Transformer and Motor Protection Scheme

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Abstract

The purpose of this project is to integrate a protected system that includes a source, transformer, and motor. In the past, Professor Shaban has had Schweitzer Engineering Laboratory's (SEL) protection relays used to open breakers during fault conditions on transformers (SEL 587) and motors (SEL 710). First, analysis was done on each of the individual components to test for functionality. Testing the transformer and motor separately provided the relay and circuit breaker coordination during fault conditions. The motor was protected against phase-to-ground, line-to-line, locked rotor, and temperature faults. As for the 3-phase transformer, the SEL 587 protected against phase-to-ground, line-to-line, and 3-phase faults. When integrated, the system will run during normal conditions and protected during fault conditions with the use of SEL relays and Cal Poly circuit breakers. Each of the relays is responsible for detecting the fault in 5 cycles and opening the local circuit breaker. The circuit breaker operation was controlled using programmed logic functions within the SEL relays.

Acknowledgements

I would like to thank both Professor Shaban and Professor Nafisi for providing a structural power program through my Cal Poly experience. They have been a proven representation of power system engineering in school and across industries. Every power class provided by the professor is kept up to date to industry standards and provide hands-on learning with industry professionals. Thank you for relaying information and wisdom throughout my stay at Cal Poly.

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Chapter 1 Introduction

The motivation behind this project started with the idea of having students simulate a power distribution protection system within a Cal Poly lab. After the analysis was done on the protection system, the student is able to understand how sources, transformers, motors, relays, and breakers work as a system to provide power to an end user. Students take on the responsibility of each component in the motor-transformer system and understand what are the important inputs or outputs. In Figure 1, the level zero diagram shows the inputs and outputs found within the motor-transformer system.

The motor-transformer system was initiated by Dr. Shaban to implement in his EE 444 Power Systems Laboratory course. After consulting with Dr. Shaban, on various occasions, we were able to develop a strategy towards relay implementation for the SEL 710 and SEL 587. To make the lab more applicable to industry, students will have the option to implement various types of faults throughout the distribution system. Another important facet implemented throughout this power distribution is safe operation. When dealing with high voltages and currents, safety precautions must be followed to ensure people and equipment safety.

In conclusion, the motor-transformer system will simulate a protection scheme for different types of loads. For example, irrigation systems will have multiple motor-transformer combination off the same bus that vary in horsepower. Each of these motor-transformer combinations need to provide adequate voltage and current to supply the load, while protecting against different types of faults.

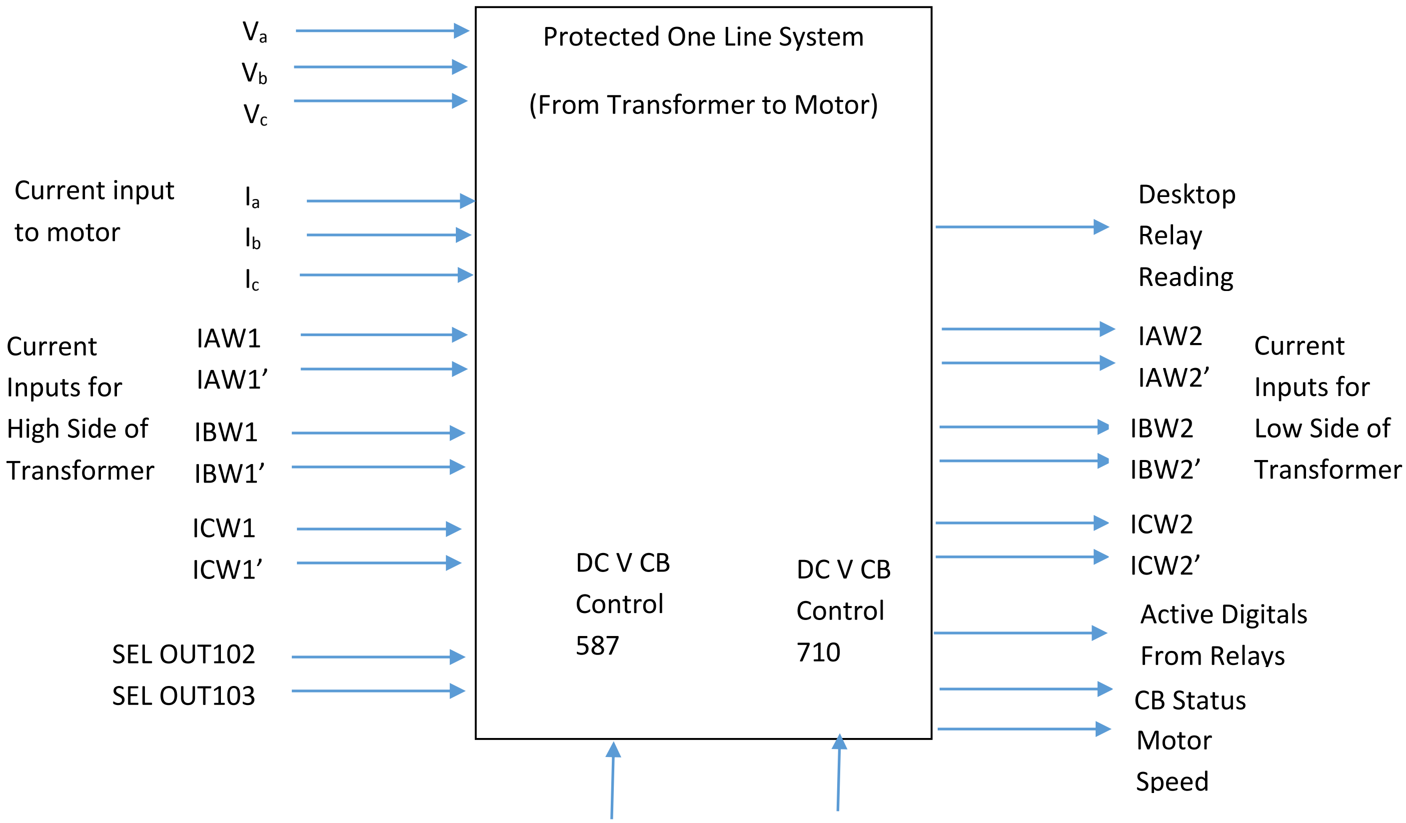


FIGURE 1
PROTECTIVE DISTRIBUTION SYSTEM ZERO LEVEL BLOCK

In Figure 1 a level zero block diagram shows basic inputs and outputs for the motor-transformer system. The 3-phase voltages and currents are the inputs coming from the source. The 125 V DC for the 587 and 710 relays needed for circuit breaker control, serving as a separate input to the system. In addition, each of the SEL relay readings can be considered an input of voltage and current magnitudes.

On the output side there is motor speed, secondary currents, circuit breaker status, and desktop relay reading from the system. The circuit breaker status shows if the fault was detected and the relay output shows the current, voltage, and type of fault information. If there is no fault in the system, the motor speed will remain constant at the end of the line.

Chapter 2 Background

Customer Needs

The customers addressed in this particular system include potential corporations involved in the oil industry, power generation, and food production. With the motors at the end of the system, it is pivotal that the entire system is protected from the source to motor to ensure continuous power delivery. Each relay is programmed to detect a fault in the system. If the fault is not detected, it will cause damage to motor-transformer system. The protection schemes used for the motor-transformer system must guarantee the safety of the people operating it. In addition, it protects the components of the system from severe damage.

Demonstration of the motor-transformer protection system to the EE 444 class, allow students visually see how the protection of a distribution system works. This provides experience with circuit breaker and relay protection across an entire system. Each part of the system can be programmed separately, and put together in two lab sessions.

Lastly, the most vital part of an electrical distribution system is safe operation and design. In this project, the primary concern was creating and analyzing the distribution system as individual and integrated levels. This was ensured by using selective tripping to protect the power equipment from excessive damage. The final integrated system must be safe and operable for the students in EE 444 lab.

Equipment

The equipment used in this lab provided by SEL or designed by a previous Cal Poly student. Both the SEL 710 motor protection relay and SEL 587 differential transformer relay were donated to the power system's labs and the circuit breakers were designed by a Cal Poly student. Each of the relays provided by SEL control the "Open" or "Close" switch of the circuit breaker with logic base signals. All equipment used in the lab were tested individually prior to integration of all components.

