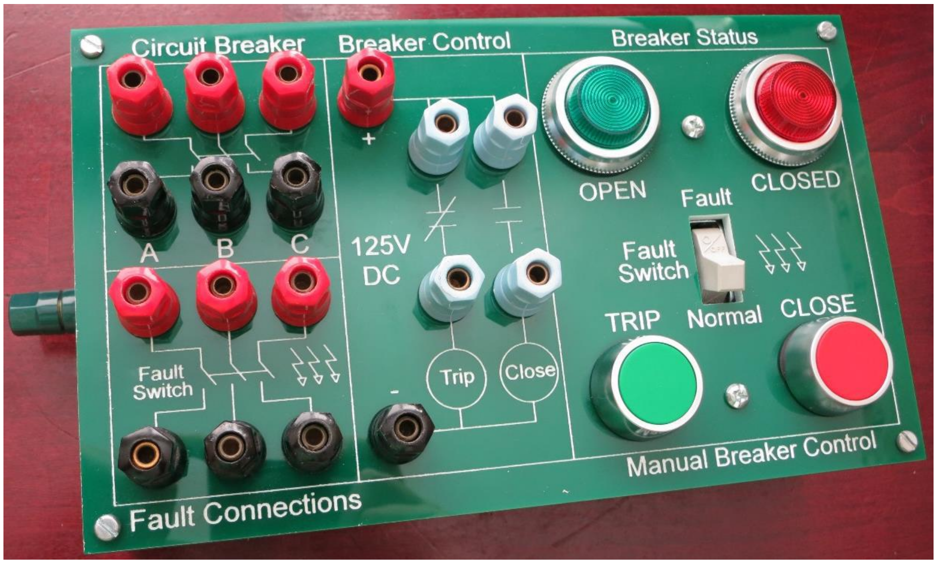

Figure 3.1: Circuit Breaker Top View

The breaker enclosure contains two modules: the circuit breaker and the fault module. The 3-phase circuit breaker module is rated for 3A continuous current and 12A momentary current per phase. The fault module uses a manual switch and 12A motor contactor to safely introduce faults, which are wired through the fault connections. When the breaker is connected to 125V DC power, red and green LEDs display breaker open/closed status, and the breaker is controllable through manual push-buttons and via relay-operated close and trip coils [10].

When the manual switch is in the “Normal” position, the fault switch is open, and the breaker operates as normal. When the switch is moved to “Fault” position, the fault switch is closed and the lines are shorted to each other or to ground, as determined by the fault connections.

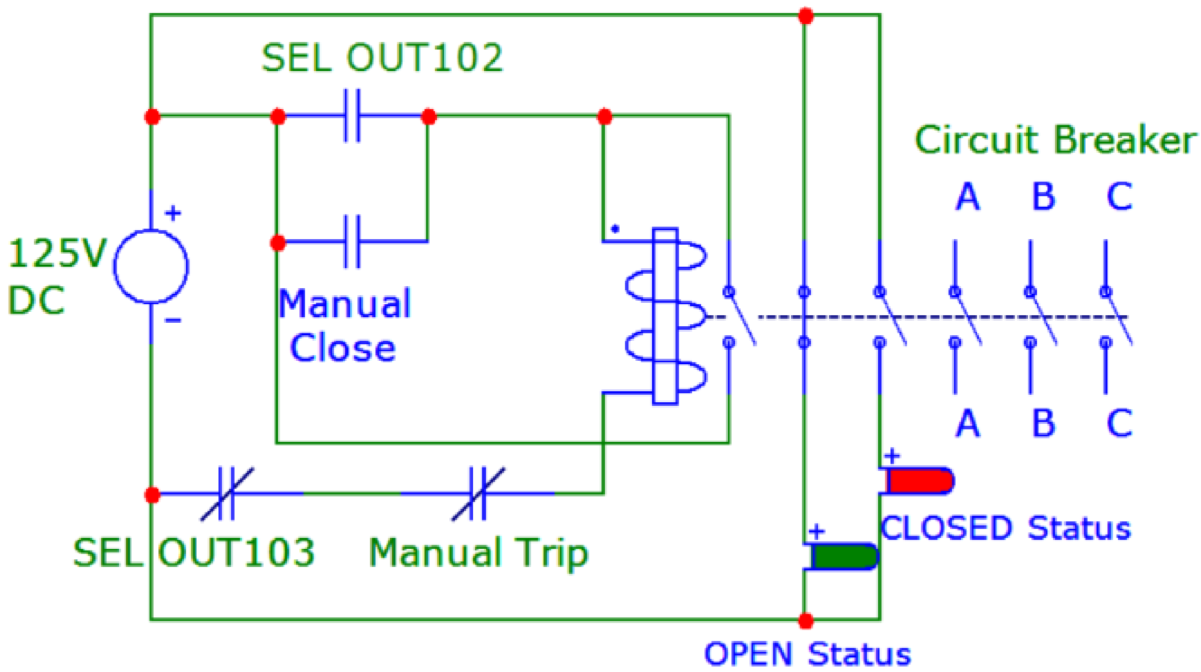

Figure 3.2: Circuit Breaker Schematic

Figure 3.2 [10] illustrates the electrical operation of the circuit breaker. SEL OUT102 and SEL OUT103 in the figure correspond to the breaker trip and close terminals in Figure 3.1, and are normally wired to the output contacts of an SEL relay. (Note that the actual output contacts used are determined by the user and may vary by relay or preference.) The breaker is normally open when first powered. In order to close the breaker, the “Trip” breaker control terminals must either be connected to relay output contacts or shorted with a jumper. Then, either the “CLOSE” pushbutton or the logic low output of relay contacts will short the normally-open contacts and close in the breaker. To open the breaker, either the “OPEN” pushbutton or a logic high output from a connected relay will apply a voltage across the normally-closed contacts, which opens the breaker.

3.2 SEL Protection Elements

The SEL protective equipment within the MPSL actively uses one or more SEL numerically identified protective elements. This section provides a brief introduction to the SEL elements used in the project and which devices they are applicable to. The technical specifications of each element and its implementation and performance are found in Chapters 7-10.

3.2.1 Element 21P: Phase Distance Protection

The phase distance element is utilized by the SEL-311L and provides protection to any faults containing at least two phases (i.e. double-line-to-ground, triple-line-to-ground, line-to-line, and three phase faults). There are four zones of protection that can be applied to a protection scheme and the theory of how they are used can be found in Section 7.3.1. The SEL relay data words associated with this element can be reviewed in Table 3.1 with an explanation of how it is used within a protective scheme trip equation [6].

TABLE 3.1: ELEMENT 21 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-311L	M1P	Zone 1 instantaneous distance protection
SEL-311L	M1PT	Zone 1 timeout for the cycle based time delayed distance protection
SEL-311L	M2P	Zone 2 instantaneous distance protection
SEL-311L	M2PT	Zone 2 timeout for the cycle based time delayed distance protection
SEL-311L	M3P	Zone 3 instantaneous distance protection
SEL-311L	M3PT	Zone 3 timeout for the cycle based time delayed distance protection
SEL-311L	M4P	Zone 4 instantaneous distance protection
SEL-311L	M4PT	Zone 4 timeout for the cycle based time delayed distance protection

3.2.2 Element 27: Undervoltage Protection

The SEL-710 relay provides two undervoltage elements that can be used for phase-to-neutral or phase-to-phase voltage-based protection, 27P1 and 27P2. Relay settings set the minimum allowed voltage as a percentage of nominal voltage and the trip time delay in seconds for each element. When the phase voltage falls below the minimum voltage for the time specified, the relay asserts the timeout relay word.

TABLE 3.2: ELEMENT 27 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-710	27P1P	Undervoltage element 1 pickup
SEL-710	27P1D	Undervoltage element 1 time delay
SEL-710	27P1T	Undervoltage element 1 timeout
SEL-710	27P2P	Undervoltage element 2 pickup
SEL-710	27P2D	Undervoltage element 2 time delay
SEL-710	27P2T	Undervoltage element 2 timeout

3.2.3 Element 49: Thermal Overload Protection

The SEL-710 relay thermal element provides protection for the motor by creating an algorithm-based thermal model of the machine, expressed as a percentage thermal capacity for rotor and stator. This thermal capacity represents an estimate of the heat in the motor that varies with time and motor current. When either thermal capacity reaches 100%, the relay trips [7].

The relay provides two methods for creating the thermal curve through the SETMETH setting. “Rating” and “Rating_1” generate curves based on motor nameplate data such as full-load amps, service factor, locked rotor amps, and hot locked rotor time. “Curve” allows the user to select one of 45 standard curves, or define a custom curve.

The MPSL uses the “Rating” method, with a hot locked rotor time of 3 seconds. 3 seconds was chosen as it allows sufficient time to demonstrate the thermal element in operation while not being long enough to damage the rotor under locked-rotor conditions. Using the nameplate data of the 1/3 hp induction motor, the 710 generates a curve similar to the example shown in Figure 3.3. When the motor current is above full load, the relay begins a countdown determined by current. Once the countdown reaches 0, the relay trips. As seen in Figure 3.3 [7], the timer is longer for lower currents, and has a minimum time equal to the hot locked rotor time.

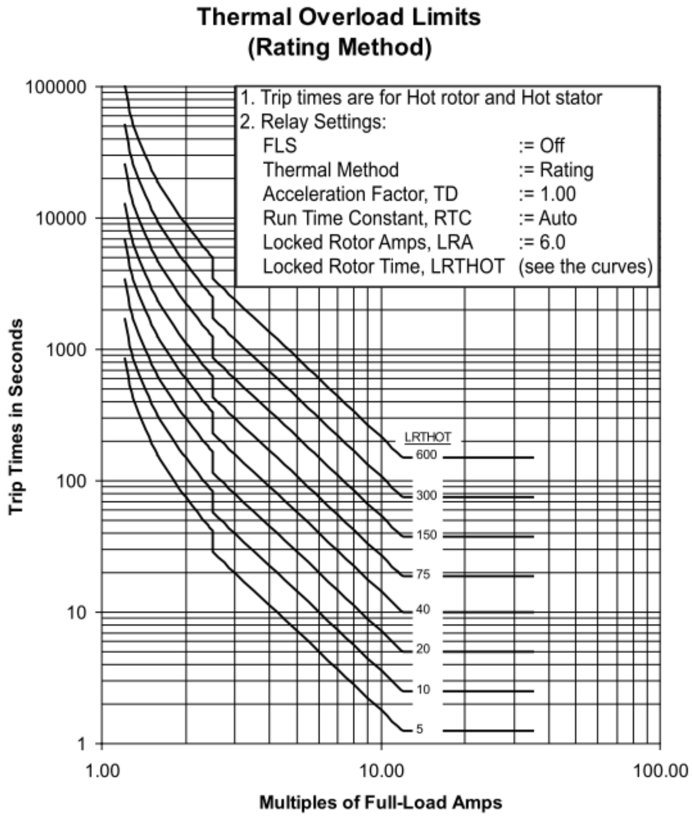

Figure 3.3: Rating Method Thermal Curve

Table 3.3, below, shows the SEL relay words associated with the 49 thermal element.

TABLE 3.3: ELEMENT 49 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-710	49A	Thermal Overload Element Pickup
SEL-710	49T_RTR	Thermal overload trip, based on rotor overload.
SEL-710	49T_STR	Thermal overload trip, based on stator overload.
SEL-710	49T	Thermal overload trip. Asserts when either 49T_RTR or 49T_STR asserts. Seen in event reports.

3.2.4 Element 50: Instantaneous/Definite-Time Overcurrent Protection

The instantaneous/definite-time overcurrent element can be utilized by the SEL-311L, SEL-387, SEL-587, and SEL-710. This element provides protection for faults base on thresholds of positive, negative, and zero sequence current. The SEL relay data words associated with this element can be reviewed in Table 3.4 with an explanation of how it is used within a protective scheme trip equation. While only the SEL-710 is actively using this element in our project, all relays with element 50 were added to Table 3.4 for completeness of understanding the element across multiple platforms [4] [5] [6] [7].

TABLE 3.4: ELEMENT 50 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-311L	50P	Instantaneous overcurrent element for positive sequence
SEL-311L	50PT	Definite-time timeout for the overcurrent element for positive sequence overcurrent
SEL-311L	50Q	Instantaneous overcurrent element for negative sequence
SEL-311L	50QT	Definite-time timeout for the overcurrent element for negative sequence overcurrent
SEL-311L	50G	Instantaneous overcurrent element for zero sequence
SEL-311L	50GT	Definite-time timeout for the overcurrent element for zero sequence overcurrent
SEL-387	50Pn1	Level 1 definite-time pickup for the overcurrent element for positive sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Pn1T	Level 1 definite-time timeout for the overcurrent timeout element for positive sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Pn2	Level 2 instantaneous overcurrent element for positive sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Pn3	Level 3 instantaneous overcurrent element for positive sequence in winding n, where n = 1,2,3, or 4

SEL-387	50Pn4	Level 4 instantaneous overcurrent element for positive sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Qn1	Level 1 definite-time pickup for the overcurrent element for negative sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Qn1T	Level 1 definite-time timeout for the overcurrent timeout element for negative sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Qn2	Level 2 instantaneous overcurrent element for negative sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Nn1	Level 1 definite-time pickup for the overcurrent element for zero sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Nn1T	Level 1 definite-time timeout for the overcurrent timeout element for zero sequence in winding n, where n = 1,2,3, or 4
SEL-387	50Nn2	Level 2 instantaneous overcurrent element for zero sequence in winding n, where n = 1,2,3, or 4
SEL-587	50Pn	Level 1 definite-time pickup for the overcurrent element for positive sequence in winding n, where n = 1 or 2
SEL-587	50PnT	Level 1 definite-time timeout for the overcurrent timeout element for positive sequence in winding n, where n = 1 or 2
SEL-587	50PnH	Level 2 instantaneous overcurrent element for positive sequence in winding n, where n = 1 or 2
SEL-587	50Qn	Definite-time pickup for the overcurrent element for negative sequence in winding n, where n = 1 or 2
SEL-587	50QnT	Definite-time timeout for the overcurrent timeout element for negative sequence in winding n, where n = 1 or 2
SEL-587	50Nn	Level 1 definite-time pickup for the overcurrent element for zero sequence in winding n, where n = 1 or 2
SEL-587	50NnT	Level 1 definite-time timeout for the overcurrent timeout element for zero sequence in winding n, where n = 1 or 2
SEL-587	50NnH	Level 2 instantaneous overcurrent element for zero sequence in winding n, where n = 1 or 2
SEL-710	50P1P	Instantaneous overcurrent element for positive sequence
SEL-710	50P1T	Definite-time timeout for the overcurrent element for positive sequence overcurrent
SEL-710	50Q1P	Instantaneous overcurrent element for negative sequence
SEL-710	50Q1T	Definite-time timeout for the overcurrent element for negative sequence overcurrent
SEL-710	50G1P	Instantaneous overcurrent element for zero sequence
SEL-710	50G1T	Definite-time timeout for the overcurrent element for zero sequence overcurrent

3.2.5 Element 51: Inverse-Time Overcurrent Protection

The inverse-time overcurrent element can be utilized by the SEL-311L, SEL-387, SEL-587, and SEL-710. This element provides protection for faults based on thresholds of positive, negative, and zero sequence current, selected curve characteristics, and time dial settings. The SEL relay data words associated with this element can be reviewed in Table 3.5 with an explanation of how it is used within a protective scheme trip equation. While only the SEL-311L, SEL-387, and SEL-587 are actively using this element in our project, all relays with element 51 were added to Table 3.5 for completeness of understanding the element across multiple platforms [4] [5] [6] [7].

TABLE 3.5: ELEMENT 51 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-311L	51P	Inverse-time overcurrent pickup element for positive sequence
SEL-311L	51PT	Inverse-time overcurrent timeout element for positive sequence overcurrent
SEL-311L	51Q	Inverse-time overcurrent pickup element for negative sequence
SEL-311L	51QT	Inverse-time overcurrent timeout element for negative sequence overcurrent
SEL-311L	51G	Inverse-time overcurrent pickup element for zero sequence
SEL-311L	51GT	Inverse-time overcurrent timeout element for zero sequence overcurrent
SEL-387	51Pn	Inverse-time overcurrent pickup element for positive sequence in winding n, where n = 1,2,3, or 4
SEL-387	51PnT	Inverse-time overcurrent timeout element for positive sequence overcurrent in winding n, where n = 1,2,3, or 4
SEL-387	51Qn	Inverse-time overcurrent pickup element for negative sequence in winding n, where n = 1,2,3, or 4
SEL-387	51QnT	Inverse-time overcurrent timeout element for negative sequence overcurrent in winding n, where n = 1,2,3, or 4

SEL-387	51Gn	Inverse-time overcurrent pickup element for zero sequence in winding n, where n = 1,2,3, or 4
SEL-387	51GnT	Inverse-time overcurrent timeout element for zero sequence overcurrent in winding n, where n = 1,2,3, or 4
SEL-587	51Pn	Inverse-time overcurrent pickup element for positive sequence in winding n, where n = 1 or 2
SEL-587	51PnT	Inverse-time overcurrent timeout element for positive sequence overcurrent in winding n, where n = 1 or 2
SEL-587	51Qn	Inverse-time overcurrent pickup element for negative sequence in winding n, where n = 1 or 2
SEL-587	51QnT	Inverse-time overcurrent timeout element for negative sequence overcurrent in winding n, where n = 1 or 2
SEL-587	51Gn	Inverse-time overcurrent pickup element for zero sequence in winding n, where n = 1 or 2
SEL-587	51GnT	Inverse-time overcurrent timeout element for zero sequence overcurrent in winding n, where n = 1 or 2
SEL-710	51P1P	Inverse-time overcurrent pickup element for positive sequence
SEL-710	51P1T	Inverse-time overcurrent timeout element for positive sequence overcurrent
SEL-710	51QP	Inverse-time overcurrent pickup element for negative sequence
SEL-710	51QT	Inverse-time overcurrent timeout element for negative sequence overcurrent
SEL-710	51G1P	Inverse-time overcurrent pickup element for zero sequence
SEL-710	51G1T	Inverse-time overcurrent timeout element for zero sequence overcurrent

3.2.6 Element 87: Differential Current Protection

The differential current element is utilized by the SEL-387 and SEL-587 within our project and provides protection to differential current faults. The theory of how differential protection is used can be found in Section 8.3.1. The SEL relay data words associated with this element can be reviewed in Table 3.6 with an explanation of how it is used within a protective scheme trip equation [4] [5].

TABLE 3.6: ELEMENT 87 SEL DATA WORDS

DEVICE	SEL DATA WORD	EXPLANATION
SEL-387	87R	Differential current element conditions met to allow trip
SEL-587	87R	Differential current element conditions met to allow trip

Chapter 4: Functional Decomposition

4.1 Decomposition Overview

Chapter 2 shows the high-level needs and system requirements for the project. This chapter shows the organizational framework of the project for both phases, in terms of inputs, outputs, and required functionality. Level 0 is at the system level, while Level 1 is at the device level. As stated in Chapter 2, the requirements for the MPSL were prescribed by the requirements for the Protective Relaying Student Laboratory [1], and as such are presented here with minor modifications.

4.2 Functional Requirements – Level 0

Figure 4.1 and Table 4.1, below, show the block diagram and functional requirements, respectively, of Phase I of the MPSL, the radial system.

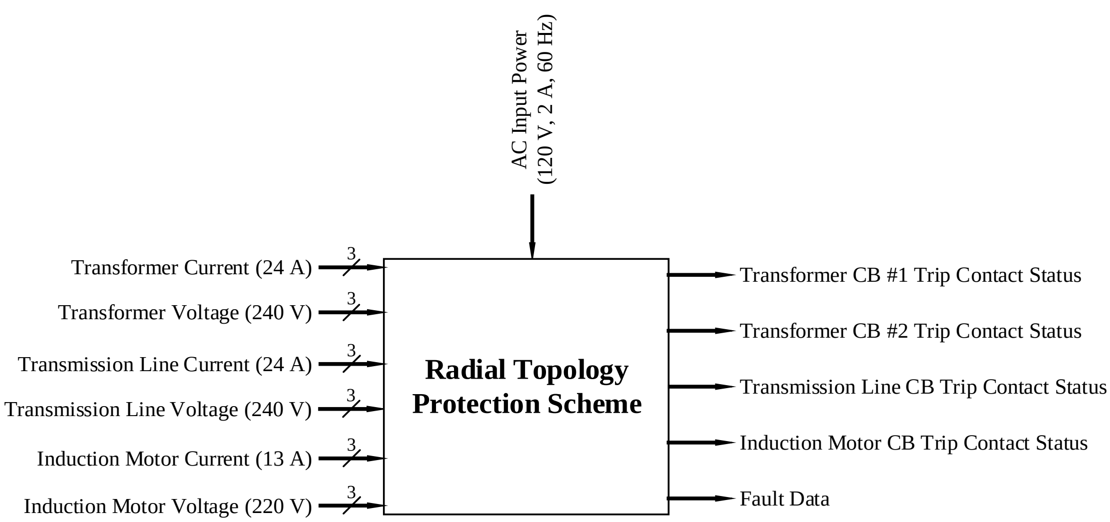

Figure 4.1: Phase I Block Diagram, Level 0

TABLE 4.1: PHASE I FUNCTIONAL REQUIREMENTS, LEVEL 0

Module	Radial Microgrid Protection Scheme
Inputs	Three-Phase Transformer Current (24 A_{rms}) Three-Phase Transformer Voltage (240 V_{rms} line-to-line) Three-Phase Transmission Line Current (24 A_{rms}) Three-Phase Transmission Line Voltage (240 V_{rms} line-to-line) Three-Phase Induction Motor Current (13 A_{rms}) Three-Phase Induction Motor Voltage (231 V_{rms} line-to-line) AC Input Power (120 V_{rms}, 2 A_{rms}, 60 Hz)
Outputs	Transformer Circuit Breaker #1 Trip Contact Status Transformer Circuit Breaker #2 Trip Contact Status Transmission Line Circuit Breaker Trip Contact Status Induction Motor Circuit Breaker Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Operate protection scheme using 120 V_{rms} input power. Detect transformer faults using voltage and current inputs from circuit. Detect transmission line faults using current inputs from circuit. Detect induction motor faults using voltage and current inputs from circuit. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events in chronological order.

Figure 4.2 and Table 4.2, below, show the block diagram and functional requirements, respectively, of Phase II of the MPSL, the bidirectional system. Additional inputs, outputs, and functionality derive from the additional devices present in the bidirectional system.

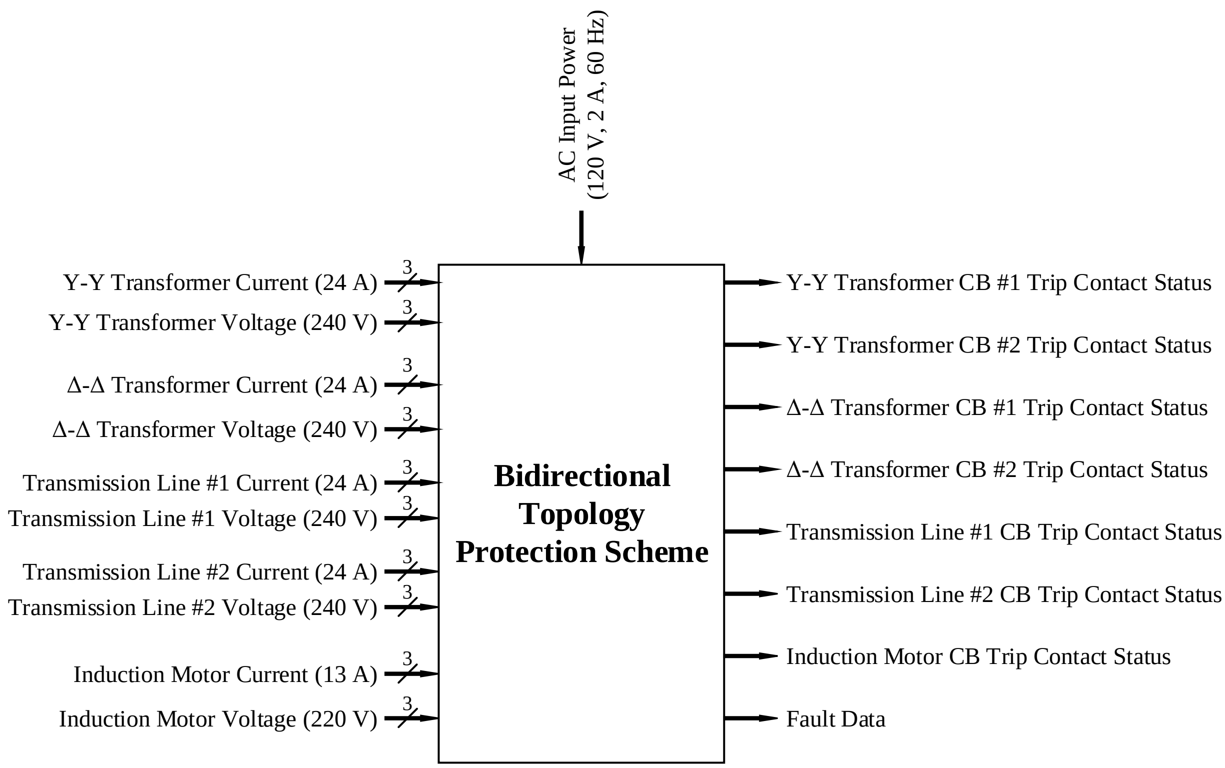

Figure 4.2: Phase II Block Diagram, Level 0

TABLE 4.2: PHASE II FUNCTIONAL REQUIREMENTS, LEVEL 0

Module	Bidirectional Microgrid Protection Scheme
Inputs	Three-Phase Y-Y Transformer Current (24 A_{rms}) Three-Phase Y-Y Transformer Voltage (240 V_{rms} line-to-line) Three-Phase Δ-Δ Transformer Current (24 A_{rms}) Three-Phase Δ-Δ Transformer Voltage (240 V_{rms} line-to-line) Three-Phase Transmission Line #1 Current (24 A_{rms}) Three-Phase Transmission Line #1 Voltage (240 V_{rms} line-to-line) Three-Phase Transmission Line #2 Current (24 A_{rms}) Three-Phase Transmission Line #2 Voltage (240 V_{rms} line-to-line) Three-Phase Induction Motor Current (13 A_{rms}) Three-Phase Induction Motor Voltage (220 V_{rms} line-to-line) AC Input Power (120 V_{rms}, 2 A_{rms}, 60 Hz)
Outputs	Y-Y Transformer Circuit Breaker #1 Trip Contact Status Y-Y Transformer Circuit Breaker #2 Trip Contact Status Δ-Δ Transformer Circuit Breaker #1 Trip Contact Status Δ-Δ Transformer Circuit Breaker #2 Trip Contact Status Transmission Line #1 Circuit Breaker Trip Contact Status Transmission Line #2 Circuit Breaker Trip Contact Status Induction Motor Circuit Breaker Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Operate protection scheme using 120 V_{rms} input power. Detect three-phase transformer faults using voltage and current inputs from circuit. Detect three-phase transmission line faults using current inputs from circuit. Detect three-phase induction motor faults using voltage and current inputs from circuit. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events in chronological order.

4.3 Functional Requirements – Level 1

The functional requirements for Level 1 describe the individual components in both Phase I and Phase II. Tables 4.3-4.8 describe functional requirements for the individual devices in the system protection scheme. Figure 4.3 shows the block diagram for the radial system, while Figure 4.4 shows the block diagram for the bidirectional system.

TABLE 4.3: SEL-311L FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	SEL-311L Line Protection Relay
Inputs	Three-Phase Transmission Line Current (24 A_{rms}) Three-Phase Transmission Line Voltage (240 V_{rms} line-to-line) AC Input Power (120 V_{rms}, 25 W, 60 Hz) [6] Demodulated IRIG-B Clock-Synchronization Signal (TTL 2.5 mA_{DC}, 2.4 V_{DC}) [8]
Outputs	Transmission Line Circuit Breaker Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Detect three-phase transmission line faults. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events chronologically to SEL-2032/3530.

TABLE 4.4: SEL-387E FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	SEL-387E Differential Relay
Inputs	Three-Phase Y-Y Transformer Current (24 A_{rms}) Three-Phase Y-Y Transformer Voltage (240 V_{rms} line-to-line) AC Input Power (120 V_{rms}, 25 W, 60 Hz) [4] Demodulated IRIG-B Clock-Synchronization Signal (TTL 2.5 mA_{DC}, 2.4 V_{DC}) [8]
Outputs	Y-Y Transformer Circuit Breaker #1 Trip Contact Status Y-Y Transformer Circuit Breaker #2 Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Detect three-phase transformer faults. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events chronologically to SEL-2032/3530.

TABLE 4.5: SEL-587 FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	SEL-587 Differential Protection Relay
Inputs	Three-Phase Δ-Δ Transformer Current (24 A_{rms}) AC Input Power (120 V_{rms}, 5.5 W, 60 Hz) [5] Demodulated IRIG-B Clock-Synchronization Signal (TTL 2.5 mA_{DC}, 2.4 V_{DC}) [8]
Outputs	Δ-Δ Transformer Circuit Breaker #1 Trip Contact Status Δ-Δ Transformer Circuit Breaker #2 Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Detect three-phase transformer faults. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events chronologically to SEL-2032/3530.

TABLE 4.6: SEL-710 FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	**SEL-710 Motor Protection Relay**
Inputs	Three-Phase Induction Motor Current (13 A_{rms}) Three-Phase Induction Motor Voltage (220 V_{rms} line-to-line) AC Input Power (120 V_{rms}, 40 VA, 60 Hz) [7] Demodulated IRIG-B Clock-Synchronization Signal (TTL 2.5 mA_{DC}, 2.4 V_{DC}) [8]
Outputs	Induction Motor Circuit Breaker Trip Contact Status Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Detect three-phase induction motor faults. Initiate circuit breaker trip signals in response to fault conditions. Collect and report abnormal system events chronologically to SEL-2032/3530.

TABLE 4.7: SEL-2032 FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	**SEL-2032 Communications Processor**
Inputs	Time-Stamped Record of Fault Data from Relays AC Input Power (120 V_{rms}, 25 W, 60 Hz) [8] Demodulated IRIG-B Clock-Synchronization Signal (TTL 3.5 V_{DC}, 120 mA_{DC}) [9]
Outputs	Demodulated IRIG-B Clock-Synchronization Signal Time-Stamped Record of Fault Data (EIA-232 Serial)
Functionality	Distribute a demodulated IRIG-B signal to synchronize all relay clocks. Collect abnormal system events from a relay, and report them chronologically to the human-machine interface.

TABLE 4.8: SEL-2407 FUNCTIONAL REQUIREMENTS, LEVEL 1

Module	**SEL-2407 Satellite-Synchronized Clock**
Inputs	AC Input Power (120 V_{rms}, 15 W + 35 VA, 60 Hz) [9]
Outputs	Demodulated an IRIG-B Clock-Synchronization Signal (TTL 3.5 V_{DC}, 120 mA_{DC}) [6]
Functionality	Send demodulated IRIG-B reference signal to SEL-2032/3530

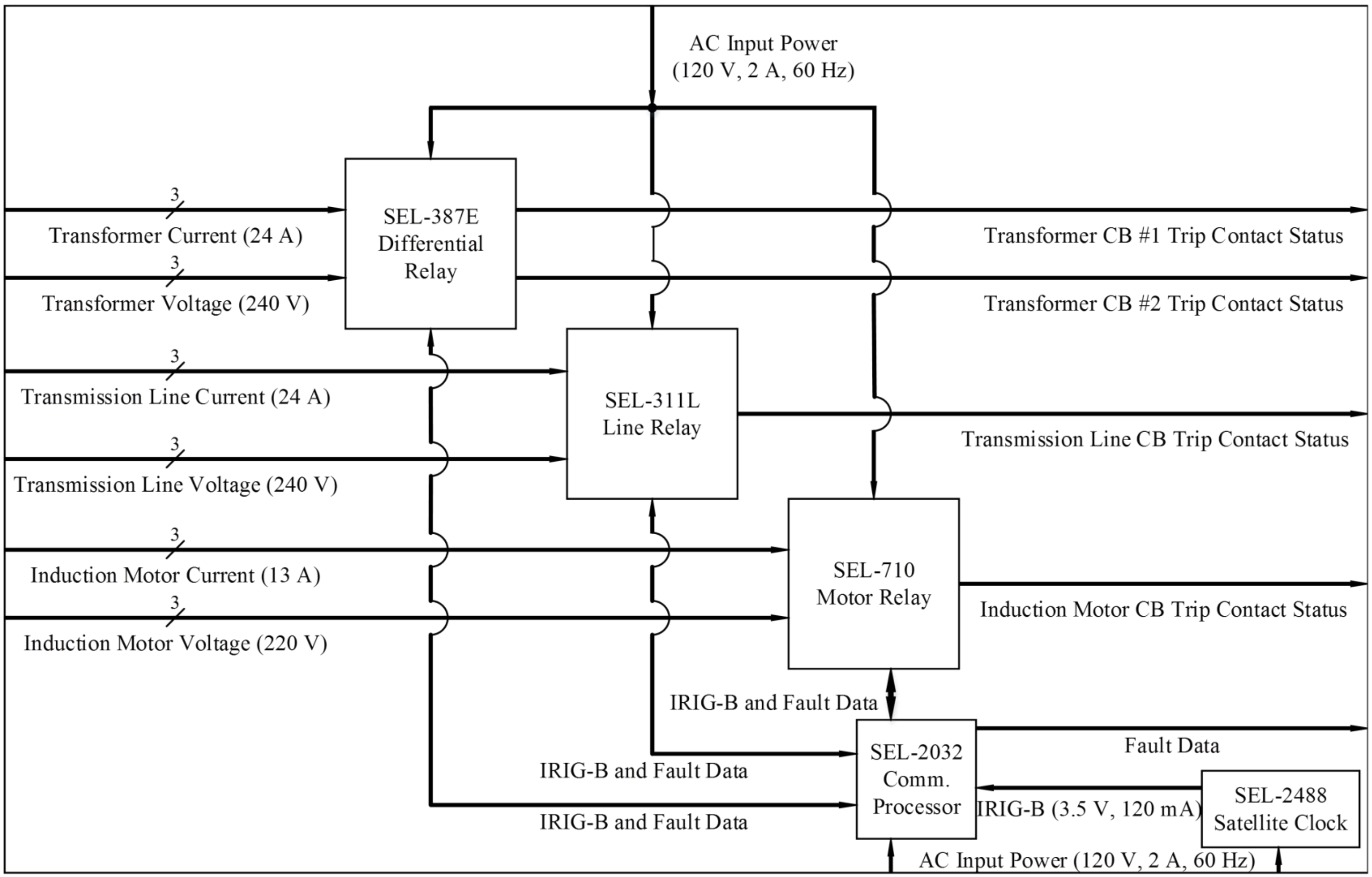

Figure 4.3: Radial System Block Diagram, Level 1

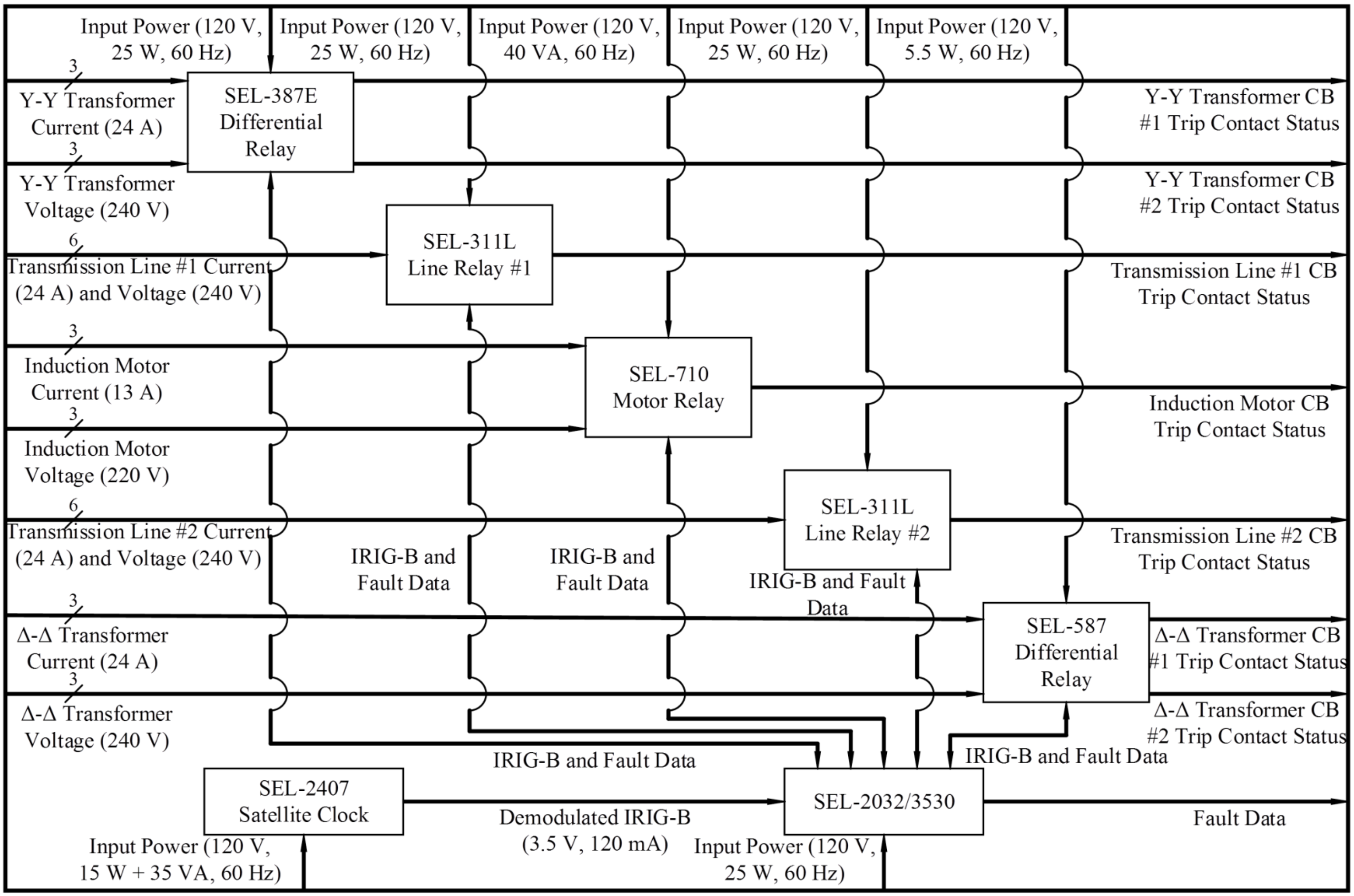

Figure 4.4 Bidirectional System Block Diagram – Level 1

Chapter 5: Project Planning

5.1 Gantt Charts for Proposed Project Timeline

The proposed timeline for the MPSL project is shown in below in Tables 5.2-5.4 and Table 5.6. Given that the MPSL consists of Phases I and II of the larger Protective Relaying Student Laboratory project, Table 5.5 (Phase III of the PRSL) is shown here for completeness.

Table 5.1 shows the coding for individual responsibilities in the overall project. This division of labor is necessary given the scope of the project and the time required for familiarization with individual protective devices. Each team member is responsible for selecting settings for one or two relays to meet the requirements laid out in Chapter 2, and the team collectively is responsible for coordination of the relays and implementation of communications processors (and eventually the SEL-3530, the automation controller, though that lies outside the scope of this project).

TABLE 5.1: KEY FOR PROPOSED PROJECT TIMELINE RESPONSIBILITIES

Symbol	Definition
(green)	Formal Progress Check with Dr. Shaban
(yellow)	Task Overseen by Ian Hellman-Wylie
(light blue)	Task Overseen by Joey Navarro
(peach)	Task Overseen by Kenan Pretzer
(purple)	Task Shared by Ian, Joey, and Kenan

Table 4: Proposed Timeline for Project Introduction

Week of	09/26/16	10/03/16	10/10/16	10/17/16	10/24/16	10/31/16	11/07/16	11/14/16	11/28/16
Prepare Proposal for Power Faculty									
Present Proposal to Power Faculty									
ID and Order Required SEL Supplies									
Requirements and Specifications	Abstract, Marketing Requirements, Engineering Specifications, Literature Search				Cost Estimate				
Sensitivity Analysis (Bidirectional System)									

Table 5.3: Proposed Timeline for Project Phase I (Radial System)

Week of	09/26/16	10/03/16	10/10/16	10/17/16	10/24/16	10/31/16	11/07/16	11/14/16	11/28/16
Component Characterization									
Choose and Test Trip Settings for SEL-311L	Iteration 1		Iteration 2						
Choose and Test Trip Settings for SEL-387	Iteration 1		Iteration 2						
Choose and Test Trip Settings for SEL-710	Iteration 1		Iteration 2						
Implement SEL-311L in Radial System									
Implement SEL-387 in Radial System									
Implement SEL-710 in Radial System									
Confirm Relay Trip Settings									
Interface SEL-2032 with SEL-311L									
Interface SEL-2032 with SEL-387									
Interface SEL-2032 with SEL-710									
Interface SEL-2032 with Entire Radial System									
Showcase Phase I Completion									

TABLE 5.4: PROPOSED TIMELINE FOR PROJECT PHASE II (BIDIRECTIONAL SYSTEM)

Week of	01/09/17	01/16/17	01/23/17	01/30/17	02/06/17
Component Characterization					
Revise and Test Trip Settings for SEL-311L	Iteration 1	Iteration 2			
Revise and Test Trip Settings for SEL-387	Iteration 1	Iteration 2			
Revise and Test Trip Settings for SEL-587	Iteration 1	Iteration 2			
Revise and Test Trip Settings for SEL-710	Iteration 1	Iteration 2			
Implement SEL-311L in Bidirectional System					
Implement SEL-387 in Bidirectional System					
Implement SEL-587 in Bidirectional System					
Implement SEL-710 in Bidirectional System					
Confirm Relay Trip Settings					
Interface SEL-2032 with Entire System					
Showcase Phase II Completion					

TABLE 5.5: PROPOSED TIMELINE FOR PROJECT PHASE III (MICROGRID)

Week of	02/13/17	02/20/17	02/27/17	03/06/17	03/13/17	03/20/17
Identify Master/Slave Communication Protocol						
Choose Slave Data to be Polled						
Interface SEL-2032 as Slave to SEL-3530						
Showcase Master/Slave Interaction in System						
Interface SEL-311L Directly to SEL-3530						
Interface SEL-387 Directly to SEL-3530						
Interface SEL-587 Directly to SEL-3530						
Interface SEL-710 Directly to SEL-3530						
Interface SEL-3530 with Entire System						
Showcase Phase III Completion						

TABLE 5.6: PROPOSED TIMELINE FOR PROJECT CONCLUSION

Week of	04/03/17	04/10/17	04/17/17	04/24/17	05/01/17	05/08/17	06/02/17
Ian Finalize Senior Project Report							
Joey Finalize Senior Project Report							
Kenan Finalize Thesis Paper							
Ian Create Senior Project Poster							
Joey Create Senior Project Poster							
Kenan Submit Thesis Paper							
Kenan Prepare Thesis Defense							
Kenan Deliver Thesis Defense							
Ian Present Senior Project							
Joey Present Senior Project							

5.2 Cost Estimate

The estimated cost for the MPSL is determined by the equipment and hardware used in the project, as well as labor costs involved in the design, construction, and testing of the system.

Table 5.7 shows the total cost associated with development of the project, including labor and required hardware. The retail costs for SEL relays, communications processor, and cables were obtained from the SEL website, as the devices used in this project were generously donated to Cal Poly, with no actual cost charged to the project. The cost estimate for labor was calculated by the following formula, found in [11], where $cost_a$ is the optimistic estimate, $cost_b$ is the most probable estimate, and $cost_c$ is the pessimistic estimate:

$$\text{Cost} = \frac{cost_a + 4 \cdot cost_b + cost_c}{6}$$

Optimistically, the project requires 15 hours of labor per week. Most probably, the project requires 24 hours per week. Pessimistically, the project requires 36 hours per week. At an hourly wage of $30, the estimated cost over the 21-week period projected in Tables 5.2-5.4 and 5.6 comes to $15,120 for 504 hours of labor.

TABLE 5.7: ESTIMATED PROJECT COSTS

Item	**Retail Unit Cost**	**Quantity**	**Cost for Project**
Circuit Breakers	$350.00	7	$2,450.00
Banana Screw-On Connectors	$0.25	100	$25.00
Gauge-12 Stranded Wire (Cost per Foot)	$0.20	500’	$100.00
Gauge-16 Stranded Wire (Cost per Foot)	$0.20	50’	$10.00
Labor (Cost per Hour)	$30.00	504	$15,120.00
SEL-311L Line Protection Relay	$5,000.00	2	$0.00
SEL-387E Differential Protection Relay	$5,780.00	1	$0.00
SEL-587 Differential Protection Relay	$2,080.00	1	$0.00
SEL-710 Motor Protection Relay	$2,500.00	1	$0.00
SEL-2032 Communications Processor	$2,840.00	1	$0.00
SEL-5030 AcSELerator QuickSet Software	$0.00	1	$0.00
SEL-C234A 10’ Serial Cable	$50.00	5	$0.00
SEL-C273A 10’ Serial Cable	$50.00	5	$250.00
Spade Crimp-On Connectors (Large)	$0.10	50	$5.00
Spade Crimp-On Connectors (Small)	$0.10	50	$5.00
Wire Ties	$1.00	30	$30.00
TOTAL			**$17,995.00**

Chapter 6: System Design

6.1 Radial System 1 Overview

The single-line diagram for Radial System 1 is shown in Figure 6.1 below. The system draws power from the 240 V, 3-phase PG&E connection present in the Energy Conversion Lab. 10 Ω current-limiting resistors prevent fault current from exceeding the 15A rating of the bench fuses. The power transformer is built into the lab bench, and is wired in a grounded wye-grounded wye configuration with a 1:1 turns ratio. The transmission line is simulated by 45 mH discrete inductors used in Cal Poly lab courses. The system load is composed of a 208V, 1/3 hp, 3-phase induction motor and a 167 Ω 3-phase resistive load. The circuit breakers described in Chapter 3 are placed in the locations shown in the single-line diagram.

Note that the current transformers (CTs) shown in the following figures are for illustrative purposes only. The actual system uses direct line connections to relay terminals, as the currents in the system are too low to require CTs.

An SEL-2032 Communications Processor acts as a port switch for the relays shown. Each relay is connected via SEL-C273 serial cable to the communications processor, while the 2032 is connected via SEL-C234A serial cable to a desktop lab computer. Using the 2032 as a port switch allows the operator to access event reports and real-time data from each relay using SEL's AcSELerator QuickSet software through the communications processor rather than running a separate cable to each relay.

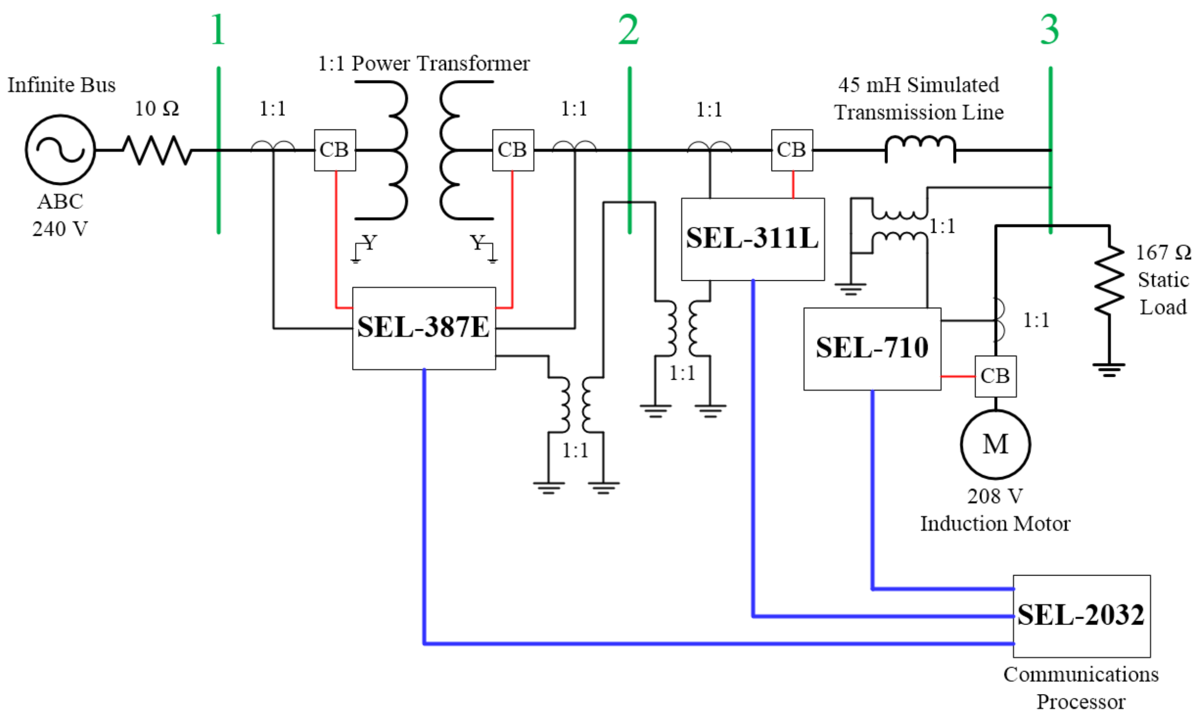

Figure 6.1: Radial System Topology, Line 1

6.2 Radial System 1 Protection

Figure 6.2, below, shows the zones of protection for the relays. Each relay provides primary protection for its zone, and backup protection for downstream zones. Redundancy is an integral part of system protection, as it ensures that relays upstream will clear a fault in the event that downstream devices fail to operate as intended. This is accomplished by setting the relay to operate as quickly as possible for faults within its primary protection zone, while using intentional delays to prevent upstream relay operation until after downstream devices have a chance to operate.

For example, consider a fault at the terminals of induction motor M, at the fault module of CB-3. The primary protection for the motor is provided by the SEL-710. The 710 should clear the fault as quickly as possible, since the fault is within the relay's primary protection zone. The SEL-311L provides backup protection for the 710, and should be set to detect the fault, but with an intentional time delay to prevent the 311L from opening CB-2 unless the 710 fails to clear it. Likewise, the SEL-387E should provide backup protection for both the 311L and the 710, but should not open breaker CB-1S until both the 311L and 710 have had a chance to clear the fault. Coordinating relays in this manner provides the necessary redundancy while limiting the amount of equipment removed from the system unnecessarily.

Table 6.1, below, lists the primary protection zones and the method of protection. Table 6.2 lists the secondary protection zones and methods for each relay.

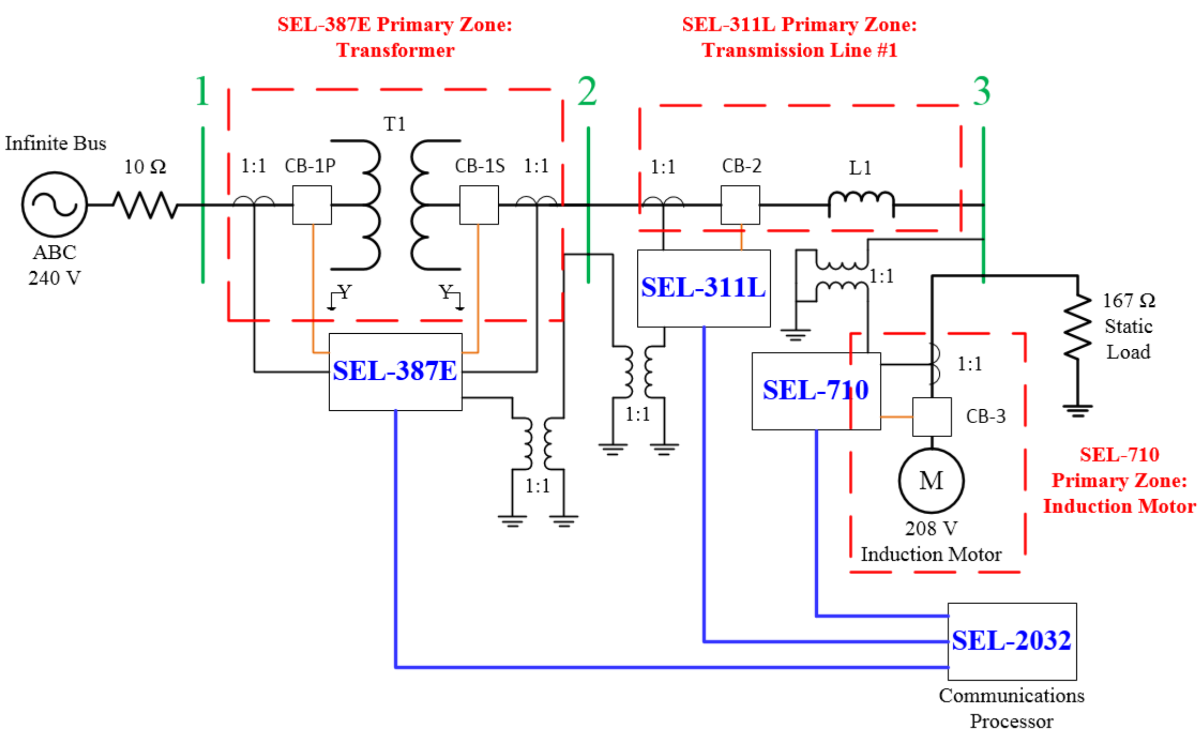

Figure 6.2: Radial System Protection Zones, Line 1

TABLE 6.1: RADIAL SYSTEM 1 PRIMARY PROTECTION ZONES AND METHODS

Relay	Primary Protection Zone	Protection Method
SEL-387E	Bus 1 – Bus 2	Instantaneous Differential
SEL-311L	Bus 2 – Bus 3	Impedance (Zones 1 and 2) and Inverse-Time Overcurrent
SEL-710	Bus 3 Induction Motor	Various*

*See Chapter 10

TABLE 6.2: RADIAL SYSTEM 1 SECONDARY PROTECTION ZONES AND METHODS

Relay	Secondary Protection Zone	Protection Method
SEL-387E	Downstream of Bus 2	Inverse-Time Overcurrent
SEL-311L	Downstream of Bus 3	Impedance (Zone 2) and Inverse-Time Overcurrent

6.3 Radial System 2 Overview and Protection

Figure 6.3, below, shows the single-line diagram for Radial System 2, which contains the second simulated transmission line, Line 2. The topology is largely identical to the first system, with the exception of the delta-connected power transformer which is protected by the SEL-587 relay. As with the first system, the circuit is protected by relays with the primary protection zones shown in Figure 6.4. Upstream relays provide backup protection for downstream faults, as before. Primary and secondary protection zones and methods are shown in Tables 6.3 and 6.4.

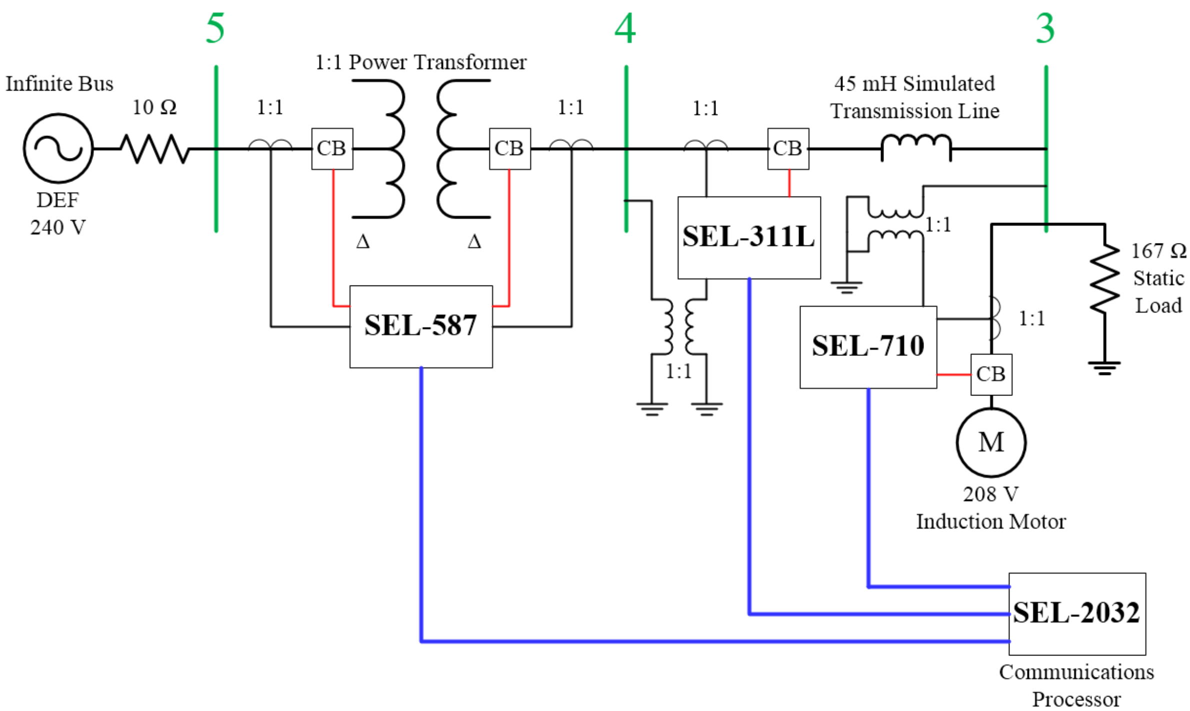

Figure 6.3: Radial System Topology, Line 2

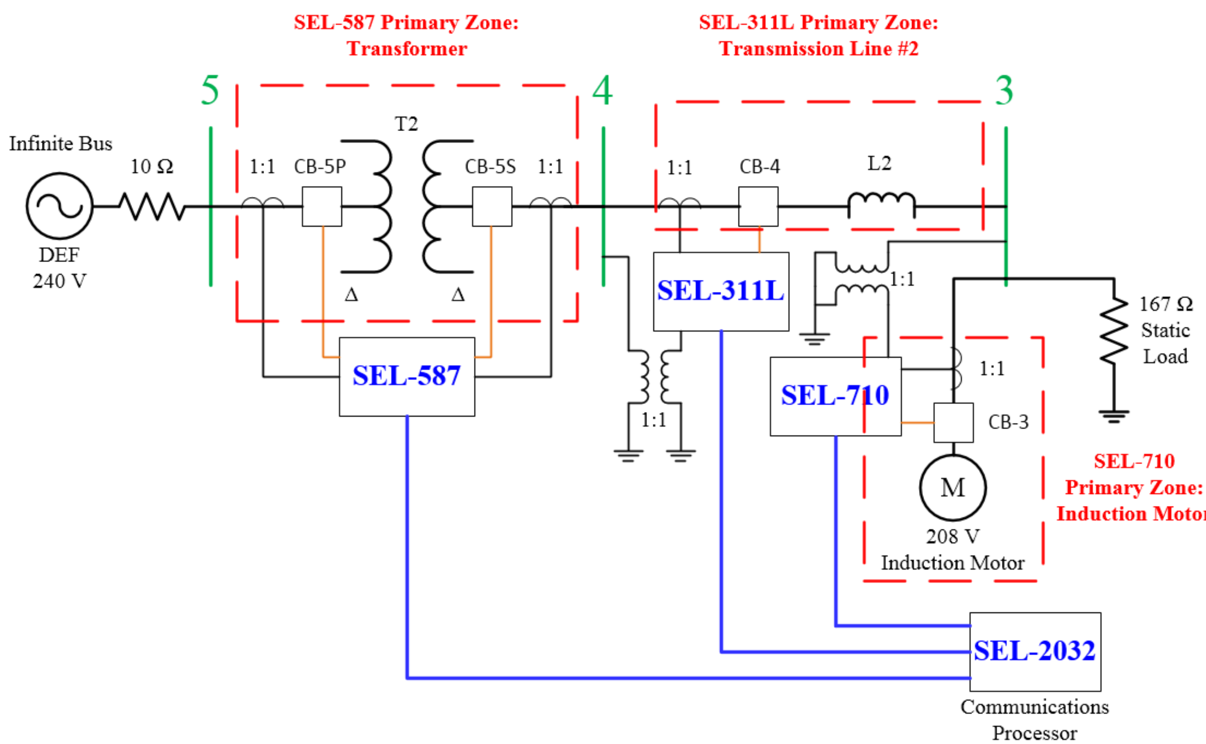

Figure 6.4: Radial System Protection Zones, Line 2

TABLE 6.3: RADIAL SYSTEM 2 PRIMARY PROTECTION ZONES AND METHODS

Relay	Primary Protection Zone	Protection Method
SEL-587	Bus 5 – Bus 4	Instantaneous Differential
SEL-311L	Bus 4 – Bus 3	Impedance (Zones 1 and 2) and Inverse-Time Overcurrent
SEL-710	Bus 3 Induction Motor	Various*

*See Chapter 10

TABLE 6.4: RADIAL SYSTEM 2 SECONDARY PROTECTION ZONES AND METHODS

Relay	Secondary Protection Zone	Protection Method
SEL-587	Downstream of Bus 4	Inverse-Time Overcurrent
SEL-311L	Downstream of Bus 3	Impedance (Zone 2) and Inverse-Time Overcurrent

6.4 Radial System Operation

Fault testing on both radial systems was done with the motor running in order to ensure the system would work for the worst case scenario. This introduced additional complexity to the system, primarily due to induction motor starting. The inrush current associated with motor starting can lead to improper operation of protective devices, which can trip for inrush current if set too sensitively. For this project, the 387E and 587 were set at reduced sensitivity to avoid tripping for inrush current. The 311L instead uses an intentional time delay to ride through inrush current. (See Appendix B and C Group 1, 2 time delay settings.)

6.5 Bidirectional System Design

Phase II of the project is the bidirectional power system shown in Figure 6.5. The bidirectional system is the two radial systems connected at the load bus, Bus 3. The system was constructed across two lab benches, where one bench contains Radial System 1, including the load bus, and the other bench contains the transformer and transmission line of Radial System 2, which is connected to the shared load bus. In this configuration, the load bus is fed by both transmission lines.

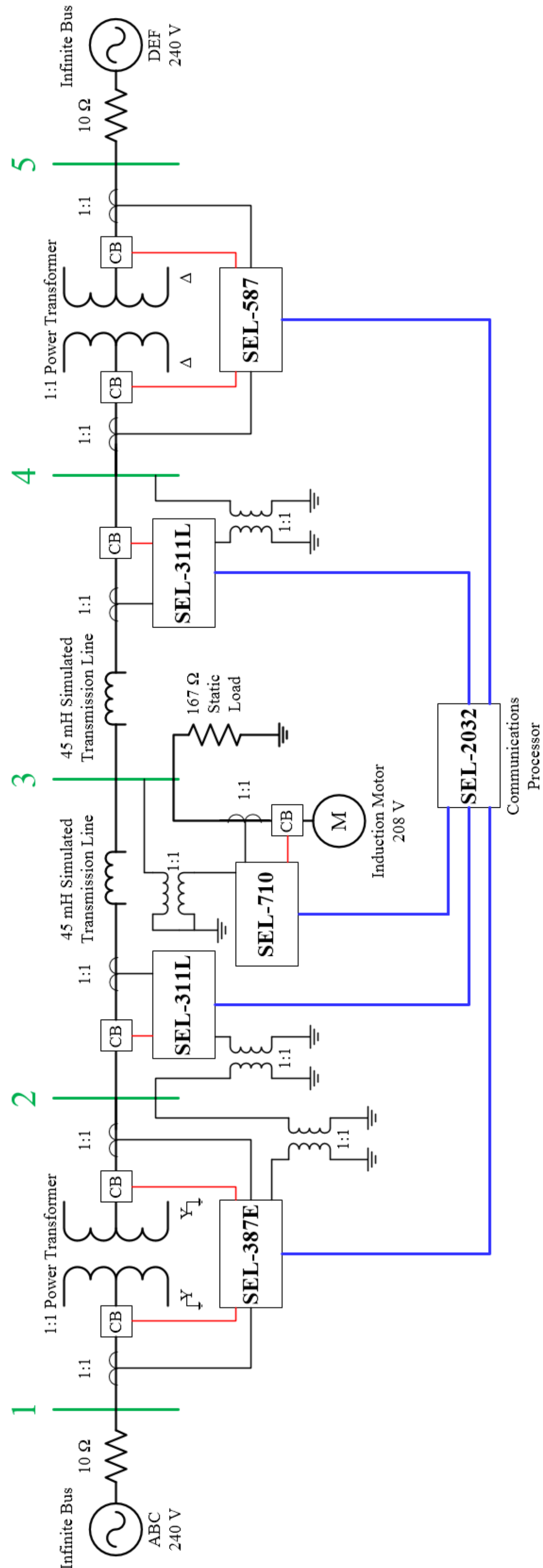

Figure 6.5: Bidirectional System Topology

6.6 Bidirectional System Protection

Primary zones of protection for each relay are shown in Figure 6.6, below. As in the radial systems, each relay provides primary protection for its own zone, while providing backup protection for downstream devices. Due to the increased complexity of the system, the protection scheme designed is necessarily more complex as a result.

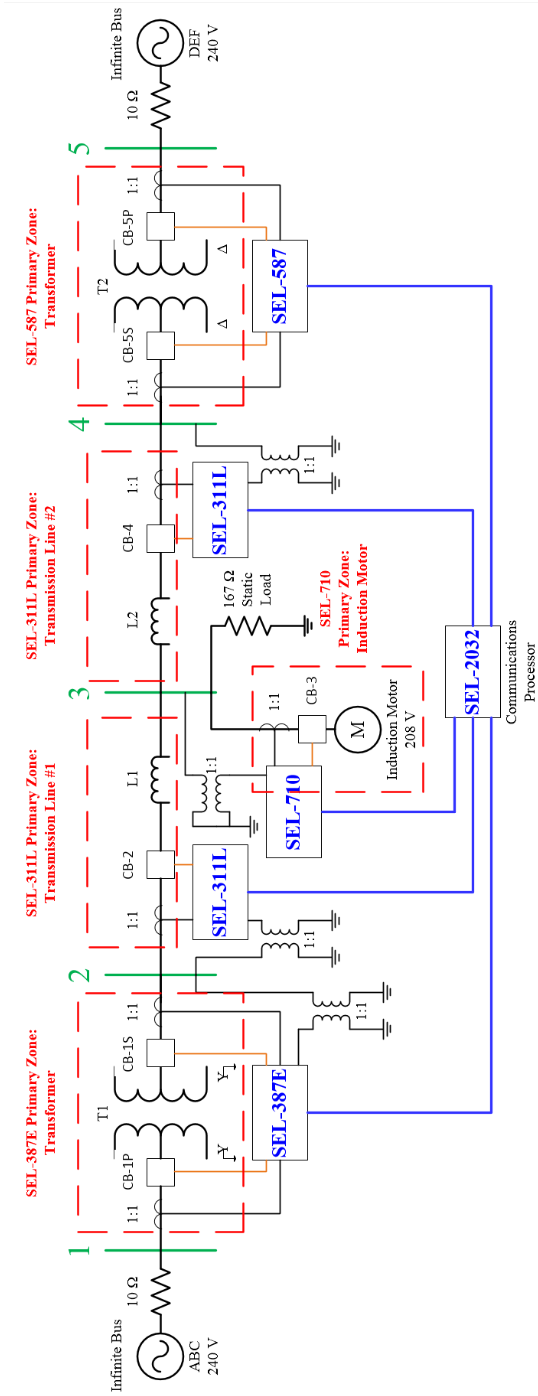

Figure 6.6: Bidirectional System Zones of Protection

Backup protection of downstream devices must now take into account that faults in the system can be fed from both sources, and adjusted accordingly. Faults at Bus 3 can be fed from source DEF when breakers on Line 1 are open, and vice-versa.

Because of this, for a fault at the motor terminals, both 311L relays provide backup protection for the lone 710, and both the 387E and the 587 provide backup for the 311Ls.

For example, consider a fault at the motor terminals, for which the 710 fails to operate (which will be the case by design for the coordination testing described in Chapter 12). Both 311Ls must operate to open breakers CB-2 and CB-4. If only one operates, the fault will still be fed from whichever line is still closed. Likewise, if the 311Ls fail to operate, both the 587 and the 387E must open their respective secondary-side breakers in order to clear the fault.

It is just as important that relays on one line do not operate unnecessarily for faults on the other. For example, a fault at Bus 2 should be cleared by the 387E opening breaker CB-1S, which clears the fault. It is not necessary, in this case, to open Line 2, which would remove power to the load bus unnecessarily. Given that only T1 is faulted, the load could still be fed via Line 2 (at a reduced voltage, of course) even when Line 1 is opened to remove the fault.

The bidirectional system can also be used to demonstrate a Permissive Overreach Transfer Trip (POTT) scheme, using the communications capabilities of the two 311L relays. Instead of two transmission lines terminating at a shared load bus, the bidirectional system can be modeled as a single transmission line (consisting of Bus 2-3-4) with a tapped load. This implementation is discussed in more detail in Chapter 7.

6.7 Bidirectional System Operation

As with the radial systems, the inrush current drawn by the induction motor during starting necessitated special precautions to prevent incorrect relay operation. The motor inrush current magnitude is sufficient to cause one or both 311L relays to trip even with programmed delay time if the system is energized improperly. For the bidirectional system, the circuit breakers must be closed “from the outside in” in order to prevent nuisance tripping on motor starting. That is, the proper sequence for system energization is:

1. Turn on source ABC and source DEF
2. Turn on 125V DC breaker supply power for both lines
3. Close CB-1P and CB-5P (transformer primary-side breakers)
4. Close CB-1S and CB-5S (transformer secondary-side breakers)
5. Close CB-2 and CB-4 (transmission line breakers)
6. Close CB-3 (motor breaker)

This sequence ensures that inrush current is not supplied by only one transmission line, which causes the 311L on that line to operate for a non-fault condition. Note that this mimics basic practice in industry, where there are specific procedures for bringing systems or portions of systems online.

Chapter 7: SEL-311L Protection

7.1 SEL-311L Introduction

The SEL-311L provides inverse-time overcurrent, impedance and permissive overreaching transfer tripping (POTT) protection to the MPSL. The SEL-311L is designed to protect transmission lines which are modeled with inductors within the MPSL. The radial system topology allows for the characterization of the inverse-time overcurrent and impedance protection elements while the bidirectional system topology allows the characterizing of the POTT protection element. This chapter gives a technical overview of each element and the element's characterization of clearing various faults.

7.2 SEL-311L Inverse-Time Overcurrent Protection

7.2.1 Overview

This section characterizes the inverse-time overcurrent protection of the SEL-311L through the detection and clearing of various faults. Phase, negative sequence, and residual ground inverse-time overcurrent protection are all enabled within the MPSL. Inverse-time overcurrent protection is primarily based off of the selection of pickup current values, curve selection, and time dial settings. The phase pickup current value 51PP setting is compared to the maximum of the phase current I_{ABC}. The negative sequence pickup current value 51QP setting is compared to the negative sequence current $3I_2$, which can be calculated $3I_2 = I_A + a^2 \bullet I_C + a \bullet I_B$ (ACB rotation). The residual ground pickup current value 51GP setting is compared to the residual ground current I_G, which can be calculated $I_G = 3I_0 = I_A + I_B + I_C$. The curve selection on all relays using an inverse-time overcurrent protection element was standardized in the MPSL to curve U1. Curve U1, as seen in Figure 7.1, is the U. S. Moderately Inverse Curve which conforms to IEEE C37.112-1996. Lastly, a time dial setting is selected to choose the location of the curve affecting the response time of the relay. Smaller time dial settings correlate to quicker response times, while the inverse is true for larger time dial settings. Since the SEL-311L is closest to the load in both of our system topologies, a low time dial setting is chosen for its operation.

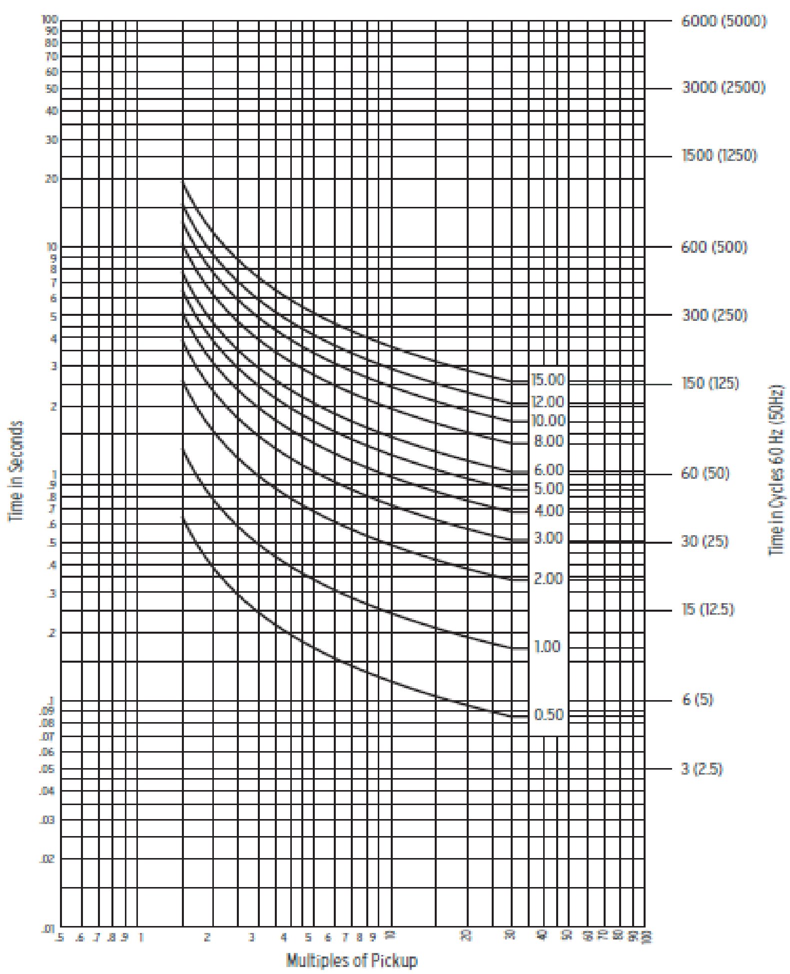

Figure 7.1: U. S. Moderately Inverse Curve U1

7.2.2 Single-Line-to-Ground Faults

Single-Line-to-Ground faults are detected by the negative sequence overcurrent element 51Q. The 51Q element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.5 and the multiples of pickup current (currently set to 0.25) detected by the relay.

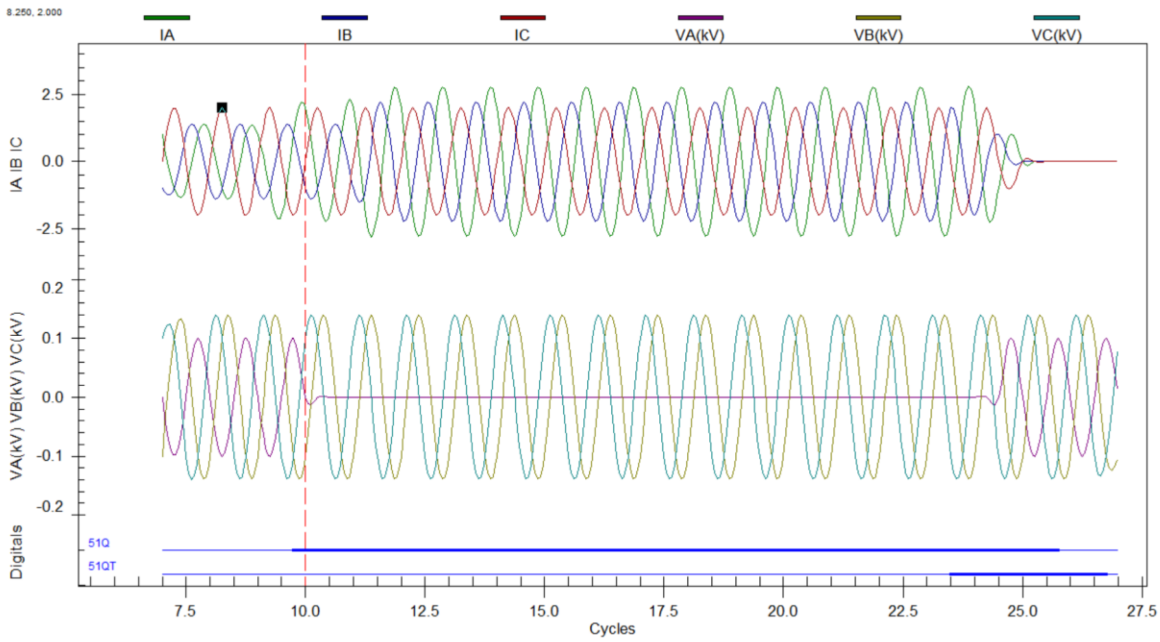

Figure 7.2: Inverse-Time Overcurrent Isolated Single-Line-to-Ground Fault

The relay detects the fault with 51Q ~10 cycles into the report seen in Figure 7.2 and clears it after ~13.5 cycles later once the timeout signal 51QT asserts.

7.2.3 Double-Line-to-Ground Faults

Double-Line-to-Ground faults are also detected and cleared with the 51Q element described above. The relay detects the fault ~9.8 cycles into the report, as seen in Figure 7.3, and clears it within ~5 cycles once the timeout signal 51QT asserts. The quicker response time when compared to the Single-Line-to-Ground fault is caused by the larger fault current generated.

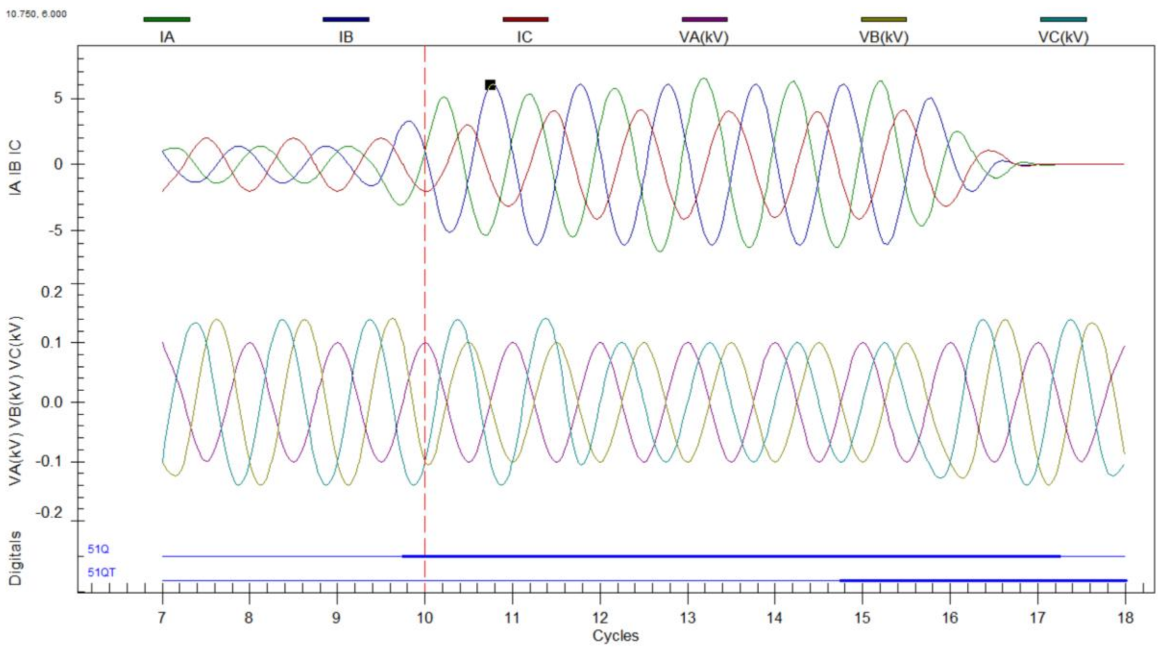

Figure 7.3: Inverse-Time Overcurrent Isolated Double-Line-to-Ground Fault

7.2.4 Triple-Line-to-Ground Faults

Triple-Line-to-Ground faults are detected by the phase overcurrent element 51P. The 51P element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.5 and multiples of the pickup current (currently set to 4.5) detected by the relay.

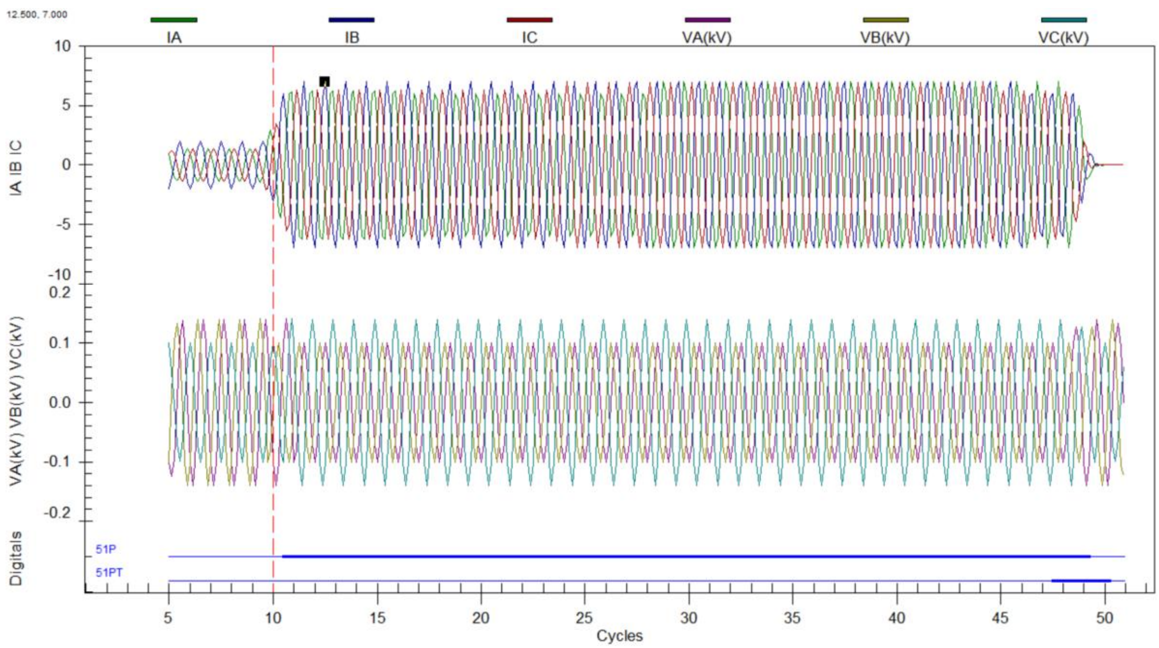

Figure 7.4: Inverse-Time Overcurrent Isolated Triple-Line-to-Ground Fault

The relay detects the fault with the 51P element ~10 cycles into the report, as seen in Figure 7.4, and the relay clears the fault within ~37.5 cycles once the timeout signal 51PT asserts. The slow response time here is due to the fault current being ~1.6 times greater than the phase pickup current of 4.5A.

7.2.5 Line-to-Line Faults

Line-to-Line faults are cleared with the 51Q element described above. The relay detects the fault with the 51Q element ~9.8 cycles into the report, as seen in Figure 7.5, and the relay clears the fault within ~5 cycles once the timeout signal 51QT asserts.

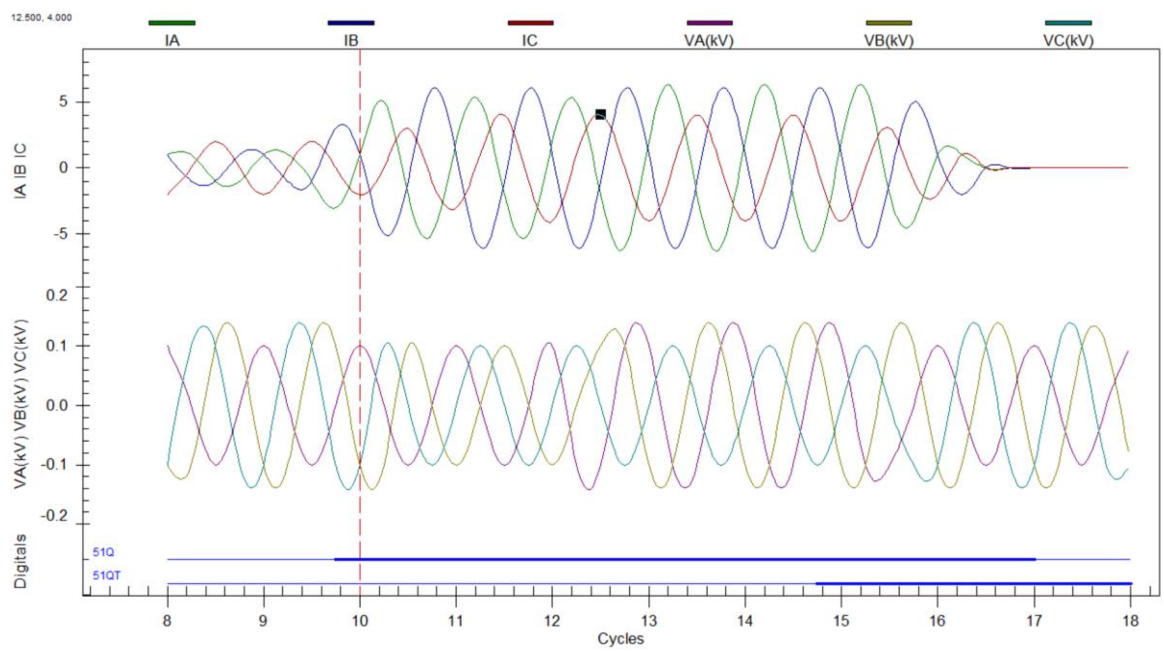

Figure 7.5: Inverse-Time Overcurrent Isolated Line-to-Line Fault

7.2.6 Three Phase Faults

Three Phase are also detected and cleared with the 51P element described above. The relay detects the fault ~10 cycles into the report, as seen in Figure 7.6, and clears it within ~38 cycles once the timeout signal 51PT asserts. The slow response time here is similar to the Triple-Line-to-Ground fault with the fault current being ~1.6 times greater than the phase pickup current of 4.5A. This fault condition is nearly identical to the Triple-Line-to-Ground fault due to the balanced system.

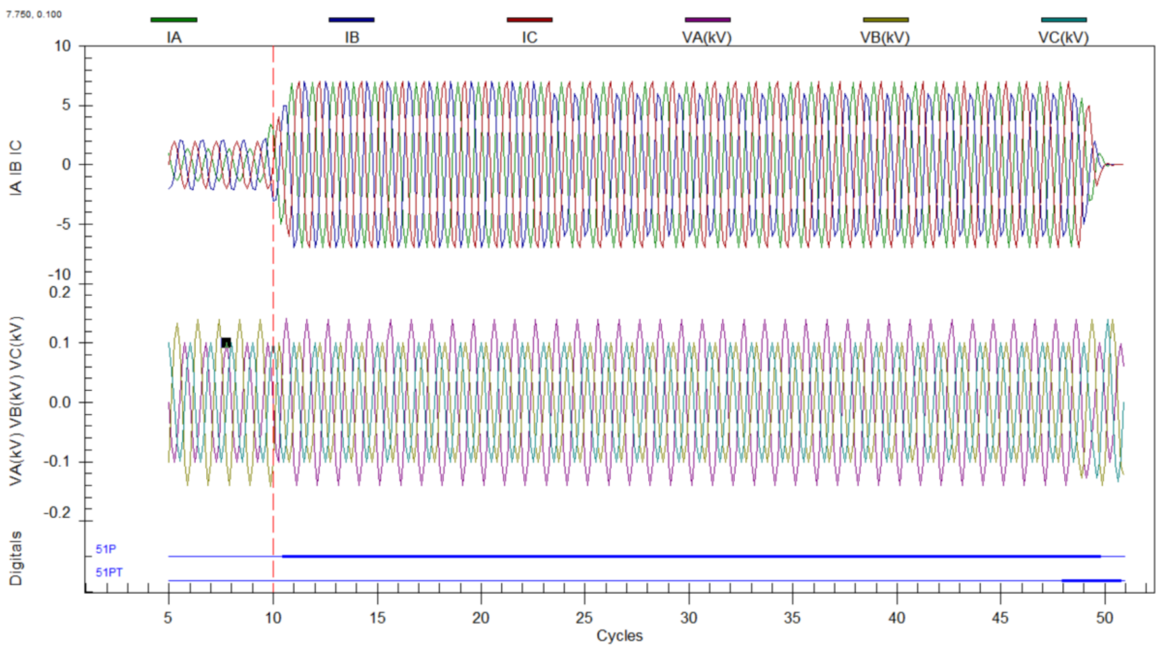

Figure 7.6: Inverse-Time Overcurrent Isolated Three Phase Fault

7.3 SEL-311L Phase Distance Protection

7.3.1 Overview

The phase distance protection is utilized in the radial system topology and the basis of the POTT scheme, described in Section 7.4, used in the bidirectional system topology. The SEL-311L is capable of using four zones of protection where zones 1 and 2 are only forward looking and zones 3 and 4 are user defined forward or reverse looking. In the MPSL, we use zone 1 with an instantaneous trip reaching ~85% of the line and zone 2 with a time delayed trip reaching ~120% of the line as seen in Figure 7.7. The zone 2 time delay is dictated by our system's load to ensure we allow the inrush current to bypass without causing a trip. The use of phase distance protection provides only protection to faults containing at least two phases (i.e. double-line-to-ground, triple-line-to-ground, line-to-line, and three phase faults).