During the experiment the SEL 710 focused on protection against under-voltage, loss of phase, line-to-line, thermal overload, and lock rotor faults. Since the motor was at the end of the circuit, there was no need for differential protection. The SEL 587 was capable of phase to ground, line-to-line, three phase fault, or differential protection. Differential protection used to protect the transformer from internal damage by checking the current magnitudes on both the primary and secondary sides. However, in the motor-transformer integrated system, all faults were simulated except for the differential protection at the transformer.

It should be noted that the circuit breakers in the lab were designed by a Cal Poly student and differ from industry standard breakers. For normal operation of the circuit, the fault switch is put in the "Normal" position. When the switch is moved to the "Fault" position, the wiring of the circuit breaker is changed to simulate the desired fault. These circuit breakers require a 125 V DC control for operation.

Chapter 3 Circuit Diagrams

Induction Motor Connections

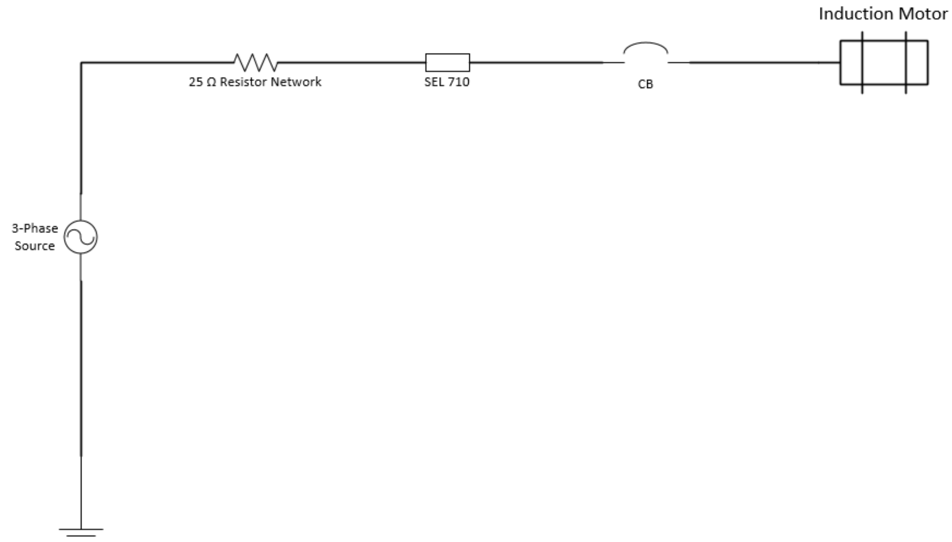


FIGURE 2

SYSTEM USED TO TEST INDUCTION MOTOR WITH SEL 710 RELAY.

The induction motor is protected using the SEL 710 motor protection relay and a local circuit breaker. The circuit in Figure 2 shows how the relay was tested in an isolated position using a 240V source, 25Ω resistor network per phase, relay, circuit breaker, and induction motor. When the relay detects a fault, the circuit breaker will open after 5 cycles. The types of faults tested for motor protection were under-voltage, loss of phase, line-to-line, thermal overload, and lock rotor faults. Characteristics that accompany motor protection include overheating, voltage imbalance, and current imbalance. Table 1 shows the pin layout for the SEL 710 to other components in the system.

In conclusion, the SEL 710 is set to protect the motor from potential damage that can occur from faults. However, the under voltage trip condition was not attainable because the SEL 710 would receive a fault if the voltage was set low upon startup, so the breaker remained open. The advantages to using the SEL 710 relay are metering, monitoring, overcurrent protection, motor protection, and integration.

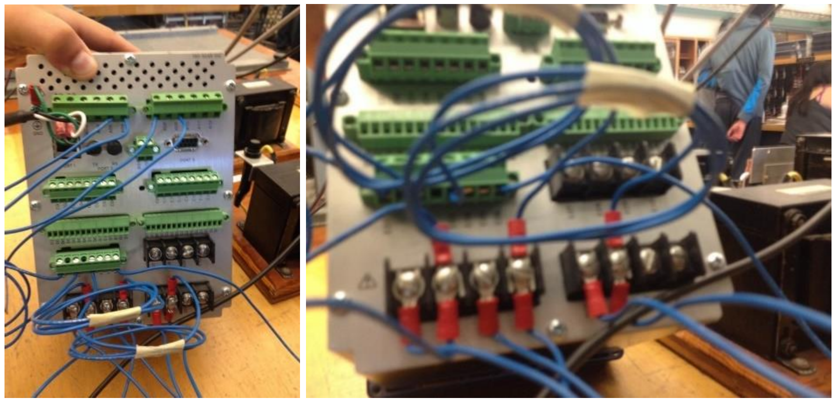


FIGURE 3
PIN LAYOUT USED FOR INDUCTION MOTOR PROTECTION AT THE END OF THE LINE USING SEL 710 RELAY.

TABLE 1
INPUT AND OUTPUT PINS FOR SEL 710 CONNECTION DIAGRAM

Signal	**SEL Connection**	**Circuit Connection**
Phase A Current In	IA (Z01)	25 Ω Resistor A
Phase A Current Out	IA (Z02)	CB 3 A In
Phase B Current In	IB (Z03)	25 Ω Resistor B
Phase B Current Out	IB (Z04)	CB 3 B In
Phase C Current In	IC (Z05)	25 Ω Resistor C
Phase C Current Out	IC (Z06)	CB 3 C In
Phase A Voltage	VA (E01)	CB 3 A In
Phase B Voltage	VB (E02)	CB 3 B In
Phase C Voltage	VC (E03)	CB 3 C In
Neutral	N (E06)	Circuit Ground
Breaker Trip (High)	OUT 102 (A05)	CB 3 Trip (High)
Breaker Trip (Low)	OUT 102 (A06)	CB 3 Trip (Low)

FIGURE 4
MOTOR NAMEPLATE USED AT THE END OF THE LINE.

Transformer

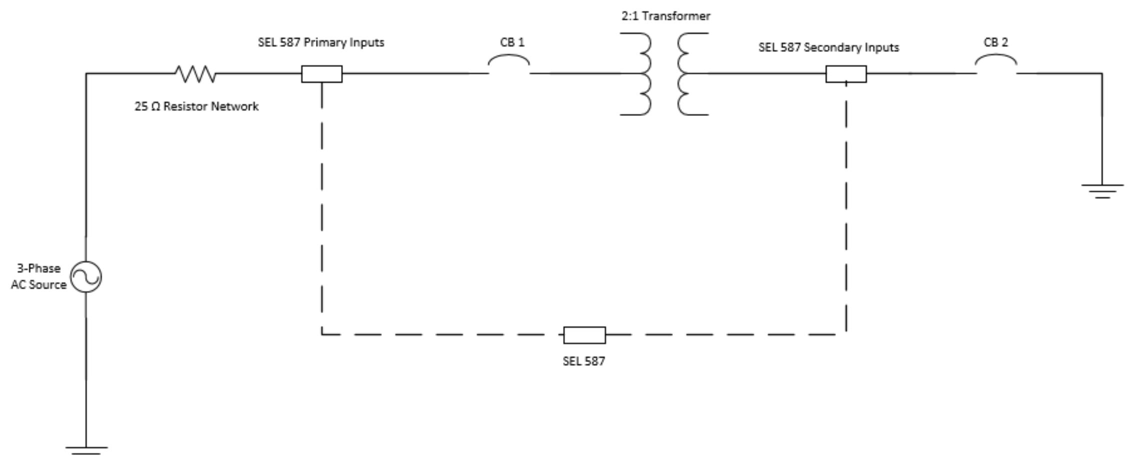


FIGURE 5
SYSTEM USED TO TEST DIFFERENTIAL RELAY SEL 587 FOR DIFFERENTIAL PROTECTION.

The current differential protection relay protects against faults within the transformer and trips breakers either on the primary or secondary side. In this experiment, a SEL 587 relay is connected to the primary and secondary side of the transformer to read current and voltage levels. These values were compared to the 2:1 transformer ratio and is used to protect against current going in and out of the component. Figure 5 shows the circuit diagram for an experimental test with 2:1 transformer and an SEL 587 relay. The pin layout for the SEL 587 is found in Table 2.