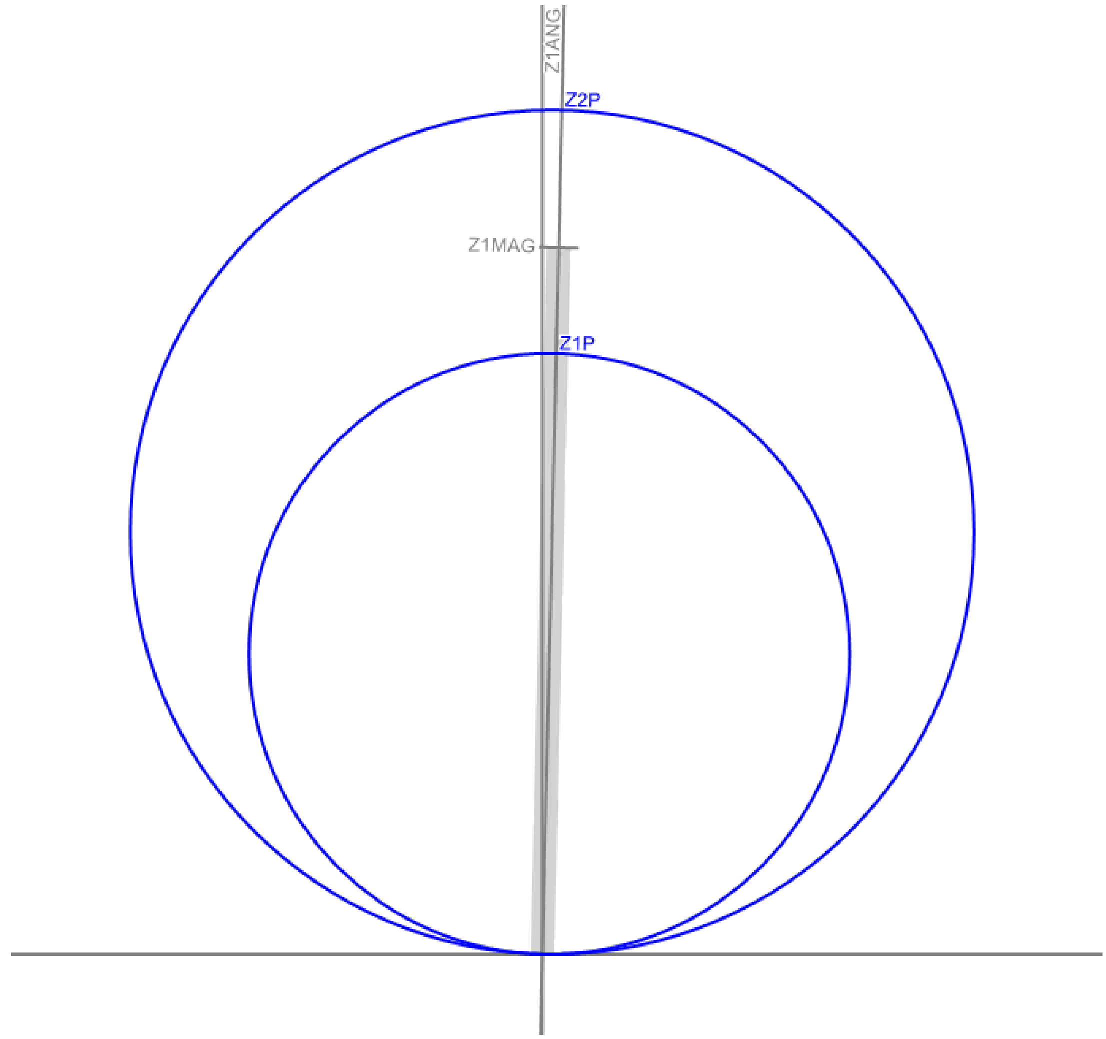

Figure 7.7: Actual Distance Relay Zones of Protection for Radial System 1

In all of the MPSL system topologies transmission lines are simulated by the use of inductors. To characterize transmission lines, the SEL-311L settings require the user to input the impedance magnitude (Z1MAG) and impedance angle (Z1ANG) of the transmission line. Industry standards would be to look up the transmission line used in a table to obtain both resistance and inductance per unit of distance to calculate these values. Since we were not afforded this opportunity we measured the resistance of the inductors with a multimeter and inductance with a bridge then used these values to calculate the impedance of our simulated transmission line in polar form.

The theory of distance protection can be illustrated with Figure 7.8 displaying different locations within the R-X plane. The red circle illustrates a zone of protection and the point outside of this zone is where an unfaulted load resides allowing for normal system operation. The point on the zone line is a balance point and once the point crosses inside the boundary of the zone it reaches a fault condition allowing the operation of a circuit breaker to trip [6].

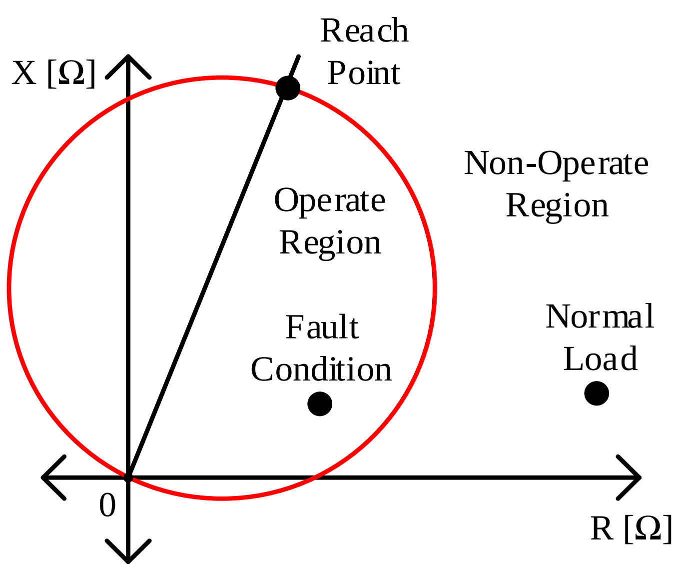

Figure 7.8: Typical Distance Protection Characteristic

7.3.2 Double-Line-to-Ground Faults

This Double-Line-to-Ground fault consists of phases A and B which correlates to the MAB2 signal that asserted ~11 cycles into the report, seen in Figure 7.9, which correlates to a phase distance fault of phases A and B in zone 2 which has a time delay associated with it. The timeout for this fault occurs ~5 cycles after detection which trips the circuit breaker.

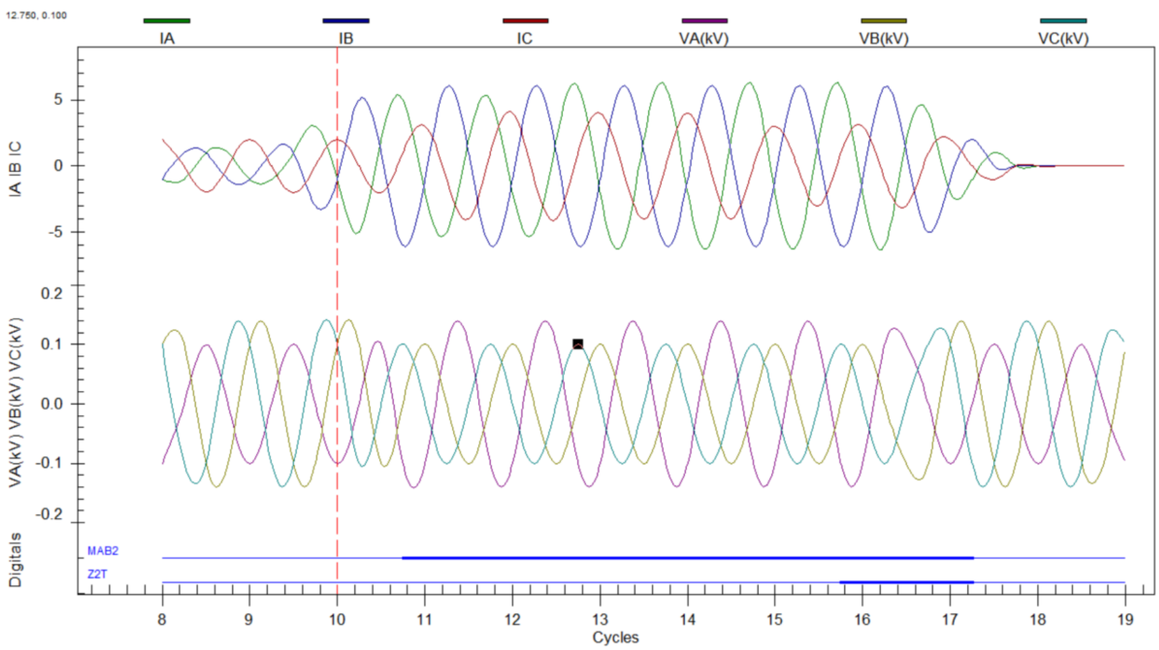

Figure 7.9: Phase Distance Isolated Double-Line-to-Ground Fault

7.3.3 Triple-Line-to-Ground Faults

This Triple-Line-to-Ground fault consists of all three phases which correlates to all three phase to phase distance words asserting (MAB2, MBC2, and MCA2) that asserted ~11 cycles into the report, seen in Figure 7.10, which correlates to a phase distance fault in zone 2 which has a time delay associated with it. The timeout for this fault occurs ~4.5 cycles after detection which trips the circuit breaker.

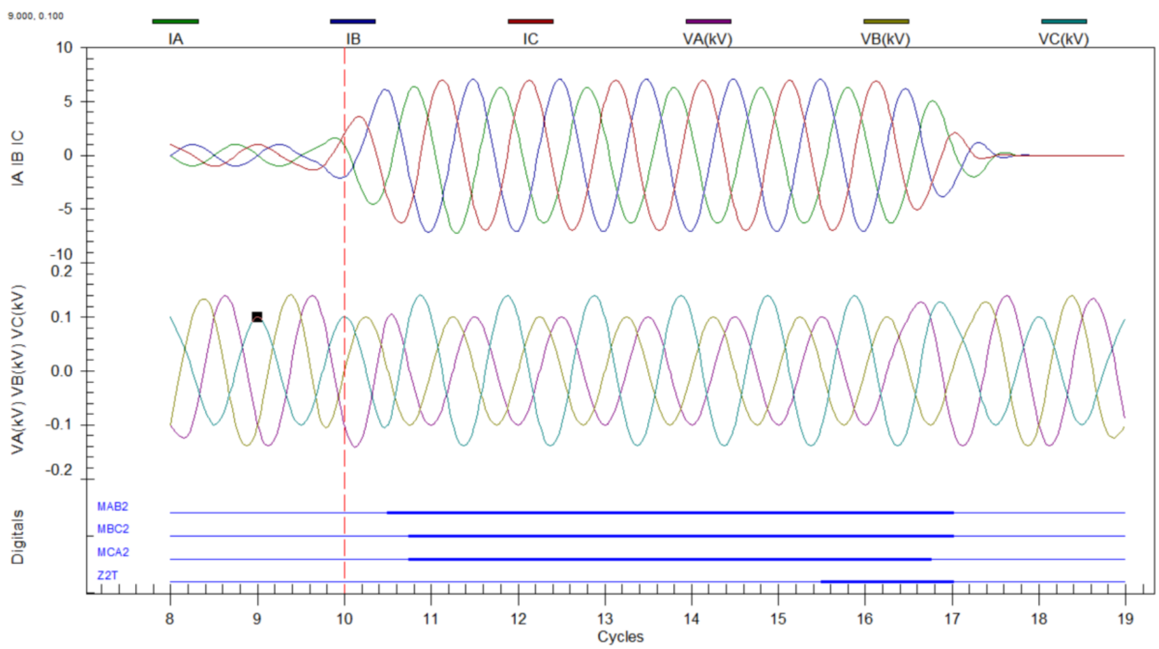

Figure 7.10: Phase Distance Isolated Triple-Line-to-Ground Fault

7.3.4 Line-to-Line Faults

This Line-to-Line fault consists of phases A and B which correlates to the MAB2 signal that asserted ~10 cycles into the report, seen in Figure 7.11, which correlates to a phase distance fault of phases A and B in zone 2 which has a time delay associated with it. The timeout for this fault occurs ~5 cycles after detection which trips the circuit breaker.

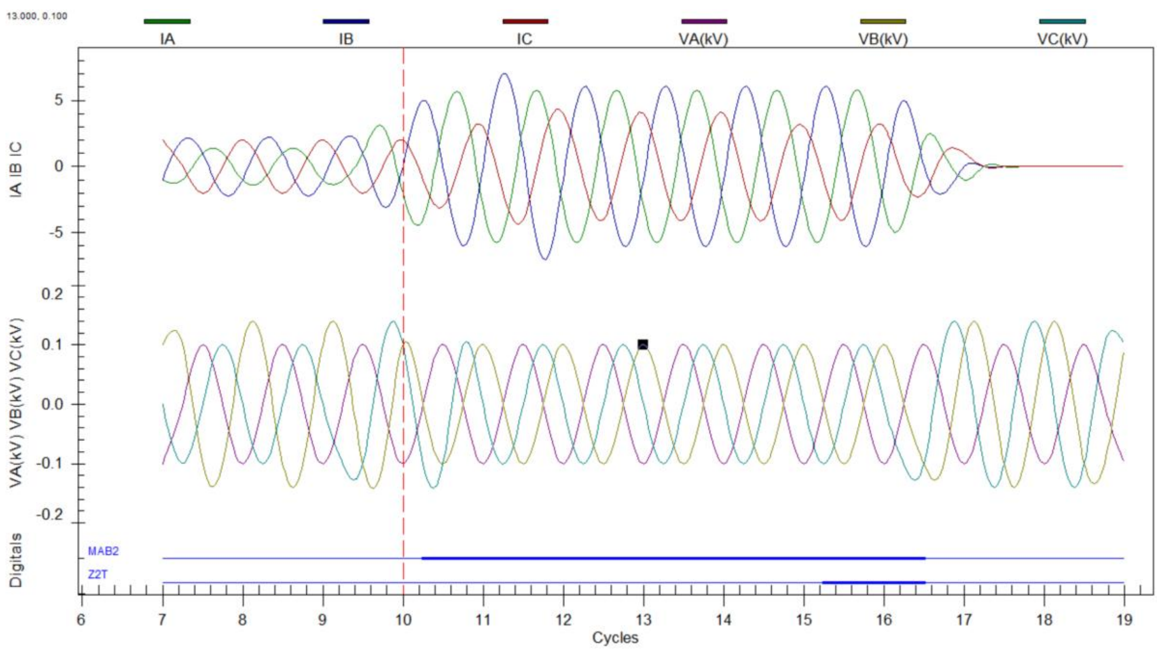

Figure 7.11: Phase Distance Isolated Line-to-Line Fault

7.3.5 Three Phase Faults

This Three Phase fault consists of all three phases which correlates to all three phase to phase distance words asserting (MAB2, MBC2, and MCA2) that asserted ~11 cycles into the report, seen in Figure 7.12, which correlates to a phase distance fault in zone 2 which has a time delay associated with it. The timeout for this fault occurs ~4.5 cycles after detection which trips the circuit breaker.

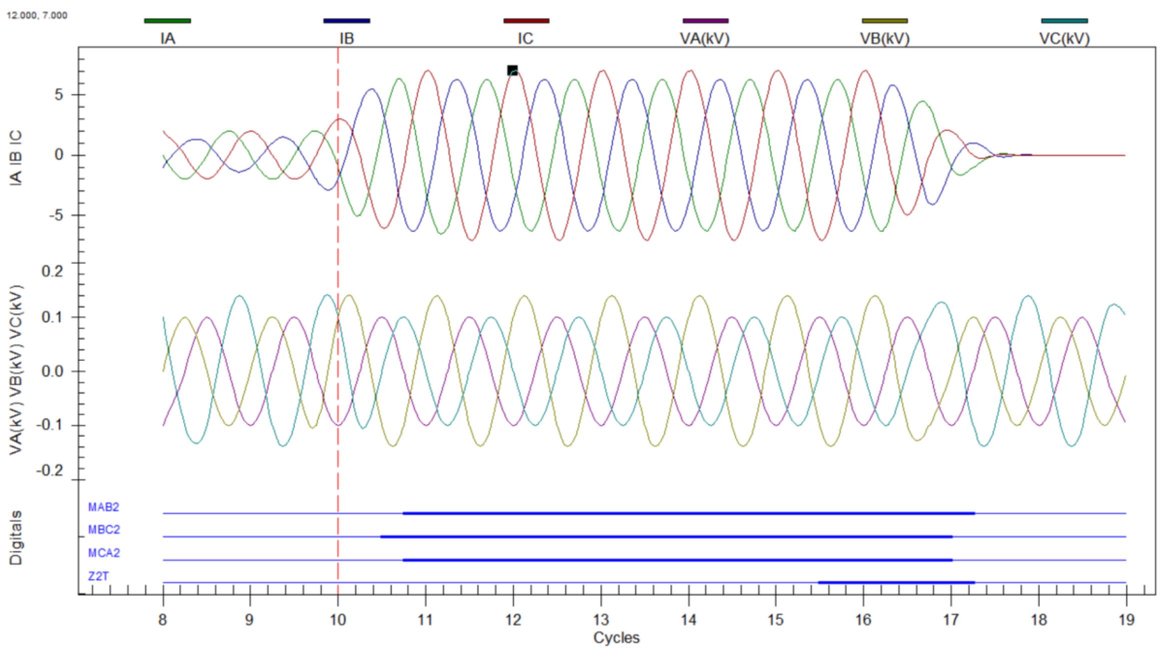

Figure 7.12: Phase Distance Isolated Three Phase Fault

7.4 SEL-311L POTT Protection

7.4.1 Overview

The permissive overreaching transfer trip (POTT) protection, as stated in Section 7.3.1, uses phase distance protection as its basis while adding the ability to override its overreaching element's need to timeout with the use of an additional SEL-311L connected via a fiber optics cable. The use of phase distance protection element provides only protection to faults containing at least two phases (i.e. double-line-to-ground, triple-line-to-ground, line-to-line, and three phase faults).

The unique part of a POTT scheme compared to using just phase distance protection is the addition of bypassing the zone 2 timeout completion while ensuring the fault was located within the transmission line. Table 7.1 lists the priority of tripping within the MPSL's POTT scheme. Priority 1 is the fastest which is meant to instantaneously clear zone 1 under reaching faults. Priority 2 in a traditional POTT scheme is as quick as a signal can travel from one SEL-311L to the other. It will trip when it has identified a zone 2 fault and the additional SEL-311L sends its permissive signal (more on this later in the section), but before zone 2 times out. Lastly, priority 3 is the slowest as it is the traditional zone 2 timeout trip seen in Section 7.3.

TABLE 7.1: MPSL POTT SCHEME TRIP LOGIC PRIORITY

Priority	Logic	Comments
1	M1P	Zone 1 instantaneous trip
2	M2P*PT1	Zone 2 indicated AND permissive trip signal from other 311L
3	M2PT	Zone 2 timeout trip

Before describing the MPSL POTT scheme, let's take a look at a traditional POTT scheme as illustrated in Figure 7.13. First, permissive signals are automatically generated when a SEL-311L identifies a forward looking zone fault. This signal is then transferred and used by the SEL-311L opposite of it. This allows for two SEL-311Ls to work in unison to trip faster by ensuring the fault is within the transmission line and not beyond it. There are three fault locations (F_1, F_2, and F_3) within the transmission line between Bus 1 and Bus 2 to be analyzed. The location of fault F_1 causes the distance element at Bus 1 to trip within priority 1 instantly and the element at Bus 2 to trip within priority 2 near instantly. The location of fault F_2 causes the distance element at Bus 1 to trip within priority 1 instantly and the element at Bus 2 to trip within priority 1 instantly as well. The location of fault F_3 causes the distance element at Bus 1 to trip within priority 2 near instantly and the element at Bus 2 to trip within priority 2 instantly.

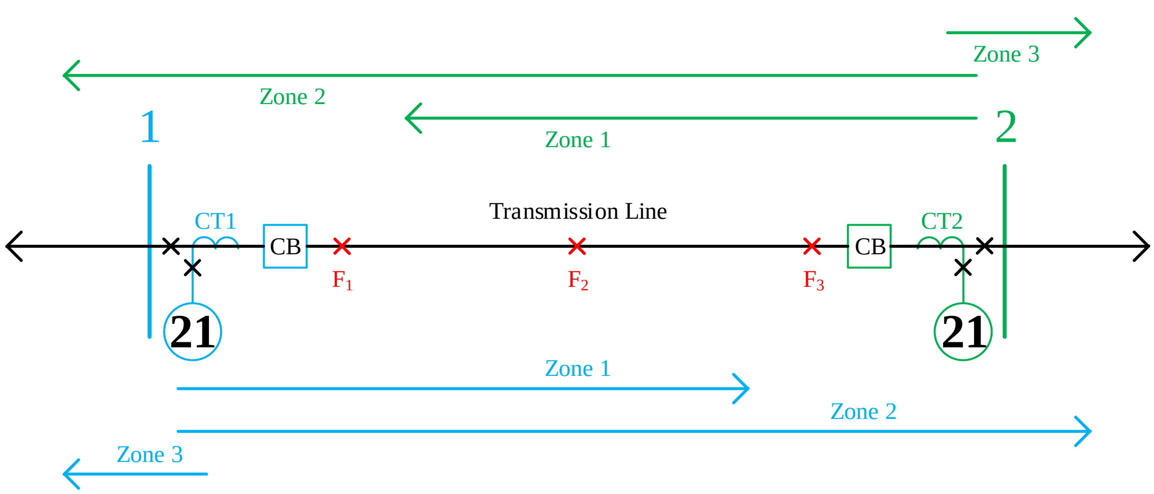

Figure 7.13: POTT Scheme Example

The MPSL POTT scheme was faced with challenges which forced the overall functionally to be less efficient than ideal operations, but still benefiting overall system protection. The MPSL has a tapped load at Bus 3, as seen in Figure 6.5, which contains a motor that draws enough inrush current to trip both SEL-311Ls when programmed with ideal POTT parameters. This was overcome by first reducing each zone 1 from ~85% to ~35% of the transmission line to under reach Bus 3 enough to prevent instantaneous tripping on inrush current while still providing sections of the line with zone 1 protection. While this prevented zone 1 from tripping, priority 2 would trip on inrush current near instantly still. Therefore, the permissive signals that the SEL-311Ls generated were passed through a variable timer long enough to allow the motor's inrush current transients to subside. This solved our problem and while it made the POTT scheme less efficient than ideal we are still able to give proof of concept and clear certain faults faster than with the inverse-time overcurrent elements. (See Appendix B and C Group 2 settings.)

7.4.2 Double Line-to-Ground Faults

All of the faults in Section 7.4 are detected in zone 2 correlating to the M2P asserting in all cases. As described in Section 7.4.1, any forward looking zone will automatically generate a key used for permissive trips which we have equated to a variable in the MPSL protection scheme. All these data words can be seen being asserted once the fault is detected in Table 7.2. The variable timer, SV1T, takes ~200 cycles in all cases to timeout to allow inrush currents to bypass as discussed before. After a short delay caused by the transmission of data across the fiber optics cable and processing time, the permissive bits, PTRX, are registered and trips of circuit breaks associated with each SEL-311L occur. The Double-Line-to-Ground faults clear ~250 cycles after detection.

TABLE 7.2: DOUBLE-LINE-TO-GROUND FAULT POTT DEMONSTRATION

TIME DELTA (mSEC)	SEL-311L DEVICE	ASSERTED ELEMENT(S)	COMMENTS
0	Line 2	M2P, KEY, SV1	Line 2 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
3	Line 1	M2P, KEY, SV1	Line 1 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
200	Line 2	SV1T	Line 2 SV1 timer times out sending permissive trip bit to line 1
212	Line 1	R1X	Line 1 receives bit used for permissive tripping
215	Line 1	PTRX, TRIP	Line 1 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout

236	Line 1	SV1T	Line 1 SV1 timer times out sending permissive trip bit to line 2
242	Line 2	R1X	Line 2 receives bit used for permissive tripping
250	Line 2	PTRX, TRIP	Line 2 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout

7.4.3 Triple-Line-to-Ground Faults

Table 7.3 describes the timing of fault detection and clearing of Triple-Line-to-Ground faults. The Triple-Line-to-Ground faults clear ~246 cycles after detection.

TABLE 7.3: TRIPLE-LINE-TO-GROUND FAULT POTT DEMONSTRATION

TIME DELTA (mSEC)	SEL-311L DEVICE	ASSERTED ELEMENT(S)	COMMENTS
0	Line 1	M2P, KEY, SV1	Line 1 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
0	Line 2	M2P, KEY, SV1	Line 2 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
200	Line 2	SV1T	Line 2 SV1 timer times out sending permissive trip bit to line 1
202	Line 1	R1X	Line 1 receives bit used for permissive tripping
212	Line 1	PTRX, TRIP	Line 1 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout
233	Line 1	SV1T	Line 1 SV1 timer times out sending permissive trip bit to line 2
242	Line 2	R1X	Line 2 receives bit used for permissive tripping
246	Line 2	PTRX, TRIP	Line 2 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout

7.4.4 Line-to-Line Faults

Table 7.4 describes the timing of fault detection and clearing of Line-to-Line faults. The Line-to-Line faults clear ~246 cycles after detection.

TABLE 7.4: LINE-TO-LINE FAULT POTT DEMONSTRATION

TIME DELTA (mSEC)	SEL-311L DEVICE	ASSERTED ELEMENT(S)	COMMENTS
0	Line 1	M2P, KEY, SV1	Line 1 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
0	Line 2	M2P, KEY, SV1	Line 2 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
200	Line 2	SV1T	Line 2 SV1 timer times out sending permissive trip bit to line 1
207	Line 1	R1X	Line 1 receives bit used for permissive tripping
212	Line 1	PTRX, TRIP	Line 1 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout
233	Line 1	SV1T	Line 1 SV1 timer times out sending permissive trip bit to line 2
237	Line 2	R1X	Line 2 receives bit used for permissive tripping
246	Line 2	PTRX, TRIP	Line 2 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout

7.4.5 Three Phase Faults

Table 7.5 describes the timing of fault detection and clearing of Three Phase faults. The Three Phase faults clear ~249 cycles after detection.

TABLE 7.5: THREE PHASE FAULT POTT DEMONSTATION

TIME DELTA (mSEC)	SEL-311L DEVICE	ASSERTED ELEMENT(S)	COMMENTS
0	Line 1	M2P, KEY, SV1	Line 1 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
3	Line 2	M2P, KEY, SV1	Line 2 picks up fault in zone 2 (M2P), generates KEY based on M2P, starts SV1 timer from KEY generation
203	Line 2	SV1T	Line 2 SV1 timer times out sending permissive trip bit to line 1
213	Line 1	R1X	Line 1 receives bit used for permissive tripping
217	Line 1	PTRX, TRIP	Line 1 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout
234	Line 1	SV1T	Line 1 SV1 timer times out sending permissive trip bit to line 2
243	Line 2	R1X	Line 2 receives bit used for permissive tripping
249	Line 2	PTRX, TRIP	Line 2 permissive bit (PTRX=RX1) registered and allows M2P to TRIP immediately prior to zone 2 timeout

Chapter 8: SEL-387E Protection

8.1 SEL-387E Introduction

The SEL-387 provides inverse-time overcurrent and differential protection to the MPSL. The SEL-387 is designed to protect transformers which are contained within the lab benches and used within the MPSL. The radial system topology allows for characterizing both the inverse-time overcurrent and differential protection elements used for the complete system coordination. This chapter gives a technical overview of each element and the element's characterization of clearing various faults

8.2 SEL-387E Inverse Time-Overcurrent Protection

8.2.1 Overview

This section characterizes the inverse-time overcurrent protection of the SEL-387 through the detection and clearing of various faults. Phase, negative sequence, and residual ground inverse-time overcurrent protection are all enabled within the MPSL. Inverse-time overcurrent protection is primarily based off of the selection of pickup current values, curve selection, and time dial settings. The phase pickup current value 51PnP setting is compared to the maximum of the phase current of a winding IAW_n, IBW_n, or ICW_n, where n is the winding number. The negative sequence pickup current value 51Qn, where n is the winding number, setting is compared to the negative sequence current $3I2W_n$, where n is the winding number, which can be calculated $3I_2$ =

$I_A + a^2 \cdot I_C + a \cdot I_B$ (ACB rotation). The residual ground pickup current value $51N_n$, where n is the winding number, setting is compared to the residual ground current $3I_0$, which can be calculated $3I_0 = I_A + I_B + I_C$. The curve selection on all relays using an inverse-time overcurrent protection element was standardized in the MPSL to curve U1. Curve U1, as seen in Figure 7.1, is the U. S. Moderately Inverse Curve which conforms to IEEE C37.112-1996. Lastly, a time dial setting is selected to choose the location of the curve affecting the response time of the relay. Smaller time dial settings correlate to quicker response times, while the inverse is true for larger time dial settings. Since the SEL-387 is located after the SEL 311L in relation to the load in both of our system topologies, a time dial setting slighter larger than the SEL 311L is chosen for its operation.

8.2.2 Single-Line-to-Ground Faults

Single-Line-to-Ground faults are detected by the negative sequence overcurrent element 51Q2 for winding 2. The 51Q2 element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.55 and the multiples of pickup current (currently set to 0.50) detected by the relay. Due to this relay protecting an element further from the load compared to the SEL-311L, one will noticed the time dial setting is slightly higher than the SEL-311L to ensure the relay trips after the SEL-311L has an opportunity to trip.

The relay detects the fault with 51Q2 ~5.5 cycles into the report as seen in Figure 8.1 and clears it after ~39.5 cycles later once the timeout signal 51Q2T asserts.

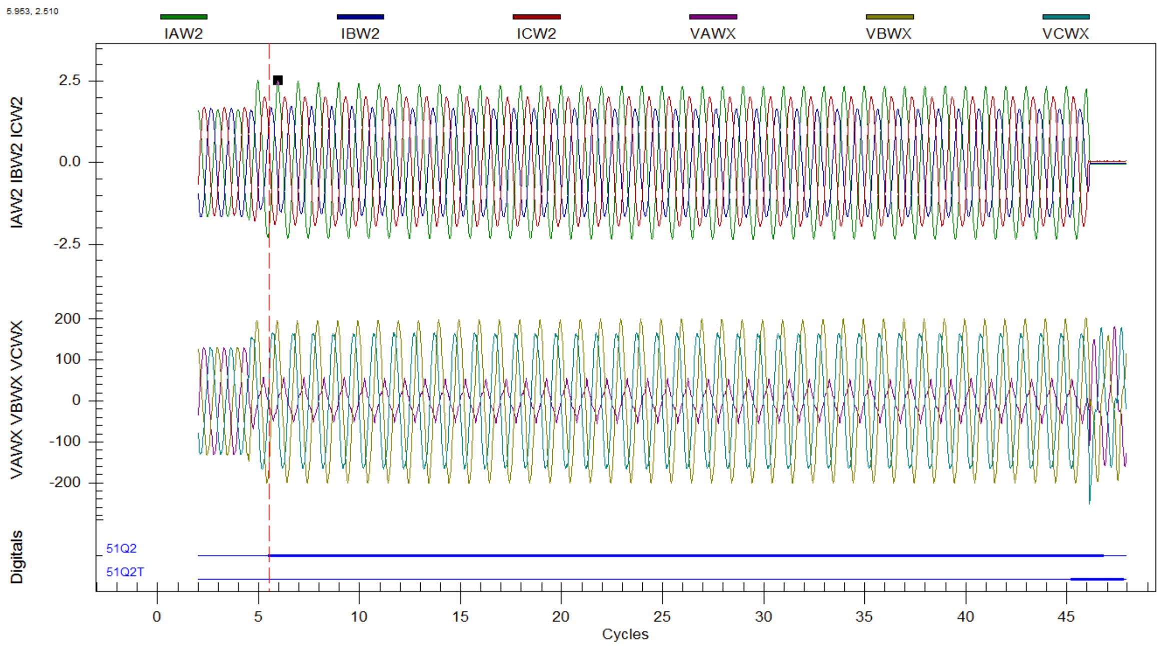

Figure 8.1: Inverse Time Overcurrent Single Line-to-Ground Fault

8.2.3 Double-Line-to-Ground Faults

Double-Line-to-Ground faults are also detected and cleared with the 51Q2 element described above. The relay detects the fault ~5.5 cycles into the report, as seen in Figure 8.2, and clears it within ~7.5 cycles once the timeout signal 51Q2T asserts. The quicker response time when compared to the Single-Line-to-Ground fault is caused by the larger fault current generated.

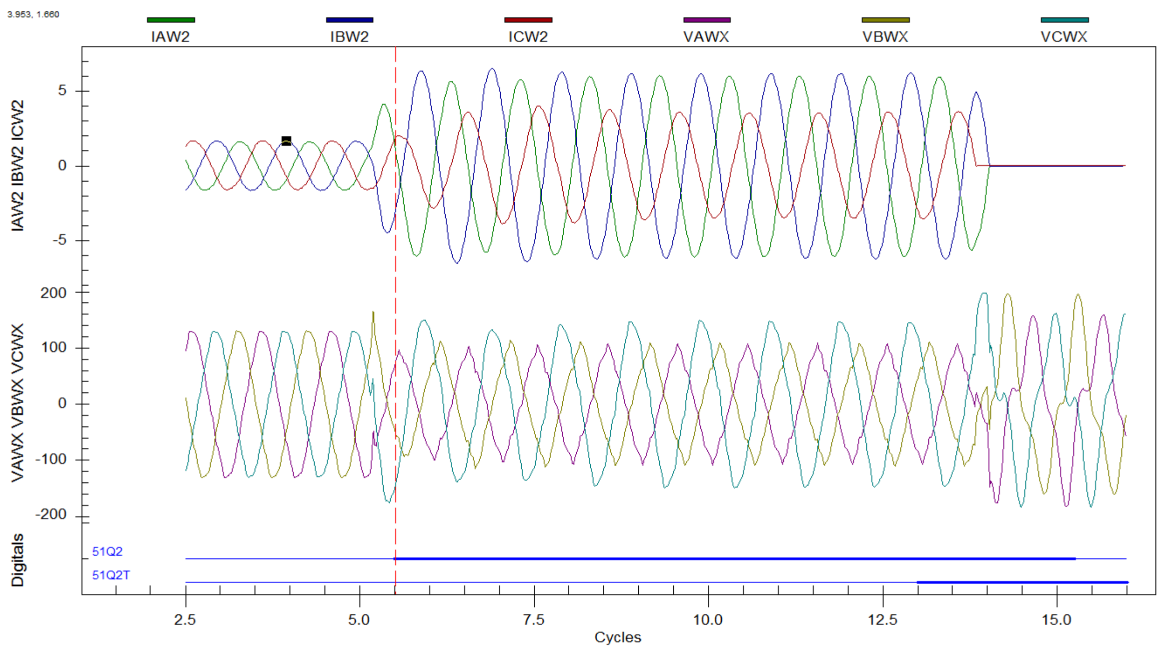

Figure 8.2: Inverse Time Overcurrent Double Line-to-Ground Fault

8.2.4 Triple-Line-to-Ground Faults

Triple-Line-to-Ground faults are detected by the phase overcurrent element 51P2 due to the large fault current. The 51P2 element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.55 and the multiples of pickup current (currently set to 4.5) detected by the relay. Just as with the 51Q2 element, this time dial setting is slightly larger than the SEL-311L's time dial setting to ensure the relay trips after the SEL-311L has an opportunity to trip.

The relay detects the fault with 51P2 ~5.5 cycles into the report as seen in Figure 8.3 and clears it after ~40 cycles later once the timeout signal 51P2T asserts.

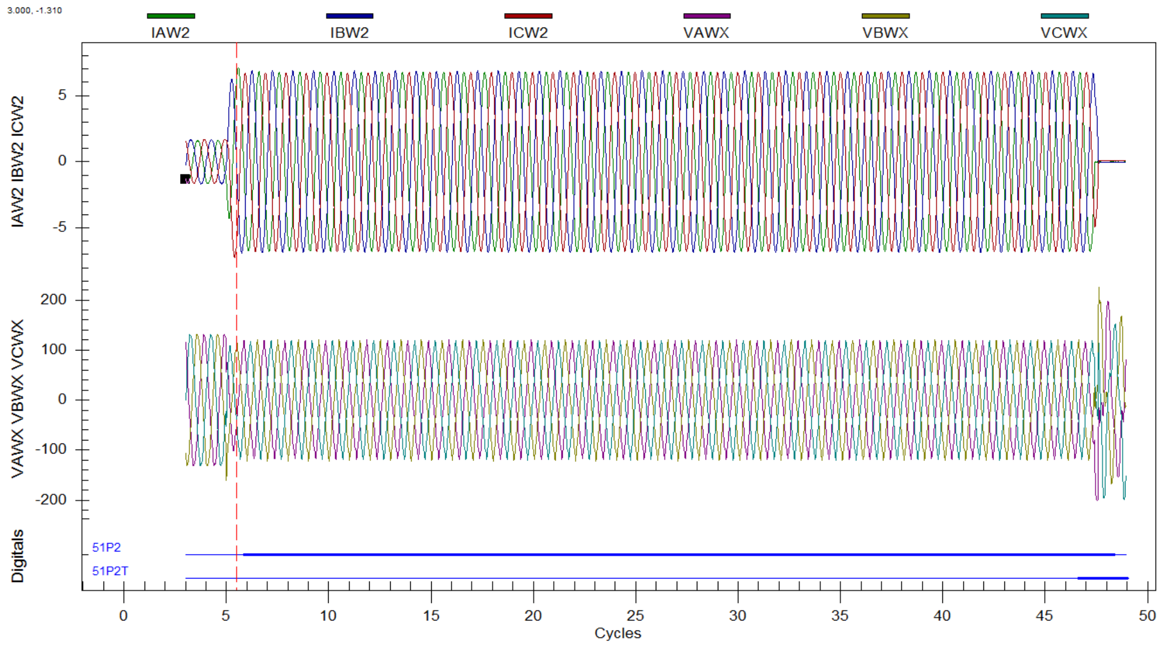

Figure 8.3: Inverse Time Overcurrent Triple Line-to-Ground Fault

8.2.5 Line-to-Line Faults

Line-to-Line faults are cleared with the 51Q2 element described above. The relay detects the fault with the 51Q2 element ~5.2 cycles into the report, as seen in Figure 8.4, and the relay clears the fault within ~7.8 cycles once the timeout signal 51Q2T asserts.

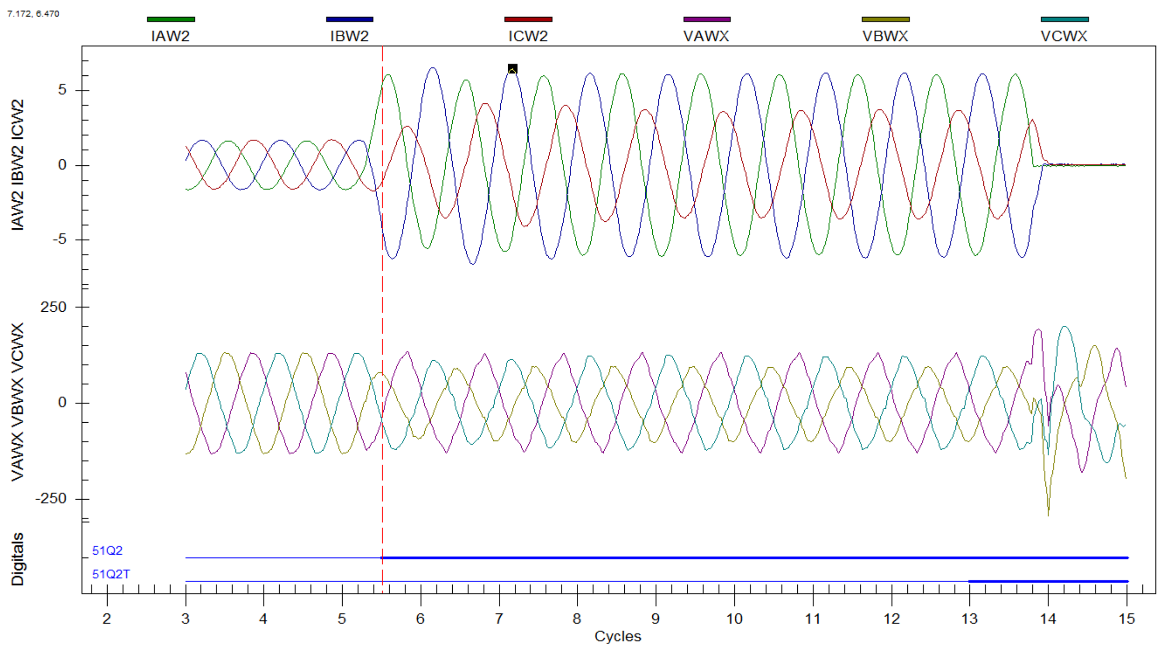

Figure 8.4: Inverse Time Overcurrent Line-to-Line Fault

8.2.6 Three Phase Faults

Three Phase are also detected and cleared with the 51P2 element described above. The relay detects the fault ~5.5 cycles into the report, as seen in Figure 8.5, and clears it within ~40 cycles once the timeout signal 51P2T asserts.

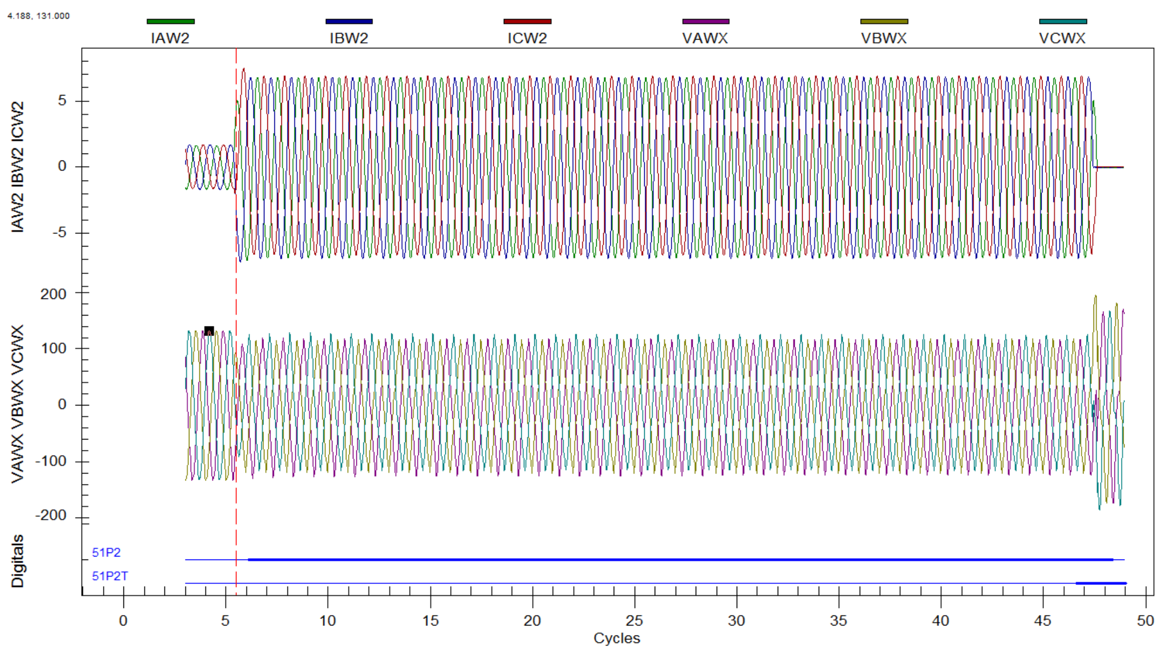

Figure 8.5: Inverse Time Overcurrent Three Phase Fault

8.3 SEL-387E Differential Protection

8.3.1 Overview

This section characterizes the differential protection of the SEL-387 through the detection and clearing of various faults. All winding currents that are measured normally would use CTs, but due to the small currents in the MPSL we connect the lines straight to the relay. The SEL-387 will then use the rated values of the transformer to convert all currents into per unit (PU) quantities to avoid comparison issues when protecting a transformer with a non-unity turns ratio. The SEL-387 additionally provides harmonic blocking. Within the MPSL, the SEL-387 is set to block 15% of both second and fourth harmonics to help with motor inrush transients and 35% of fifth harmonics to help protect against overexcitation conditions within the transformer.

The SEL-387 differential protection allows for a user to define the operation and restraint regions through the use of five parameters O87P (minimum operating pickup current), SLP1 (slope 1), IRS1 (point where the slope SLP2 begins which intersects with SLP1), SLP2 (slope 2), and U87P (unrestrained pickup current) as illustrated in Figure 8.6. The restraint and operate regions for the SEL-387 within the MPSL are defined as follows: O87P = 0.3, SLP1 = 25%, IRS1 = 3.0, SLP2 = 50%, U87P = 3.0. Under normal conditions the current into the transformer is equivalent to the current leaving the transformer and thus no differential trips will occur. For faults external to the transformer CTs without transformer saturation will also not cause a differential trip since again current in is equivalent to current out. Once current becomes unbalanced due to internal faults or transformer saturation the relay will determine if the point is above the user defined curve. If it is, the relay will trip for differential.

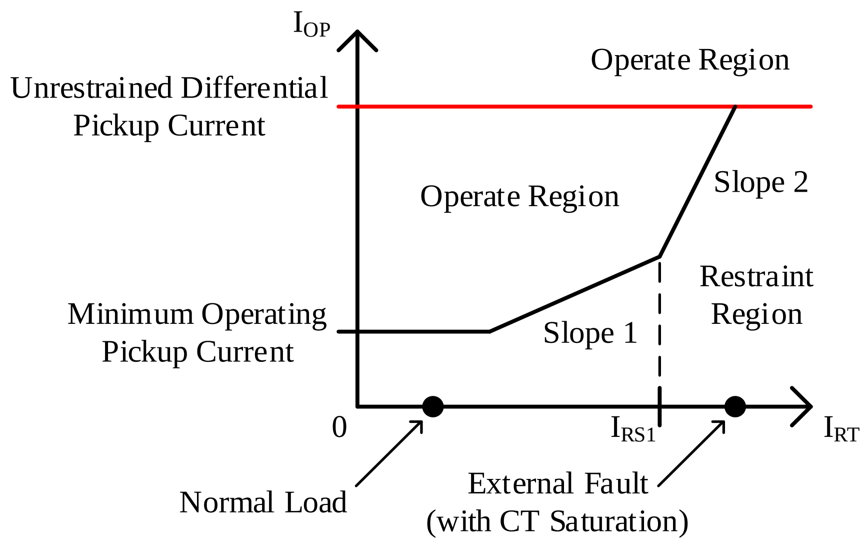

Figure 8.6: Operate vs Restraint Current Characteristic

8.3.2 Single-Line-to-Ground Faults

There were Single-Line-to-Ground faults injected into the system at both Bus 1 and Bus 2 to test the differential protection. The Single-Line-to-Ground fault on Bus 1 as seen in Figure 8.7 takes ~2.5 cycles from detection to clear. The Single-Line-to-Ground fault on Bus 2 as seen in Figure 8.8 takes ~2 cycles from detection to clear.

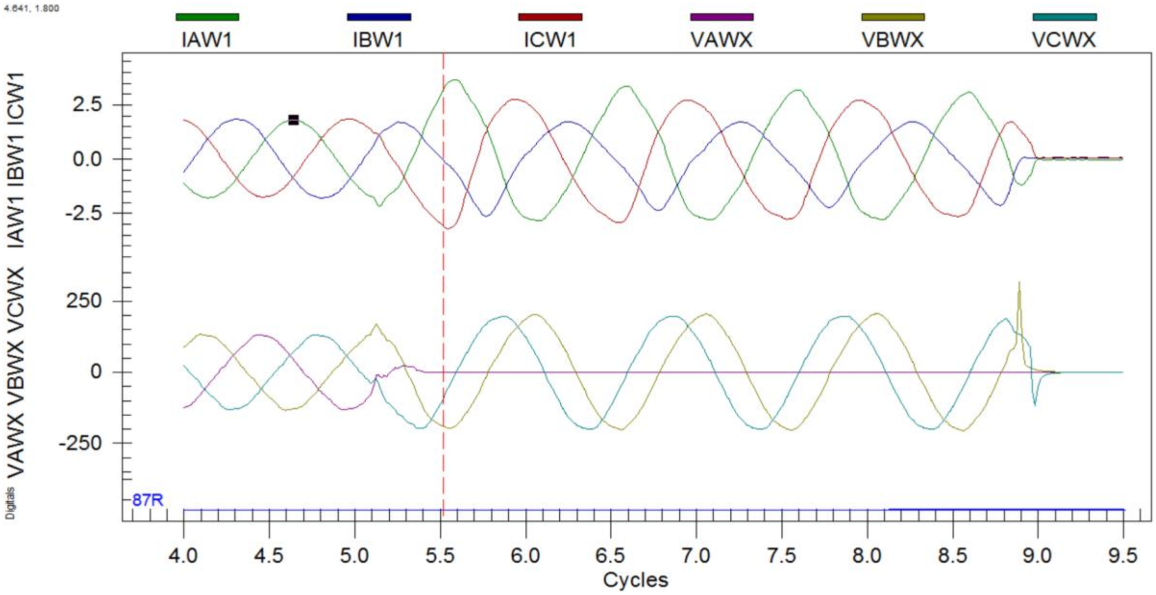

Figure 8.7: Differential Single Line-to-Ground Fault, Bus 1

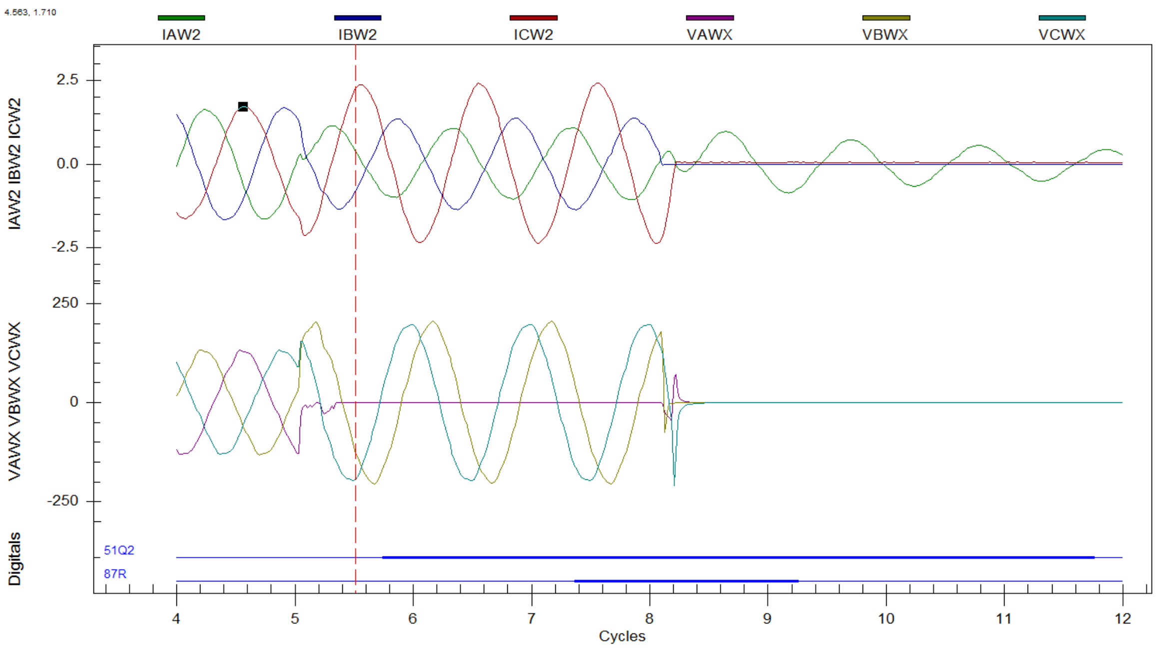

Figure 8.8: Differential Single Line-to-Ground Fault, Bus 2

8.3.3 Double-Line-to-Ground Faults

There were Double-Line-to-Ground faults injected into the system at both Bus 1 and Bus 2 to test the differential protection. The Double-Line-to-Ground fault on Bus 1, the transformer's winding one, as seen in Figure 8.9 takes ~2 cycles from detection to clear. The Double-Line-to-Ground fault on Bus 2, the transformer's winding two, as seen in Figure 8.10 takes ~2.5 cycles from detection to clear.

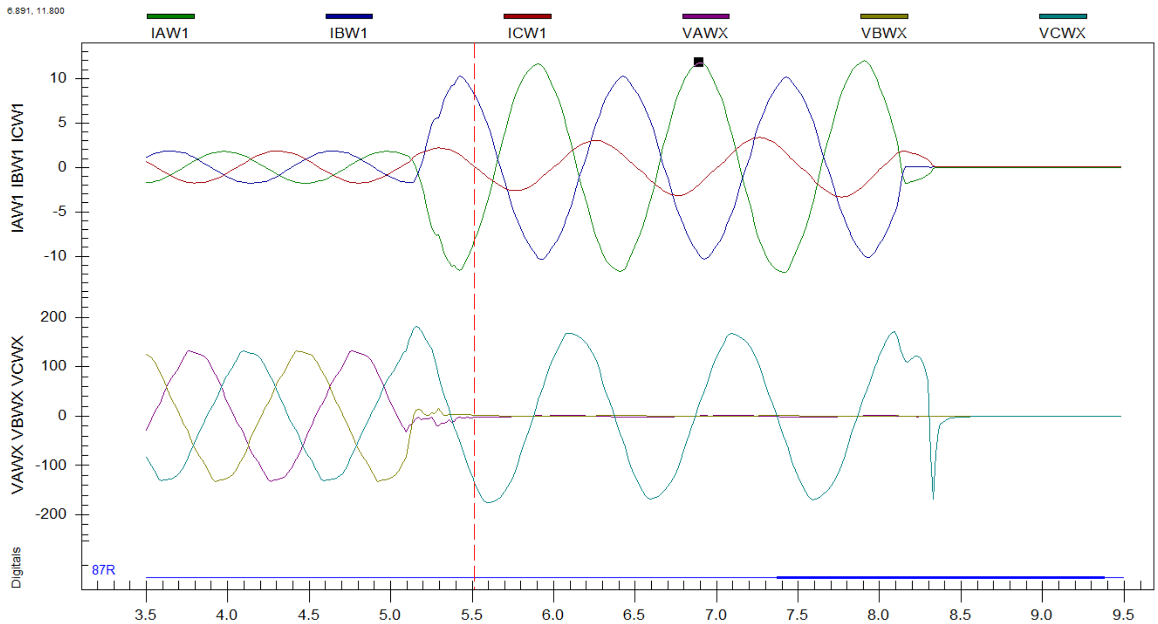

Figure 8.9: Differential Double Line-to-Ground Fault, Bus 1

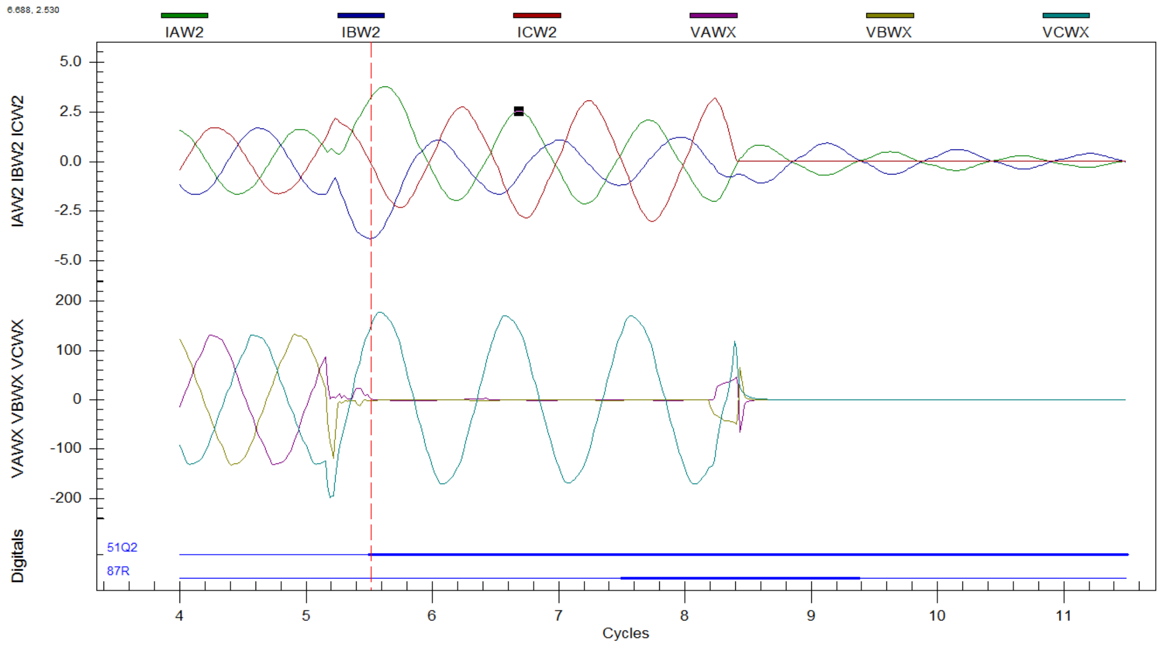

Figure 8.10: Differential Double Line-to-Ground Fault, Bus 2

8.3.4 Triple-Line-to-Ground Faults

There were Triple-Line-to-Ground faults injected into the system at both Bus 1 and Bus 2 to test the differential protection. The Triple-Line-to-Ground fault on Bus 1, the transformer's winding one, as seen in Figure 8.11 takes ~2.2 cycles from detection to clear. The Triple-Line-to-Ground fault on Bus 2, the transformer's winding two, as seen in Figure 8.12 takes ~2.5 cycles from detection to clear.

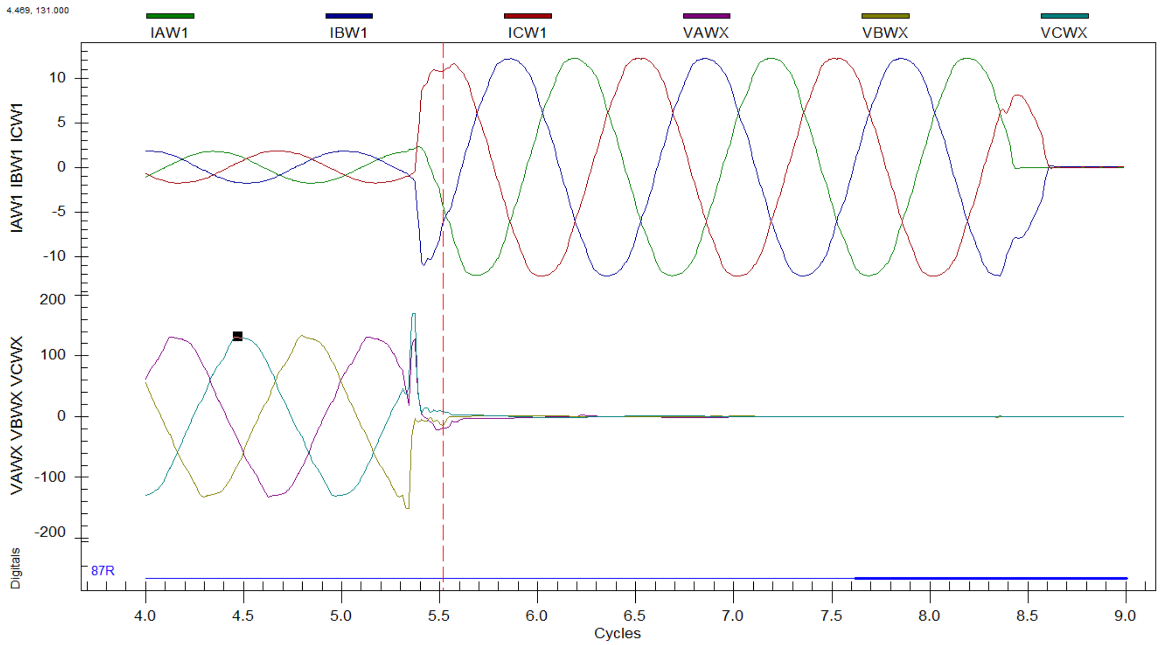

Figure 8.11: Differential Triple Line-to-Ground Fault, Bus 1

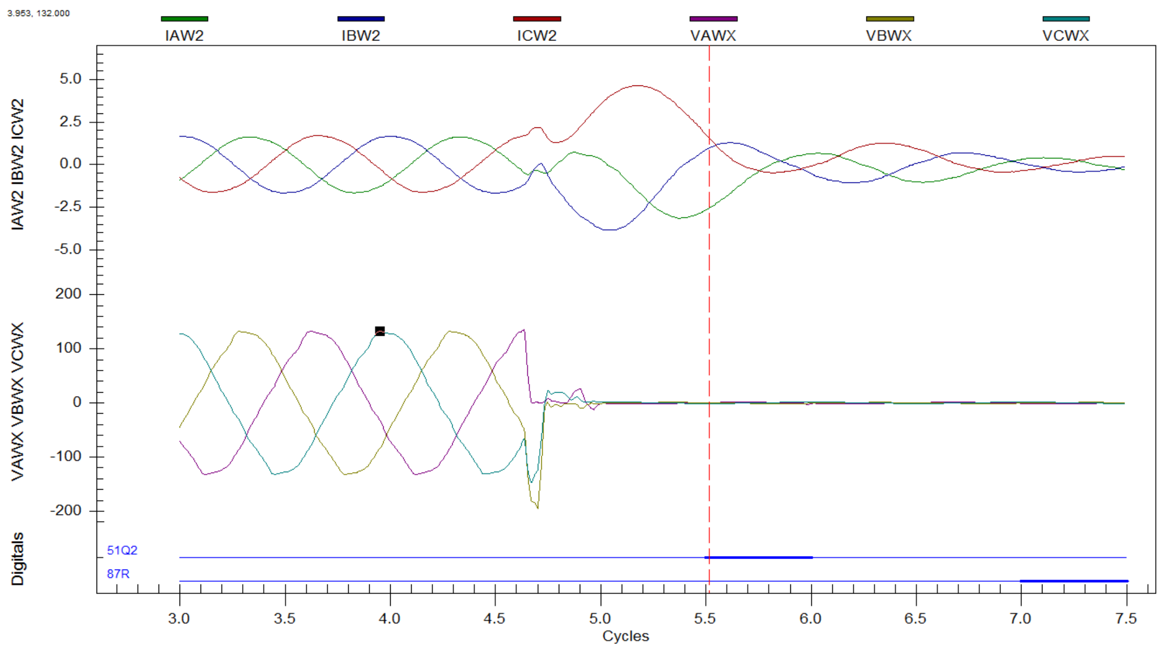

Figure 8.12: Differential Triple Line-to-Ground Fault, Bus 2

8.3.5 Line-to-Line Faults

There were Line-to-Line faults injected into the system at both Bus 1 and Bus 2 to test the differential protection. The Line-to-Line fault on Bus 1, the transformer's winding one, as seen in Figure 8.13 takes ~2.5 cycles from detection to clear. The Line-to-Line fault on Bus 2, the transformer's winding two, as seen in Figure 8.14 takes ~2.5 cycles from detection to clear.

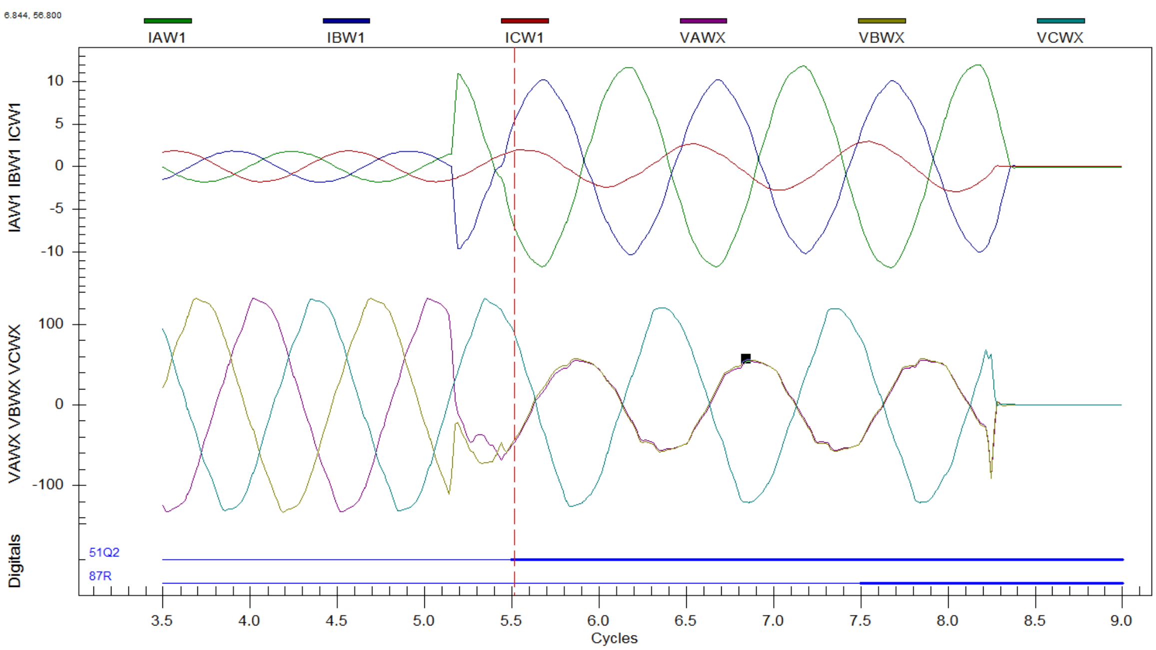

Figure 8.13: Differential Line-to-Line Fault, Bus 1

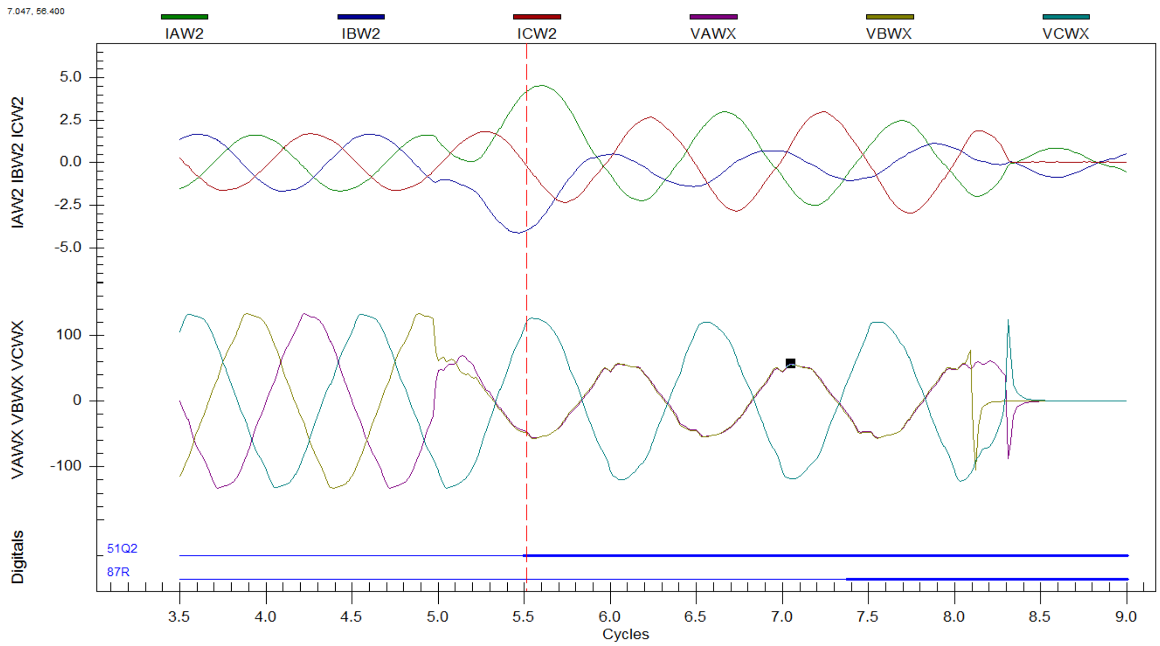

Figure 8.14: Differential Line-to-Line Fault, Bus 2

8.3.6 Three Phase Faults

There were Three Phase faults injected into the system at both Bus 1 and Bus 2 to test the differential protection. The Three Phase fault on Bus 1, the transformer's winding one, as seen in Figure 8.15 takes ~2 cycles from detection to clear. The Three Phase fault on Bus 2, the transformer's winding two, as seen in Figure 8.16 takes ~2.2 cycles from detection to clear.

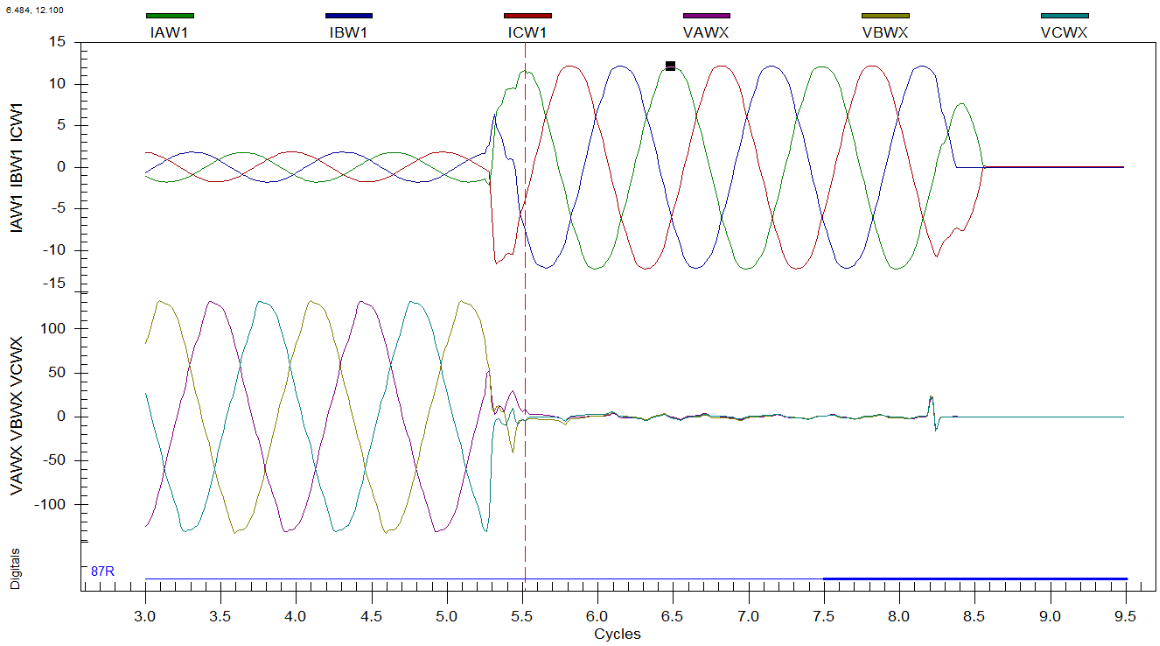

Figure 8.15: Differential Three Phase Fault, Bus 1

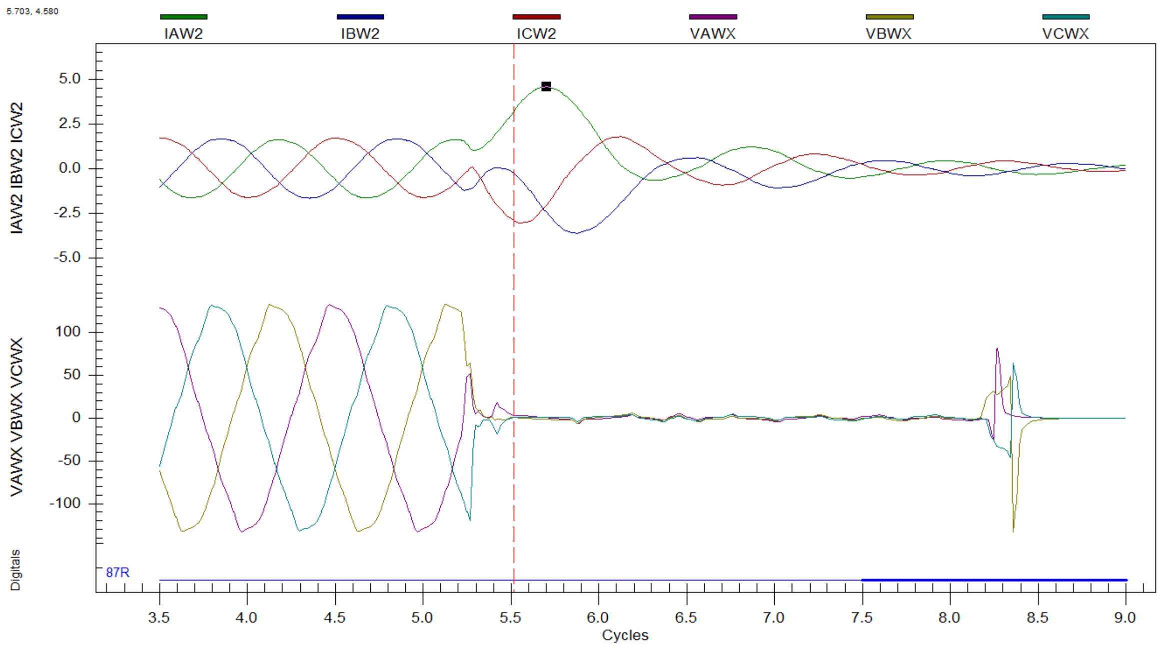

Figure 8.16: Differential Three Phase Fault, Bus 2

Chapter 9: SEL-587 Protection

9.1 SEL-587 Introduction

The SEL-587 provides inverse-time overcurrent and differential protection to the MPSL similar to the SEL-387. The SEL-587 is a more cost efficient product than the SEL-387, though it comes at the price of reduced functionality. The SEL-587 is designed to protect transformers which are contained within the lab benches and used within the MPSL. The radial system topology allows for characterizing both the inverse-time overcurrent and differential protection elements used for the complete system coordination. This chapter gives a technical overview of each element and the element's characterization of clearing various faults

9.2 SEL-587 Inverse-Time Overcurrent Protection

9.2.1 Overview

This section characterizes the inverse-time overcurrent protection of the SEL-587 through the detection and clearing of various faults. Phase, negative sequence, and residual ground inverse-time overcurrent protection are all enabled within the MPSL. Inverse-time overcurrent protection is primarily based off of the selection of pickup current values, curve selection, and time dial settings. The phase pickup current value 51PnP setting is compared to the maximum of the phase current of a winding IAW_n, IBW_n, or ICW_n, where n is the winding number. The negative sequence pickup current value 51Qn, where n is the winding number, setting is compared to the negative sequence current 3I2, which can be calculated $3I_2 = I_A + a^2 \cdot I_C + a \cdot I_B$ (ACB rotation). The residual ground pickup current value $51N_nP$, where n is the winding number, setting is compared to the residual ground current $3I_0$, which can be calculated $3I_0 = I_A + I_B + I_C$. The curve selection on all relays using an inverse-time overcurrent protection element was standardized in the MPSL to curve U1. Curve U1, as seen in Figure 7.1, is the U. S. Moderately Inverse Curve which conforms to IEEE C37.112-1996. Lastly, a time dial setting is selected to choose the location of the curve affecting the response time of the relay. Smaller time dial settings correlate to quicker response times, while the inverse is true for larger time dial settings. Since the SEL-587 is located after the SEL-311L in relation to the load in both of our system topologies, a time dial setting slighter larger than the SEL-311L and comparable to the SEL-387 is chosen for its operation. [5]

9.2.2 Single-Line-to-Ground Faults

Single-Line-to-Ground faults are detected by the negative sequence overcurrent element 51Q2 for winding 2. The 51Q2 element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.55 and the multiples of pickup current (currently set to 0.50) detected by the relay. Due to this relay protecting an element further from the load compared to the SEL-311L, one will noticed the time dial setting is slightly higher than the SEL-311L to ensure the relay trips after the SEL-311L has an opportunity to trip first.

Due to the SEL-587's inability to store large cycle event reports, there will be some figures within Chapter 9 that will not contain both the pickup and trip signal leading edges. The relay detects the fault with 51Q2 prior to the report generation as seen in Figure 9.1 and clears it at ~4.2 cycles into the report once the timeout signal 51Q2T asserts notated by the "T" above the signal.

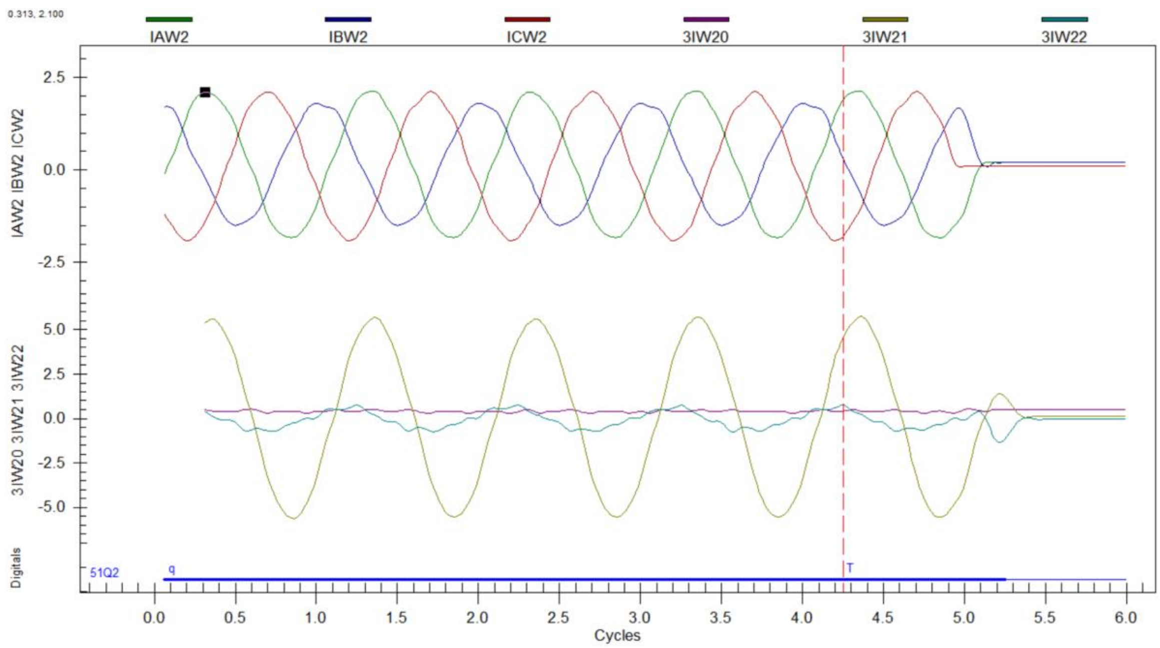

Figure 9.1: Inverse Time Overcurrent Single Line-to-Ground Fault

9.2.3 Double-Line-to-Ground Faults

Double-Line-to-Ground faults are also detected and cleared with the 51Q2 element described above. The relay detects the fault with 51Q2 prior to the report generation as seen in Figure 9.2 and clears it at ~4.2 cycles into the report once the timeout signal 51Q2T asserts notated by the “T” above the signal.

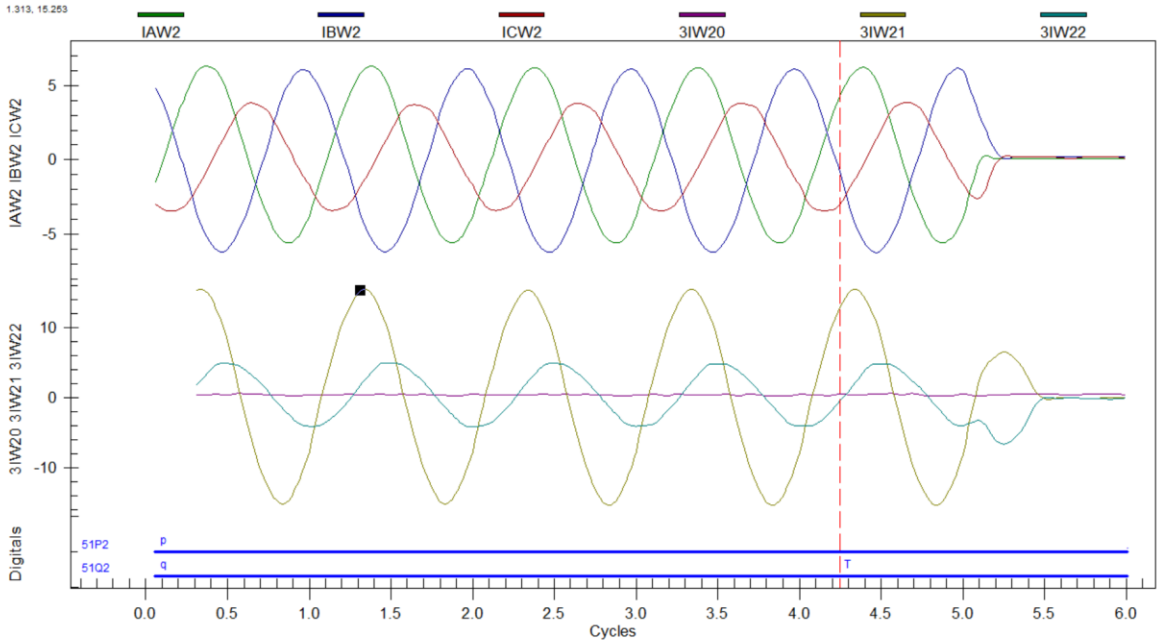

Figure 9.2: Inverse Time Overcurrent Double Line-to-Ground Fault

9.2.4 Triple-Line-to-Ground Faults

Triple-Line-to-Ground faults are detected by the phase overcurrent element 51P2 due to the large fault current. The 51P2 element has an inverse-time characteristic meaning it trips based off our time dial setting of 0.55 and the multiples of pickup current (currently set to 4.5) detected by the relay. Just as with the 51Q2 element, this time dial setting is slightly larger than the SEL-311L's time dial setting to ensure the relay trips after the SEL-311L has an opportunity to trip.

The relay detects the fault with 51P2 prior to the report generation as seen in Figure 9.3 and clears it at ~4.2 cycles into the report once the timeout signal 51P2T asserts notated by the "T" above the signal.

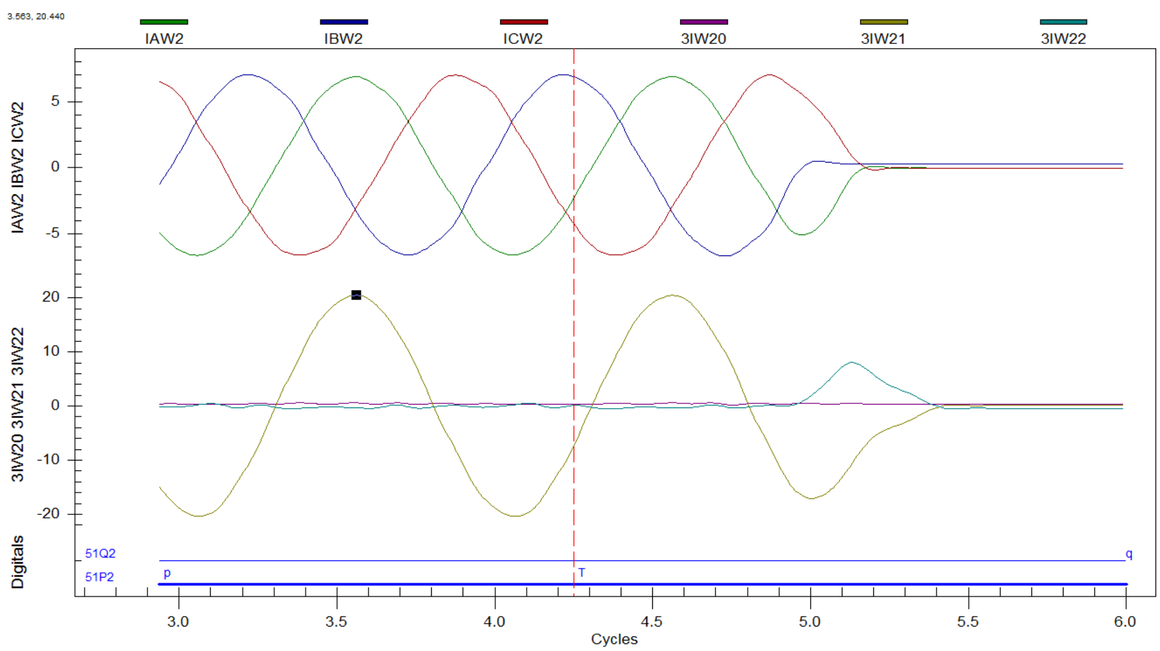

Figure 9.3: Inverse Time Overcurrent Triple Line-to-Ground Fault

9.2.5 Line-to-Line Faults

Line-to-Line faults are cleared with the 51Q2 element described above. The relay detects the fault with 51Q2 prior to the report generation as seen in Figure 9.4 and clears it at ~4.2 cycles into the report once the timeout signal 51Q2T asserts notated by the “T” above the signal.

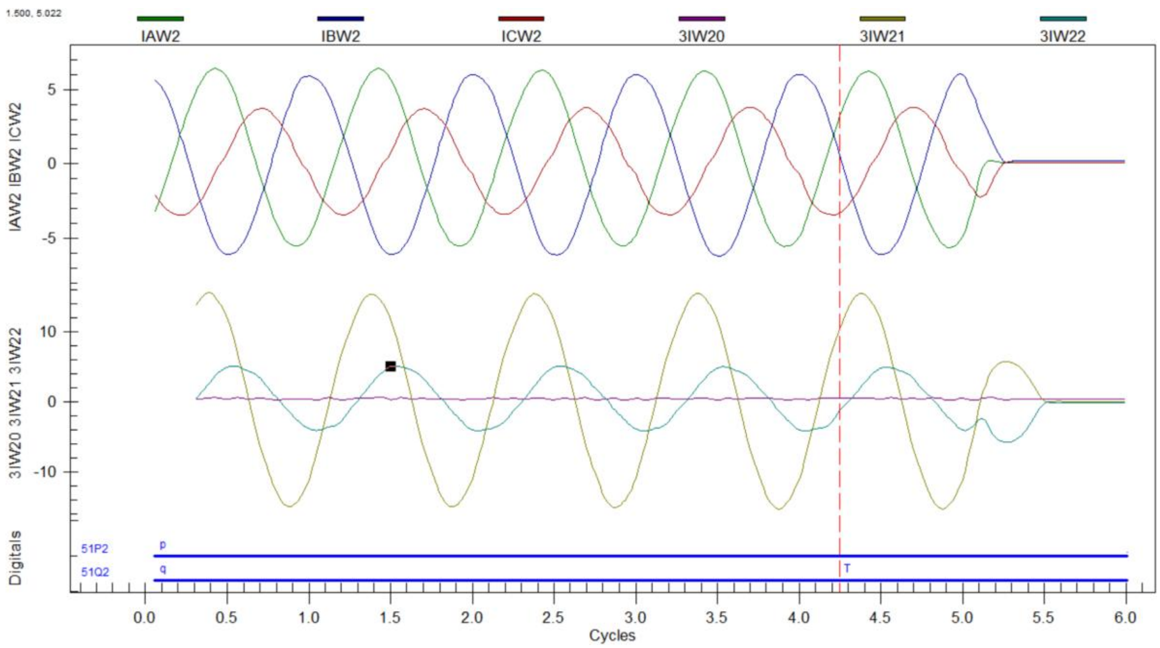

Figure 9.4: Inverse Time Overcurrent Line-to-Line Fault

9.2.6 Three Phase Faults

Three Phase are also detected and cleared with the 51P2 element described above. The relay detects the fault with 51P2 prior to the report generation as seen in Figure 9.5 and clears it at ~4.2 cycles into the report once the timeout signal 51P2T asserts notated by the “T” above the signal.

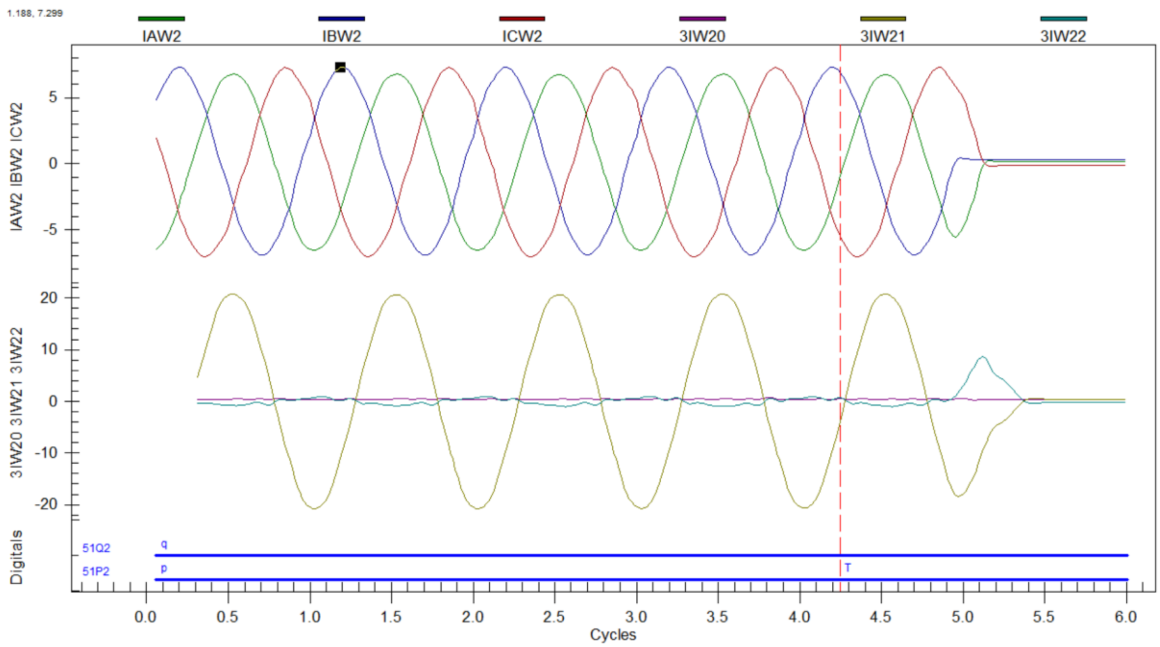

Figure 9.5: Inverse Time Overcurrent Three Phase Fault

9.3 SEL-587 Differential Protection

9.3.1 Overview

This section characterizes the differential protection of the SEL-587 through the detection and clearing of various faults. All winding currents that are measured normally would use CTs, but due to the small currents in the MPSL we connect the lines straight to the relay. The SEL-587 will then use the rated values of the transformer to convert all currents into per unit (PU) quantities to avoid comparison issues when protecting a transformer with a non-unity turns ratio. The SEL-587 additionally provides harmonic blocking. Within the MPSL, the SEL-587 is set to block 15% of both second and fourth harmonics to help with motor inrush transients and 35% of fifth harmonics to help protect against overexcitation conditions within the transformer.

The SEL-587 differential protection, similar to the SEL-387, allows for a user to define the operation and restraint regions through the use of five parameters O87P (minimum operating pickup current), SLP1 (slope 1), IRS1 (point where the slope SLP2 begins which intersects with SLP1), SLP2 (slope 2), and U87P (unrestrained pickup current) as illustrated in Figure 8.6. The restraint and operate regions for the SEL-587 within the MPSL are defined as follows: O87P = 0.4, SLP1 = 40%, IRS1 = 3.0, SLP2 = 50%, U87P = 10.0. Due to issues with transformer saturation in the radial system 2, the SEL-587 had to be desensitized to not trip under normal operation. The O87P minimum pickup was moved from 0.3 to 0.4 and SLP1 from 25% to 40%. These changes expanded the restraint region enough to allow for the operation of SEL-587 without erroneous errors.

Under normal conditions the current into the transformer is equivalent to the current leaving the transformer and thus no differential trips will occur. For faults external to the transformer CTs without transformer saturation will also not cause a differential trip since again current in is equivalent to current out. Once current becomes unbalanced due to internal faults or transformer saturation the relay will determine if the point is above the user defined curve. If it is, the relay will trip for differential.

9.3.2 Single-Line-to-Ground Faults

Single-Line-to-Ground fault is injected into the system at Bus 4, the transformer's second winding, to test the differential protection. The fault on Bus 4 as seen in Figure 9.6 takes ~2.3 cycles from detection to clear.