The primary purpose of the SEL 587 is to protect the transformer from any potential internal damage. When a fault is detected, a signal is sent to open the high-voltage side circuit breaker. In the case of a line-to-line fault, the system will detect the fault and trip the secondary side breaker. If a fault is detected within the differential protection zone of the transformer, the relay will operate the breakers on both sides of the transformer.

TABLE 2
INPUT AND OUTPUT PINS FOR SEL 587 CONNECTION DIAGRAM

Signal	SEL Connection	Circuit Connection
Primary Current In (A)	IAW 1 (101)	CB 1 A Out
Primary Current Out (A)	IAW 1 (102)	XFRMR A In
Secondary Current In (A)	IAW 2 (107)	CB 2 A Out
Secondary Current Out (A)	IAW 2 (108)	Load A
Primary Current In (B)	IBW 1 (103)	CB 1 B Out
Primary Current Out (B)	IBW 1 (104)	XFRMR B In
Secondary Current In (B)	IBW 2 (109)	CB 2 B Out
Secondary Current Out (B)	IBW 2 (110)	Load B
Primary Current In (C)	ICW 1 (105)	CB 1 C Out
Primary Current Out (C)	ICW 1 (106)	XFRMR C In
Secondary Current In (C)	ICW 2 (111)	CB 2 C Out
Secondary Current Out (C)	ICW 2 (112)	Load C
CB 1 Trip (High)	OUT 1 (203)	CB 1 Trip (High)
CB 1 Trip (Low)	OUT 1 (204)	CB 1 Trip (Low)
CB 2 Trip (High)	OUT 2 (205)	CB 2 Trip (High)
CB 2 Trip (Low)	OUT 2 (206)	CB 2 Trip (Low)

The phase to ground, line-to-line, three phase faults, and differential protection were set on the secondary side of the transformer. This is because the circuit breaker has normal and fault conditions so a fault can be set at a specific location in the circuit.

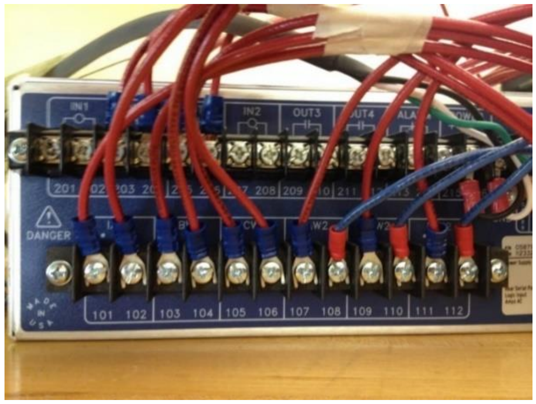


FIGURE 6

Rear Panel of SEL 587 relay used to protect transformer.

FIGURE 7

Front Panel for SEL 587. Displays both normal operation and potential fault conditions.

The front panel of the SEL 587 indicates status of the transformer. Figure 6 shows the rear panel of the SEL 587 and the wire connections were made from Table 2 to local circuit breakers. This type of relay provides both overcurrent and differential current protection to a transformer. The overcurrent protection is done by tripping a local circuit breaker for both the primary and secondary sides of the transformer. Differential protection occurs if there is an imbalance between the primary and secondary currents. The relay is programmed to understand what ratio and connection type is being used for the transformer. When a fault does occur during differential current imbalance, the circuit breaker will trip on the primary or secondary side of the transformer. The location of the open circuit breaker depends on where the current imbalance is detected.

Transformer and Motor Connections

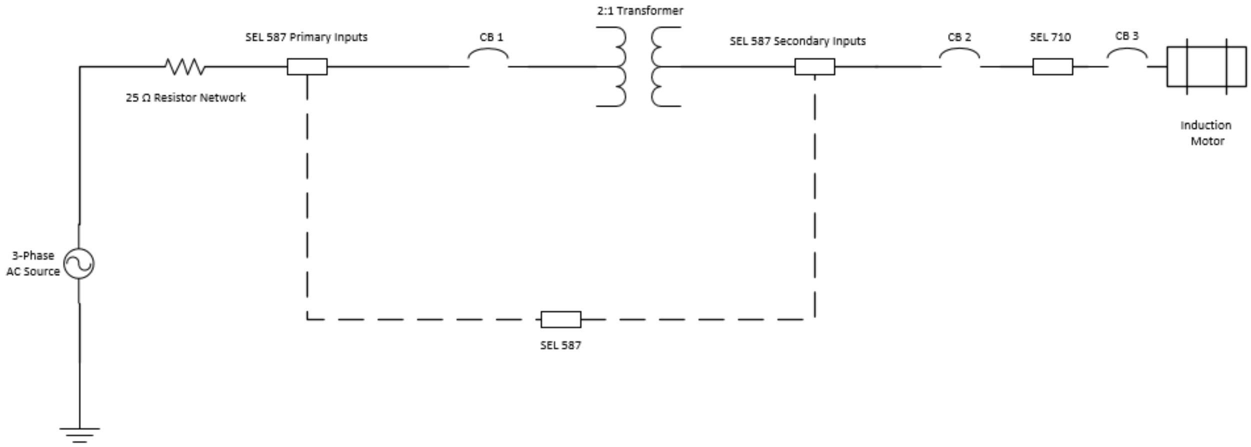


FIGURE 8

FULL DISTRIBUTION SYSTEM FROM SOURCE TO TRANSFORMER TO INDUCTION MOTOR.

TABLE 3

COMPONENT LIST AND DESCRIPTION.

Name	Value
3-Phase Source	240 V
3 - Resistor Network	25 Ω each phase
CB 1	SEL 587 Circuit Breaker
Transformer Ratio	1:1
CB 2	SEL 587 Circuit Breaker
CB 3	SEL 710 Circuit Breaker
Motor	Hampden 208V 1.4 A 60 cycle 3 phase Induction Motor

After the relays prove to run in an isolated test conditions, the system was integrated as shown in Figure 8. During the experiment, the transformer ratio was changed to a 1:1 to increase the voltage supplied to the motor. Since the ratio of the transformer was changed the amount of current running from the transformer to the motor increased. To adjust for this current increase, the sensitivity setting (O87P) was increased according to the manufacturer recommendation of 0.3A, and allowed for greater current levels during normal operation. Once adjusted the overcurrent protection for both the motor and transformer were shown as satisfactory after testing. As for the SEL 710, an issue that came up was that the voltage provided to the motor was below the motor voltage rating. The change in the transformer to provide a 1:1 ratio helped provide sufficient voltage to the motor. In addition, when the motor received too much current from the transformer a locked rotor fault would display on the SEL 710. To correct overcurrent conditions a load was added between the transformer and motor. In conclusion, the SEL 587 settings had to be changed due to sensitivity levels and the SEL 710 settings remained the constant.

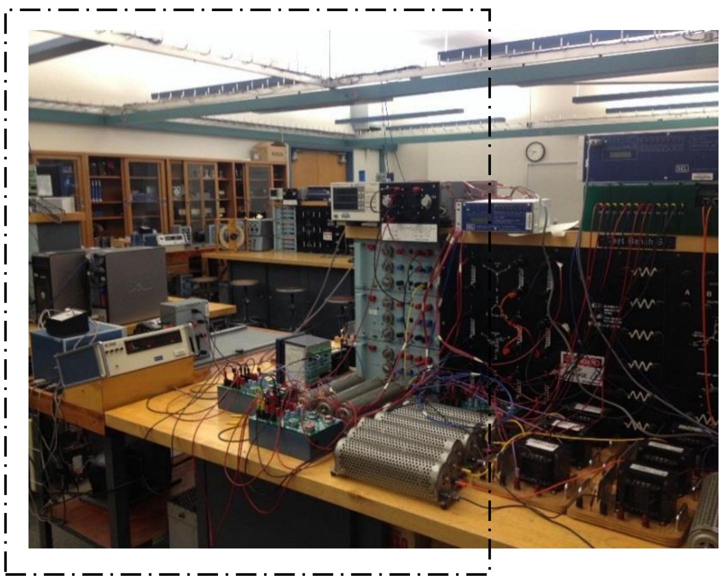


FIGURE 9

PHYSICAL CONNECTIONS OF SOURCE, TRANSFORMER, AND MOTOR.