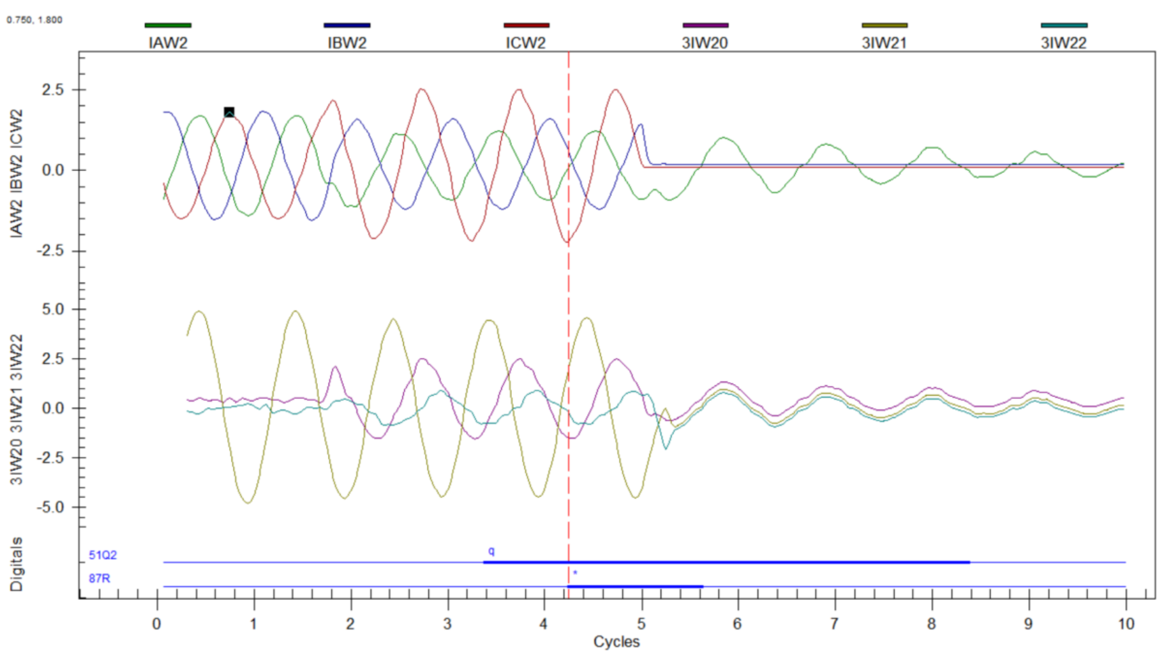

Figure 9.6: Differential Single Line-to-Ground Fault

9.3.3 Double-Line-to-Ground Faults

Double-Line-to-Ground fault is injected into the system at Bus 4, the transformer's second winding, to test the differential protection. The fault on Bus 4 as seen in Figure 9.7 takes ~2.1 cycles from detection to clear.

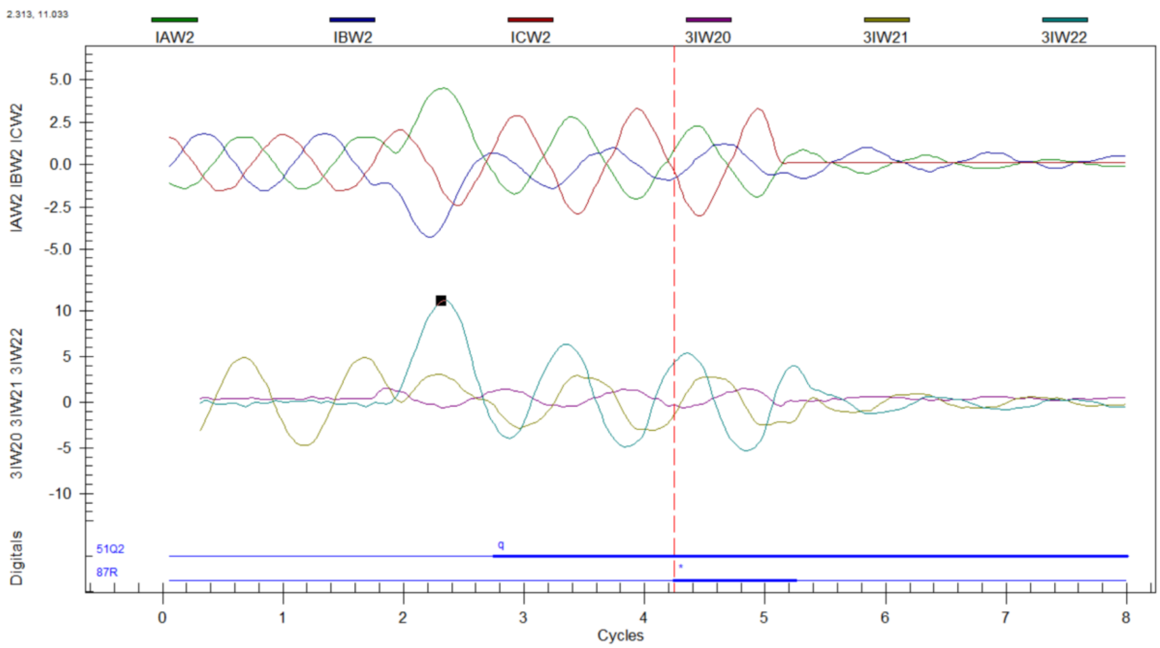

Figure 9.7: Differential Double line-to-Ground Fault

9.3.4 Triple-Line-to-Ground Faults

Triple-Line-to-Ground fault is injected into the system at Bus 4, the transformer's second winding, to test the differential protection. The fault on Bus 4 as seen in Figure 9.8 takes ~2.5 cycles from detection to clear.

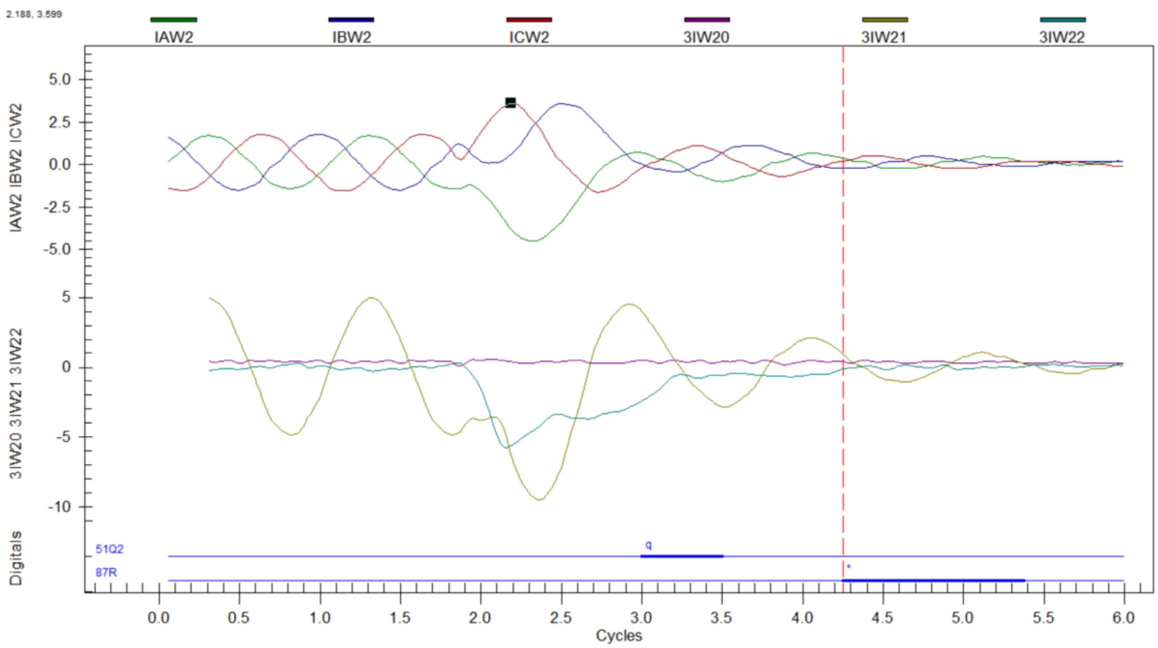

Figure 9.8: Differential Triple Line-to-Ground Fault

9.3.5 Line-to-Line Faults

There were Line-to-Line faults injected into the system at both Bus 4 and Bus 5 to test the differential protection. The Line-to-Line fault on Bus 5, the transformer's winding one, as seen in Figure 9.9 takes ~2.5 cycles from detection to clear. The Line-to-Line fault on Bus 2, the transformer's winding two, as seen in Figure 9.10 takes ~2.2 cycles from detection to clear.

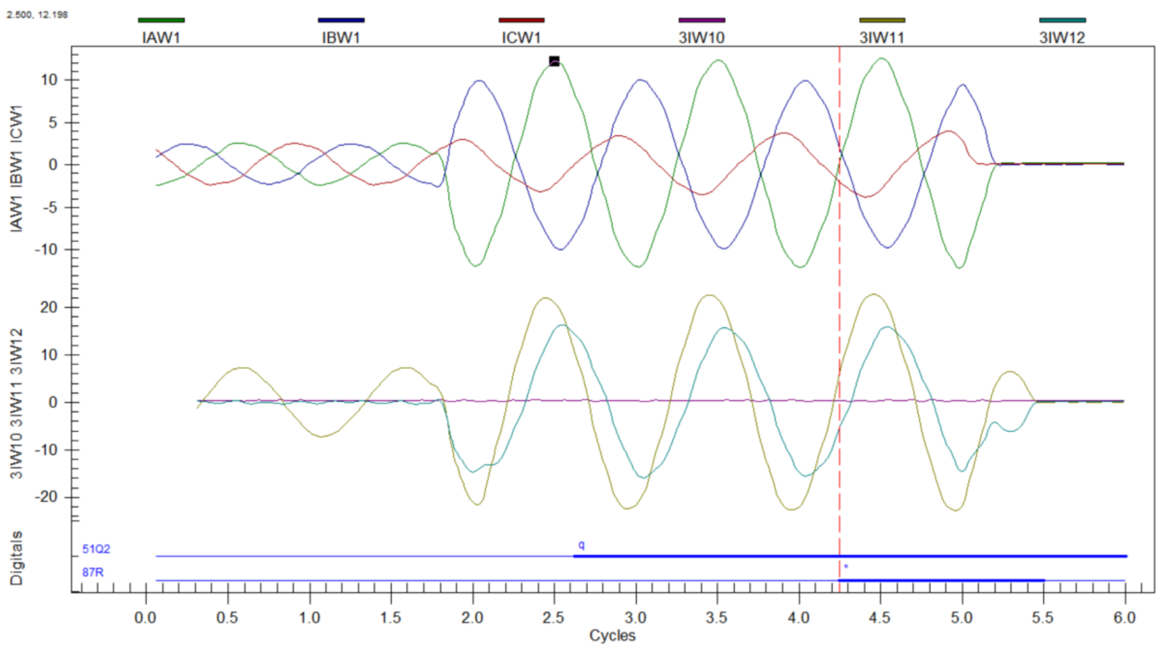

Figure 9.9: Differential Line-to-Line Fault, Bus 5

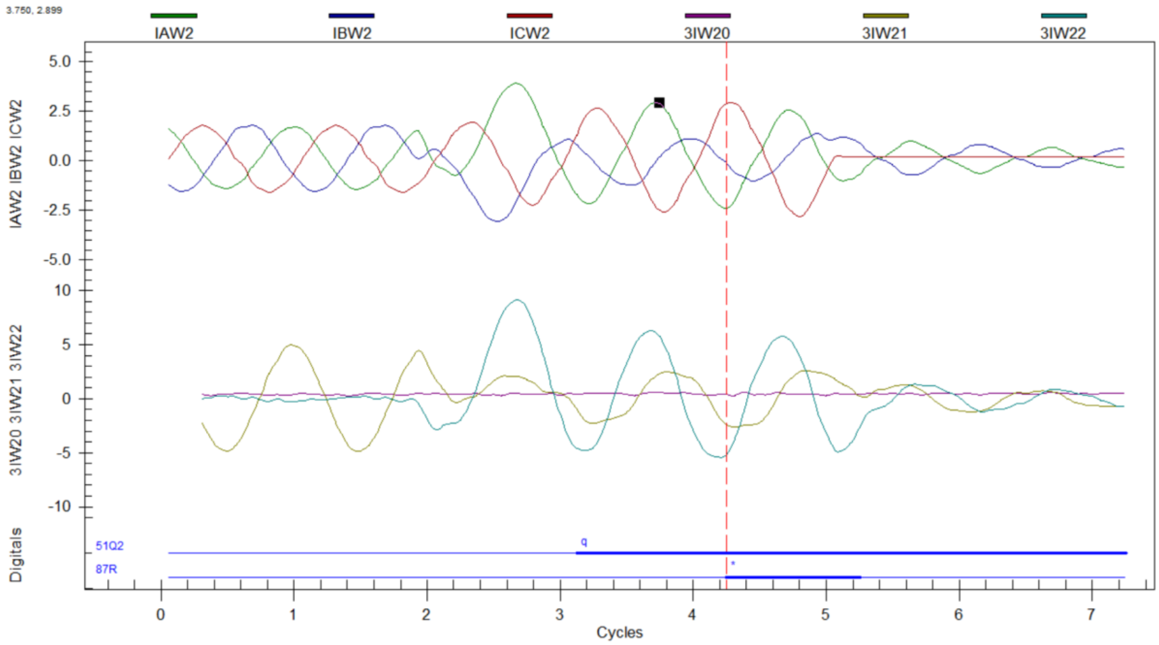

Figure 9.10: Differential Line-to-Line Fault, Bus 4

9.3.6 Three Phase Faults

There were Three Phase faults injected into the system at both Bus 4 and Bus 5 to test the differential protection. The Three Phase fault on Bus 5, the transformer's winding one, as seen in Figure 9.11 takes ~2.3 cycles from detection to clear. The Three Phase fault on Bus 2, the transformer's winding two, as seen in Figure 9.12 takes ~2.7 cycles from detection to clear.

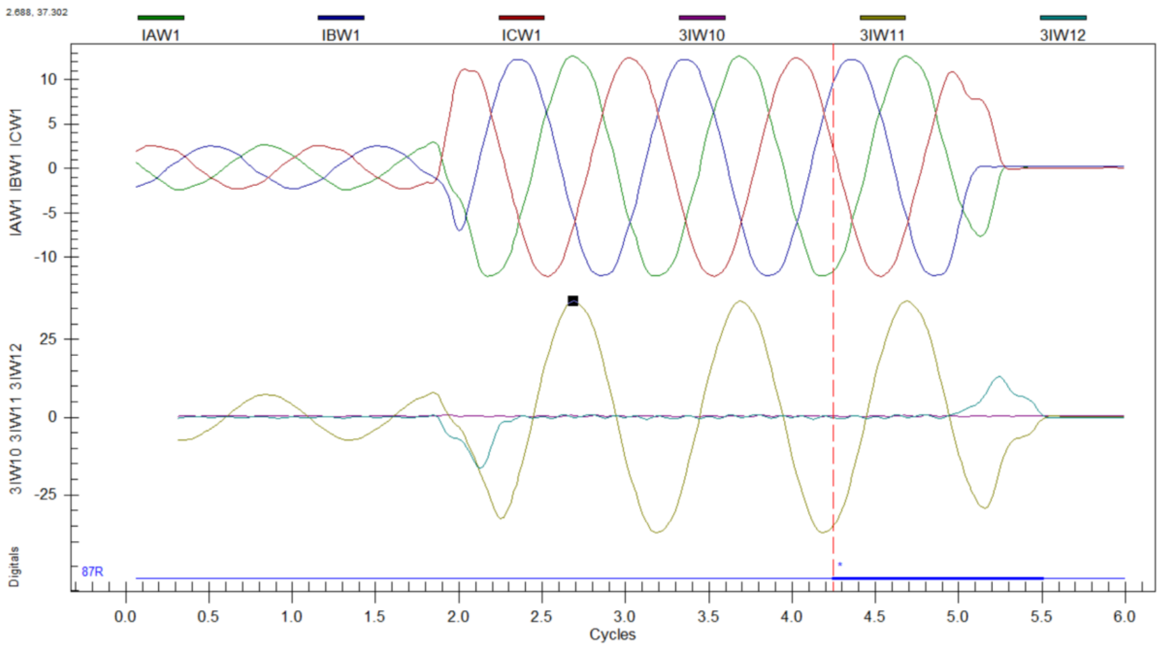

Figure 9.11: Differential Three Phase Fault, Bus 5

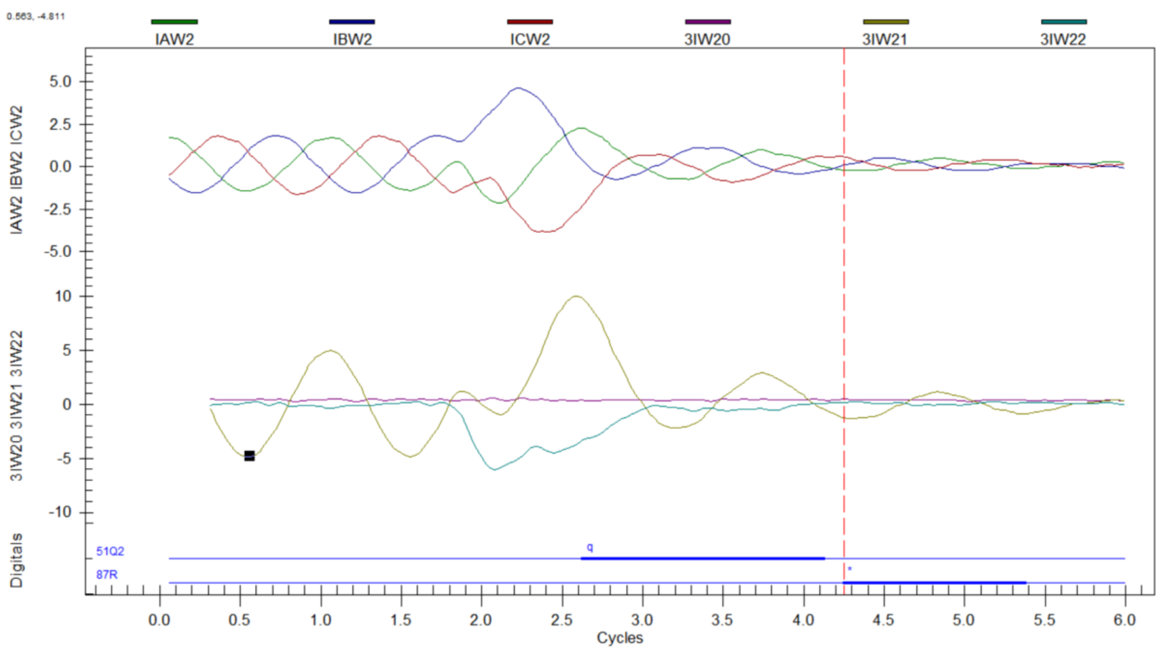

Figure 9.12: Differential Three Phase Fault, Bus 4

Chapter 10: SEL-710 Protection

10.1 SEL-710 Introduction

The SEL-710 Motor Protection Relay provides protection for a 208 V, 1/3 hp, 3-phase induction motor connected to Bus 3, the load bus, in the radial and bidirectional systems. The relay operates breaker CB-3 in response to faults at the motor terminals and for abnormal operating conditions including undervoltage, thermal overload, and locked rotor.

Settings for the 710 were chosen based on motor nameplate information, operational testing, and recommended settings from the instruction manual. The motor nameplate gives a nominal voltage of 208 V, service factor 1.35, and full-load current (FLA) of 2.4 A.

For the radial system, laboratory testing revealed that voltage drops across the current-limiting resistors and the transmission line result in a no-load voltage of 170 V_{LL} (line-to-line) at the motor terminals with a no-load current of 1.41 A. Full-load current was 2.4 A at 139 V_{LL}, and locked rotor current was 4 A at 124 V_{LL}. Based on these measurements, relay settings in the radial systems were chosen based on FLA = 1.6 A at nominal voltage of 170 V, and are shown in Group 1 settings in Appendix F.

For the bidirectional system, the motor current and voltage was: 1.6 A at 190 VLL for no-load, 3.3 A at 160 VLL for full-load, and 5.3 A at 124 VLL at locked rotor. As a result of this testing, relay settings in the bidirectional system were chosen based on 2.4 FLA and 190 V nominal voltage, and are shown in Group 2 settings in Appendix F.

10.2 SEL-710 Overcurrent Protection

10.2.1 Overview

Faults at the motor terminals are detected by instantaneous overcurrent elements in the relay. Pickup settings are based on multiples of full-load amps (FLA). The 710 is primary protection for the motor and does not provide backup protection for any other device, so there are no intentional time delays added to the timeout elements. The following faults were introduced at the motor terminals, i.e., wired in the fault module of CB-3 in Figure 6.2.

10.2.2 Single-Line-to-Ground Faults

Single line-to-ground faults are detected by the residual overcurrent element, 50G1. The residual overcurrent element in the 710 uses a current mathematically derived from measured phase currents. The element has a minimum time delay of 0.1 seconds, which was used. Pickup was set to 0.5x FLA (0.8 A).

This element was used to demonstrate additional functionality in the relay, and could be used in practice when a neutral CT was not available. The 710 also offers the 50N element, which uses a direct measurement of neutral current to operate.

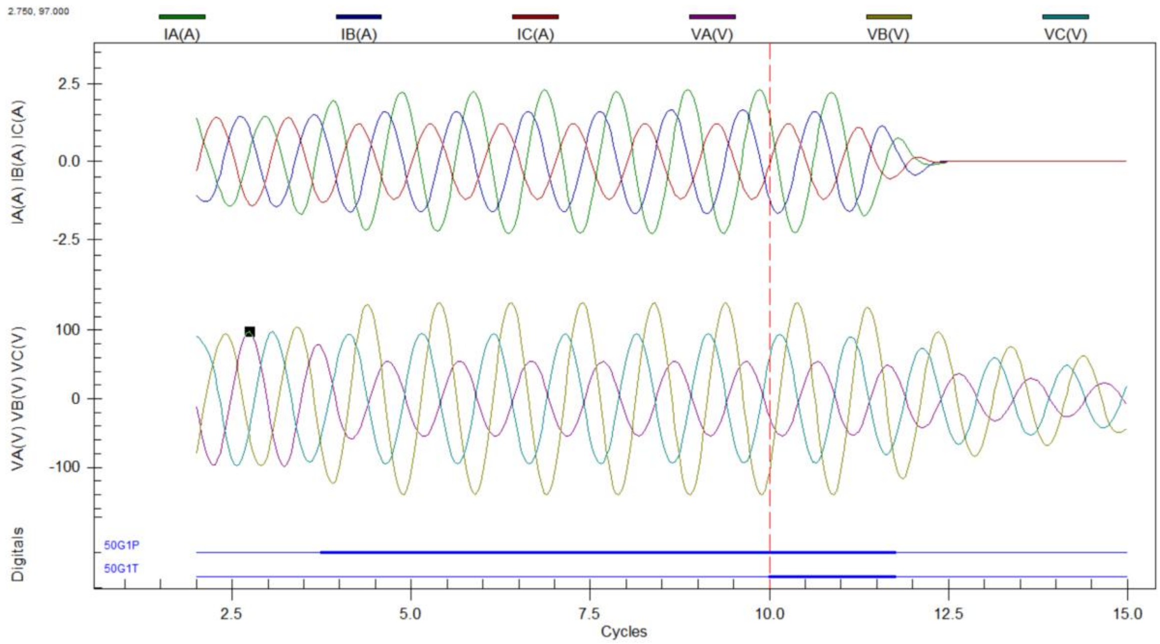

Figure 10.1: Residual Overcurrent Single Line to Ground Fault

Figure 10.1 shows the relays response to a single line-to-ground fault. The 50G1P pickup element asserts at ~3.5 cycles, indicating that the relay has detected the fault. The residual overcurrent element timeout 50G1T asserts 6 cycles later, which corresponds to the 0.1s delay in the relay settings. Since 50G1T is included in the Trip equation (TR) in the Group 1 settings, the relay opens breaker CB-3, and motor currents go to zero two cycles later, indicating the breaker is open and the fault removed.

Note that the front panel display of the 710 correctly displays “Ground Flt” when element 50G is the trip output to indicate a ground fault.

10.2.3 Double-Line-to-Ground Faults

Faults other than single line-to-ground are detected with phase overcurrent element 50P1. Pickup 50P1P was set to 3.00 x FLA with no time delay.

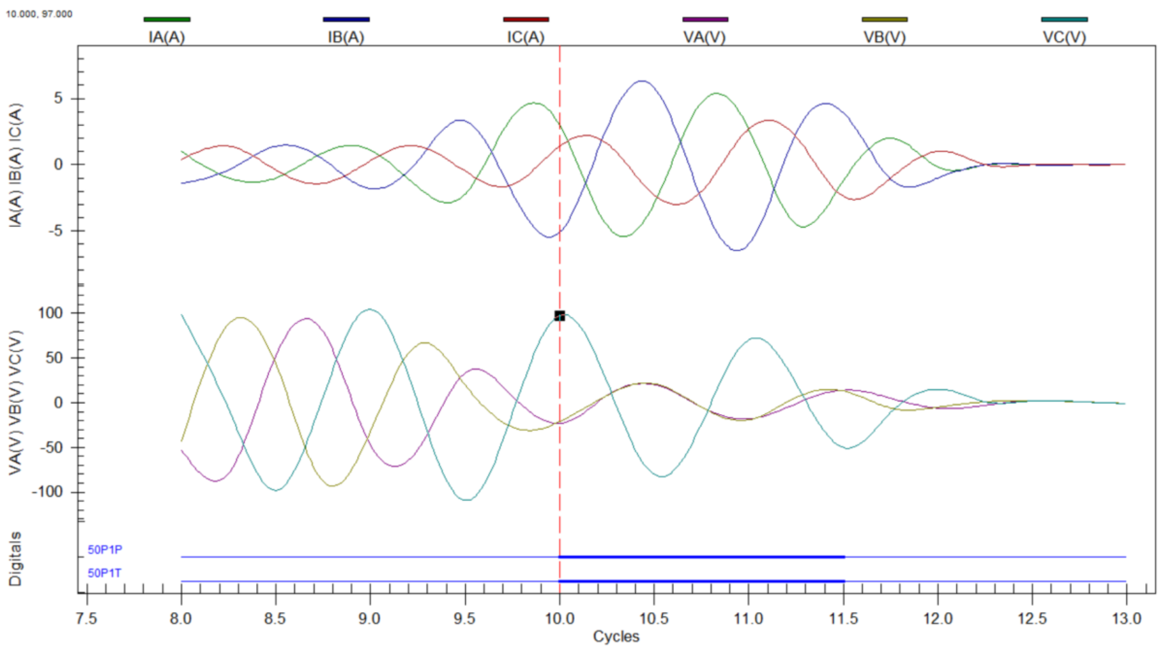

Figure 10.2: Instantaneous Phase Overcurrent Double Line-to-Ground Fault

Figure 10.2 shows the relay's response to a double line-to-ground fault. 50P1P asserts at 10 cycles into the event report. Since there is no time delay, 50P1T asserts at the same time. 50P1T is in the trip equation, and the relay opens breaker CB-3, clearing the fault 2 cycles later.

Note that for overcurrent faults, the relay front panel indicates an "Overcurrent" condition on the text display as well as indicator LED.

10.2.4 Triple-Line-to-Ground Faults

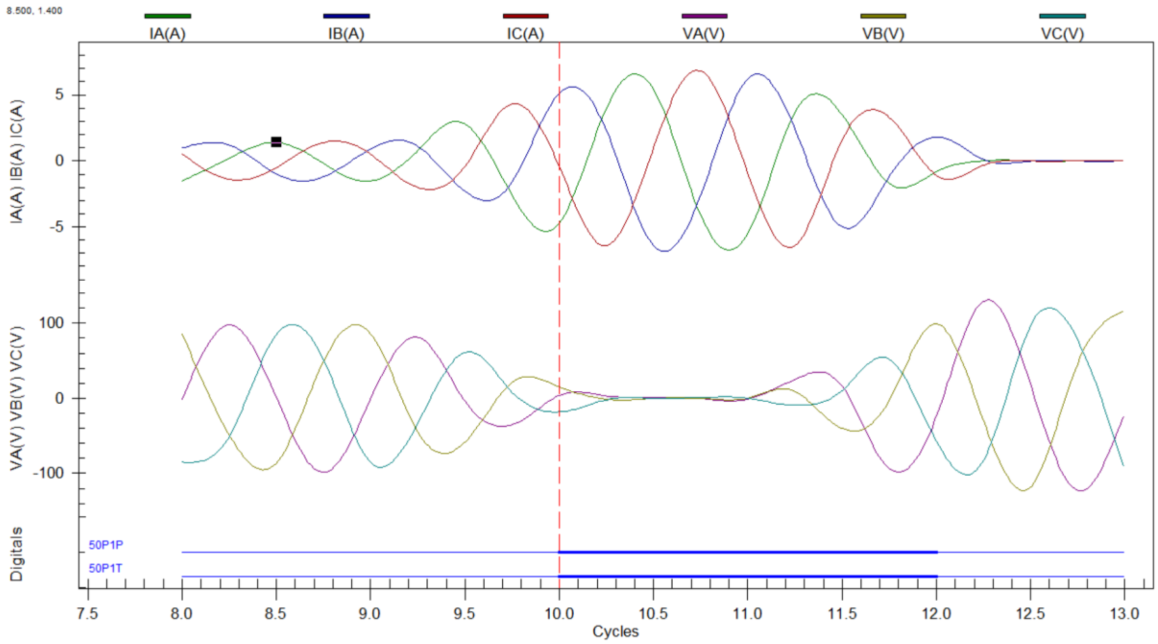

Figure 10.3: Instantaneous Phase Overcurrent Triple Line-to-Ground Fault

Figure 10.3 shows the relay's response to a triple line-to-ground fault. 50P1P asserts at 10 cycles into the event report, along with 50P1T. The relay operates to open breaker CB-3, clearing the fault 2 cycles later.

10.2.5 Line-to-Line Faults

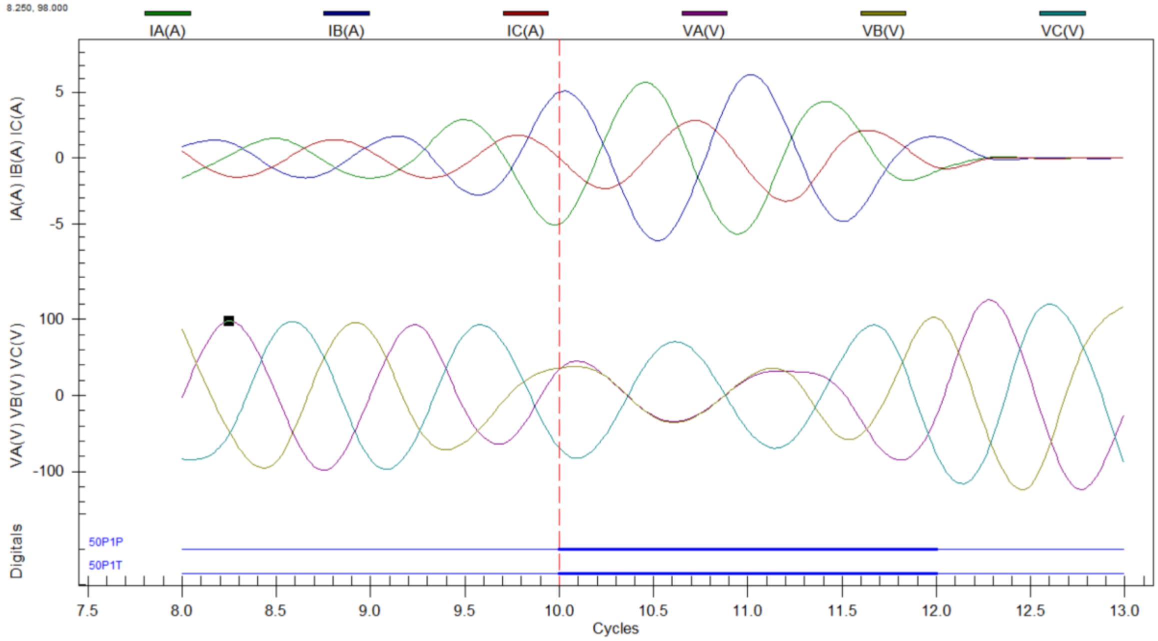

Figure 10.4: Instantaneous Phase Overcurrent Line-to-Line Fault

Figure 10.4 shows the relay's response to a line-to-line fault. 50P1P asserts at 10 cycles into the event report, along with 50P1T. The relay operates to open breaker CB-3, clearing the fault 2 cycles later.

Not appearing here, the negative sequence overcurrent element, 50Q, provides redundancy for unbalanced faults involving two phases. It also protects the motor against phase loss, as an alternative to the current imbalance (46) element. 50Q settings are shown in Appendix F.

10.2.6 Three Phase Faults

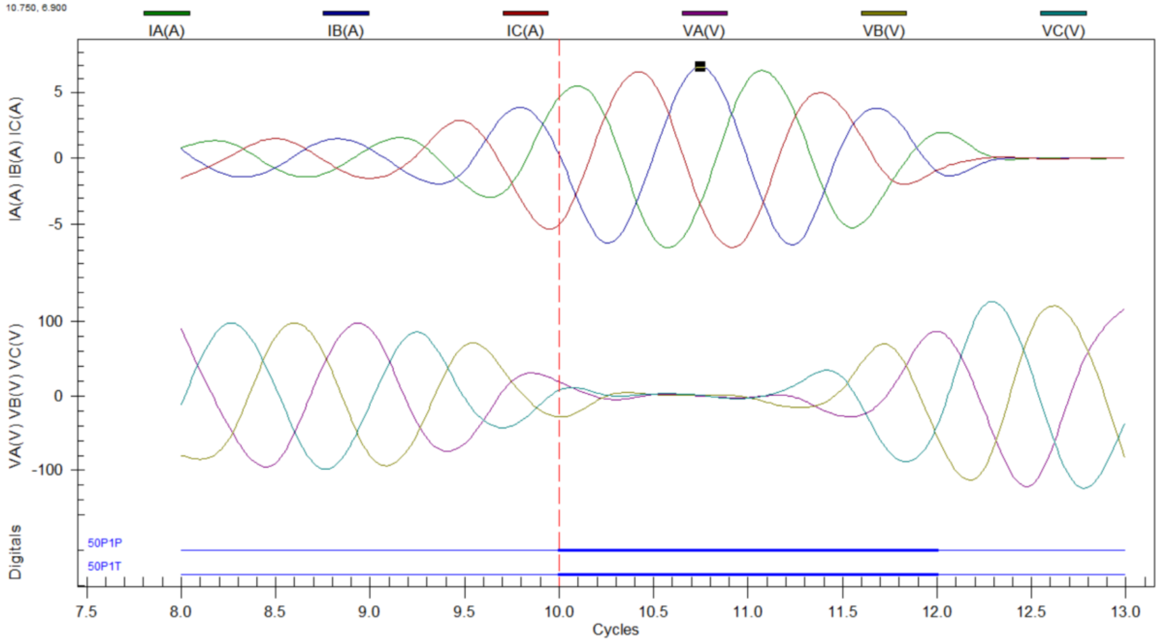

Figure 10.5: Instantaneous Phase Overcurrent Three-Phase Fault

Figure 10.5 shows the relay's response to a line-to-line fault. 50P1P asserts at 10 cycles into the event report, along with 50P1T. The relay operates to open breaker CB-3, clearing the fault 2 cycles later.

10.3 SEL-710 Undervoltage Protection

Undervoltage protection is enabled on the 710 through the 27P1 element, which is set to a percentage of the motor nominal voltage (Vnm) selected. For this project, due to system constraints, the motor's no-load voltage was used instead of the nameplate value.

Element 27 pickup 27P1P was set to 0.70 x Vnm, with a time delay of 3 seconds. Settings were tested by increasing the motor load until VLL decreased to 70% of nominal and waiting for 3 seconds.

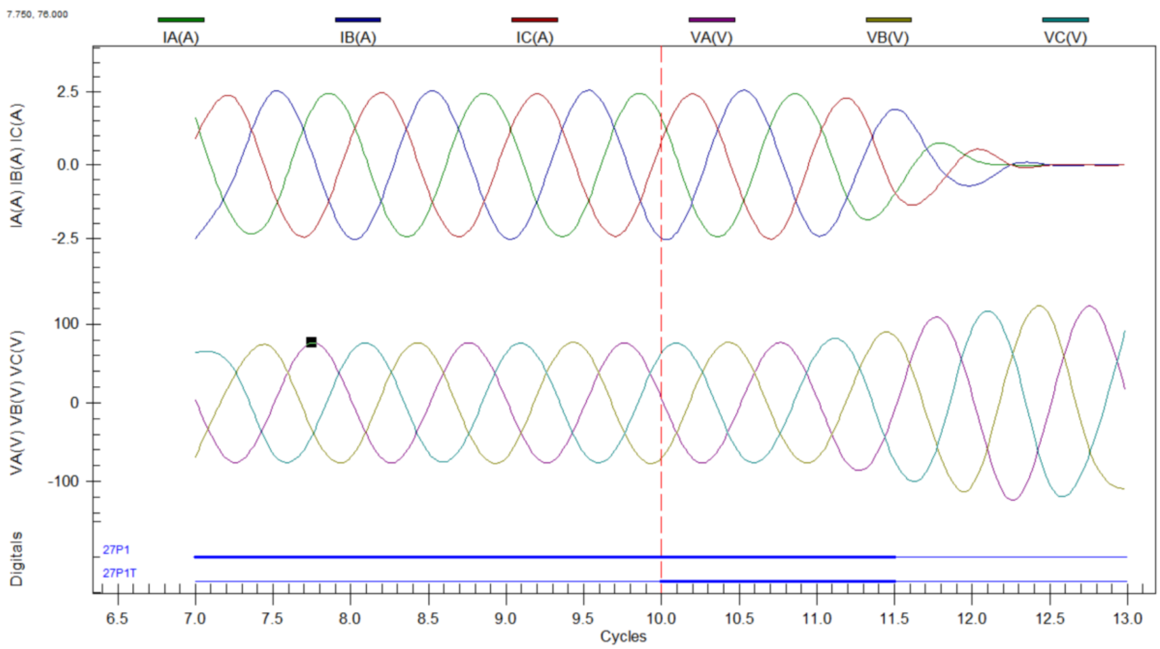

Figure 10.6: Induction Motor Phase Undervoltage

Figure 10.6 shows the relay's response to an undervoltage condition. 27P1 indicates that the relay detects the undervoltage, and 27P1T asserts 3 seconds after 27P1. Note that the relay event reports in the 710 are either 15 or 64 cycles long, so showing the entire undervoltage event is not possible. Again, the breaker takes 2 cycles to open after the timeout is asserted.

10.4 SEL-710 Locked-Rotor Protection

Locked rotor protection is provided by the 710's thermal element, 49. Settings are chosen for motor locked rotor amps (LRA1) and hot locked rotor time (LRTHOT1). The relay then trips in hot locked rotor time at locked rotor amps.

For this project, LRA = 2.5 x FLA and LRTHOT = 3 seconds. A locked rotor time of 3 seconds provides enough time to observe the relay's response to a locked rotor condition as well as thermal overload, but not so much time as to incur motor damage from high rotor currents.

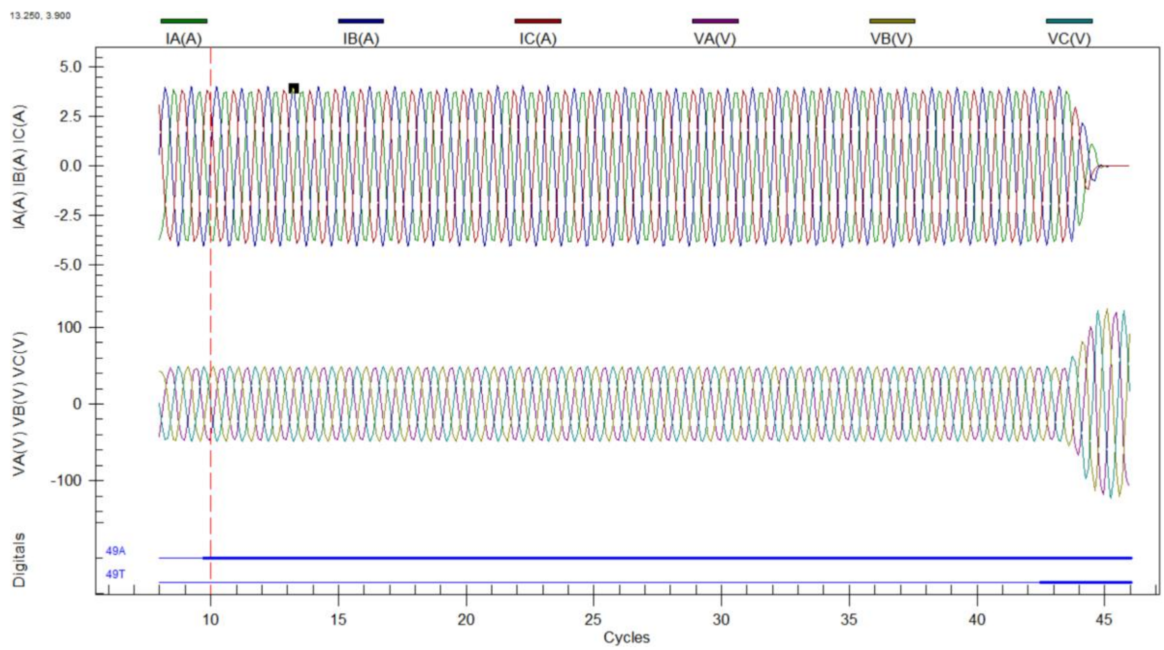

Figure 10.7: Induction Motor Locked Rotor

Figure 10.7 shows the relay's response to a locked rotor condition. 49A is asserted, which indicates the relay detects current above FLA, and in this case above LRA. 3 seconds later, thermal element timeout 49T asserts, and the relay trips the breaker, isolating the motor. Note again that the full 3 second duration obviously cannot be shown in a 64-cycle event report.

10.5 SEL-710 Thermal Overload Protection

Thermal overload protection is enabled in the relay by enabling element 49 (E49MOTOR = YES). As described in section 3.2.3, the relay uses motor characteristics to produce a thermal curve similar to the one shown in Figure 3.2. Using the locked rotor settings in the previous section with thermal method "Rating" used, the thermal overload element was tested by increasing motor loading until motor current approximately 1.5 x FLA was measured at the motor terminals. Based on this current, the time to trip is given by the following equation [7]:

$$T_p = \left[\frac{T_O \bullet (TD + 0.2)}{\ln\left[\frac{I_L^2 - (0.9 \bullet SF)^2}{I_L^2 - SF^2}\right]} \right] \bullet \ln\left[\frac{I^2 - (0.9 \bullet SF)^2}{I^2 - SF^2}\right]$$

where

T_p = trip time in seconds

T_O = LRTHOT setting

T_D = acceleration factor setting

I_L = LRA setting

SF = motor service factor

I = motor current in multiples of FLA

Using these values, expected trip time Tp is approximately 28 s.

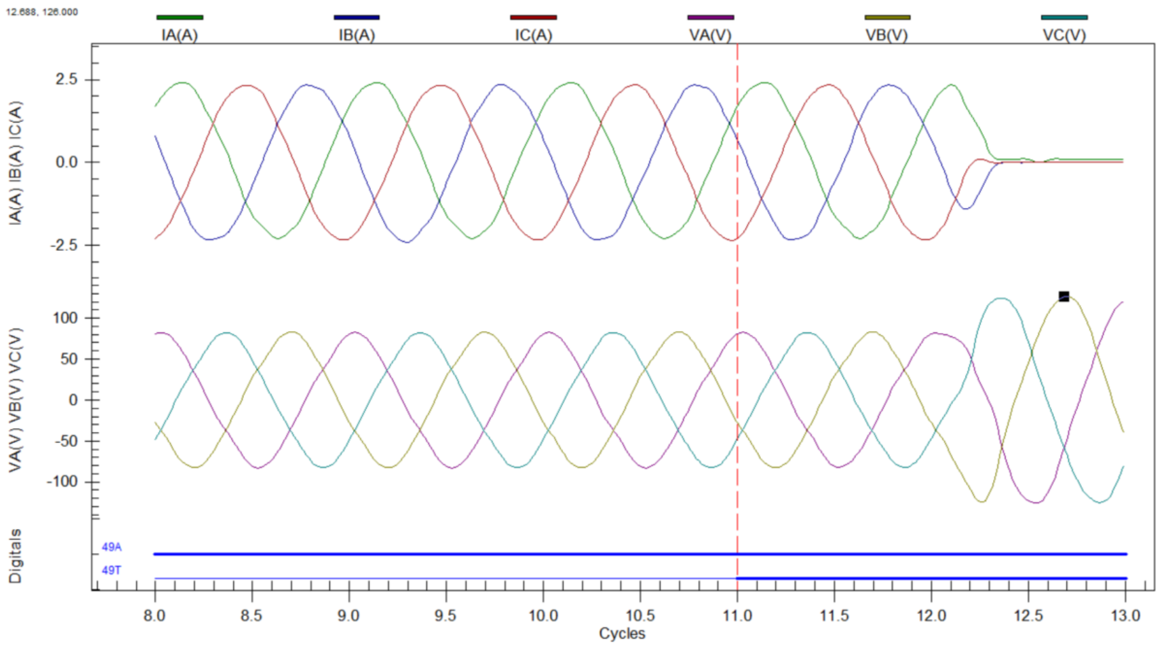

Figure 10.8: Induction Motor Thermal Overload

Figure 10.8 shows the relay's response when motor load was increased until motor current was 1.5 x FLA. Based on the above equation, the expected trip time was approximately 28 s.

After the motor load was increased gradually above FLA, the front panel of the 710 displayed a countdown starting from ~100 seconds. The countdown quickly ran down to ~30 seconds when motor current reached 1.5 X FLA. When the front panel count reached 0, the relay tripped the breaker, which corresponds to the assertion of 49T in Figure 10.8.

Chapter 11: Radial System Coordination

11.1 Radial Coordination Overview

This chapter demonstrates relay coordination in the radial system shown in Figure 6.1. This coordination is accomplished by placing a fault at the terminals of the induction motor, and selecting relay settings such that the relays trip in the following order assuming downstream devices fail to operate: the 710 should trip first, followed by the 311L, followed finally by the 387E.

A fault at the motor terminals is within the primary protection zone of the 710, which should clear the fault as soon as possible, i.e., with no intentional delay. If the 710 does not operate, the 311L should then trip the transmission line, providing backup for the 710. This is accomplished by introducing a time delay in the zone 2 distance element and the inverse time-overcurrent elements of the 311L so that it will not trip immediately for faults outside of its primary protection zone (the transmission line). If both fail to operate, the 387E should open the breaker on the secondary side of the transformer, providing backup protection for the 311L and the 710. This is accomplished by introducing a higher time dial setting for the overcurrent elements of the 387E, ensuring that it trips later than the 311L for faults outside of its primary protection zone (the transformer).