The dotted portion from Figure 9 displays the connection from source, resistors, transformers, and motor protection. There is a circuit breaker for the transformer and motor associated to the distribution system. Each of the wire connections are grouped by phase and checked for connection prior to each fault test.

Chapter 4 Testing and Analysis

Induction Motor and SEL 710 Testing

First, the induction motor SEL 710 relay is tested for under-voltage, loss of phase, line-to-line, locked rotor, and thermal overload faults. These faults are the five most common faults found on induction motors and can lead to sever damage from excess current. There is a three phase 208 V source feeding the induction motor and a 125V DC feeding the circuit breaker.

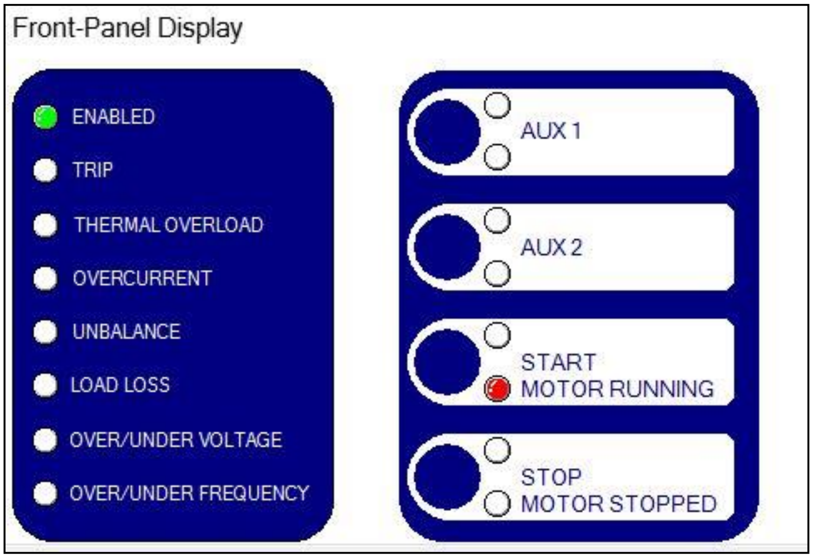


FIGURE 10
INITIAL FRONT-PANEL DISPLAY WITH NORMAL SETUP AND OPEN CIRCUIT BREAKERS.

The first thing to test for the SEL 710 was the normal operation of the system. If running correctly the front-panel display should be identical to Figure 10. After getting the system to run, the relay is programmed to protect the motor from all five types of faults. Figure 11 shows the general settings for the SEL 710 relay.

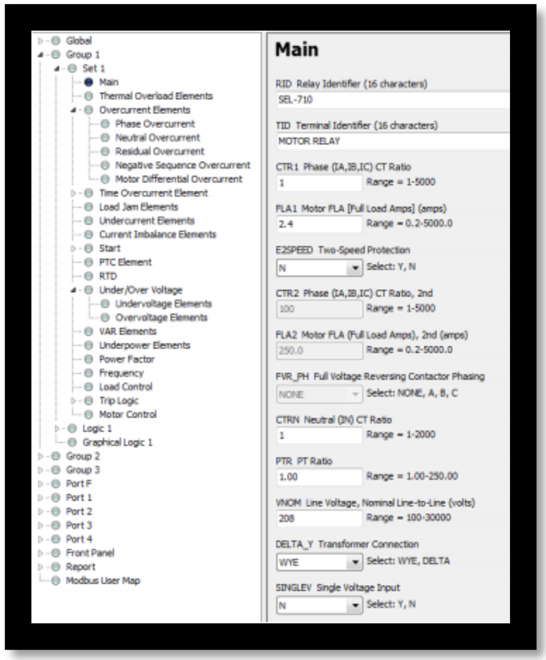


FIGURE 11
GENERAL SETTINGS USED FOR SEL 710 MOTOR PROTECTION RELAY.

Under-Voltage Detection

In Figure 12 you will find the event report displaying current, voltage, and active digitals read by the SEL 710. The red-dotted line is where the fault is detected and shows how the phase/magnitude of the current and voltage is effected for an under-voltage fault. As expected, the currents converge to 0 A after 5 cycles of the under-voltage condition, which is indicated by the red circle on the graph. An under-voltage fault occurs when there is a power surge in the system and is usually set to 80-90% of the motor nameplate voltage (208 V). A surge will cause an increase in current and motor heating. However, during startup a motor may experience temporary under-voltage causing the SEL 710 relay to send an “Open” signal to the circuit breaker.

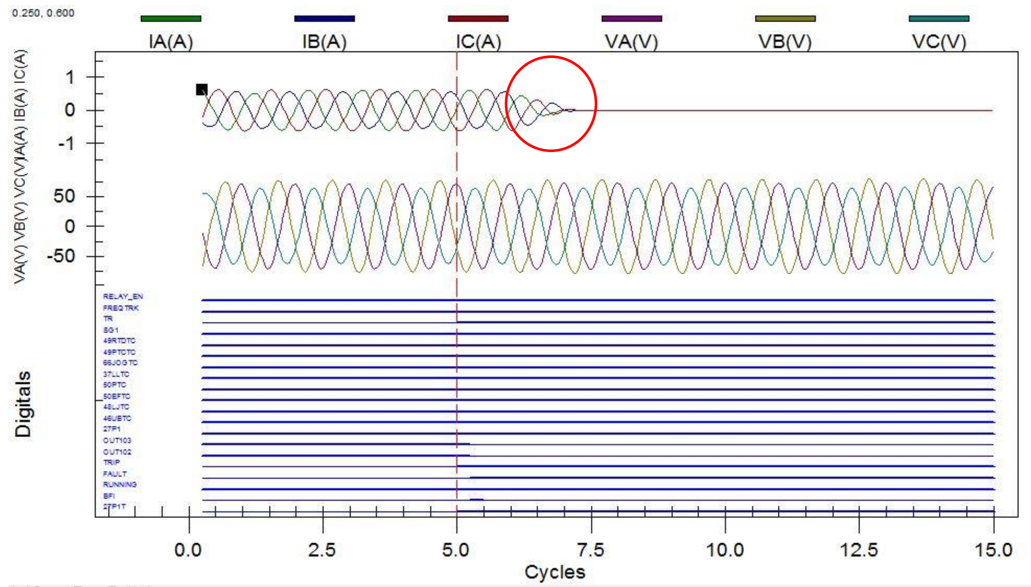


FIGURE 12

WAVEFORMS SHOWING PHASE VOLTAGE LEVELS DURING UNDER-VOLTAGE FAULT.

When using the AcSELerator there is an option to read the front panel of the relay via computer. This application allows you to view what kind of trip occurred and whether the motor is still running. Below in Figure 13 is the Front-Panel Display for an under-voltage trip.

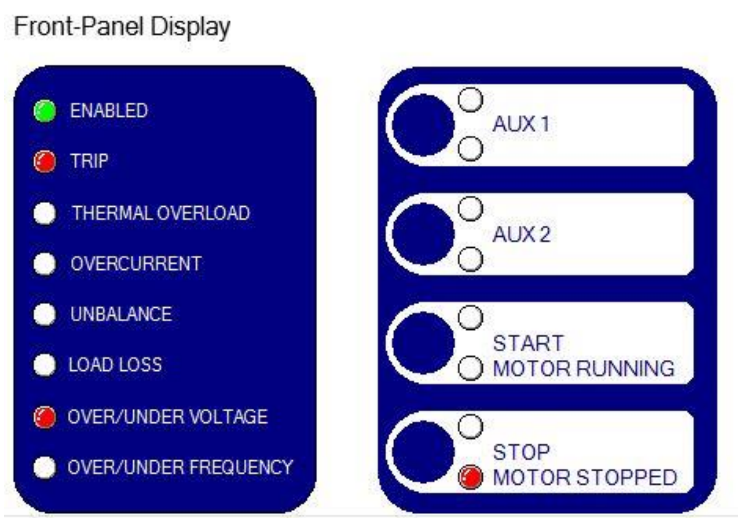


FIGURE 13

FRONT PANEL DISPLAY AFTER FAULT FOR UNDER-VOLTAGE OCCURS.

Loss of Phase

A loss of phase fault occurs when one phase of a three-phase system is lost. In industry, this is caused by a blown fuse, broken wire, worn contact, or mechanical failure. The voltage and current will eventually converge to zero when a phase is lost. However, this takes time and may cause damage to the motor. Figure 14 shows the circuit connections used to implement a loss of phase fault in the motor. For normal motor operation, the switched is moved to the "Fault" position. To simulate a loss of phase A, the switch moved to the "Normal" position.

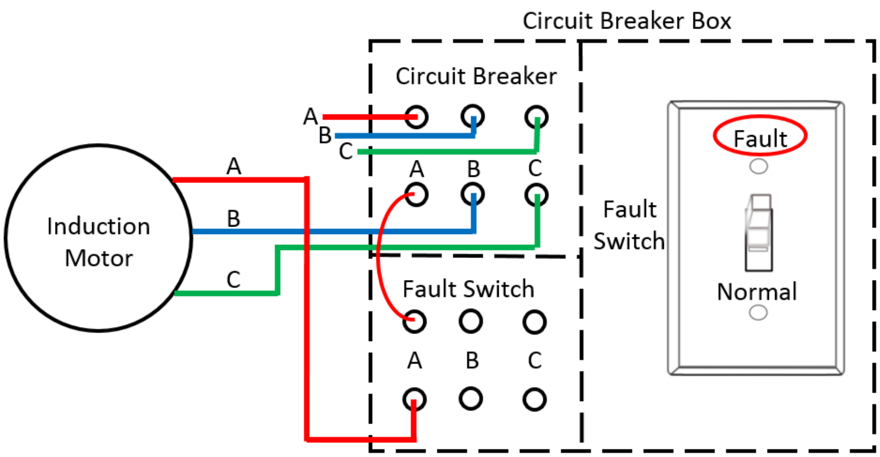
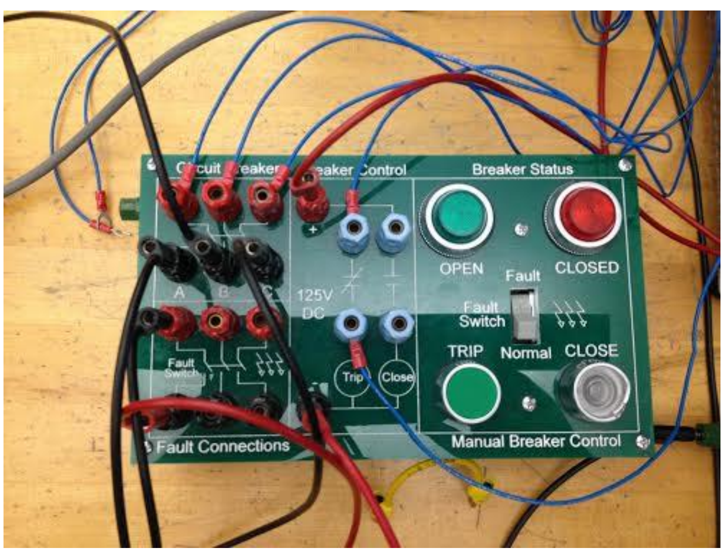


FIGURE 14
CIRCUIT BREAKER CONNECTION FOR NORMAL AND FAULT CONNECTION TO GENERATE LOSS OF PHASE DIAGRAM. *[4]*



In the event report shown in Figure 15, the magnitude of the current in phase A is 0 A while phases B and C are still sinusoidal. After 5 cycles, the SEL 710 detects no current in phase A motor and opens the breaker

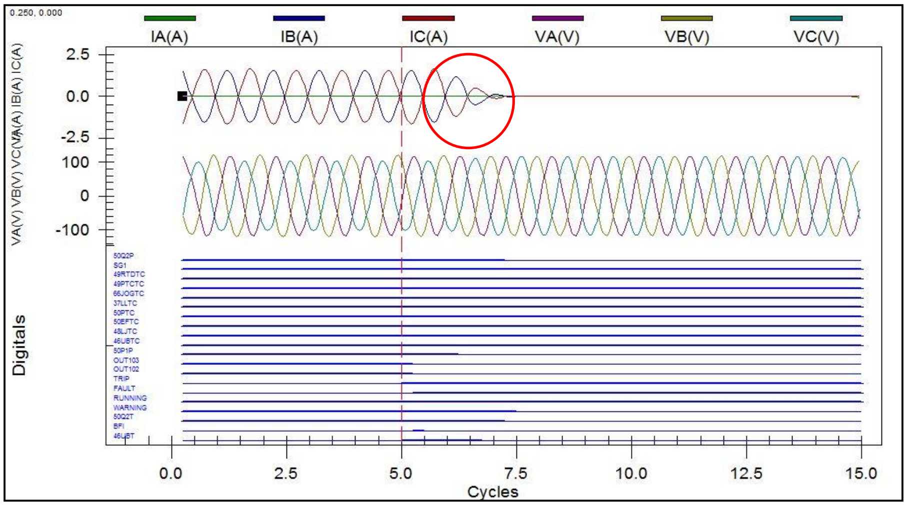


FIGURE 15

WAVEFORMS SHOWING PHASE VOLTAGE LEVELS DURING LOSS OF PHASE.

Figure 16, shows the front panel display for an unbalanced due to the loss of phase A fault. This shows that the motor did stop after a fault was detected and the relay is working appropriately. Since the motor will be at the end of the distribution system, relays should operate instantaneously.

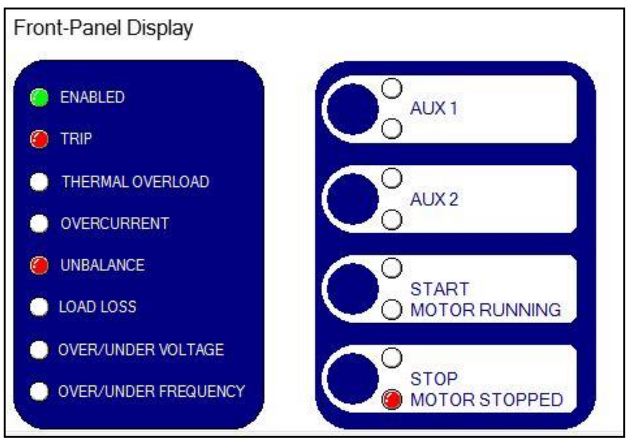


FIGURE 16

FRONT-PANEL DISPLAY FOR LOSS OF PHASE FAULT GENERATED.

Phase A to Phase B Fault (Line-to-Line)

To simulate a line-to-line fault both phase A and phase B were connected as shown in Figure 17. When the switch is moved from “Normal” to “Fault” position, it will cause a line-to-line fault.

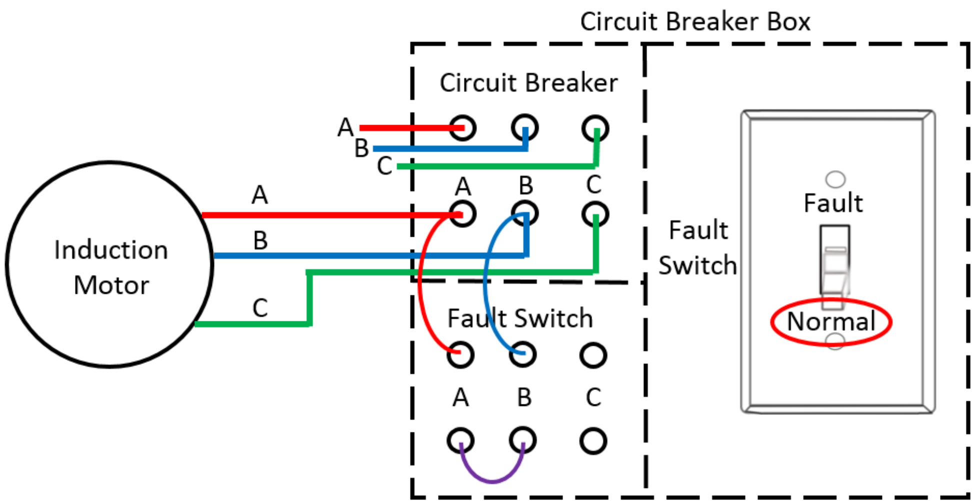
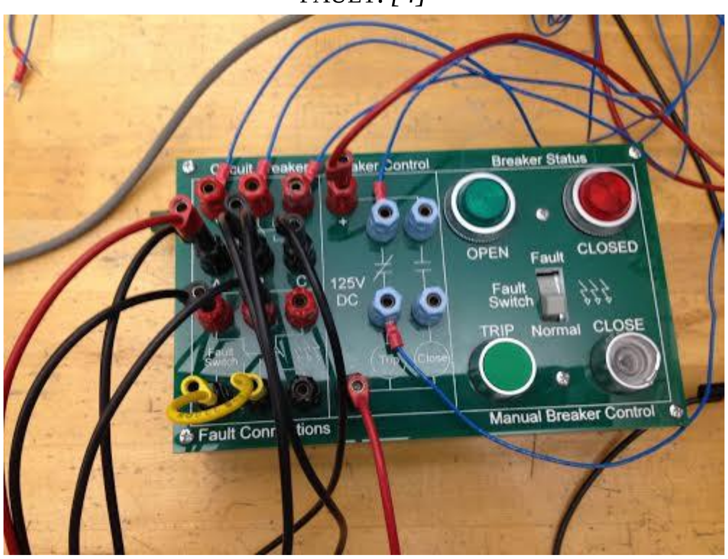