This is demonstrated in practice by wiring a fault at the motor terminals, and preventing devices from tripping by shorting the trip coils of the circuit breakers CB-2 and CB-3, but not CB-1S (allowing the 387E to clear the fault). Although the breakers cannot trip, the relays record the trip events, allowing for event analysis. Since the relays are time-synchronized by the timing signal provided by the SEL-2032 Communications Processor from the SEL-2407 Satellite Clock, the events are on a common time base. Looking at the events reveals when the relays would have tripped had the trip coils not been shorted, allowing verification of the coordination scheme.

See Appendix H for the procedure for using the 2032 for port switching between connected relays and synchronized timing signal distribution.

11.2 Single Line-to-Ground Fault

Tables 11.1 and 11.2 show the response of the relays to a single line-to-ground fault at the terminals of the motor. “Time delta” indicates the time elapsed referenced to the first relay pickup element to assert after the fault was introduced.

TABLE 11.1: RADIAL COORDINATION FAULT DETECTION, SINGLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L	51Q	Fault Detected
10	387E	51Q2	Fault Detected
11	710	50G1P	Fault Detected

All three relays detect the fault within a cycle of each other. The 387E and the 311L assert the pickups for their respective negative-sequence inverse time-overcurrent elements, while the 710 asserts the pickup for its residual ground element. Note that in the radial system, single line-to-ground fault detection is based on negative sequence currents, since the phase overcurrent elements in the 311L and 287E are set above fault current magnitude to avoid tripping for inrush current.

TABLE 11.2: RADIAL COORDINATION TRIP SEQUENCE, SINGLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
115	710	50G1T, TRIP	Timeout and Trip
230	311L	51QT, TRIP	Timeout and Trip
622	387E	51Q2T, TRIP	Timeout and Trip

The 710 asserts its trip signal at 115 ms, which corresponds to the 0.1 s time delay on the 50G element. At 230 ms, the 311L asserts its trip signal based on the timeout of its 51Q element. At 622 ms, the 387E successfully trips based on the timeout of its 51Q2 element, clearing the fault and demonstrating the correct tripping sequence for the protection scheme.

11.3 Double Line-to-Ground Fault

Tables 11.3 and 11.4 show the response of the relays to a double line-to-ground fault at the motor terminals.

TABLE 11.3: RADIAL COORDINATION FAULT DETECTION, DOUBLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L	51Q	Fault Detected
6	387E	51Q2	Fault Detected
22	710	50P1P	Fault Detected

As in the single line-to-ground fault, fault current is detected by the 51Q element in both the 311L and the 387E. Fault current is above the pickup for the 710's 50P element, which operates faster than the 50G.

TABLE 11.4: RADIAL COORDINATION TRIP SEQUENCE, DOUBLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
22	710	TRIP	Instantaneous Trip
87	311L	51QT, TRIP	Timeout and Trip
139	387E	51Q2T, TRIP	Timeout and Trip

Greater fault current magnitude results in faster tripping for the 51 elements of the 311L and 387E. The 710's 50P element has no time delay, so it trips within two cycles of fault detection. Coordination is maintained even with faster trip times.

11.4 Triple Line-to-Ground Fault

Tables 11.5 and 11.6 show the response of the relays to a triple line-to-ground fault at the motor terminals.

TABLE 11.5: RADIAL COORDINATION FAULT DETECTION, TRIPLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L	M2P	Fault Detected
6	710	50P1P	Fault Detected
11	387E	51P2	Fault Detected

For a triple line-to-ground fault at the motor terminals, fault current is above the phase overcurrent pickup of the 387E and the zone 2 distance pickup of the 311L. As before, the 50P element of the 710 detects the fault.

TABLE 11.6: RADIAL COORDINATION TRIP SEQUENCE, TRIPLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
6	710	TRIP	Instantaneous Trip
417	311L	M2PT, TRIP	Timeout and Trip
707	387E	51P2T, TRIP	Timeout and Trip

The relays maintain proper coordination, though trip times are slower than for a double line-to-ground fault. This is due to the intentional time delay added to the 311L's distance element and the 387E's 51P element, which is necessary to ride through motor inrush current. Since the fault is three-phase, negative sequence currents are not present for fault detection.

11.5 Line-to-Line Fault

Tables 11.7 and 11.8 show the response of the relays to a line-to-line fault at the motor terminals.

TABLE 11.7: RADIAL COORDINATION FAULT DETECTION, LINE-TO-LINE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	SEL 311L	51Q	Fault Detected
32	SEL 710	50P1P	Fault Detected
32	SEL 387E	51Q2	Fault Detected

As in the double-line-to-ground, the fault is detected by the 50P element of the 710, and the 51Q element of the 311L and 387E.

TABLE 11.8: RADIAL COORDINATION TRIP SEQUENCE, LINE-TO-LINE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
32	SEL 710	TRIP	Instantaneous Trip
87	SEL 311L	51QT, TRIP	Timeout and Trip
157	SEL 387E	51Q2T, TRIP	Timeout and Trip

The presence of negative sequence fault current allows the relays to trip based on the faster settings of the 51Q elements, while maintaining coordination.

11.6 Three-Phase Fault

Tables 11.9 and 11.10 show the response of the relays to a three-phase fault at the motor terminals.

TABLE 11.9: RADIAL COORDINATION FAULT DETECTION, 3 PHASE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	SEL 311L	M2P	Fault Detected
6	SEL 710	50P1P	Fault Detected
11	SEL 387E	51P2	Fault Detected

As in the triple line-to-ground fault, the fault is detected in the 710's 50P element, the Zone 2 distance element of the 311L, and the 51P element of the 387E.

TABLE 11.10: RADIAL COORDINATION TRIP SEQUENCE, 3 PHASE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
6	SEL 710	TRIP	Instantaneous Trip
416	SEL 311L	M2PT, TRIP	Timeout and Trip
706	SEL 387E	51P2T, TRIP	Timeout and Trip

As in the case of the triple line-to-ground fault, trip times are slower than in the double line-to-ground fault due to relay element sensitivity. Coordination is maintained, at the protection scheme operates within the required 1 second clearance time dictated by the project requirements.

Chapter 12: Bidirectional System Coordination

12.1 Bidirectional Coordination Overview

Coordination of the bidirectional system shown in Figure 6.5 follows the same general principles as coordination in the radial system. By applying a fault condition at Bus 3 and preventing breakers CB-2, -3, and -4 from opening, the sequence of relay operation can be determined by looking at the time-synchronized event reports of each relay.

Unlike the radial system, the bidirectional system is fed from two sources: ABC and DEF. Therefore, opening only one line will not remove a fault at Bus 3, which can still be fed from the other line. Therefore, the protection scheme must open both lines to clear the fault, and relays must be coordinated for the entire system to do so. This means that for a fault at the motor terminals, the 710 should operate first, both 311Ls should operate next, and the 387E and 587 should both operate, but only after all other relays.

As in the radial system, the 710 has no intentional time delay added to its settings. The 311Ls use a low time dial setting to coordinate with the 710. The 387E and 587 use higher time dials to coordinate with the 311Ls and therefore with the 710.

12.2 Single Line-to-Ground Fault

Tables 12.1 and 12.2 show the response of the relays to a single line-to-ground fault at the motor terminals.

TABLE 12.1: BIDIRECTIONAL FAULT DETECTION, SINGLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L - LINE 1	51Q	Fault Detected
1	710	50G1P	Fault Detected
6	311L - LINE 2	51Q	Fault Detected
9	387E	51Q2	Fault Detected
1360	587	51Q2	Fault Detected

All relays except the 587 detect the fault almost immediately. As in the radial system, the 710 uses the 50G element, which has a small time delay, to detect the fault. The other relays use 51Q elements to detect the fault, as the low fault current magnitude is below phase overcurrent pickups, which are purposefully set to avoid relays incorrectly operating on motor inrush current.

The 587 takes over a second to detect the fault with the 51Q element on winding 2, due to low fault current magnitude and heavy transformer saturation under even pre-fault conditions. This combination makes single line-to-ground faults the hardest to detect and the slowest to be cleared by the transformer protection relays.

TABLE 12.2: BIDIRECTIONAL RELAY OPERATION, SINGLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
105	710	50G1T, TRIP	Timeout and Trip
321	311L - LINE 1	51QT, TRIP	Timeout and Trip
401	311L - LINE 2	51QT, TRIP	Timeout and Trip
1735	387E	51Q2T, TRIP	Timeout and Trip
2593	587	51Q2T, TRIP	Timeout and Trip

The 710 trips after the 0.1s delay of the 50G element. The 311Ls trip in a comparable amount of time to radial system. The differential relays, however, take a few seconds to trip, due to the low fault current magnitude. Fault current due to faults at the motor bus is split between the lines, so each differential relay sees a very small fault current magnitude, resulting in long trip times for the 587 and 387E. These relays, however, are two steps removed from the comparatively low-current fault, which makes the delay tolerable, though not ideal.

As desired, the relays display proper coordination.

12.3 Double Line-to-Ground Fault

Tables 12.3 and 12.4 show the response of the relays to a double line-to-ground fault at the motor terminals.

TABLE 12.3: BIDIRECTIONAL FAULT DETECTION, DOUBLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L - LINE 1	51Q	Fault Detected
1	311L - LINE 2	51Q	Fault Detected
2	387E	51Q2	Fault Detected
7	710	50P1P	Fault Detected
9	587	51Q2	Fault Detected

As was the case in the radial system, the 710 picks up the higher-current double line-to-ground fault with the 50P element, while the other relays again rely on the 51Q element.

TABLE 12.4: BIDIRECTIONAL RELAY OPERATION, DOUBLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
7	710	TRIP	Instantaneous Trip
80	311L - LINE 2	51QT, TRIP	Timeout and Trip
84	311L - LINE 1	51QT, TRIP	Timeout and Trip
109	587	51Q2T, TRIP	Timeout and Trip
114	387E	51Q2T, TRIP	Timeout and Trip

Relays trip in the proper order, and much faster than was the case for the single line-to-ground fault. The relays remain coordinated correctly, even though the total time for every relay to trip is only 114 ms.

12.4 Triple Line-to-Ground Fault

Tables 12.5 and 12.6 show the response of the relays to a triple line-to-ground fault at the motor terminals.

TABLE 12.5: BIDIRECTIONAL FAULT DETECTION, TRIPLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L - LINE 1	M2P	Fault Detected
2	311L - LINE 2	M2P	Fault Detected
6	710	50P1P	Fault Detected
7	587	51P2	Fault Detected
8	387E	51P2	Fault Detected

As was the case for the radial system, the higher fault current for the triple line-to-ground fault is detected by the higher 51P elements in the differential relays, while the 311Ls detect the fault in Zone 2 with their distance elements, as is expected.

TABLE 12.6: BIDIRECTIONAL RELAY OPERATION, TRIPLE LINE-TO-GROUND

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
6	710	TRIP	Instantaneous Trip
217	311L - LINE 1	PTRX, TRIP	Permissive Signal Received and Trip
248	311L - LINE 2	PTRX, TRIP	Permissive Signal Received and Trip
699	587	51P2T, TRIP	Timeout and Trip
701	387E	51P2T, TRIP	Timeout and Trip

Use of the POTT scheme between the two 311Ls (as detailed in Chapter 7) reduces the trip time for the line relays from the ~400 ms seen in the single line-to-ground fault to ~200 ms. By bypassing the individual distance element timeouts, the time-to-trip is reduced significantly, enhancing the response of the protection scheme overall.

The use of time-delayed 51P elements in the differential relays result in a longer trip time than was the case for the double line-to-ground fault, through comparable to that of the radial system.

12.5 Line-to-Line Fault

Tables 12.7 and 12.8 show the response of the relays to a line-to-line fault at the motor terminals.

TABLE 12.7: BIDIRECTIONAL FAULT DETECTION, LINE-TO-LINE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	311L - LINE 1	51Q	Fault Detected
1	311L - LINE 2	51Q	Fault Detected
11	587	51Q2	Fault Detected
13	710	50P1P	Fault Detected
28	387E	51Q2	Fault Detected

Just as in the double line-to-ground fault, the line and transformer relays detect the negative-sequence fault current, while the 710 uses the instantaneous phase overcurrent element.

TABLE 12.8: BIDIRECTIONAL RELAY OPERATION, LINE-TO-LINE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
13	710	TRIP	Instantaneous Trip
85	311L - LINE 2	51QT, TRIP	Timeout and Trip
88	311L - LINE 1	51QT, TRIP	Timeout and Trip
111	587	51Q2T, TRIP	Timeout and Trip
140	387E	51Q2T, TRIP	Timeout and Trip

Again as in the double line-to-ground fault, the relays operate quickly, requiring less than 150 ms for the slowest relay to operate.

12.6 Three-Phase Fault

Tables 12.9 and 12.19 show the response of the relays to a three phase fault at the motor terminals.

TABLE 12.9: BIDIRECTIONAL FAULT DETECTION, THREE PHASE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	710	50P1P	Fault Detected
0	311L - LINE 2	M2P	Fault Detected
1	311L - LINE 1	M2P	Fault Detected
10	587	51P2	Fault Detected
35	387E	51P2	Fault Detected

Not surprisingly, the relay response to the fault is almost identical to that seen during the triple line-to-ground fault.

TABLE 12.10: BIDIRECTIONAL RELAY OPERATION, THREE PHASE

TIME DELTA (mSEC)	SEL RELAY DEVICE	ASSERTED ELEMENTS	COMMENT
0	710	TRIP	Instantaneous Trip
213	311L - LINE 1	PTRX, TRIP	Permissive Signal Received and Trip
245	311L - LINE 2	PTRX, TRIP	Permissive Signal Received and Trip
701	587	51P2T, TRIP	Timeout and Trip
751	387E	51P2T, TRIP	Timeout and Trip

Again as in the triple line-to-ground fault, the POTT scheme of the 311Ls results in faster trip times, while the differential relays time out normally. Coordination is maintained, and the slowest relay still operates within three quarters of a second.

Chapter 13: Conclusion

13.1 Challenges Encountered

Any project of this scope and complexity would necessarily present challenges for the designers and this one was no exception. Early difficulties resulted from unfamiliarity with the circuit breakers and relay wiring, while later challenges came primarily from the rather steep learning curve of relay programming and the intricacies of each individual relay. Several of the challenges encountered, and the solutions thereto, are included here that others may learn from our experiences.

When the radial system was initially constructed and the circuit breakers described in Chapter 3 were connected, the manual Close button would not close the circuit breakers even when powered. After locating the circuit breaker schematic shown in Figure 3.2, it was discovered that the Trip coil terminals (which correspond to "SEL OUT103" in the figure) must either be shorted with a jumper or connected to the output contacts of an SEL relay in order to complete the 125 VDC circuit when the Close button was pressed.

Early on, even wiring the relays correctly was difficult. The differential relays (the 387E and 587) require that careful attention be paid to current polarities when connecting phase wires to the relay input windings. For a differential relay, reversing the direction of current in one of the windings causes the relay to continuously see operating current regardless of system condition. It was necessary to carefully read the relevant sections in the instruction manuals (as well as contact SEL for engineering support) to ensure that current polarities were correctly wired.

Speaking of wiring, accidentally changing phase sequence can cause relay misoperation. PG&E uses an ACB phase sequence in their system, to which the MPSL is tied via the 240 V source. Connecting the transmission line in an ABC sequence results in connected relays tripping for negative sequence (in the case of the 387E and 587) or for incorrect phase rotation (PHROT in the 710 settings). Carefully checking relay connections fixes this.

The 3 kVA bench transformers used in the project operate continuously in saturation, especially in delta-delta configuration, and can pull over an amp of magnetization current even while operating at no-load condition. The current harmonics associated with this transformer overexcitation can cause differential relays to operate whenever the transformer is energized and for nominal load currents. In the case of the 587, this was solved by decreasing the relay's differential sensitivity (the O87P setting) or utilizing the fifth-harmonic blocking feature (the PTC5 setting) of the relay can prevent misoperation. For the MPSL, slightly reduced sensitivity was chosen, as harmonic-blocking at high sensitivity levels resulted in rare, through unpredictable, nuisance trips. The lower sensitivity was sufficient to detect all internal transformer faults, and was therefore chosen for increased security.

In the same vein, the presence of an induction motor complicated the project due mostly to the inrush current associated with motor starting. Relay overcurrent settings must take this inrush current into account in order to avoid overcurrent trips for short-duration inrush currents. The issue becomes manageable with system characterization and measurement of load and inrush currents before choosing relay settings.

13.2 Summary of Results

The project was concluded successfully, satisfying the engineering specifications driven by the marketing requirements covered in Chapter 2 and shown in Table 2.1 and Table 2.2. As shown in Chapters 7 through 10, all faults in primary protection zones are cleared within 1 second. Secondary protection for each zone is provided by upstream relays, ensuring that faults are cleared even in the event of primary protection failure. The protection scheme is time-coordinated, with events recorded on a common time base, as detailed in Chapters 11 and 12. As required in Table 2.2, the induction motor is protected not only against faults but also from abnormal operations including overload, locked rotor, and undervoltage conditions. Thorough device and system characterization ensures that the protection scheme does not operate for permissible normal operating conditions, including large inrush current during motor startup and while energizing and de-energizing transformers. Finally, this report is intended to provide a useful resource for future students, serving to increase the Electrical Engineering Department’s knowledge base in microprocessor relays.

13.3 Future Work

The MPSL and its parent project, the PRSL, are designed to form the basis of a new Cal Poly Microgrid project. To that end, adding local generation in the form of a synchronous generator or solar panels will allow the system to be islanded from PG&E. Local storage, in the form of batteries, will supplement local generation and also provide additional fault current for protective relays. Adding a switchable capacitor bank at the load bus will provide voltage support for the induction motor and allow exercises in power factor correction and reactive power management, a significant issue in modern power transmission as well as microgrids.

The MPSL also provides an excellent test bed for automation controllers, such as the SEL-3530 Real Time Automation Controller (RTAC). The RTAC can be programmed to control the system in response to changing conditions, such as automatically closing in a capacitor bank in response to low motor voltage, or closing in a synchronous generator when connection to PG&E is lost. Using SEL's Diagram Builder software, the RTAC can be used to create an HMI on a remote workstation that displays currents and voltages in the system in real time, as might be found in a refinery substation or electric power utility operations center.

References

[1] K. W. Pretzer, "Protective Relaying Student Laboratory," M.S. thesis, Dept. Elect. Eng., California Polytechnic State Univ., San Luis Obispo, Ca, 2017.

[2] J. L. Blackburn and T. J. Domin, *Protective Relaying: Principles and Applications*, 4th Ed., Boca Raton, FL: CRC Press, 2014.

[3] SKM Systems Analysis, Inc., "Equipment damage motor curves," 2012. [Online]. Available: http://www.skm.com/applicationguides6.html.

[4] *SEL-387E Relay Instruction Manual*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2016. Available: https://selinc.com/products/387e/.

[5] *SEL-587-0,-1 Relay Instruction Manual*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2015. Available: https://selinc.com/products/587/.

[6] *SEL-311L,-6 Relay Instruction Manual*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2015. Available: https://selinc.com/products/311L.

[7] *SEL-710 Relay Instruction Manual*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2015. Available: https://selinc.com/products/710.

[8] *SEL-2032 Communications Processor Instruciton Manual*, Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2015. Available: https://selinc.com/products/2032.

[9] *SEL-2407 Satellite Synchronized Clock Instruction Manual*, Schweitzer Engineering Laboratories, Inc., Pullman,WA, 2016. Available: https://selinc.com/products/2407.

[10] O. Corulli, "Motor Protection Lab Experiment using SEL-710," senior project report, Dept. Elect. Eng., California Polytechnic State Univ., San Luis Obispo, CA, 2013.

[11] R. M. Ford and C. S. Coulston, "Project Management," in *Design for Electrical and Computer Engineers*, New York, NY, McGraw-Hill, 2008, p. 205.

APPENDIX A: PROJECT COSTS

Table A.1 details the material costs incurred for the project. Compare with estimated project costs in Chapter 5.

TABLE A.1: PROJECT COSTS

Item	Quantity	Unit Cost	Cost
#10 Spade Terminal, 100 pcs.	1	$6.19	$6.19
#10 Spade Terminal, 75 pcs.	1	$6.97	$6.97
Banana Plug, Colored 25 pcs.	6	$10.99	$65.94
Cable Zip Ties, 1000 pcs.	1	$5.79	$5.79
Command Clips	3	$9.98	$29.94
Crimp Tool	1	$5.95	$5.95
M10 Ring Crimp Terminal, 50 pcs.	1	$10.99	$10.99
Velcro Straps (50 per pack)	1	$7.99	$7.99
Wire-12 AWG, 100 ft	1	$20.37	$20.37
Wire-12 AWG, 50 ft	8	$12.97	$103.76
Wire-12 AWG, 50 ft	2	$11.37	$22.74
Total			**$286.63**

APPENDIX B: SEL-311L LINE 1 SETTINGS

Global			
Setting	**Description**	**Range**	**Value**
TGR	Group Change Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00	1800.00
NFREQ	Nominal Frequency (Hz)	Select: 50, 60	60
PHROT	Phase Rotation	Select: ABC, ACB	ACB
DATE_F	Date Format	Select: MDY, YMD	MDY
FP_TO	Front Panel Timeout (minutes)	Range = 0.00 to 30.00	15.00
SCROLD	Display Update Rate (seconds)	Range = 1 to 60	5
LER	Length of Event Report (cycles)	Select: 15, 30, 60	60
PRE	Cycle Length of Prefault in Event Report (cycles in increments of 1)	Range = 1 to 59	10
DCLOP	DC Battery LO Voltage Pickup (Vdc)	Range = 20.00 to 300.00, OFF	OFF
DCHIP	DC Battery HI Voltage Pickup (Vdc)	Range = 20.00 to 300.00, OFF	OFF
IN101D	Input 101 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
IN102D	Input 102 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
IN103D	Input 103 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
IN104D	Input 104 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
IN105D	Input 105 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
IN106D	Input 106 Debounce Time (cycles in 0.25 increments)	Range = 0.00 to 2.00	0.00
EPMU	Synchronized Phasor Measurement	Select: Y, N	N
Global			

Group 1			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	SEL-311L
TID	Terminal Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	LINE 1 (RADIAL)
CTR	Local Phase (IA,IB,IC) CT Ratio, CTR:1	Range = 1 to 6000	1
APP	Application	Select: 87L, 87L21, 87L21P, 87LSP, 311L	311L
EADVS	Advanced Settings Enable	Select: Y, N	Y
E87L	Number of 87L Terminals	Select: 2, 3, 3R, N	N
CTRP	Polarizing (IPOL) CT Ratio, CTRP:1	Range = 1 to 6000	200
PTR	Phase (VA,VB,VC) PT Ratio, PTR:1	Range = 1.00 to 10000.00	1.00
PTRS	Synch. Voltage (VS) PT Ratio, PTRS:1	Range = 1.00 to 10000.00	2000.00
Z1MAG	Pos-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	17.33
Z1ANG	Pos-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.68
Z0MAG	Zero-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	17.33
Z0ANG	Zero-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.68
LL	Line Length (unitless)	Range = 0.10 to 999.00	100.00
EFLOC	Fault Location Enable	Select: Y, N	N
E21P	Enable Mho Phase Distance Elements	Select: N, 1-4, 1C-4C	3
ECCVT	CCVT Transient Detection Enable	Select: Y, N	N
Z1P	Reach Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.73

Group 1			
Setting	**Description**	**Range**	**Value**
Z2P	Reach Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	20.70
Z3P	Reach Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
50PP1	Phase-Phase Overcurrent Fault Detector Zone 1 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP2	Phase-Phase Overcurrent Fault Detector Zone 2 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP3	Phase-Phase Overcurrent Fault Detector Zone 3 (Amps secondary)	Range = 0.50 to 170.00	0.50
E21MG	Enable Mho Ground Distance Elements	Select: N, 1-4	3
Z1MG	Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.73
Z2MG	Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	20.70
Z3MG	Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
E21XG	Enable Quad Ground Distance Elements	Select: N, 1-4	N
50L1	Zone 1 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L2	Zone 2 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L3	Zone 3 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ1	Zone 1 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ2	Zone 2 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ3	Zone 3 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
k0M1	Zone 1 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A1	Zone 1 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69

Group 1			
Setting	**Description**	**Range**	**Value**
k0M	Zone 2,3,&4 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A	Zone 2,3,&4 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69
Z1PD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	22.00
Z2PD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	25.00
Z3PD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	25.00
Z1GD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	2.00
Z2GD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3GD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z1D	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2D	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3D	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
E50P	Enable Phase Overcurrent Elements	Select: N, 1-3	N
E50G	Enable Residual Ground Overcurrent Elements	Select: N, 1-4	N
E50Q	Enable Negative-Sequence Overcurrent Elements	Select: N, 1-4	N
E51P	Enable Phase Time-Overcurrent Elements	Select: Y, N	Y

Group 1			
Setting	**Description**	**Range**	**Value**
51PP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	4.50
51PC	Curve	Select: U1-U5, C1-C5	U1
51PTD	Time Dial	Range = 0.50 to 15.00	0.50
51PRS	Electromechanical Reset Delay	Select: Y, N	N
E51G	Enable Residual Ground Time-Overcurrent Elements	Select: Y, N	Y
51GP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51GC	Curve	Select: U1-U5, C1-C5	U1
51GTD	Time Dial	Range = 0.50 to 15.00	0.50
51GRS	Electromechanical Reset Delay	Select: Y, N	N
E51Q	Enable Negative-Sequence Time-Overcurrent Elements	Select: Y, N	Y
51QP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51QC	Curve	Select: U1-U5, C1-C5	U1
51QTD	Time Dial	Range = 0.50 to 15.00	0.50
51QRS	Electromechanical Reset Delay	Select: Y, N	N
EOOS	Enable Out-of-Step Elements	Select: Y, N	N
ELOAD	Enable Load Encroachment Elements	Select: Y, N	N
E32	Enable Directional Control Elements	Select: Y, AUTO	AUTO
ELOP	Loss-Of-Potential Enable	Select: Y, Y1, N	N
DIR3	Level 3 Direction	Select: F, R	R
DIR4	Level 4 Direction	Select: F, R	F
ORDER	Ground Directional Element Priority	Select: I, Q, V, OFF	QVI
EVOLT	Enable Voltage Element Enables	Select: Y, N	N
E25	Synchronism Check Enable	Select: Y, N	N

Group 1			
Setting	**Description**	**Range**	**Value**
E81	Frequency Elements Enables	Select: N, 1-6	N
E79	Reclosures Enables	Select: N, 1-4	N
ESOTF	Enable Switch-Onto-Fault	Select: Y, N	N
ECOMM	Comm.-Assisted Trip Scheme Enables	Select: N, POTT, DCUB1, DCUB2, DCB	N
EZ1EXT	Zone 1 Extension	Select: Y, N	N
EDEM	Demand Metering Type	Select: THM, ROL	THM
DMTC	Time Constant (minutes)	Select: 5, 10, 15, 30, 60	60
PDEMP	Phase Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
GDEMP	Residual Ground Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
QDEMP	Negative-Sequence Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
TDURD	Minimum Trip Duration Time (cycles in 0.25 increments)	Range = 2.00 to 16000.00	2.00
TOPD	Trip Open Pole Dropout Delay (cycles in 0.25 increments)	Range = 2.00 to 8000.00	2.00
CFD	Close Failure Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	60.00
3POD	Three-Pole Open Time Delay (cycles in 0.25 increments)	Range = 0.00 to 60.00	0.50
OPO	Open Pole Option	Select: 27, 52	52
50LP	Load Detection Phase Pickup (Amps secondary)	Range = 0.25 to 100.00, OFF	0.25
ELAT	SELogic Latch Bit Enables	Select: N, 1-16	16
EDP	SELogic Display Point Enables	Select: N, 1-16	16
ESV	SELogic Variable Timers Enables	Select: N, 1-16	N
Group 1			

SELogic 1			
Setting	**Description**	**Range**	**Value**
TR	Direct Trip Conditions	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	M1P + M2PT + M3PT + 51PT + 51GT + 51QT
DTT	Direct Transfer Trip Conditions	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
ULTR	Unlatch Trip Conditions	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	!(50L + 51G)
52A	Circuit breaker status	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	IN101
CL	Close conditions (other than automatic reclosing or CLOSE command)	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	CC
ULCL	Unlatch close conditions	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	TRIP + TRIP87
51PTC	Phase	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	1
51GTC	Residual Ground	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	1
51QTC	Negative-Sequence	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	1
OUT101	Output Contact 101	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	!TRIP
DP1	Display Point 1	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	52A
DP2	Display Point 2	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	CHXAL
DP3	Display Point 3	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	CHYAL

SELogic 1			
Setting	**Description**	**Range**	**Value**
ER	Event Report Trigger Conditions	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	/M2P + /Z2G + /51G + /51Q + /51P + /LOP + /M1P + /Z1G + /M3P + /Z3G
FAULT	Fault Indication	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	51G + 51Q + M2P + Z2G + 51P + M1P + Z1G + M3P + Z3G
E32IV	Enable for V0 Polarized and IN Polarized Elements	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	1
ESTUB	Stub Bus Logic Enable	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T1X	87L Channel X, Transmit Bit 1	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	KEY
T2X	87L Channel X, Transmit Bit 2	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T3X	87L Channel X, Transmit Bit 3	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T4X	87L Channel X, Transmit Bit 4	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T1Y	87L Channel Y, Transmit Bit 1	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T2Y	87L Channel Y, Transmit Bit 2	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T3Y	87L Channel Y, Transmit Bit 3	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
T4Y	87L Channel Y, Transmit Bit 4	Valid range = Boolean equation using word bit elements and the legal operators: ! / \ ( ) * +	0
SELogic 1			

Group 2			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	SEL-311L
TID	Terminal Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	LINE 1 (BIDIRECTIONAL)
CTR	Local Phase (IA,IB,IC) CT Ratio, CTR:1	Range = 1 to 6000	1
APP	Application	Select: 87L, 87L21, 87L21P, 87LSP, 311L	87LSP
EADVS	Advanced Settings Enable	Select: Y, N	Y
EHST	High Speed Tripping	Select: SP1, SP2, N	N
EHSDTT	Enable High Speed Direct Transfer Trip	Select: Y, N	N
EDD	Enable Disturbance Detect	Select: Y, N	N
ETAP	Tapped Load Coordination	Select: Y, N	N
EOCTL	Enable Open CT Logic	Select: Y, N	N
PCHAN	Primary 87L Channel	Select: X, Y	X
EHSC	Hot-Standby Channel Feature	Select: Y, N	N
CTR_X	CTR at Terminal Connected to Channel X	Range = 1 to 6000	1
87LPP	Phase 87L (Amps secondary)	Range = 1.00 to 10.00, OFF	OFF
87L2P	3I2 Negative-Sequence 87L (Amps secondary)	Range = 0.50 to 5.00, OFF	OFF
87LGP	Ground 87L (Amps secondary)	Range = 0.50 to 5.00, OFF	OFF
CTALRM	Ph. Diff. Current Alarm Pickup (Amps secondary)	Range = 0.50 to 10.00	0.50
87LR	Outer Radius	Range = 2.0 to 8.0	6.0
87LANG	Angle (degrees)	Range = 90 to 270	195

Group 2			
Setting	**Description**	**Range**	**Value**
CTRP	Polarizing (IPOL) CT Ratio, CTRP:1	Range = 1 to 6000	200
PTR	Phase (VA,VB,VC) PT Ratio, PTR:1	Range = 1.00 to 10000.00	1.00
PTRS	Synch. Voltage (VS) PT Ratio, PTRS:1	Range = 1.00 to 10000.00	2000.00
Z1MAG	Pos-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	41.69
Z1ANG	Pos-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.00
Z0MAG	Zero-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	41.69
Z0ANG	Zero-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.00
LL	Line Length (unitless)	Range = 0.10 to 999.00	100.00
EFLOC	Fault Location Enable	Select: Y, N	N
E21P	Enable Mho Phase Distance Elements	Select: N, 1-4	3
ECCVT	CCVT Transient Detection Enable	Select: Y, N	N
Z1P	Reach Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.73
Z2P	Reach Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	43.00
Z3P	Reach Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
50PP1	Phase-Phase Overcurrent Fault Detector Zone 1 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP2	Phase-Phase Overcurrent Fault Detector Zone 2 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP3	Phase-Phase Overcurrent Fault Detector Zone 3 (Amps secondary)	Range = 0.50 to 170.00	0.50
E21MG	Enable Mho Ground Distance Elements	Select: N, 1-4	3
Z1MG	Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.73

Group 2			
Setting	**Description**	**Range**	**Value**
Z2MG	Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	43.00
Z3MG	Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
E21XG	Enable Quad Ground Distance Elements	Select: N, 1-4	3
XG1	Zone 1 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	6.24
XG2	Zone 2 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	9.36
XG3	Zone 3 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	1.87
RG1	Zone 1 Resistance (Ohms secondary)	Range = 0.05 to 50.00	2.50
RG2	Zone 2 Resistance (Ohms secondary)	Range = 0.05 to 50.00	5.00
RG3	Zone 3 Resistance (Ohms secondary)	Range = 0.05 to 50.00	6.00
XGPOL	Quad Ground Polarizing Quantity	Select: I2, IG	I2
TANG	Non-Homogenous Correction Angle (degrees)	Range = -45.0 to 45.0	-3.0
50L1	Zone 1 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L2	Zone 2 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L3	Zone 3 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ1	Zone 1 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ2	Zone 2 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ3	Zone 3 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
k0M1	Zone 1 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A1	Zone 1 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69

Group 2			
Setting	**Description**	**Range**	**Value**
k0M	Zone 2,3,&4 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A	Zone 2,3,&4 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69
Z1PD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	OFF
Z2PD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	22.00
Z3PD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	OFF
Z1GD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2GD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3GD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z1D	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2D	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3D	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
E50P	Enable Phase Overcurrent Elements	Select: N, 1-3	N
E50G	Enable Residual Ground Overcurrent Elements	Select: N, 1-4	N
E50Q	Enable Negative-Sequence Overcurrent Elements	Select: N, 1-4	N
E51P	Enable Phase Time-Overcurrent Elements	Select: Y, N	Y

Group 2			
Setting	**Description**	**Range**	**Value**
51PP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	4.50
51PC	Curve	Select: U1-U5, C1-C5	U1
51PTD	Time Dial	Range = 0.50 to 15.00	0.50
51PRS	Electromechanical Reset Delay	Select: Y, N	N
E51G	Enable Residual Ground Time-Overcurrent Elements	Select: Y, N	Y
51GP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51GC	Curve	Select: U1-U5, C1-C5	U1
51GTD	Time Dial	Range = 0.50 to 15.00	0.50
51GRS	Electromechanical Reset Delay	Select: Y, N	N
E51Q	Enable Negative-Sequence Time-Overcurrent Elements	Select: Y, N	Y
51QP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51QC	Curve	Select: U1-U5, C1-C5	U1
51QTD	Time Dial	Range = 0.50 to 15.00	0.53
51QRS	Electromechanical Reset Delay	Select: Y, N	N
EOOS	Enable Out-of-Step Elements	Select: Y, N	N
ELOAD	Enable Load Encroachment Elements	Select: Y, N	N
E32	Enable Directional Control Elements	Select: Y, AUTO	AUTO
ELOP	Loss-Of-Potential Enable	Select: Y, Y1, N	Y1
EBBPT	Busbar PT LOP Logic Enable	Select: Y, N	N
DIR3	Level 3 Direction	Select: F, R	R
DIR4	Level 4 Direction	Select: F, R	F

Group 2			
Setting	**Description**	**Range**	**Value**
ORDER	Ground Directional Element Priority	Select: I, Q, V, OFF	QVI
EVOLT	Enable Voltage Element Enables	Select: Y, N	N
E25	Synchronism Check Enable	Select: Y, N	N
E81	Frequency Elements Enables	Select: N, 1-6	N
E79	Reclosures Enables	Select: N, 1-4	N
ESOTF	Enable Switch-Onto-Fault	Select: Y, N	N
ECOMM	Comm.-Assisted Trip Scheme Enables	Select: N, POTT, DCUB1, DCUB2, DCB	POTT
Z3RBD	Zone 3 Reverse Block Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00	5.00
EBLKD	Echo Block Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	10.00
ETDPU	Echo Time Delay Pickup (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	2.00
EDURD	Echo Duration Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00	4.00
EWFC	Weak-Infeed Enable	Select: Y, N	N
EZ1EXT	Zone 1 Extension	Select: Y, N	N
EDEM	Demand Metering Type	Select: THM, ROL	THM
DMTC	Time Constant (minutes)	Select: 5, 10, 15, 30, 60	60
PDEMP	Phase Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
GDEMP	Residual Ground Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
QDEMP	Negative-Sequence Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
TDURD	Minimum Trip Duration Time (cycles in 0.25 increments)	Range = 2.00 to 16000.00	9.00
TOPD	Trip Open Pole Dropout Delay (cycles in 0.25 increments)	Range = 2.00 to 8000.00	2.00

Group 2			
Setting	**Description**	**Range**	**Value**
CFD	Close Failure Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	60.00
3POD	Three-Pole Open Time Delay (cycles in 0.25 increments)	Range = 0.00 to 60.00	0.50
OPO	Open Pole Option	Select: 27, 52	52
50LP	Load Detection Phase Pickup (Amps secondary)	Range = 0.25 to 100.00, OFF	0.25
ELAT	SELogic Latch Bit Enables	Select: N, 1-16	16
EDP	SELogic Display Point Enables	Select: N, 1-16	16
ESV	SELogic Variable Timers Enables	Select: N, 1-16	1
SV1PU	SV1 Timer Pickup (cycles in 0.25 increments)	Range = 0.00 to 999999.00	14.00
SV1DO	SV1 Timer Dropout (cycles in 0.25 increments)	Range = 0.00 to 999999.00	0.00
Group 2			

SELogic 2			
Setting	**Description**	**Range**	**Value**
TR	Direct Trip Conditions		M1P + M2PT + M3PT + 51PT + 51GT + 51QT
TRCOMM	Communications-Assisted Trip Conditions		M2P
DTT	Direct Transfer Trip Conditions		0
E3PT	Three-Pole Trip Enable		0
ULTR	Unlatch Trip Conditions		SPO + 3PO
PT1	Permissive Trip 1 (used for ECOMM = POTT, DCUB1, or DCUB2)		R1X
52AA	Circuit breaker status A-Phase		IN101
52AB	Circuit breaker status B-Phase		IN102
52AC	Circuit breaker status C-Phase		IN103
CL	Close conditions (other than automatic reclosing or CLOSE command)		CC

SELogic 2			
Setting	**Description**	**Range**	**Value**
ULCL	Unlatch close conditions		TRIP + TRIP87
51PTC	Phase		1
51GTC	Residual Ground		1
51QTC	Negative-Sequence		1
87LTC	87L Torque Control Equation		1
SV1	SELogic Control Equation Variable 1		KEY
OUT101	Output Contact 101		!TRIP
DP1	Display Point 1		52A
DP2	Display Point 2		CHXAL
DP3	Display Point 3		CHYAL
ER	Event Report Trigger Conditions		/M2P + /Z2G + /51G + /51Q + /51P + /LOP + /M1P + /Z1G + /M3P + /Z3G
FAULT	Fault Indication		51G + 51Q + M2P + Z2G + 51P + M1P + Z1G + M3P + Z3G
BSYNCH	Block Synchronism Check Elements		0
CLMON	Close Bus Monitor		0
E32IV	Enable for V0 Polarized and IN Polarized Elements		1
ESTUB	Stub Bus Logic Enable		0
T1X	87L Channel X, Transmit Bit 1		SV1T
T2X	87L Channel X, Transmit Bit 2		0
T3X	87L Channel X, Transmit Bit 3		0
T4X	87L Channel X, Transmit Bit 4		0
T1Y	87L Channel Y, Transmit Bit 1		0
T2Y	87L Channel Y, Transmit Bit 2		0
T3Y	87L Channel Y, Transmit Bit 3		0
T4Y	87L Channel Y, Transmit Bit 4		0
SELogic 2			

SER			
Setting	**Description**	**Range**	**Value**
SER1	Sequential Events Recorder 1, 24 elements max. (enter NA to null)	Valid range = 0, NA or a list of relay elements.	TRIP, 51P, 51G, 51Q, 51PT, 51GT, 51QT
SER2	Sequential Events Recorder 2, 24 elements max. (enter NA to null)	Valid range = 0, NA or a list of relay elements.	TRIP, M1P, M2P, M2PT
SER3	Sequential Events Recorder 3, 24 elements max. (enter NA to null)	Valid range = 0, NA or a list of relay elements.	TRIP, PTRX
SER			

Channel X			
Setting	**Description**	**Range**	**Value**
EADDCX	Channel X Address Check	Select: Y, G, N	N
RBADXP	Continuous Dropout Alarm (Seconds)	Range = 1 to 1000	1
AVAXP	Packets Lost in Last 10,000 Alarm	Range = 1 to 5000	10
DBADXP	One Way Channel Delay Alarm (msec.)	Range = 1 to 24	10
TIMRX	Timing Source (I=Internal, E=External)	Select: I, E	E
Channel X			

Channel Y			
Setting	**Description**	**Range**	**Value**
EADDCY	Channel Y Address Check	Select: Y, G, N	N
RBADYP	Continuous Dropout Alarm (Seconds)	Range = 1 to 1000	1
AVAYP	Packets Lost in Last 10,000 Alarm	Range = 1 to 5000	10
DBADYP	One Way Channel Delay Alarm (msec.)	Range = 1 to 24	10
TIMRY	Timing Source (I=Internal, E=External)	Select: I, E	E
Channel Y			

Port 2			
Setting	**Description**	**Range**	**Value**
PROTO	Protocol	Select: SEL, LMD, DNP, MBA, MB8A, MBGA, MBB, MB8B, MBGB	SEL
T_OUT	Minutes to Port Time-out	Range = 0 to 30	15
DTA	Meter Format	Select: Y, N	N
SPEED	Baud Rate	Select: 300, 1200, 2400, 4800, 9600, 19200, 38400	19200
AUTO	Send Auto Messages to Port	Select: Y, N	Y
BITS	Data Bits	Select: 6-8	8
RTSCTS	Enable Hardware Handshaking	Select: Y, N	N
PARITY	(Odd, Even, None)	Select: O, E, N	N
FASTOP	Fast Operate Enable	Select: Y, N	N
STOP	Stop Bits	Select: 1, 2	1
Port 2			

APPENDIX C: SEL-311L LINE 2 SETTINGS

Group 1			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	SEL-311L
TID	Terminal Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	LINE 2 (RADIAL)
CTR	Local Phase (IA,IB,IC) CT Ratio, CTR:1	Range = 1 to 6000	1
APP	Application	Select: 87L, 87L21, 87L21P, 87LSP, 311L	311L
EADVS	Advanced Settings Enable	Select: Y, N	Y
E87L	Number of 87L Terminals	Select: 2, 3, 3R, N	N
CTRP	Polarizing (IPOL) CT Ratio, CTRP:1	Range = 1 to 6000	200
PTR	Phase (VA,VB,VC) PT Ratio, PTR:1	Range = 1.00 to 10000.00	1.00
PTRS	Synch. Voltage (VS) PT Ratio, PTRS:1	Range = 1.00 to 10000.00	2000.00
Z1MAG	Pos-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	24.37
Z1ANG	Pos-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	89.00
Z0MAG	Zero-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	24.37
Z0ANG	Zero-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	89.00
LL	Line Length (unitless)	Range = 0.10 to 999.00	100.00
EFLOC	Fault Location Enable	Select: Y, N	N
E21P	Enable Mho Phase Distance Elements	Select: N, 1-4, 1C-4C	3
ECCVT	CCVT Transient Detection Enable	Select: Y, N	N

Group 1			
Setting	**Description**	**Range**	**Value**
Z1P	Reach Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	13.35
Z2P	Reach Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	22.90
Z3P	Reach Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
50PP1	Phase-Phase Overcurrent Fault Detector Zone 1 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP2	Phase-Phase Overcurrent Fault Detector Zone 2 (Amps secondary)	Range = 0.50 to 170.00	0.50
50PP3	Phase-Phase Overcurrent Fault Detector Zone 3 (Amps secondary)	Range = 0.50 to 170.00	0.50
E21MG	Enable Mho Ground Distance Elements	Select: N, 1-4	3
Z1MG	Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	13.35
Z2MG	Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	22.90
Z3MG	Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
E21XG	Enable Quad Ground Distance Elements	Select: N, 1-4	N
50L1	Zone 1 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L2	Zone 2 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50L3	Zone 3 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ1	Zone 1 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ2	Zone 2 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ3	Zone 3 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
k0M1	Zone 1 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726

Group 1			
Setting	**Description**	**Range**	**Value**
k0A1	Zone 1 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69
k0M	Zone 2,3,&4 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A	Zone 2,3,&4 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69
Z1PD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2PD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3PD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z1GD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2GD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3GD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z1D	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2D	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3D	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
E50P	Enable Phase Overcurrent Elements	Select: N, 1-3	N
E50G	Enable Residual Ground Overcurrent Elements	Select: N, 1-4	N
E50Q	Enable Negative-Sequence Overcurrent Elements	Select: N, 1-4	N