FIGURE 17

CIRCUIT BREAKER CONNECTION FOR NORMAL AND FAULT CONNECTION TO GENERATE PHASE TO PHASE FAULT. *[4]*



To generate a line-to-line fault the wiring is shown in Figure 17. The user switches the breaker from “Fault” to “Normal” operation to generate a line-to-line fault and the fault should be detected in 5 cycles. In Figure 18 the red circle indicates that phase A and phase B are at the same current magnitude, while phase C has a lower current magnitude. This current imbalance was detected by the relay and opened the circuit breaker.

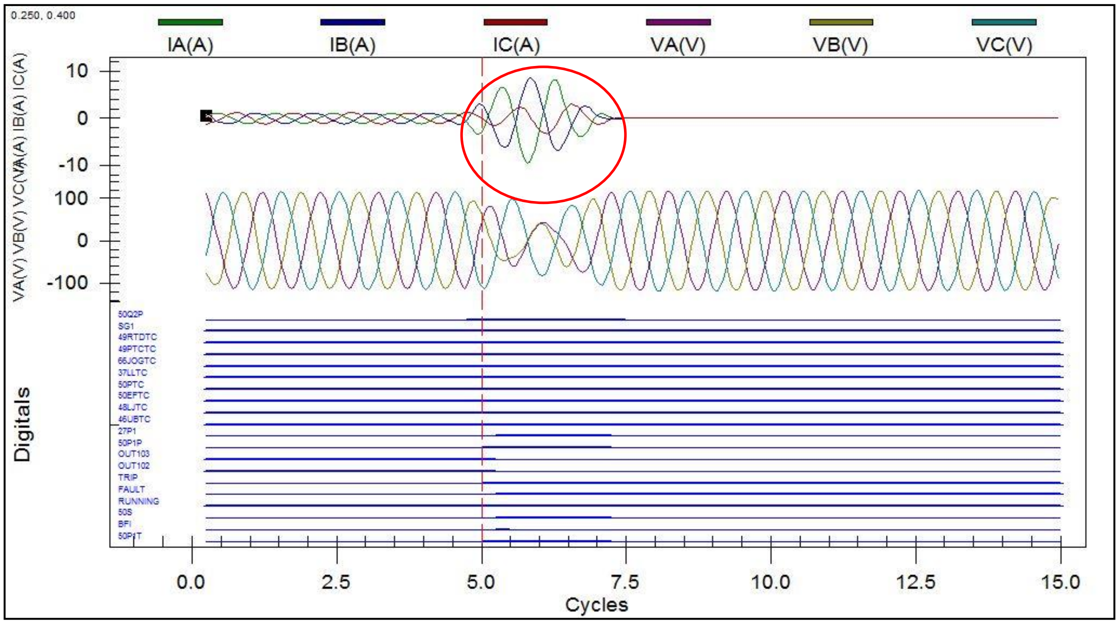


FIGURE 18

WAVEFORMS SHOWING PHASE VOLTAGE LEVELS DURING PHASE TO PHASE FAULT.

Locked Rotor Fault

A locked rotor condition occurs when the load torque is greater than motor capability. Under locked rotor faults, the current drawn can reach up to 3.5 times the rated current. When the rotor is locked, the input current increases. This can cause heat or mechanical damage to the motor in the event of a fault. Figure 19 shows the increased magnitude of the currents due to locked rotor. After 5 cycles of locked rotor conditions, the relay opened the breaker.

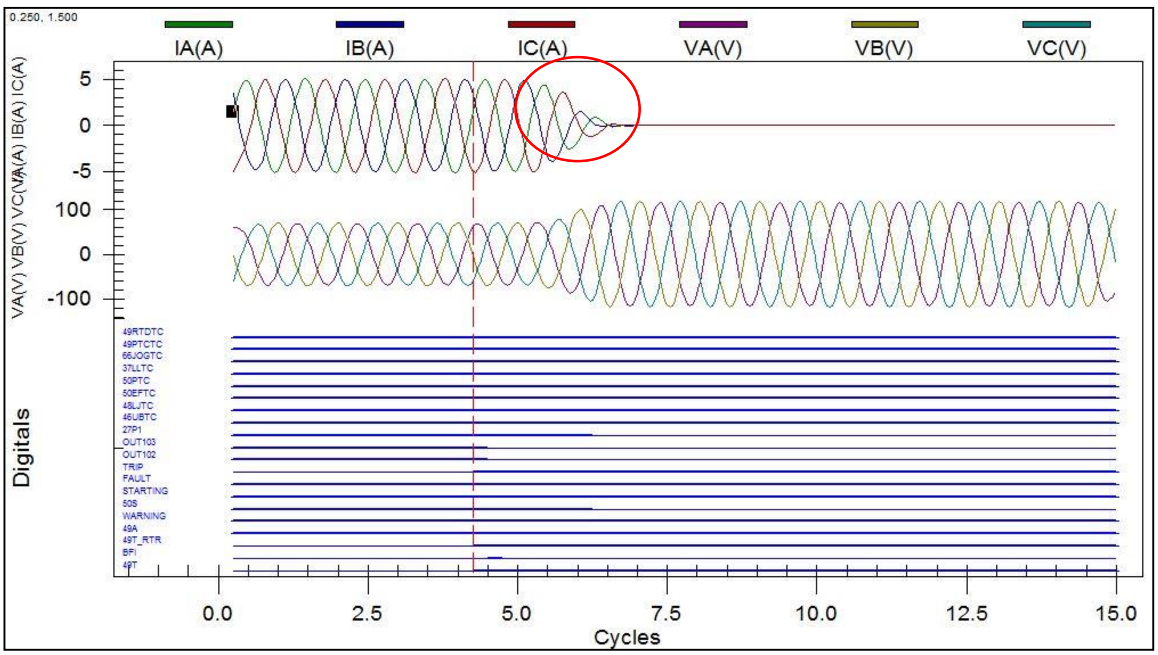
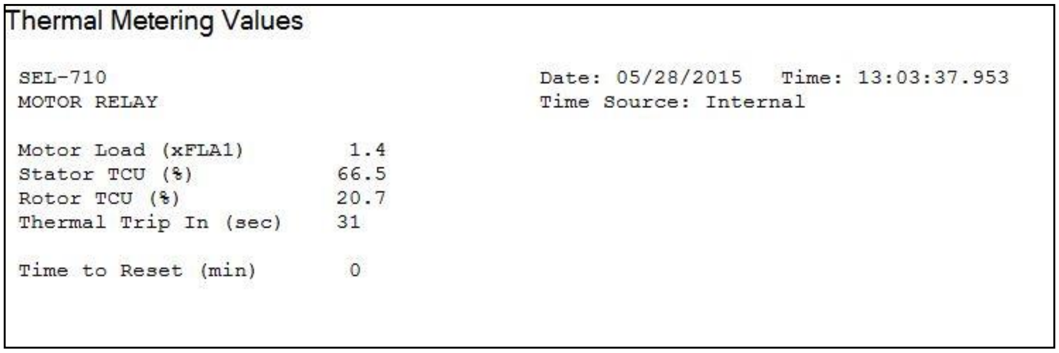


FIGURE 19

WAVEFORMS SHOWING PHASE VOLTAGE LEVELS DURING LOCKED ROTOR FAULT.

Thermal Overload Fault

Another advantage of the SEL 710 relay is the ability to detect thermal overload fault conditions. A thermal overload fault can occur during mechanical over loading, stalling of motor shaft, low supply voltage (increase currents), or sudden loss in supply voltage. After 30 seconds of a thermal overload status, the SEL 710 relay will open the breaker. In Figure 20 the thermal trip completed in 31 seconds by implementing a locked rotor amperage of 2.4 A.



Thermal Metering Values

```
SEL-710                                 Date: 05/28/2015   Time: 13:03:37.953
MOTOR RELAY                             Time Source: Internal

Motor Load (xFLA1)          1.4
Stator TCU (%)             66.5
Rotor TCU (%)              20.7
Thermal Trip In (sec)      31

Time to Reset (min)         0
```

FIGURE 20

METERING VALUES TO GENERATE A THERMAL OVERLOAD CONDITION.

In Figure 21, the locked rotor amps were increased to provide a thermal overload condition. This resembles either a decreased voltage or high current startup condition. In Figure 21, the current magnitude reaches 2.4 A compared to the previous 1.4 A rating of the induction motor.

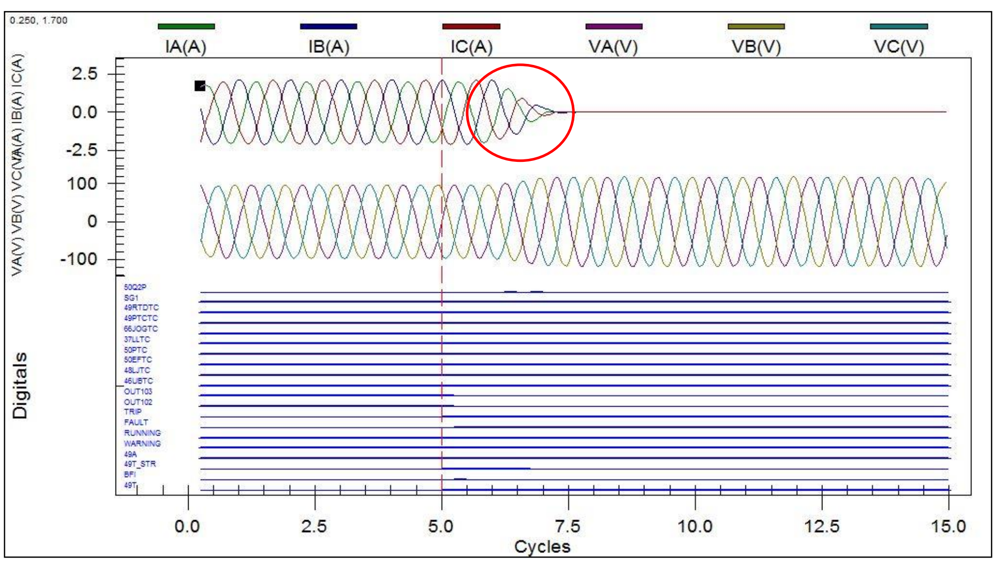


FIGURE 21

WAVEFORMS SHOWING PHASE VOLTAGE LEVELS DURING THERMAL FAULT.

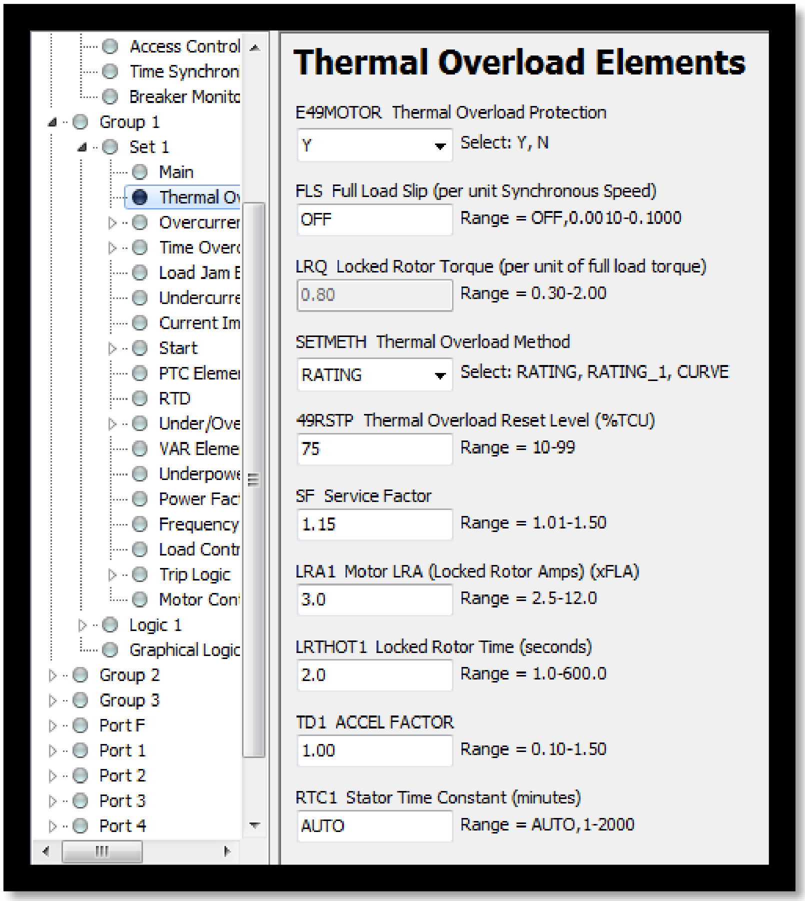


FIGURE 22
THERMAL SETTINGS FOR SEL 710 MOTOR FAULT.

Transformer and SEL 587 Testing/Analysis

Next, the transformer was tested for differential protection using a SEL 587 with local circuit breakers (on both the primary and secondary sides). For this experiment, the transformer was tested for delta-delta, delta-wye, wye-delta, and wye-wye configurations with a 2:1 transformer ratio. Each test looked for 5 cycle response times for the SEL 587 to open a breaker during three-phase to ground and line-line faults. In addition, the tests were done on both the primary and secondary sides of the transformer. In this experiment, no current transformers were used, but the relay CT must be set accordingly. In Figure 23 a Y-Y setting is shown with CT1 = CT2 = 1. These settings were adjusted with values of 1 or $\sqrt{3}$ depending on the connection type. Also, the sensitivity setting on the SEL 587 (087P) was adjust to 0.1 after determining that current and voltage conditions for the experiment.

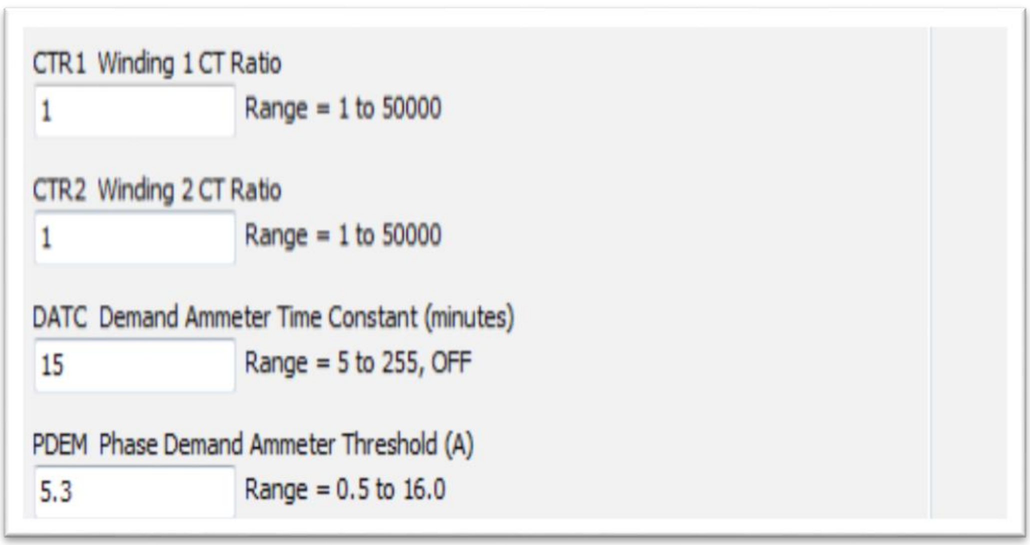


FIGURE 23
GENERAL SETTINGS USED FOR SEL 587 DIFFERENTIAL RELAY WITH 1:1 TRANSFORMER.