Group 1			
Setting	**Description**	**Range**	**Value**
E51P	Enable Phase Time-Overcurrent Elements	Select: Y, N	Y
51PP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	4.50
51PC	Curve	Select: U1-U5, C1-C5	U1
51PTD	Time Dial	Range = 0.50 to 15.00	0.50
51PRS	Electromechanical Reset Delay	Select: Y, N	N
E51G	Enable Residual Ground Time-Overcurrent Elements	Select: Y, N	Y
51GP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51GC	Curve	Select: U1-U5, C1-C5	U1
51GTD	Time Dial	Range = 0.50 to 15.00	0.50
51GRS	Electromechanical Reset Delay	Select: Y, N	N
E51Q	Enable Negative-Sequence Time-Overcurrent Elements	Select: Y, N	Y
51QP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51QC	Curve	Select: U1-U5, C1-C5	U1
51QTD	Time Dial	Range = 0.50 to 15.00	0.50
51QRS	Electromechanical Reset Delay	Select: Y, N	N
EOOS	Enable Out-of-Step Elements	Select: Y, N	N
ELOAD	Enable Load Encroachment Elements	Select: Y, N	N
E32	Enable Directional Control Elements	Select: Y, AUTO	AUTO
ELOP	Loss-Of-Potential Enable	Select: Y, Y1, N	N
DIR3	Level 3 Direction	Select: F, R	R
DIR4	Level 4 Direction	Select: F, R	F
ORDER	Ground Directional Element Priority	Select: I, Q, V, OFF	QVI

Group 1			
Setting	**Description**	**Range**	**Value**
EVOLT	Enable Voltage Element Enables	Select: Y, N	N
E25	Synchronism Check Enable	Select: Y, N	N
E81	Frequency Elements Enables	Select: N, 1-6	N
E79	Reclosures Enables	Select: N, 1-4	N
ESOTF	Enable Switch-Onto-Fault	Select: Y, N	N
ECOMM	Comm.-Assisted Trip Scheme Enables	Select: N, POTT, DCUB1, DCUB2, DCB	N
EZ1EXT	Zone 1 Extension	Select: Y, N	N
EDEM	Demand Metering Type	Select: THM, ROL	THM
DMTC	Time Constant (minutes)	Select: 5, 10, 15, 30, 60	60
PDEMP	Phase Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
GDEMP	Residual Ground Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
QDEMP	Negative-Sequence Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
TDURD	Minimum Trip Duration Time (cycles in 0.25 increments)	Range = 2.00 to 16000.00	2.00
TOPD	Trip Open Pole Dropout Delay (cycles in 0.25 increments)	Range = 2.00 to 8000.00	2.00
CFD	Close Failure Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	60.00
3POD	Three-Pole Open Time Delay (cycles in 0.25 increments)	Range = 0.00 to 60.00	0.50
OPO	Open Pole Option	Select: 27, 52	52
50LP	Load Detection Phase Pickup (Amps secondary)	Range = 0.25 to 100.00, OFF	0.25
ELAT	SELogic Latch Bit Enables	Select: N, 1-16	16
EDP	SELogic Display Point Enables	Select: N, 1-16	16
ESV	SELogic Variable Timers Enables	Select: N, 1-16	N
Group 1			

Group 2			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	SEL-311L
TID	Terminal Identifier (30 chars)	Range = ASCII string with a maximum length of 30.	LINE 2 (BIDIRECTIONAL)
CTR	Local Phase (IA,IB,IC) CT Ratio, CTR:1	Range = 1 to 6000	1
APP	Application	Select: 87L, 87L21, 87L21P, 87LSP, 311L	311L
EADVS	Advanced Settings Enable	Select: Y, N	N
E87L	Number of 87L Terminals	Select: 2, 3, 3R, N	2
EHST	High Speed Tripping	Select: 1-6, N	N
EHSDTT	Enable High Speed Direct Transfer Trip	Select: Y, N	N
EDD	Enable Disturbance Detect	Select: Y, N	N
ETAP	Tapped Load Coordination	Select: Y, N	N
EOCTL	Enable Open CT Logic	Select: Y, N	N
PCHAN	Primary 87L Channel	Select: X, Y	X
EHSC	Hot-Standby Channel Feature	Select: Y, N	N
CTR_X	CTR at Terminal Connected to Channel X	Range = 1 to 6000	1
87LPP	Phase 87L (Amps secondary)	Range = 1.00 to 10.00, OFF	OFF
87L2P	3I2 Negative-Sequence 87L (Amps secondary)	Range = 0.50 to 5.00, OFF	OFF
87LGP	Ground 87L (Amps secondary)	Range = 0.50 to 5.00, OFF	OFF
CTALRM	Ph. Diff. Current Alarm Pickup (Amps secondary)	Range = 0.50 to 10.00	0.50
87LR	Outer Radius	Range = 2.0 to 8.0	6.0
87LANG	Angle (degrees)	Range = 90 to 270	195

Group 2			
Setting	**Description**	**Range**	**Value**
CTRP	Polarizing (IPOL) CT Ratio, CTRP:1	Range = 1 to 6000	200
PTR	Phase (VA,VB,VC) PT Ratio, PTR:1	Range = 1.00 to 10000.00	1.00
PTRS	Synch. Voltage (VS) PT Ratio, PTRS:1	Range = 1.00 to 10000.00	2000.00
Z1MAG	Pos-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	41.69
Z1ANG	Pos-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.00
Z0MAG	Zero-Seq Line Impedance Magnitude (Ohms secondary)	Range = 0.05 to 255.00	41.69
Z0ANG	Zero-Seq Line Impedance Angle (degrees)	Range = 5.00 to 90.00	88.00
LL	Line Length (unitless)	Range = 0.10 to 999.00	100.00
EFLOC	Fault Location Enable	Select: Y, N	N
E21P	Enable Mho Phase Distance Elements	Select: N, 1-4, 1C-4C	3
ECCVT	CCVT Transient Detection Enable	Select: Y, N	N
Z1P	Reach Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.50
Z2P	Reach Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	43.00
Z3P	Reach Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00
50PP1	Phase-Phase Overcurrent Fault Detector Zone 1 (Amps secondary)	Range = 0.50 to 170.00	0.50
E21MG	Enable Mho Ground Distance Elements	Select: N, 1-4	3
Z1MG	Zone 1 (Ohms secondary)	Range = 0.05 to 64.00, OFF	14.50
Z2MG	Zone 2 (Ohms secondary)	Range = 0.05 to 64.00, OFF	43.00
Z3MG	Zone 3 (Ohms secondary)	Range = 0.05 to 64.00, OFF	5.00

Group 2			
Setting	**Description**	**Range**	**Value**
E21XG	Enable Quad Ground Distance Elements	Select: N, 1-4	3
XG1	Zone 1 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	6.24
XG2	Zone 2 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	9.36
XG3	Zone 3 Reactance (Ohms secondary)	Range = 0.05 to 64.00, OFF	1.87
RG1	Zone 1 Resistance (Ohms secondary)	Range = 0.05 to 50.00	2.50
RG2	Zone 2 Resistance (Ohms secondary)	Range = 0.05 to 50.00	5.00
RG3	Zone 3 Resistance (Ohms secondary)	Range = 0.05 to 50.00	6.00
50L1	Zone 1 Phase Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
50GZ1	Zone 1 Residual Current FD (Amps secondary)	Range = 0.50 to 100.00	0.50
k0M1	Zone 1 ZSC Factor Mag (unitless)	Range = 0.000 to 6.000	0.726
k0A1	Zone 1 ZSC Factor Ang (degrees)	Range = -180.00 to 180.00	-3.69
Z1PD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	OFF
Z2PD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	22.00
Z3PD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	OFF
Z1GD	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2GD	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00

Group 2			
Setting	**Description**	**Range**	**Value**
Z3GD	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z1D	Zone 1 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z2D	Zone 2 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
Z3D	Zone 3 Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	5.00
E50P	Enable Phase Overcurrent Elements	Select: N, 1-3	N
E50G	Enable Residual Ground Overcurrent Elements	Select: N, 1-4	N
E50Q	Enable Negative-Sequence Overcurrent Elements	Select: N, 1-4	N
E51P	Enable Phase Time-Overcurrent Elements	Select: Y, N	Y
51PP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	4.50
51PC	Curve	Select: U1-U5, C1-C5	U1
51PTD	Time Dial	Range = 0.50 to 15.00	0.50
51PRS	Electromechanical Reset Delay	Select: Y, N	N
E51G	Enable Residual Ground Time-Overcurrent Elements	Select: Y, N	Y
51GP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51GC	Curve	Select: U1-U5, C1-C5	U1
51GTD	Time Dial	Range = 0.50 to 15.00	0.50
51GRS	Electromechanical Reset Delay	Select: Y, N	N
E51Q	Enable Negative-Sequence Time-Overcurrent Elements	Select: Y, N	Y

Group 2			
Setting	**Description**	**Range**	**Value**
51QP	Pickup (Amps secondary)	Range = 0.25 to 16.00, OFF	0.25
51QC	Curve	Select: U1-U5, C1-C5	U1
51QTD	Time Dial	Range = 0.50 to 15.00	0.53
51QRS	Electromechanical Reset Delay	Select: Y, N	N
EOOS	Enable Out-of-Step Elements	Select: Y, N	N
ELOAD	Enable Load Encroachment Elements	Select: Y, N	N
E32	Enable Directional Control Elements	Select: Y, AUTO	AUTO
ELOP	Loss-Of-Potential Enable	Select: Y, Y1, N	Y
EBBPT	Busbar PT LOP Logic Enable	Select: Y, N	N
DIR3	Level 3 Direction	Select: F, R	R
DIR4	Level 4 Direction	Select: F, R	F
ORDER	Ground Directional Element Priority	Select: I, Q, V, OFF	QVI
EVOLT	Enable Voltage Element Enables	Select: Y, N	N
E25	Synchronism Check Enable	Select: Y, N	N
E81	Frequency Elements Enables	Select: N, 1-6	N
E79	Reclosures Enables	Select: N, 1-4	N
ESOTF	Enable Switch-Onto-Fault	Select: Y, N	N
ECOMM	Comm.-Assisted Trip Scheme Enables	Select: N, POTT, DCUB1, DCUB2, DCB	POTT
Z3RBD	Zone 3 Reverse Block Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00	5.00
EBLKD	Echo Block Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	10.00
ETDPU	Echo Time Delay Pickup (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	2.00

Group 2			
Setting	**Description**	**Range**	**Value**
EDURD	Echo Duration Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00	4.00
EWFC	Weak-Infeed Enable	Select: Y, N	N
EZ1EXT	Zone 1 Extension	Select: Y, N	N
EDEM	Demand Metering Type	Select: THM, ROL	THM
DMTC	Time Constant (minutes)	Select: 5, 10, 15, 30, 60	60
PDEMP	Phase Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
GDEMP	Residual Ground Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
QDEMP	Negative-Sequence Pickup (Amps secondary)	Range = 0.50 to 16.00, OFF	OFF
TDURD	Minimum Trip Duration Time (cycles in 0.25 increments)	Range = 2.00 to 16000.00	9.00
TOPD	Trip Open Pole Dropout Delay (cycles in 0.25 increments)	Range = 2.00 to 8000.00	2.00
CFD	Close Failure Time Delay (cycles in 0.25 increments)	Range = 0.00 to 16000.00, OFF	60.00
3POD	Three-Pole Open Time Delay (cycles in 0.25 increments)	Range = 0.00 to 60.00	0.50
OPO	Open Pole Option	Select: 27, 52	52
50LP	Load Detection Phase Pickup (Amps secondary)	Range = 0.25 to 100.00, OFF	0.25
ELAT	SELogic Latch Bit Enables	Select: N, 1-16	16
EDP	SELogic Display Point Enables	Select: N, 1-16	16
ESV	SELogic Variable Timers Enables	Select: N, 1-16	1
SV1PU	SV1 Timer Pickup (cycles in 0.25 increments)	Range = 0.00 to 999999.00	12.00
SV1DO	SV1 Timer Dropout (cycles in 0.25 increments)	Range = 0.00 to 999999.00	0.00
Group 2			

APPENDIX D: SEL-387E SETTINGS

Global			
Setting	**Description**	**Range**	**Value**
LER	Length of Event Report	Select: 15, 29, 60	60
PRE	Length of Prefault in Event Report	1-59cyc	4
NFREQ	Nominal Frequency	Select: 50, 60	60
PHROT	Phase Rotation	Select: ABC, ACB	ACB
DELTA_Y	Phase Potential Connection	Select: Y, D	Y
DATE_F	Date Format	Select: MDY, YMD	MDY
SCROLD	Display Update Rate	1-60S	2
FP_TO	Front Panel Timeout	OFF, 0-30 min	16
TGR	Group Change Delay	0-900S	3
BKMON1	Bkr 1 Monitor Input(SELogic Equation)		TRIP1
B1COP1	Close/Open Operations Set Point 1 max	1-65000	10000
B1KAP1	kA Interrupted Set Point 1 min	0.1-999kA	1.2
B1COP2	Close/Open Operations Set Point 2 max	1-65000	160
B1KAP2	kA Interrupted Set Point 2 min	0.1-999kA	8.0
B1COP3	Close/Open Operations Set Point 3 max	1-65000	12
B1KAP3	kA Interrupted Set Point 3 min	0.1-999kA	20.0
BKMON2	Bkr 2 Monitor Input(SELogic Equation)		(TRIP2 + TRIP3 + TRIP4)
B2COP1	Close/Open Operations Set Point 1 max	1-65000	10000
B2KAP1	kA Interrupted Set Point 1 min	0.1-999kA	1.2
B2COP2	Close/Open Operations Set Point 2 max	1-65000	160

Global			
Setting	**Description**	**Range**	**Value**
B2KAP2	kA Interrupted Set Point 2 min	0.1-999kA	8.0
B2COP3	Close/Open Operations Set Point 3 max	1-65000	12
B2KAP3	kA Interrupted Set Point 3 min	0.1-999kA	20.0
BKMON3	Bkr 3 Monitor Input(SELogic Equation)		TRIP3 + TRIP4
B3COP1	Close/Open Operations Set Point 1 max	1-65000	10000
B3KAP1	kA Interrupted Set Point 1 min	0.1-999kA	1.2
B3COP2	Close/Open Operations Set Point 2 max	1-65000	160
B3KAP2	kA Interrupted Set Point 2 min	0.1-999kA	8.0
B3COP3	Close/Open Operations Set Point 3 max	1-65000	12
B3KAP3	kA Interrupted Set Point 3 min	0.1-999kA	20.0
ETHRU	Enable Through Fault Event Winding	Select: N, 1-3	N
Global			

Group 1			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (39 Characters)		387E_Y-Y
TID	Terminal Identifier (59 Characters)		BENCH5
E87W1	Enable Wdg1 in Differential Element	Select: N, Y, Y1	Y1
E87W2	Enable Wdg2 in Differential Element	Select: N, Y, Y1	Y1
E87W3	Enable Wdg3 in Differential Element	Select: N, Y, Y1	N
EOC1	Enable Wdg1 O/C Elements and Dmd. Thresholds	Select: N, Y	N

Group 1			
Setting	**Description**	**Range**	**Value**
EOC2	Enable Wdg2 O/C Elements and Dmd. Thresholds	Select: N, Y	Y
EOC3	Enable Wdg3 O/C Elements and Dmd. Thresholds	Select: N, Y	N
EOCC	Enable Combined O/C Elements	Select: N, Y	N
E24	Enable Volts/Hertz Protection	Select: N, Y	N
E27	Enable Undervoltage Protection	Select: N, Y	N
E59	Enable Overvoltage Protection	Select: N, Y	N
E81	Enable Frequency Protection	Select: N, 1-6	N
ESLS1	Enable SELogic Set 1	Select: N, Y	N
ESLS2	Enable SELogic Set 2	Select: N, Y	N
ESLS3	Enable SELogic Set 3	Select: N, Y	N
W1CT	Wdg 1 CT Connection	Select: D, Y	Y
W2CT	Wdg 2 CT Connection	Select: D, Y	Y
W3CT	Wdg 3 CT Connection	Select: D, Y	Y
CTR1	Wdg 1 CT Ratio	1-50000	1
CTR2	Wdg 2 CT Ratio	1-50000	1
CTR3	Wdg 3 CT Ratio	1-50000	1
MVA	Maximum Power Xfmr Capacity	OFF,0.2-5000.0 MVA	OFF
ICOM	Define Internal CT Connection Compensation	Select: N, Y	N
PTR	PT Ratio	1-6500	1
COMPANG	Compensation Angle	0-360deg	0
VIWDG	Voltage-Current Winding	Select: 1-3, 12	1
TPVI	Three Phase Voltage Input	Select: N, Y	Y
TAP1	Wdg 1 Current Tap	0.50-155.00	3.00
TAP2	Wdg 2 Current Tap	0.50-155.00	3.00
O87P	Restrained Element Current PU	0.10-1.00 TAP	0.30
SLP1	Restraint Slope 1 Percentage	5-100%	25

Group 1			
Setting	**Description**	**Range**	**Value**
SLP2	Restraint Slope 2 Percentage	OFF,25-200%	50
IRS1	Restraint Current Slope 1 Limit	1.0-20.0 TAP	3.0
U87P	Unrestrained Element Current PU	1-20 TAP	3.0
PCT2	2nd Harmonic Blocking Percentage	OFF,5-100%	15
PCT4	4th Harmonic Blocking Percentage	OFF,5-100%	15
PCT5	5th Harmonic Blocking Percentage	OFF,5-100%	35
TH5P	5th Harmonic Alarm Threshold	OFF,0.02-3.2 TAP	OFF
DCRB	DC Ratio Blocking	Select: N, Y	Y
HRSTR	Harmonic Restraint	Select: N, Y	Y
E32I	Enable 32I(SELogic Equation)		0
50P21P	Phase Def-Time O/C Lvl 1 PU	OFF,0.25-100A,sec	OFF
50P22P	Phase Inst O/C Lvl 2 PU	OFF,0.25-100.00A,sec	OFF
50P23P	Phase Inst O/C Lvl 3 PU	OFF,0.25-100.00A,sec	OFF
50P24P	Phase Inst O/C Lvl 4 PU	OFF,0.25-100.00A,sec	OFF
51P2P	Phase Inv-Time O/C PU	OFF,0.50-16.00A,sec	4.50
51P2C	Phase Inv-Time O/C Curve	Select: U1, U2, U3, U4, U5, C1, C2, C3, C4, C5	U1
51P2TD	Phase Inv-Time O/C Time-Dial	0.50-15.00	0.55
51P2RS	Phase Inv-Time O/C EM Reset	Select: N, Y	N
51P2TC	51P2 Torque Control (SELogic Equation)		1
50Q21P	Neg-Seq Def-Time O/C Lvl 1 PU	OFF,0.25-100A,sec	OFF
50Q22P	Neg-Seq Inst O/C Lvl 2 PU	OFF,0.25-100.00A,sec	OFF
51Q2P	Neg-Seq Inv-Time O/C PU	OFF,0.50-16.00A,sec	0.50
51Q2C	Neg-Seq Inv-Time O/C Curve	Select: U1, U2, U3, U4, U5, C1, C2, C3, C4, C5	U1

Group 1			
Setting	**Description**	**Range**	**Value**
51Q2TD	Neg-Seq Inv-Time O/C Time-Dial	0.50-15.00	0.55
51Q2RS	Neg-Seq Inv-Time O/C EM Reset	Select: N, Y	N
51Q2TC	51Q2 Torque Control (SELogic Equation)		1
50N21P	Res. Def-Time O/C Lvl 1 PU	OFF,0.25-100.00A,sec	OFF
50N22P	Res. Inst O/C Lvl 2 PU	OFF,0.25-100.00A,sec	OFF
51N2P	Res. Inv-Time O/C PU	OFF,0.50-16.00A,sec	0.50
51N2C	Res. Inv-Time O/C Curve	Select: U1, U2, U3, U4, U5, C1, C2, C3, C4, C5	U1
51N2TD	Res. Inv-Time O/C Time-Dial	0.50-15.00	0.55
51N2RS	Res. Inv-Time O/C EM Reset	Select: N, Y	N
51N2TC	51N2 Torque Control (SELogic Equation)		1
DATC2	Demand Ammeter Time Constant	OFF,5-255min	15
PDEM2P	Phase Demand Ammeter Thresh	0.50-16.00A,sec	7.00
QDEM2P	Neg-Seq Demand Ammeter Thresh	0.50-16.00A,sec	1.00
NDEM2P	Res. Demand Ammeter Thresh	0.50-16.00A,sec	1.00
TDURD	Trip Duration Delay	4.000-8000.000 cyc	9.000
CFD	Close Failure Delay	OFF, 0.000-8000.000 cyc	OFF
TR1			87R + OC1
TR2			87R + 51P2T + OC2
TR3			51Q2T
TR4			51N2T
ULTR1			!50P13
ULTR2			!50P23
ULTR3			!50P33
ULTR4			!(50P13 + 50P23 + 50P33)
52A1			IN101
52A2			IN102
52A3			IN103
CL1			CC1 + LB4 + /IN104

Group 1			
Setting	**Description**	**Range**	**Value**
CL2			CC2 + /IN105
CL3			CC3 + /IN106
ULCL1			TRIP1 + TRIP4
ULCL2			TRIP2 + TRIP4
ULCL3			TRIP3 + TRIP4
ER			/50P11 + /51P1 + /51Q1 + /51P2 + /51Q2 + /51N2 + /51P3
OUT101			!TRIP1
OUT102			!(TRIP2 + TRIP3 + TRIP4)
Group 1			

Report			
Setting	**Description**	**Range**	**Value**
SER1			IN101, IN102, IN103, IN104, IN105, IN106
SER2			OUT101, OUT102, OUT103, OUT104, OUT105, OUT106, OUT107
SER3			51Q2T, 51Q2, 87R, 51P2T, 51P2, 51N2T, 51N2, TRIP1, TRIP2, TRIP3, TRIP4
SER4			0
Report			

Port 2			
Setting	**Description**	**Range**	**Value**
PROTO	Protocol	Select: SEL, LMD, DNP	SEL
SPEED	Baud rate	Select: 300, 1200, 2400, 4800, 9600, 19200, 19.2	19200
BITS	Data bits	Select: 7, 8	8
PARITY	Parity	Select: N, E, O	N
STOP	Stop bits	Select: 1, 2	1
T_OUT	Timeout	0-30 min	30
AUTO	Send auto messages to port	Select: N, Y	Y
RTSCTS	Enable hardware handshaking	Select: N, Y	N

Port 2			
Setting	**Description**	**Range**	**Value**
FASTOP	Fast operate enable	Select: N, Y	N
Port 2			

Port 3			
Setting	**Description**	**Range**	**Value**
PROTO	Protocol	Select: SEL, LMD, DNP	SEL
SPEED	Baud rate	Select: 300, 1200, 2400, 4800, 9600, 19200, 19.2	19200
BITS	Data bits	Select: 7, 8	8
PARITY	Parity	Select: N, E, O	N
STOP	Stop bits	Select: 1, 2	1
T_OUT	Timeout	0-30 min	30
AUTO	Send auto messages to port	Select: N, Y	Y
RTSCTS	Enable hardware handshaking	Select: N, Y	N
FASTOP	Fast operate enable	Select: N, Y	N
Port 3			

Appendix E: SEL-587 Settings

Device			
Setting	**Description**	**Range**	**Value**
RID	Relay Identifier (12 characters)	Range = ASCII string with a maximum length of 12.	587_D-D
TID	Terminal Identifier (12 characters)	Range = ASCII string with a maximum length of 12.	BENCH5
MVA	Maximum Power Transformer Capacity (MVA)	Range = 0.2 to 5000.0, OFF	OFF
TRCON	Xfmr	Select: YY, YDAC, YDAB, DACDAC, DABDAB, DABY, DACY, OTHER	DACDAC
CTCON	CT Connection	Select: YY	YY
RZS	Remove I0 from Y Connection Compensation	Select: Y, N	N
CTR1	Winding 1 CT Ratio	Range = 1 to 50000	1
CTR2	Winding 2 CT Ratio	Range = 1 to 50000	1
DATC	Demand Ammeter Time Constant (minutes)	Range = 5 to 255, OFF	15
PDEM	Phase Demand Ammeter Threshold (A)	Range = 0.5 to 16.0	5.3
QDEM	Neg.-Seq. Demand Ammeter Threshold (A)	Range = 0.5 to 16.0	1.0
NDEM	Residual Demand Ammeter Threshold (A)	Range = 0.5 to 16.0	1.0
TAP1	Winding 1 Current Tap	Range = 0.50 to 160.00	3.00
TAP2	Winding 2 Current Tap	Range = 0.50 to 160.00	3.00
IN1	Input 1	Select: NA, 52A1, !52A1, TCEN, TCBL	NA

Device			
Setting	**Description**	**Range**	**Value**
IN2	Input 2	Select: NA, 52A2, !52A2, TCEN, TCBL	NA
O87P	Operating Current PU (TAP)	Range = 0.2 to 1.0	0.4
SLP1	Restraint Slope 1 (%)	Range = 5 to 100	40
SLP2	Restraint Slope 2 (%)	Range = 25 to 200, OFF	50
IRS1	Restraint Current Slope 1 Limit (TAP)	Range = 1.0 to 16.0	3.0
U87P	Inst Unrestrained Current PU (TAP)	Range = 1.0 to 16.0	10.0
PCT2	2nd Harmonic Blocking Percentage (%)	Range = 5 to 100, OFF	15
PCT4	4th Harmonic Blocking Percentage (%)	Range = 5 to 100, OFF	15
PCT5	5th Harmonic Blocking Percentage (%)	Range = 5 to 100, OFF	35
TH5	5th Harmonic Threshold (TAP)	Range = 0.2 to 3.2	0.3
TH5D	5th Harmonic Alarm TDPU (cyc)	Range = 0.000 to 8000.000	30.000
DCRB	DC Ratio Blocking	Select: Y, N	Y
HRSTR	Harmonic Restraint	Select: Y, N	Y
50P1P	Phase Def.-Time O/C PU	Range = 0.5 to 80.0, OFF	OFF
50P1H	Phase Inst O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
51P1P	Phase Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	OFF
50Q1P	Neg.-Seq. Def.-Time O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
51Q1P	Neg.-Seq. Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	OFF
50N1P	Residual Def.-Time O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
50N1H	Residual Inst O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF

Device			
Setting	**Description**	**Range**	**Value**
51N1P	Residual Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	OFF
50P2P	Phase Def.-Time O/C PU	Range = 0.5 to 80.0, OFF	OFF
50P2H	Phase Inst O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
51P2P	Phase Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	4.5
51P2C	Phase Inv.-Time O/C Curve	Select: U1, U2, U3, U4, C1, C2, C3, C4	U1
51P2TD	Phase Inv.-Time O/C Time-Dial	Range = 0.50 to 15.00	0.55
51P2RS	Phase Inv.-Time O/C EM Reset	Select: Y, N	N
50Q2P	Neg.-Seq. Def.-Time O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
51Q2P	Neg.-Seq. Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	0.5
51Q2C	Neg.-Seq. Inv.-Time O/C Curve	Select: U1, U2, U3, U4, C1, C2, C3, C4	U1
51Q2TD	Neg.-Seq. Inv.-Time O/C Time-Dial	Range = 0.50 to 15.00	0.55
51Q2RS	Neg.-Seq. Inv.-Time O/C EM Reset	Select: Y, N	N
50N2P	Residual Def.-Time O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
50N2H	Residual Inst O/C PU (A)	Range = 0.5 to 80.0, OFF	OFF
51N2P	Residual Inv.-Time O/C PU (A)	Range = 0.5 to 16.0, OFF	OFF
LTRP	Latch Trips	Select: Y, N, NL, 1-3	N
TDURD	Minimum Trip Duration Time Delay (cyc)	Range = 0.000 to 2000.000	9.000
TXPU	Timer X Pickup Delay (cyc)	Range = 0.000 to 8000.000	0.000
TXDO	Timer X Dropout Delay (cyc)	Range = 0.000 to 8000.000	0.000

Device			
Setting	**Description**	**Range**	**Value**
TYPU	Timer Y Pickup Delay (cyc)	Range = 0.000 to 8000.000	0.000
TYDO	Timer Y Dropout Delay (cyc)	Range = 0.000 to 8000.000	0.000
NFREQ	Nominal Frequency (Hz)	Select: 50, 60	60
PHROT	Phase Rotation	Select: ABC, ACB	ACB
Device			

Logic			
Setting	**Description**	**Range**	**Value**
X	(SELogic Equation)		NA
Y	(SELogic Equation)		NA
MTU1	(SELogic Equation)		87R + OC1
MTU2	(SELogic Equation)		87R + 51P2T + 51Q2T + OC2
MTU3	(SELogic Equation)		51N2T
MER	(SELogic Equation)		87R + 51P2T + 51Q2T + 51N2T + 51P1P + 51Q2P + 51N2P
OUT1	(SELogic Equation)		!TRP1
OUT2	(SELogic Equation)		!TRP2 * !TRP3
OUT3	(SELogic Equation)		NA
OUT4	(SELogic Equation)		NA
Logic			

Port			
Setting	**Description**	**Range**	**Value**
PROTOCOL	Port Protocol	Select: SEL, LMD	SEL
SPEED	Baud Rate (bps)	Select: 300, 1200, 2400, 4800, 9600, 19200, 38400	19200
DATA_BITS	Number Data Bits	Select: 7, 8	8
PARITY	Parity	Select: O, E, N	N
STOP	Stop Bits (bits)	Select: 1, 2	1
TIMEOUT	Timeout (min)	Range = 0 to 30	10
AUTO	Auto Message Output	Select: Y, N	Y
RTS_CTS	Enable RTS/CTS Handshaking	Select: Y, N	N
FAST_OP	Enable Fast Operate	Select: Y, N	N
Port			

APPENDIX F: SEL-710 SETTINGS

Global				
Setting	**Description**	**Range**	**Value**	**Comment**
APP	Application WARNING: Nameplate sets most settings to Defaults, See on-line help.	Select: FULL, NAMEPLATE	FULL	
PHROT	Phase Rotation	Select: ABC, ACB	ACB	
FNOM	Rated Frequency (Hz)	Select: 50, 60	60	
DATE_F	Date Format	Select: MDY, YMD, DMY	MDY	
FAULT	Fault Condition (SELogic)		TRIP	
TGR	Group Change Delay (seconds)	Range = 0-400	1	
SS1	Select Settings Group1 (SELogic)		0	(Set to '1' for Radial System Settings)
SS2	Select Settings Group2 (SELogic)		1	(Set to '1' for Bidirectional System Settings)
SS3	Select Settings Group3 (SELogic)		0	
IRIGC	IRIG-B Control Bits Definition	Select: NONE, C37.118	NONE	
UTC_OFF	Offset from UTC (hours, in 0.25 hour increments)	Range = -24.00 to 24.00	0.00	
DST_BEGM	Month To Begin DST	Range = OFF,1-12	OFF	
52ABF	52A Interlock in BF Logic	Select: Y, N	N	
BFD	Breaker Failure Delay (seconds)	Range = 0.00-2.00	0.50	
BFI	Breaker Failure Initiate (SELogic)		R_TRIG TRIP	
AI301NAM	AI301 Instrument Tag Name (8 characters)		AI301	
AI301TYP	AI301 Input Type	Select: I, V	I	
AI301L	AI301 Low Input Value	Range = -20.480 to 20.480	4.000	

Global				
Setting	**Description**	**Range**	**Value**	**Comment**
AI301H	AI301 High Input Value	Range = -20.480 to 20.480	20.000	
AI301EU	AI301 Engineering Units (16 characters)		mA	
AI301EL	AI301 Low Input Engineering Units	Range = -99999.000 to 99999.000	4.000	
AI301EH	AI301 High Input Engineering Units	Range = -99999.000 to 99999.000	20.000	
AI302NAM	AI302 Instrument Tag Name (8 characters)		AI302	
AI302TYP	AI302 Input Type	Select: I, V	I	
AI302L	AI302 Low Input Value	Range = -20.480 to 20.480	4.000	
AI302H	AI302 High Input Value	Range = -20.480 to 20.480	20.000	
AI302EU	AI302 Engineering Units (16 characters)		mA	
AI302EL	AI302 Low Input Engineering Units	Range = -99999.000 to 99999.000	4.000	
AI302EH	AI302 High Input Engineering Units	Range = -99999.000 to 99999.000	20.000	
AI303NAM	AI303 Instrument Tag Name (8 characters)		AI303	
AI303TYP	AI303 Input Type	Select: I, V	I	
AI303L	AI303 Low Input Value	Range = -20.480 to 20.480	4.000	
AI303H	AI303 High Input Value	Range = -20.480 to 20.480	20.000	
AI303EU	AI303 Engineering Units (16 characters)		mA	
AI303EL	AI303 Low Input Engineering Units	Range = -99999.000 to 99999.000	4.000	
AI303EH	AI303 High Input Engineering Units	Range = -99999.000 to 99999.000	20.000	

Global				
Setting	**Description**	**Range**	**Value**	**Comment**
AI304NAM	AI304 Instrument Tag Name (8 characters)		AI304	
AI304TYP	AI304 Input Type	Select: I, V	I	
AI304L	AI304 Low Input Value	Range = -20.480 to 20.480	4.000	
AI304H	AI304 High Input Value	Range = -20.480 to 20.480	20.000	
AI304EU	AI304 Engineering Units (16 characters)		mA	
AI304EL	AI304 Low Input Engineering Units	Range = -99999.000 to 99999.000	4.000	
AI304EH	AI304 High Input Engineering Units	Range = -99999.000 to 99999.000	20.000	
AO304AQ	AO304 Analog Quantity (Off, 1 analog quantity)		OFF	
BLKMBSET	Block Modbus Settings Edit	Select: NONE, R_S, ALL	NONE	
TIME_SRC	IRIG Time Source	Select: IRIG1, IRIG2	IRIG1	
EBMON	Enable Breaker Monitor	Select: Y, N	N	
Global				

Group 1				
Setting	**Description**	**Range**	**Value**	**Comment**
RID	Relay Identifier (16 characters)		SEL-710	
TID	Terminal Identifier (16 characters)		MOTOR RELAY	
CTR1	Phase (IA,IB,IC) CT Ratio	Range = 1-5000	1	
FLA1	Motor FLA [Full Load Amps] (amps)	Range = 0.2-5000.0	1.6	Radial System
E2SPEED	Two-Speed Protection	Select: Y, N	N	
CTRN	Neutral (IN) CT Ratio	Range = 1-2000	1	

Group 1				
Setting	**Description**	**Range**	**Value**	**Comment**
PTR	PT Ratio	Range = 1.00-250.00	1.00	
VNOM	Line Voltage, Nominal Line-to-Line (volts)	Range = 100-30000	170	
DELTA_Y	Transformer Connection	Select: WYE, DELTA	WYE	
SINGLEV	Single Voltage Input	Select: Y, N	N	
E49MOTOR	Thermal Overload Protection	Select: Y, N	Y	
FLS	Full Load Slip (per unit Synchronous Speed)	Range = OFF,0.0010-0.1000	OFF	
SETMETH	Thermal Overload Method	Select: RATING, RATING_1, CURVE	RATING	
49RSTP	Thermal Overload Reset Level (%TCU)	Range = 10-99	75	
SF	Service Factor	Range = 1.01-1.50	1.35	
LRA1	Motor LRA (Locked Rotor Amps) (xFLA)	Range = 2.5-12.0	2.5	
LRTHOT1	Locked Rotor Time (seconds)	Range = 1.0-600.0	3.0	
TD1	ACCEL FACTOR	Range = 0.10-1.50	1.00	
RTC1	Stator Time Constant (minutes)	Range = AUTO,1-2000	AUTO	
TCAPU	Thermal Overload Alarm Pickup (%TCU)	Range = OFF,50-99	85	
TCSTART	Start Inhibit Level (%TCU)	Range = OFF,1-99	OFF	
COOLTIME	Stopped Cool Time (minutes)	Range = 1-6000	3	
50P1P	Phase Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	3.00	
50P2P	Phase Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	

Group 1				
Setting	**Description**	**Range**	**Value**	**Comment**
50P1D	Phase Overcurrent Trip Delay (seconds)	Range = 0.00-5.00	0.00	
50N1P	Neutral Overcurrent Trip Pickup (amps pri)	Range = OFF,0.01-25.00	OFF	
50N2P	Neutral Overcurrent Alarm Pickup (amps pri)	Range = OFF,0.01-25.00	OFF	
50G1P	Residual Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	0.50	
50G2P	Residual Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	
50G1D	Residual Overcurrent Trip Delay (seconds)	Range = 0.00-5.00	0.10	
50Q1P	Negative Sequence Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	0.50	
50Q2P	Negative Sequence Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	
50Q1D	Negative Sequence Overcurrent Trip Delay (seconds)	Range = 0.10-120.00	0.15	
ESTAR_D	Star-Delta	Select: Y, N	N	
E47T	Phase Reversal Detection	Select: Y, N	Y	
SPDSDLYT	Speed Switch Trip Delay (seconds)	Range = OFF,1-240	OFF	
SPDSDLYA	Speed Switch Alarm Delay (seconds)	Range = OFF,1-240	OFF	
E49RTD	RTD Enable	Select: INT, EXT, NONE	NONE	
27P1P	UV TRIP LEVEL (Off, 0.02-1.00; xVnm)	Range = OFF,0.02-1.00 xVnm	OFF	
27P2P	UV WARN LEVEL (Off, 0.02-1.00; xVnm)	Range = OFF,0.02-1.00 xVnm	OFF	

Group 1				
Setting	**Description**	**Range**	**Value**	**Comment**
59P1P	OV TRIP LEVEL (Off, 0.02-1.20; xVnm)	Range = OFF,0.02-1.20 xVnm	OFF	
59P2P	OV WARN LEVEL (Off, 0.02-1.20; xVnm)	Range = OFF,0.02-1.20 xVnm	OFF	
TDURD	Minimum Trip Time (seconds)	Range = 0.0-400.0	0.5	
TR	Trip (SELogic)		49T OR 50P1T OR 50G1T OR 50Q1T OR (27P1T AND NOT LOP) OR STOP	
STREQ	Start (SELogic)		PB03	
Group 1				

Logic 1				
Setting	**Description**	**Range**	**Value**	**Comment**
ELAT	SELogic Latches	Range = N,1-32	N	
ESV	SELogic Variables/Timers	Range = N,1-32	1	
ESC	SELogic Counters	Range = N,1-32	N	
EMV	SELogic Math Variables	Range = N,1-32	N	
SV01	SV_ Input (SELogic)		WDGTRIP OR BRGTRIP OR OTHTRIP OR AMBTRIP OR REMTRIP OR 37PT OR VART	

Logic 1				
Setting	**Description**	**Range**	**Value**	**Comment**
			OR PTCTRIP OR 81D1T OR 81D2T OR 81D3T OR 81D4T OR 50Q1T OR 87M1T OR 87M2T	
OUT101FS	OUT101 Fail-Safe	Select: Y, N	N	
OUT102FS	OUT102 Fail-Safe	Select: Y, N	Y	
OUT103FS	OUT103 Fail-Safe	Select: Y, N	Y	
OUT101	(SELogic)		HALARM OR SALARM	
OUT102	(SELogic)		NOT START	
OUT103	(SELogic)		TRIP OR PB04	
Logic 1				

Group 2				
Setting	**Description**	**Range**	**Value**	**Comment**
RID	Relay Identifier (16 characters)		SEL-710	
TID	Terminal Identifier (16 characters)		MOTOR RELAY	
CTR1	Phase (IA,IB,IC) CT Ratio	Range = 1-5000	1	
FLA1	Motor FLA [Full Load Amps] (amps)	Range = 0.2-5000.0	2.1	Bidirectional System
E2SPEED	Two-Speed Protection	Select: Y, N	N	
CTRN	Neutral (IN) CT Ratio	Range = 1-2000	1	
PTR	PT Ratio	Range = 1.00-250.00	1.00	
VNOM	Line Voltage, Nominal Line-to-Line (volts)	Range = 100-30000	190	
DELTA_Y	Transformer Connection	Select: WYE, DELTA	WYE	

Group 2				
Setting	**Description**	**Range**	**Value**	**Comment**
SINGLEV	Single Voltage Input	Select: Y, N	N	
E49MOTOR	Thermal Overload Protection	Select: Y, N	Y	
FLS	Full Load Slip (per unit Synchronous Speed)	Range = OFF,0.0010-0.1000	OFF	
SETMETH	Thermal Overload Method	Select: RATING, RATING_1, CURVE	RATING	
49RSTP	Thermal Overload Reset Level (%TCU)	Range = 10-99	75	
SF	Service Factor	Range = 1.01-1.50	1.35	
LRA1	Motor LRA (Locked Rotor Amps) (xFLA)	Range = 2.5-12.0	2.5	
LRTHOT1	Locked Rotor Time (seconds)	Range = 1.0-600.0	1.0	
TD1	ACCEL FACTOR	Range = 0.10-1.50	1.00	
RTC1	Stator Time Constant (minutes)	Range = AUTO,1-2000	AUTO	
TCAPU	Thermal Overload Alarm Pickup (%TCU)	Range = OFF,50-99	85	
TCSTART	Start Inhibit Level (%TCU)	Range = OFF,1-99	OFF	
COOLTIME	Stopped Cool Time (minutes)	Range = 1-6000	3	
50P1P	Phase Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	3.00	
50P2P	Phase Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	
50P1D	Phase Overcurrent Trip Delay (seconds)	Range = 0.00-5.00	0.00	
50N1P	Neutral Overcurrent Trip Pickup (amps pri)	Range = OFF,0.01-25.00	OFF	

Group 2				
Setting	**Description**	**Range**	**Value**	**Comment**
50N2P	Neutral Overcurrent Alarm Pickup (amps pri)	Range = OFF,0.01-25.00	OFF	
50G1P	Residual Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	0.50	
50G2P	Residual Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	
50G1D	Residual Overcurrent Trip Delay (seconds)	Range = 0.00-5.00	0.10	
50Q1P	Negative Sequence Overcurrent Trip Pickup (xFLA)	Range = OFF,0.10-20.00	0.50	
50Q2P	Negative Sequence Overcurrent Alarm Pickup (xFLA)	Range = OFF,0.10-20.00	OFF	
50Q1D	Negative Sequence Overcurrent Trip Delay (seconds)	Range = 0.10-120.00	0.15	
E47T	Phase Reversal Detection	Select: Y, N	Y	
TDURD	Minimum Trip Time (seconds)	Range = 0.0-400.0	0.5	
TR	Trip (SELogic)		49T OR 50P1T OR 50G1T OR 50Q1T OR (27P1T AND NOT LOP) OR STOP	
STREQ	Start (SELogic)		PB03	
Group 2				

Logic 2				
Setting	**Description**	**Range**	**Value**	**Comment**
ELAT	SELogic Latches	Range = N,1-32	N	
ESV	SELogic Variables/Timers	Range = N,1-32	1	

Logic 2				
Setting	**Description**	**Range**	**Value**	**Comment**
ESC	SELogic Counters	Range = N,1-32	N	
EMV	SELogic Math Variables	Range = N,1-32	N	
SV01	SV_ Input (SELogic)		WDGTRIP OR BRGTRIP OR OTHTRIP OR AMBTRIP OR REMTRIP OR 37PT OR VART OR PTCTRIP OR 81D1T OR 81D2T OR 81D3T OR 81D4T OR 50Q1T OR 87M1T OR 87M2T	
OUT101FS	OUT101 Fail-Safe	Select: Y, N	N	
OUT102FS	OUT102 Fail-Safe	Select: Y, N	Y	
OUT103FS	OUT103 Fail-Safe	Select: Y, N	Y	
OUT101	(SELogic)		HALARM OR SALARM	
OUT102	(SELogic)		NOT START	
OUT103	(SELogic)		TRIP OR PB04	
Logic 2				

Port 3				
Setting	**Description**	**Range**	**Value**	**Comment**
PROTO	Protocol	Select: SEL, MOD, MBA, MBB, MB8A,	SEL	

Port 3				
Setting	**Description**	**Range**	**Value**	**Comment**
		MB8B, MBTA, MBTB		
SPEED	Data Speed (bps)	Select: 300, 1200, 2400, 4800, 9600, 19200, 38400	19200	
BITS	Data Bits (bits)	Select: 7, 8	8	
PARITY	Parity	Select: O, E, N	N	
STOP	Stop Bits (bits)	Select: 1, 2	1	
RTSCTS	Hardware Handshaking	Select: Y, N	N	
T_OUT	Port Time-Out (minutes)	Range = 0-30	5	
AUTO	Send Auto Messages to Port	Select: Y, N	Y	
FASTOP	Fast Operate	Select: Y, N	N	
Port 3				

Front Panel				
Setting	**Description**	**Range**	**Value**	**Comment**
EDP	Display Points Enable	Range = N,1-32	4	
ELB	Local Bits Enable	Range = N,1-32	N	
FP_TO	Front-Panel Timeout	Range = OFF,1-30	15	
FP_CONT	Front-Panel Contrast	Range = 1-8	4	
FP_AUTO	Front-Panel Automessages	Select: OVERRIDE, ROTATING	OVERRIDE	
RSTLED	Reset Trip-Latched LEDs On Close	Select: Y, N	Y	
T01LEDL	Trip Latch T_LED	Select: Y, N	Y	
T01_LED	(SELogic)		49T OR AMBTRIP OR BRGTRIP OR OTHTRIP	

Front Panel				
Setting	**Description**	**Range**	**Value**	**Comment**
			OR WDGTRIP	
T02LEDL	Trip Latch T_LED	Select: Y, N	Y	
T02_LED	(SELogic)		50P1T OR 50N1T OR 50G1T	
T03LEDL	Trip Latch T_LED	Select: Y, N	Y	
T03_LED	(SELogic)		46UBT OR 47T	
T04LEDL	Trip Latch T_LED	Select: Y, N	Y	
T04_LED	(SELogic)		LOSSTRIP OR 37PT	
T05LEDL	Trip Latch T_LED	Select: Y, N	Y	
T05_LED	(SELogic)		(NOT STOPPED AND 27P1T) OR 59P1T	
T06LEDL	Trip Latch T_LED	Select: Y, N	Y	
T06_LED	(SELogic)		87M1T OR 87M2T	
PB1A_LED	(SELogic)		PB01	
PB2A_LED	(SELogic)		PB02	
PB3A_LED	(SELogic)		PB03	
PB4A_LED	(SELogic)		PB04	
PB1B_LED	(SELogic)		0	
PB2B_LED	(SELogic)		0	
PB3B_LED	(SELogic)		STARTING OR RUNNING	
PB4B_LED	(SELogic)		STOPPED	
DP01	Display Point (60 characters)		RID, "{16}"	
DP02	Display Point (60 characters)		TID, "{16}"	
DP03	Display Point (60 characters)		IAV, "I MOTOR {6} A"	

Front Panel				
Setting	**Description**	**Range**	**Value**	**Comment**
DP04	Display Point (60 characters)		TCUSTR, "Stator TCU {3} %"	
Front Panel				

Report				
Setting	**Description**	**Range**	**Value**	**Comment**
SER1	(24 Relay Word bits)		IN101 IN102 PB01 PB02 PB03 PB04 ABSLO TBSLO NOSLO THERMLO TRIP PB04 50P1P 50G1P 50Q1P	
SER2	(24 Relay Word bits)		49T 49T_STR 49T_RTR LOSSTRIP JAMTRIP 46UBT 50P1T RTDT PTCTRIP 50G1T VART 37PT 27P1T 59P1T 47T 55T SPDSTR 50N1T SMTRIP 81D1T 81D2T OTHTRIP 87M1T 87M2T	
SER3	(24 Relay Word bits)		AMBTRIP PTCFLT RTDFLT COMMIDLE COMMLOSS REMTRIP RSTTRGT 49A LOSSALRM JAMALRM 46UBA RTDA 55A 50N2T 50G2T VARA 37PA 27P2T 59P2T 50P2T 50Q1T 50Q2T	
SER4	(24 Relay Word bits)		SPDSAL 81D3T 81D4T OTHALRM AMBALRM SALARM WARNING LOADUP LOADLOW 50P2T STOPPED RUNNING STARTING STAR	

Report				
Setting	**Description**	**Range**	**Value**	**Comment**
			DELTA START SPEED2	
EALIAS	Enable ALIAS Settings	Range = N,1-20	15	
ALIAS1	(59 characters)		STARTING MOTOR_STARTING BEGINS ENDS	
ALIAS2	(59 characters)		RUNNING MOTOR_RUNNING BEGINS ENDS	
ALIAS3	(59 characters)		STOPPED MOTOR_STOPPED BEGINS ENDS	
ALIAS4	(59 characters)		JAMTRIP LOAD_JAM_TRIP PICKUP DROPOUT	
ALIAS5	(59 characters)		LOSSTRIP LOAD_LOSS_TRIP PICKUP DROPOUT	
ALIAS6	(59 characters)		LOSSALRM LOAD_LOSS_ALARM PICKUP DROPOUT	
ALIAS7	(59 characters)		46UBA UNBALNC_I_ALARM PICKUP DROPOUT	
ALIAS8	(59 characters)		46UBT UNBALNC_I_TRIP PICKUP DROPOUT	
ALIAS9	(59 characters)		49A THERMAL_ALARM PICKUP DROPOUT	
ALIAS10	(59 characters)		49T THERMAL_TRIP PICKUP DROPOUT	
ALIAS11	(59 characters)		47T PHS_REVRSL_TRIP PICKUP DROPOUT	
ALIAS12	(59 characters)		PB01 FP_AUX1 PICKUP DROPOUT	
ALIAS13	(59 characters)		PB02 FP_AUX2 PICKUP DROPOUT	

Report				
Setting	**Description**	**Range**	**Value**	**Comment**
ALIAS14	(59 characters)		PB03 FP_START PICKUP DROPOUT	
ALIAS15	(59 characters)		PB04 FP_STOP PICKUP DROPOUT	
ER	Event Report Trigger (SELogic)		R_TRIG LOSSALRM OR R_TRIG 46UBA OR R_TRIG 49A OR R_TRIG 37PA OR R_TRIG 55A OR R_TRIG VARA	
LER	Length of Event Report (cycles)	Select: 15, 64	64	
PRE	Prefault Length (cycles)	Range = OFF,1-59	10	
MSRR	MSR Resolution (cycles)	Select: 0.25, 0.5, 1, 2, 5, 20	5	
MSRTRG	MSR Report Trigger (SELogic)		0	
LDLIST	Load Profile List (17 Analog Quantities)		NA	
LDAR	Load Profile Acquisition Rate (minutes)	Select: 5, 10, 15, 30, 60	15	
Report				

APPENDIX G: ABET SENIOR PROJECT ANALYSIS

Project Title: Protective Relaying Student Laboratory

Student's Name: Ian Hellman-Wylie Student's Signature: ______________________

Student's Name: Joey Navarro Student's Signature: ______________________

Advisor's Name: Dr. Ali Shaban Advisor's Initials: ______Date: ____/____/2017

1) Summary of Functional Requirements

See Chapter 2 for functional requirements.

2) Primary Constraints

The primary constraints for the project include the requirements for fault type, clearing time, protective devices, and system topology given in Chapter 2. The protection scheme used in the MPSL was designed using these constraints, which played a large role in determining the protection elements and individual relay settings that could be used in order to meet the project's requirements.

On particular constraint was the time required to complete the project. Programming the relays required a great deal of research, training, and, most of all, practice in order to produce a protection scheme that was reliable, safe, and fulfilled all requirements, especially in the three academic quarters available.

3) Economics

This project requires a significant amount of capital, both human and financial. The financial capital required is mitigated by the donation of the comparatively expensive SEL devices used in the project, as well as the additional units available. This allows Cal Poly to replicate or expand the system with little monetary expenditure, especially given SEL's willingness to provide discounts on on-campus training and possibly future purchases (or outright donations).

This project represented a significant time investment in terms of man-hours spent becoming familiar with the equipment. Given that microprocessor-based relay programming is not a part of the current University curriculum, a large portion of our time was spent building a knowledge and resource base and becoming competent in basic relay programming. A substantial part of any future project based on the system will require the same.

That being said, the addition of laboratory coursework and, if feasible, continued on-site training (perhaps on a yearly basis, to coincide with EE 518/EE 444) will give students the opportunity to achieve basic competence in relay programming in class, thus allowing them to less project hours reinventing the wheel, so to speak.

4) If Manufactured on a Commercial Basis

If manufactured on a commercial basis, the primary costs come from labor and purchase of the SEL equipment. From Table 5.2, the SEL devices would cost $23,200. Since this project is intended for educational institutions, however, it may be possible to acquire the relays through donation or lending, which would reduce the financial burden significantly.

Assuming SEL devices can be acquired via donation, and labor requirements are reduced to 200 hours due to improved efficiency and replication rather than invention, the cost of the project would be $8,875. Rounding up to an even $10,000 for the final price would return a profit of $1,125 per system, which would cover minor unforeseen expenses while keeping the price low to accommodate the budgetary constraints that educational institutions often face.

5) Environmental

The MPSL itself has minimal environmental impact, other than those detailed in the Sustainability section below. The goal of the project, however, is to help educate future protection engineers who will have the responsibility of protecting the public and the environment from power system faults and the consequences thereof.

6) Manufacturability

The MPSL uses commercially-available equipment and hardware and does not require specialized technical assembly skills or manufacturing techniques. The most demanding parts of construction are related to making wires and then wiring the system, which can reasonably be done by anyone who can cut and strip 12 AWG wire and turn a screwdriver.

Implementation of the system, especially if modified from our design to meet a customer's individual needs, requires custom relay settings and possibly protection schemes. In general, however, if a user can create the project as developed, those skills translate readily to other SEL relays and protection schemes.

7) Sustainability

Microprocessor relays, like all electronic devices, are manufactured from materials that must be mined and processed, depleting the Earth's natural resources. This also applies to the equipment being protected: transformers, electric machines, etc.

A properly-designed protection scheme, however, helps to mitigate and/or prevent equipment damage or even destruction from power system faults and other abnormal conditions. This ensures that electrical power equipment remains in service for many years, reducing the need to properly dispose of or recycle those items. By improving the education of students in power system protection, this project aims to help train future protection engineers in creating power systems that are safe and reliable, reducing the need for equipment disposal and environmental impacts.

8) Ethical

The MPSL has been designed to serve the goals in the IEEE code of ethics [12] by providing a platform for students to improve their understanding of power system protection devices and the proper application of such devices, in order to support the next generation of protection engineers, whose work makes power systems safer for operators, customers, and the environment.

9) Health and Safety

The MPSL is intended to be used by electrical engineering students in the Cal Poly laboratory setting, and as such has been designed to introduce no additional safety risks beyond those present in existing power systems courses such as EE 295 and EE 444. The MPSL system uses 240 V, 3-phase power, and momentary currents as high as 12 A may be present in the system during fault testing. Proper electrical safety precautions should be taken at all times while using the system, and Cal Poly's laboratory safety guidelines should be followed. For student safety, all work on the MPSL should be done using the buddy system, and at least two students should be present whenever the system is energized.

10) Social and Political

The primary stakeholder in the project is the Electrical Engineering Department at Cal Poly, who requested this project as part of the expansion and modernization of the power systems curriculum. Secondary stakeholders include the university as a whole, as well as electrical engineering students, particularly those focusing on power systems and protection engineering.

The MPSL benefits the department by adding a laboratory system suitable for laboratory coursework, senior projects, and integration into the Cal Poly Microgrid project. The project justifies the support, both financial and administrative, that the Department has given. The MPSL benefits students by improving the quality of their education with practical, hands-on experience that comports with the "Learn by Doing" philosophy of the University. The University as a whole benefits by remaining a high quality choice for students and their sweet, sweet tuition money.

11) Development

The MPSL is not about innovation, per se, but rather the application of existing technologies and the experience gained thereby. That being said, using SEL relays requires familiarity with relay operation and programming, which was gained by reviewing documentation and attending training through SEL University. As protection is as much an art as it is a science, the intricacies of system protection schemes and relay settings can only be gained through experience, which this project provides.

APPENDIX H: PROGRAMMING THE SEL-2032 COMMUNICATIONS PROCESSOR

The following guide instructs the user in programming the SEL-2032 Communications Processor to act as a port switch between connected relays and to distribute a synchronized timing signal from the SEL-2407 Satellite Clock. This is an excerpt from [1], Appendix N.

Program the SEL-2020/32

1. Open the SEL-5020 Settings Assistant software (H.1).

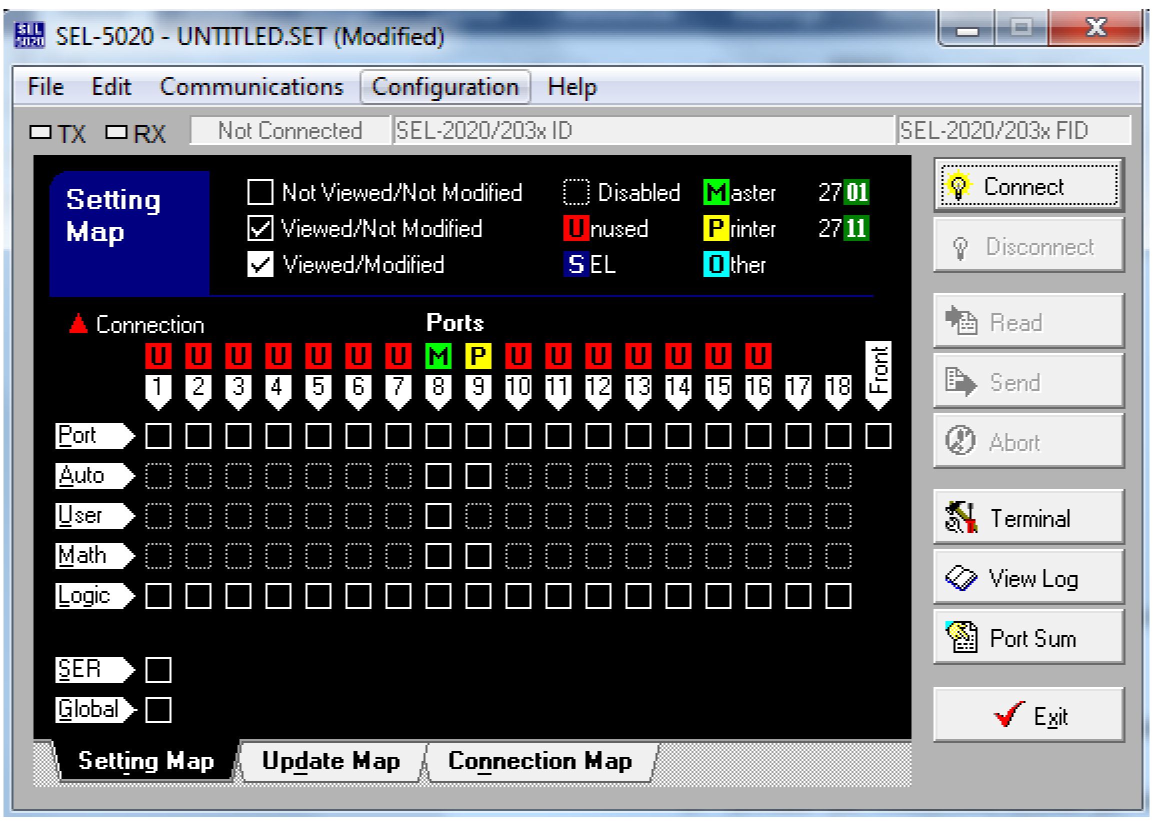

Figure H.1: SEL-5020 Settings Assistant Software Main Screen

2. Configure the SEL-2020/32 rear-panel master serial port (first-time device setup only).
    a. Connect SEL-2020/32 front-panel Port F to the main serial port on the back of the computer (surrounded by a light turquoise color) using an SEL-C234A serial cable.
    b. Open AcSELerator QuickSet and the Communication Parameters window (Communications, Parameters) (Figure H.X)
    c. Connect to the SEL-2020/32 (guess the baud rate as either 2400 or 9600 and enter the default level 1 and 2 passwords: OTTER and TAIL). Click Apply. Ask for help if you get stuck on this step.
    d. Open the AcSELerator QuickSet terminal window (Communications, Terminal) and press the ENTER key (on the keyboard). If you do not see an '*' displayed at the top of the window, you failed to successfully complete the previous step.
    e. Type ACC followed by ENTER to gain level 1 access to the communications processor (Figure H.2).
    f. Type the level one password (OTTER).
    g. Type 2AC followed by ENTER to gain level 2 access to the communications processor.
    h. Type the level two password (TAIL).
    i. Type SET P 10 followed by ENTER to change the settings for serial port 10.
    j. Type M to use serial port 10 on the communications processor as the master port that communicates with the computer (Figure H.3). Type the ENTER key five times until the first Communications Settings prompt appears.
    k. Type 19200 to set the port 10 baud rate to a faster speed. Type the ENTER key.
    l. Continue to type the ENTER key until asked whether you want to save the settings changes. Type Y followed by ENTER.

```
*acc

Password: ? OTTER

                                              Date: 05/20/17    Time: 23:53:58

Level 1
*>2AC

Password: ? TAIL
```

Figure H.2: Obtaining Level 1 and Level 2 Access to a Communications Processor

```
Device Type (U=Unused, S=SEL IED, O=Other IED,
            P=Printer, M=Master)              DEVICE  = S     ? M

Communications Type (S=SEL, L=LMD)          PROTOCOL= S     ?

Enable Fast Operate commands on this port (Y/N)FAST_OP = N     ?

Port Identification String
PORTID  =""
 ?

Modem Settings

Modem Control (Y/N)                         MODEM   = N     ?

Communications Settings

Baud Rate (300, 600, 1200, 2400, 4800, 9600,
          19200, 38400)                     BAUD    = 19200 ? 19200

Number data bits (7,8)                      DATABIT = 8     ?

Stop Bits (1,2)                             STOPBIT = 2     ?

Parity (N,O,E,1,0)                          PARITY  = N     ?

Enable RTS/CTS handshaking (Y/N)            RTS_CTS = N     ?

Enable XON/XOFF flow control (Y/N)          XON_XOFF= Y     ?

Port Timeout in minutes (0.0-120.0)         TIMEOUT = OFF   ?

Echo received characters (Y/N)              ECHO    = Y     ?

Automatic help messages enabled (Y/N)       AUTO_HELP= Y     ?

Transparent Communications Termination Sequence

First delay time (0-600 seconds)            TERTIME1= 1     ?

Termination string
TERSTRING="\004"
```

Figure H.3: Establish SEL-2020/32 Master Port Using QuickSet Terminal

2. Remove the serial cable from port F, and connect the SEL-2020/32 Port 10 to the main serial port on the back of the computer (surrounded by a light turquoise color) using an SEL-C234A serial cable.

3. Define communication parameters for the 2020/32:
    a. Select Configuration, Connection Directory.
    b. In the Connection Directory, select Add.
    c. In the Communication Parameters (Figure H.4), type in a name for the 2020/32 unit (like Bench5_2020). Choose a Serial connection and baud rate of 19200 (the default baud rate is 2400, but has been previously changed to 19200 on this unit). If the standard SEL-C234A serial cable is being used, select Direct to COM1 as the Communication Port (standard desktop PC serial port, surrounded by a turquoise color). Click OK.
    d. Back on the Communication Directory screen, select Set as Default to make this 2020/32 the default communication network. Click Close to return to the main screen.

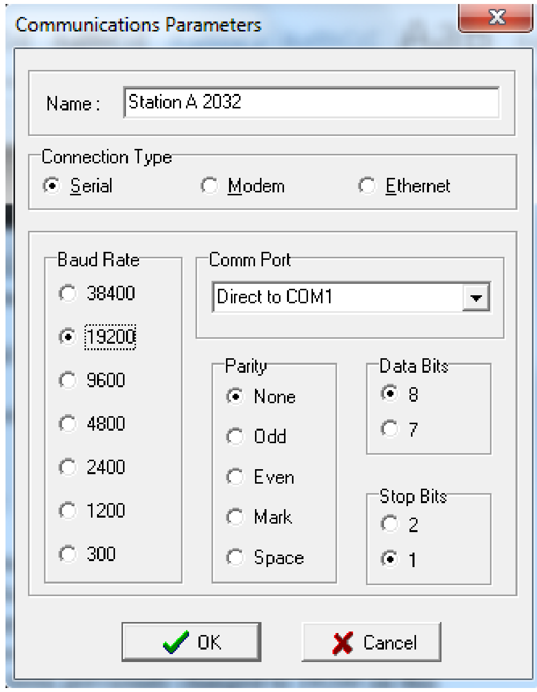

Figure H.4: SEL-2032/20 Communications Parameters

4. Define the communications device:
    e. Select File, New.
    f. Select SEL-2020/32 as the hardware, with I/O Board checked (Figure H.5). For the Connection Options, select the name of the 2020/32 network you created previously (e.g. Bench5_2020). Click OK.
    g. Save the settings file being created by selecting File, Save As to create a record of the settings to be used.

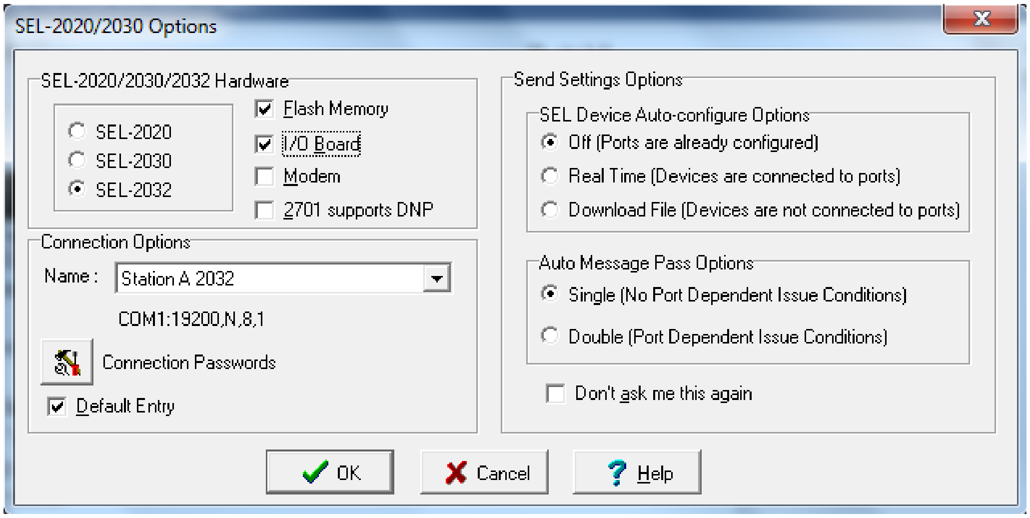

Figure H.5: Defining SEL-2020/32 Device Options

5. Enter the settings for the master port (port 10) on the communications processor (Figure H.6).
    a. Select Edit, Port Settings to bring up the Port Settings window for the 2020/32 being programmed.
    b. Select Port Number 10.
    c. Select Master as the Device.
    d. Change the Baud setting to 19200.
    e. Click OK.

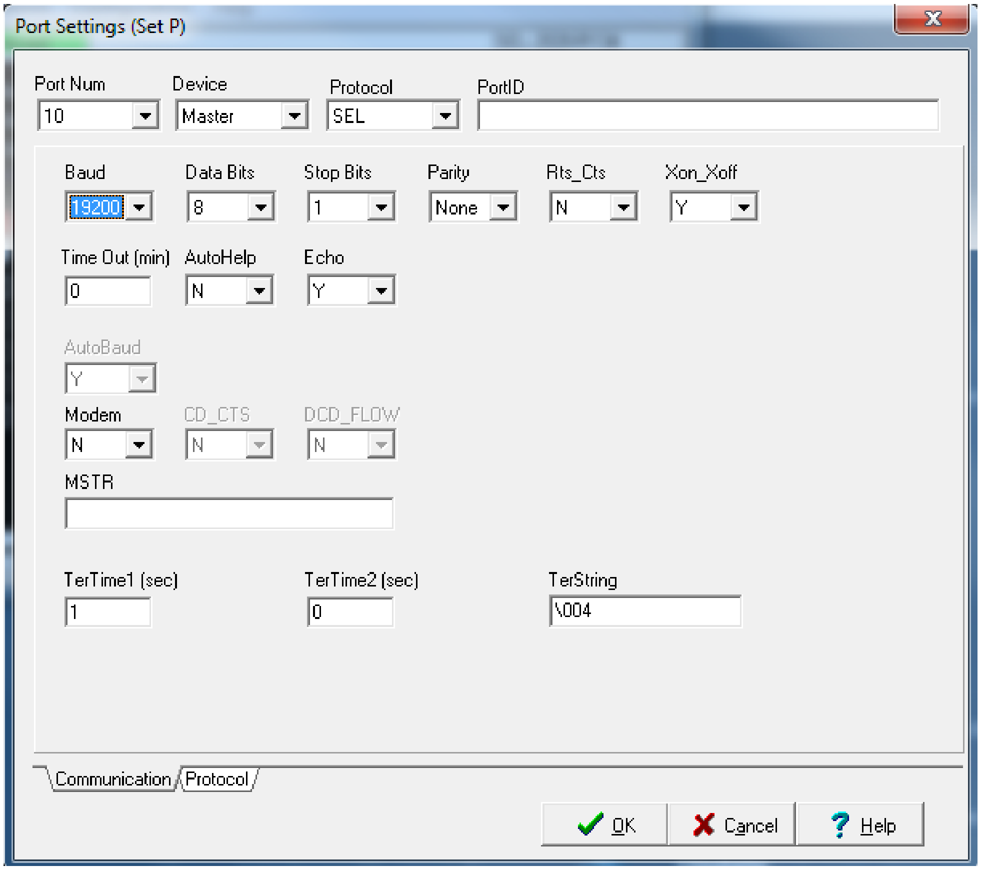

Figure H.6: Defining SEL-2020/32 Device Options

6. Establish a connection with the SEL-2020/32 communications processor:
   a. Make sure that you have disconnected the active communication between QuickSet and the communications processor (Communications, Disconnect from the QuickSet main window).
   b. On the main screen, click Connect (Figure H.7) to bring up the terminal window.
   c. A Password window may quickly come up prompting you for the level 1 password (the default is OTTER). Proceed to the next step if asked, instead, for the level 2 password. Check Save password as default so that you do not have to enter it again during this work session. Click Ok.
   d. Another Password window should quickly come up prompting you for the Level 2 password (the default is TAIL). Check Save password as default so that you do not have to enter it again during this work session. Click Ok.
   e. Returning to the main screen, you should see a status of “Connected” with a green background at the top of the screen (Figure H.8).
   f. Save your progress (File, Save).

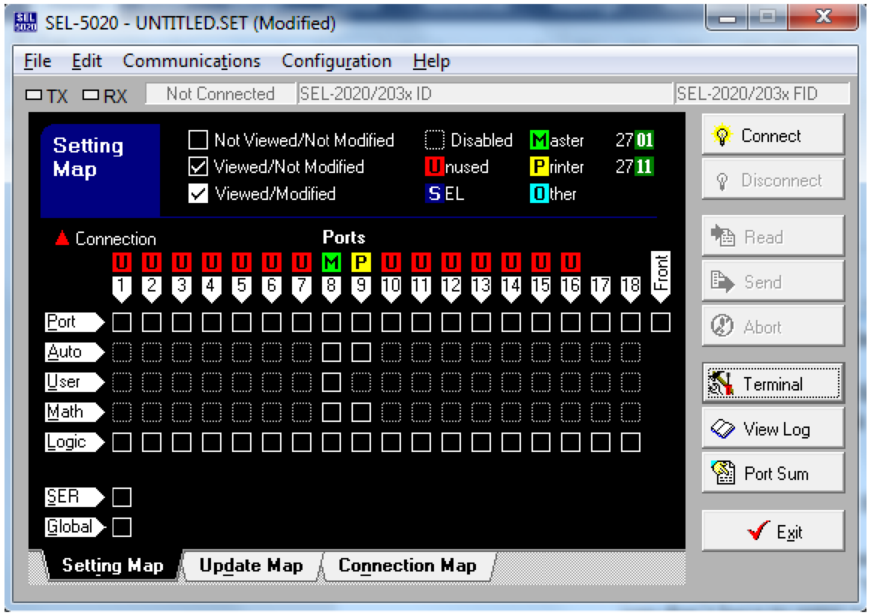

Figure H.7: Main Screen before Establishing Connection

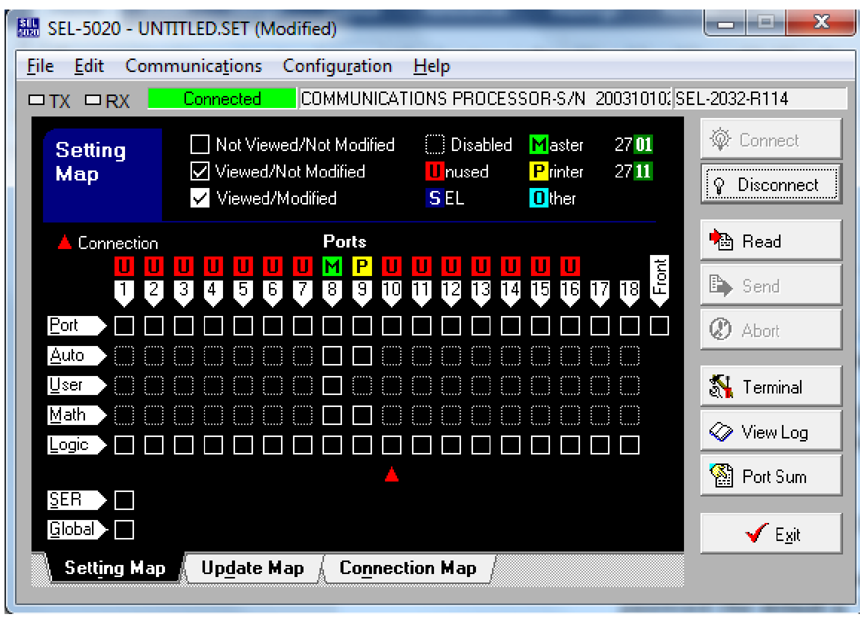

Figure H.8: Main Screen after Establishing Connection

7. Connect and configure an SEL-387E differential relay:
   a. Connect an SEL-C273A serial cable between Port 1 on the back of the 2020/32 and Port 2 on the back of the SEL-387E.

b. Select Edit, Port Settings to bring up the Port Settings window for the 2020/32 being programmed. Select the port (Port 1) to which the serial cable is connected on the 2020/32. Identify the relay Device as an SEL (Figure H.9).
c. Configure the connection between the SEL-2020/32 and SEL-387E using the special SEL autoconfiguration feature by selecting AutoConfig. The 2020/32 will talk to the 387E to determine its current relevant parameters.
d. Select Real Time AC in the Autoconfiguration Options window which pops up. Note that the 2020/32 front-panel RX and TX lights for Port 1 should soon begin blinking as the 2020/32 communicates with the 387E.
e. When the autoconfiguration procedure finishes, the Port Settings window fills in all necessary data fields for the connected 387E relay (Figure H.10). Click Ok.

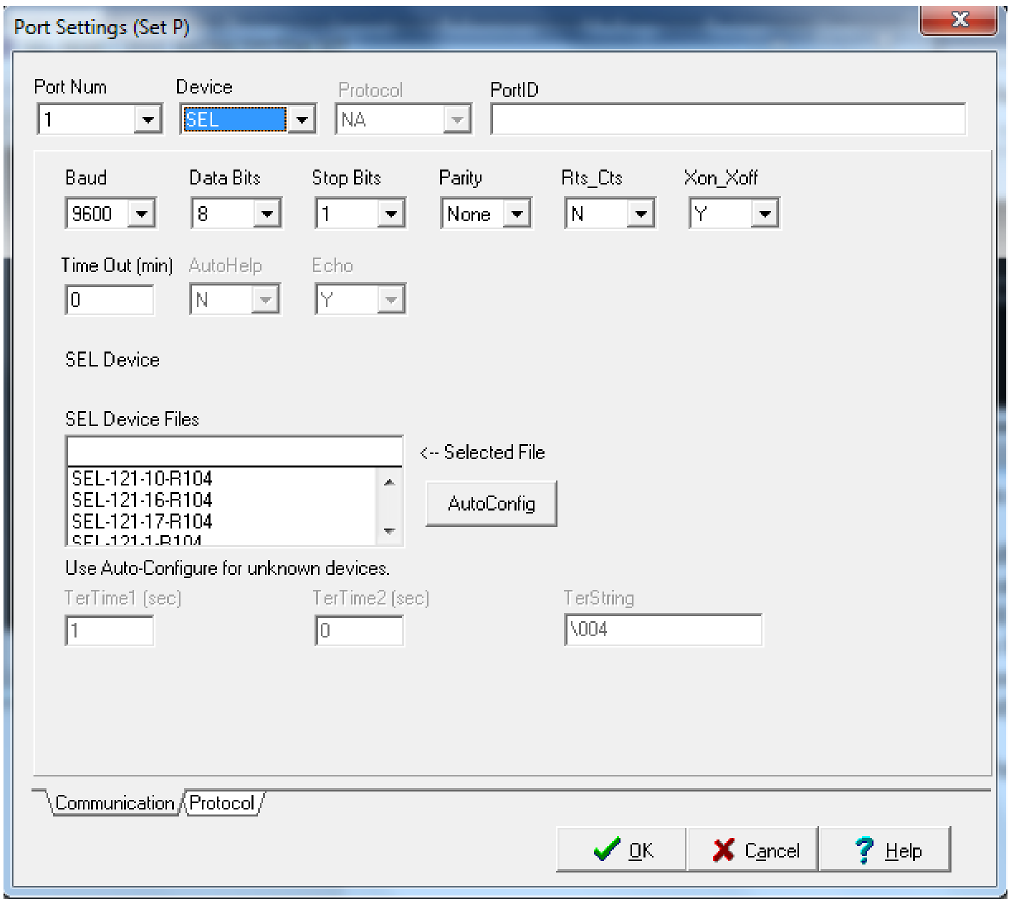

Figure H.9: Port Settings Window

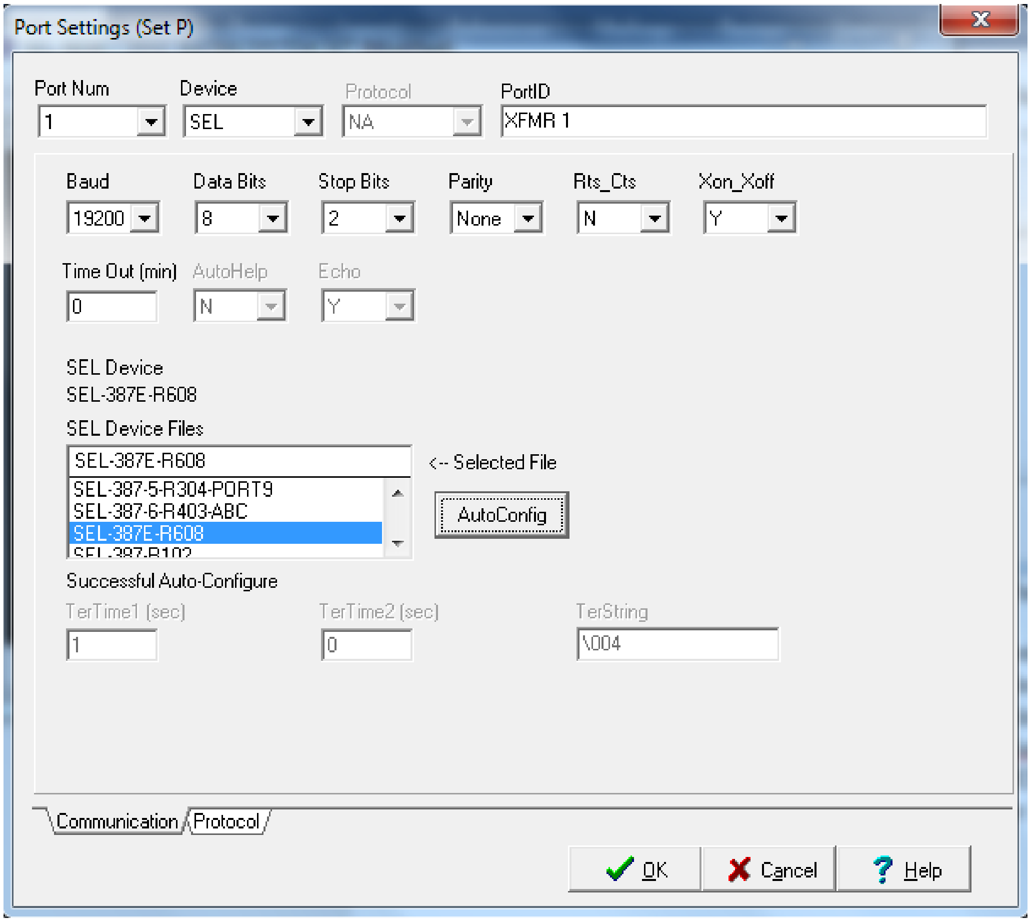

Figure H.10: SEL-387E Port Settings

8. Connect and configure an SEL-311L line current relay:
    a. Connect an SEL-C273A serial cable between Port 2 on the back of the 2020/32 and Port 2 on the back of the SEL-311L.
    b. Select Edit, Port Settings to bring up the Port Settings window for the 2020/32 being programmed. Select the port (Port 2) to which the serial cable is connected on the 2020/32. Identify the relay Device as an SEL.
    c. Configure the connection between the 2020/32 and 311L using the special SEL autoconfiguration feature by selecting AutoConfig. The 2020/32 will talk to the 311L to determine its current relevant parameters.
    d. Select Real Time AC in the Autoconfiguration Options window which pops up. Note that the 2020/32 front-panel RX and TX lights for Port 2 should soon begin blinking as the 2020/32 communicates with the 311L.
    e. When the autoconfiguration procedure finishes, the Port Settings window fills in all necessary data fields for the connected 311L relay (Figure H.11). Click Ok.

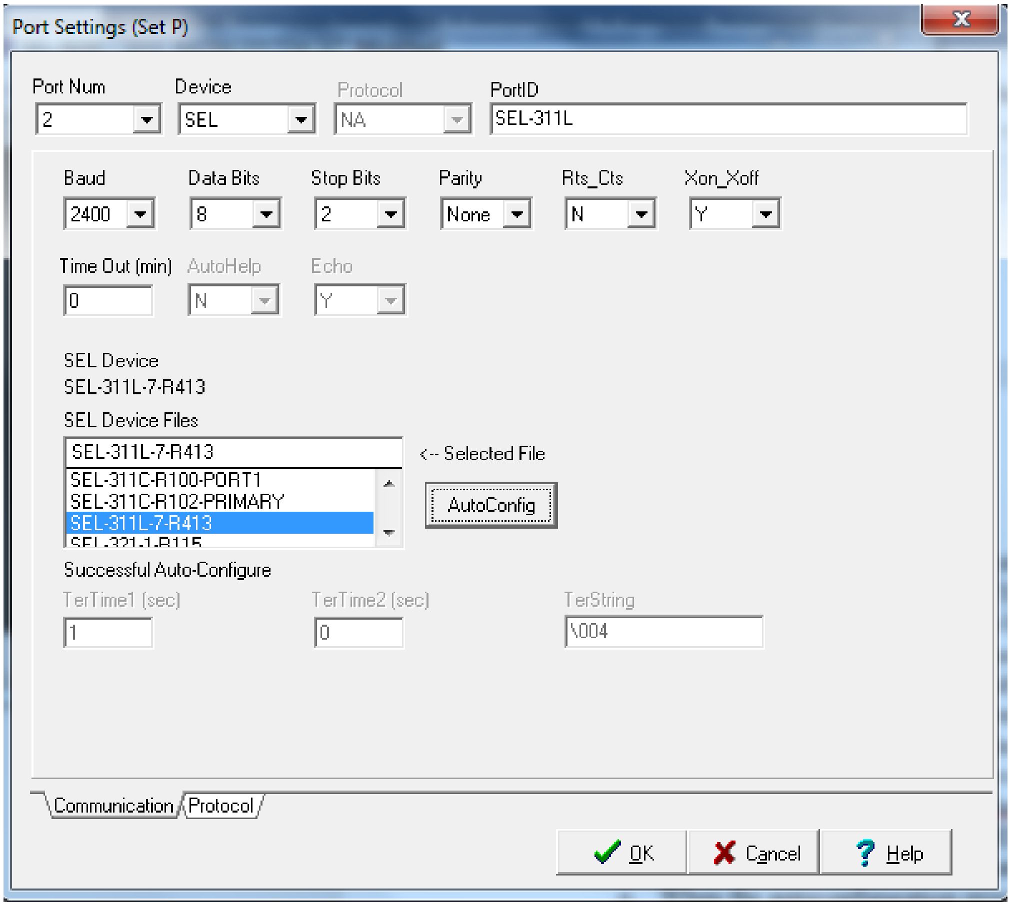

Figure H.11: SEL-311L Port Settings

9. Connect and configure an SEL-710 motor relay:
    a. Connect an SEL-C273A serial cable between Port 3 on the back of the 2020/32 and Port F on the front of the SEL-710.
    b. Select Edit, Port Settings to bring up the Port Settings window for the 2020/32 being programmed. Select the port (Port 3) to which the serial cable is connected on the 2020/32. Identify the relay Device as an SEL.
    c. Configure the connection between the 2020/32 and 710 using the special SEL autoconfiguration feature by selecting AutoConfig. The 2020/32 will talk to the 710 to determine its current relevant parameters.
    d. Select Real Time AC in the Autoconfiguration Options window which pops up. Note that the 2020/32 front-panel RX and TX lights for Port 3 should soon begin blinking as the 2020/32 communicates with the 710.
    e. When the autoconfiguration procedure finishes, the Port Settings window fills in all necessary data fields for the connected 710 relay (Figure H.12). Click Ok.
    f. Save this SEL-5020 file.

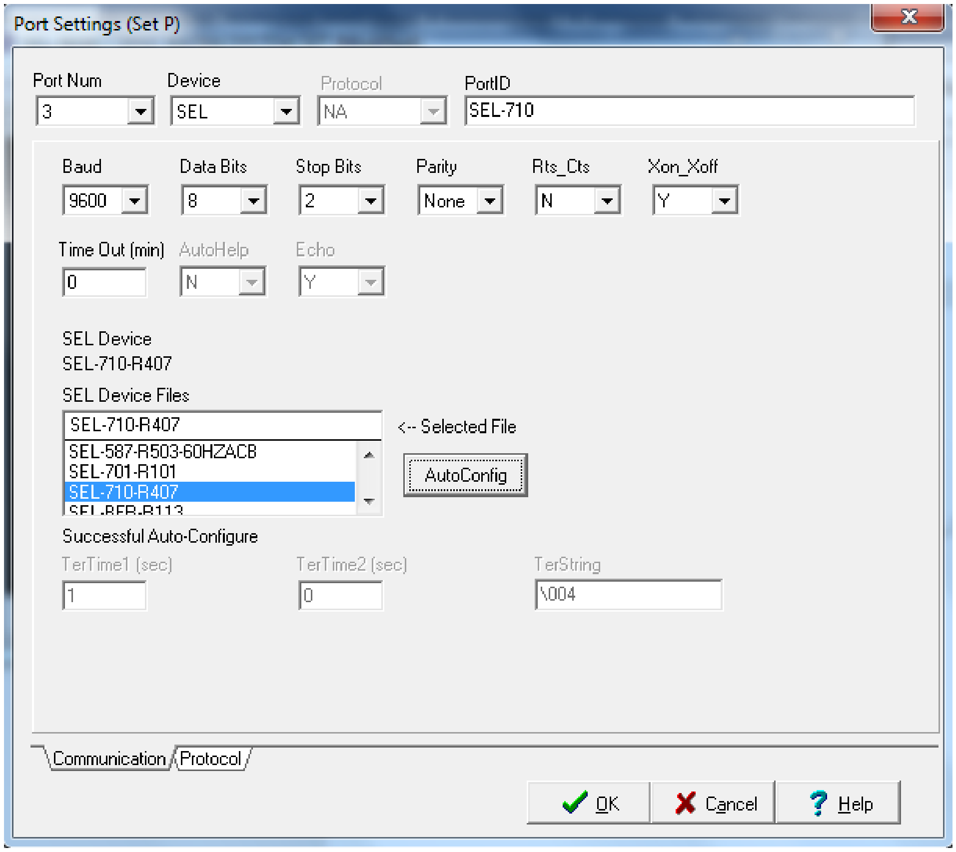

Figure H.12: SEL-710 Port Settings

10. Select Disconnect on the right side of the main screen of the SEL-5020 software.

11. Connect the OUT1 back-panel terminal of an SEL-2407 Satellite-Synchronized Clock (if available) to the SEL-2020/32 back-panel IRIG-B input terminal with a BNC-to-BNC cable. Confirm from the front-panel display on the SEL-2407 that the clock locks onto a satellite (the green Satellite Lock LED lights up). After initially powering up, the SEL-2407 does not generate an IRIG-B output signal until the unit obtains a successful satellite lock. The unit continues to generate an IRIG-B signal after this initial lock, even after losing the connection to the satellite.

12. Open the AcSELerator QuickSet software. This program allows you to access the data stored on the relays but requires that the 2020/32 already be programmed (hence the need for the SEL-5020 Settings Assistant Software).

13. On the home screen of QuickSet, select Communication to define the communication parameters of the 2020/32 unit to which the relays are

connected. In the Communication Parameters window which comes up (Figure H.13), choose Serial Active Connection Type, COM1: Communications Port as the serial connection on the computer, and a Data Speed of 19200 (the default baud rate is 2400; Port 10 on the 2020/32 was specifically increased to 19200 to mitigate timeout errors during data transmission). Recall that the default Level One Password on the 2020/32 is OTTER and that the default Level Two Password on the 2020/32 is TAIL. Click Apply to initiate a communication link with the 2020/32. The RX and TX lights in the lower-left corner of the screen should blink. Click OK. **Note:** A link cannot be established if the 2020/32 is still connected through the 5020 software.

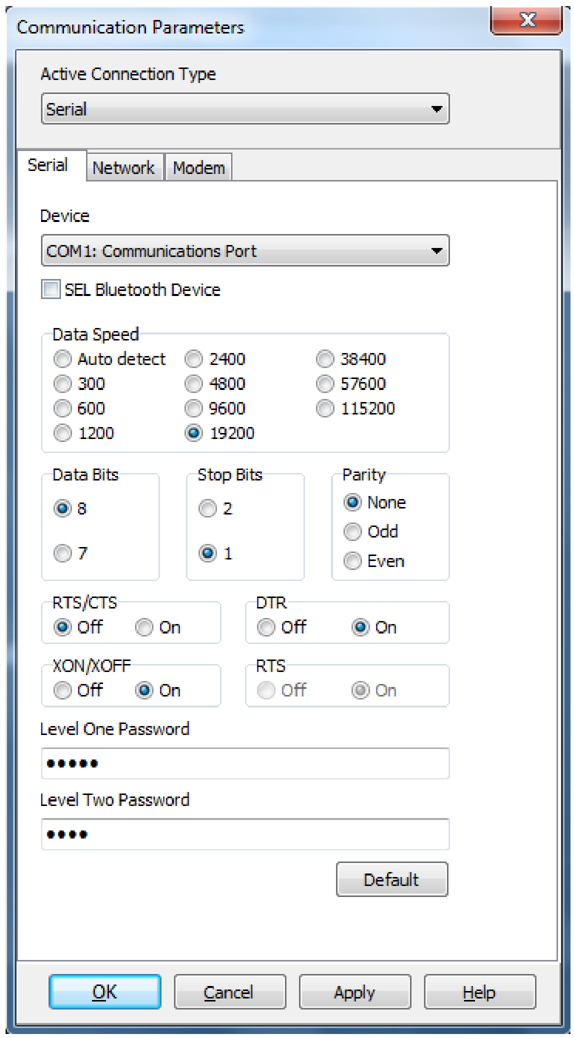

Figure H.13: AcSELerator QuickSet Communication Parameters Window