First, a three-phase to ground fault was implemented with a 0.08 seconds (5 cycle) trip time. In Figure 24 the 5 cycles are circled in red showing the fault operation and the response after the circuit breaker was opened. The three-phase to ground fault was tested again at the primary side of the transformer and displayed similar results.

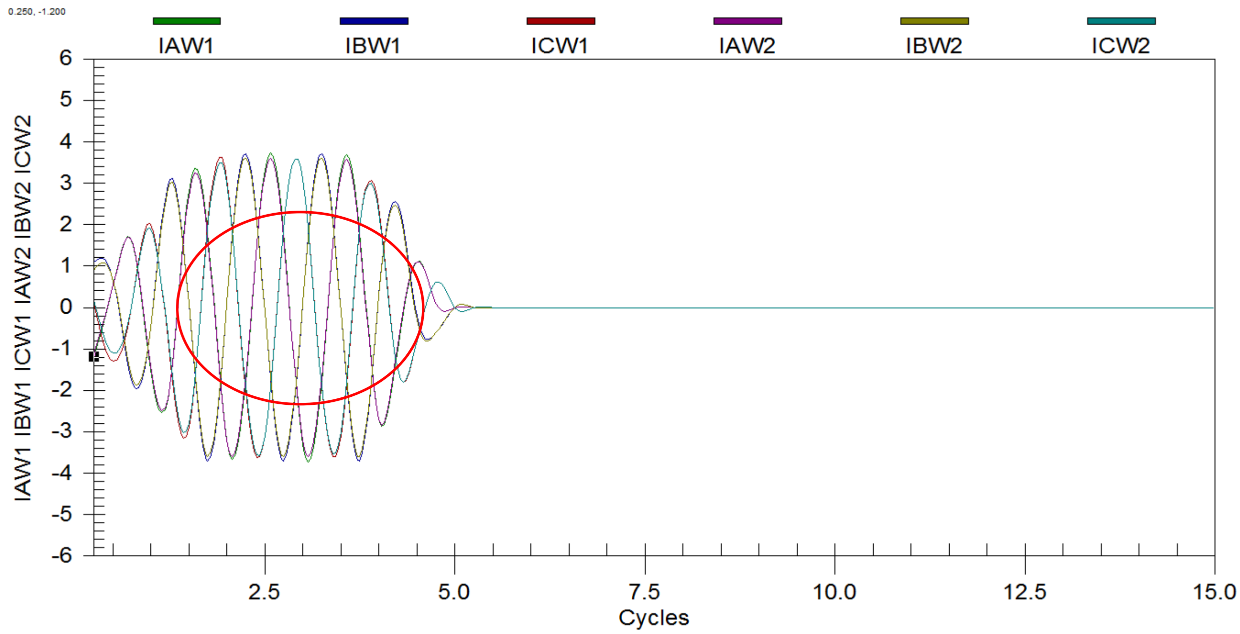


FIGURE 24
3-PHASE FAULT TIME OF RESPONSE 5 CYCLES.

Next, a line-to-line fault was simulated and opened the circuit breaker at the secondary side. In Figure 25, the 5 cycles are circled in red showing current imbalances. This fault was done on both the primary and secondary currents with similar results. In both Figure 24 and Figure 25, the event reports were taken from the secondary side of the transformer. Once the fault was detected the event reports shows the transition from normal operation to the type of fault implemented.

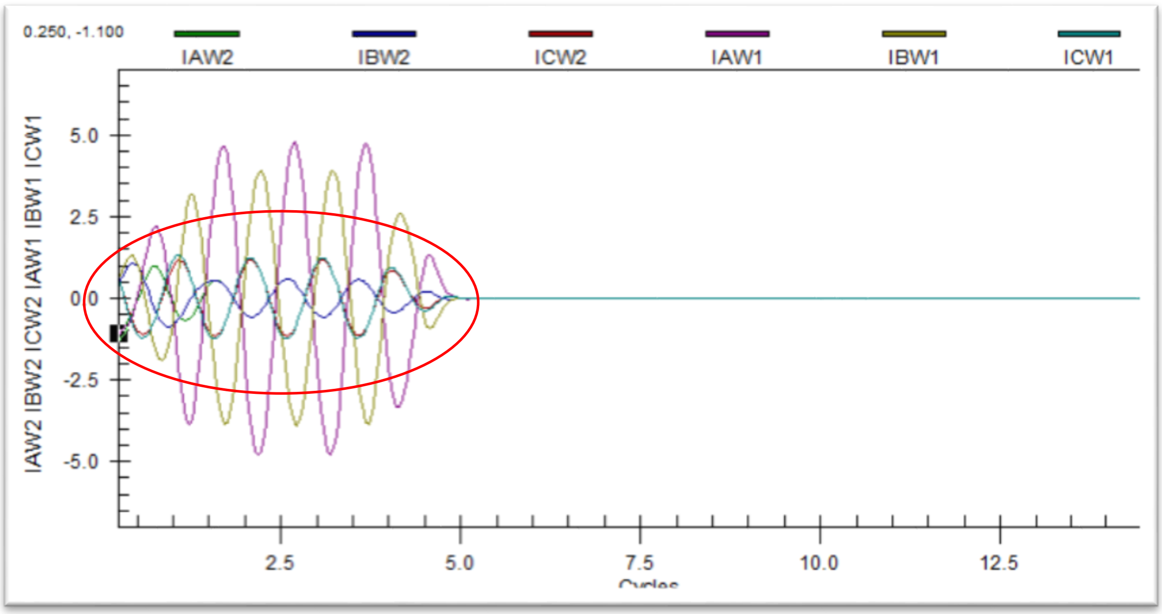


FIGURE 25
LINE TO LINE FAULT BETWEEN PHASE A AND B.

In conclusion, the transformer is protected against faults at both the primary and the secondary side of the transformer. The differential protection used by the SEL 587 compared the turns ratio of the transformer to the current levels on the primary and secondary sides of the transformer. To protect equipment, the cycles recorded by the SEL 587 can be decreased to open breakers at a faster pace.

Source, Transformer, and Induction Motor Testing/Analysis

Lastly, the distribution system was integrated using the source, 1:1 transformer, SEL 587, induction motor, SEL 710, and circuit breakers. The differential relay protected against single-phase to ground, line-to-line, and 3-phase faults at the secondary side. The induction motor relay protected for under-voltage, loss of phase, line-to-line, thermal overload, and lock rotor faults. The transformer ratio was changed to 1:1 (wye-wye) to provide sufficient voltage to the motor during normal operation. This was done because the lab only provided an induction motor rated at 208 V. Since the transformer has a 1:1 turns ratio, the SEL 587 (O87P) had to be increased from 0.1 to 0.3 so low faults conditions weren't detected by the SEL 587. The reason for increased sensitivity settings is due to high supply voltage and addition of the motor to the system. This increase in magnitude provides enough protection for the transformer and allows the distribution system to run under normal conditions.

Chapter 5 Conclusion

The principles of power system protection are monitoring, testing, and repairing power systems within a facility. In this project, we looked at forced faults that were pre-determined, but unfortunately, we do not have the capability to have a running system with metering that can show how voltage and current levels change throughout time. This project showed how to view different kinds of faults graphically and on relay displays. The fundamentals behind this project push for efficient design and service of a distribution system. The ability to design a system takes creativity, along with knowledge of codes, equipment, and personnel. By considering codes, mechanical, architecture, and safety conditions the electrical engineer's design plays a vital role in how a building runs as a whole. An engineer is responsible for providing power designs to residential, commercial, or industrial size facilities that can protect against various types of fault conditions. A successful engineer learns from previous projects and continuously adapts to new technology or designs.

This type of project is great for simulating multiple different loads at the end of a one-line system. Induction motors are highly efficient and low maintenance motors that provide power-rating requirements at a lower cost. Types of industries that uses motor-transformer systems as loads include irrigation, refineries, and food processing. The motor-transformer load combination in this experiment shows the type of equipment and protection needed at the end of a system. This motor-transformer protection system can be repeated multiple times at different motor and transformer size depending on the load amount needed by the industrial plant.

Appendix

TABLE 6
APPENDIX D — ANALYSIS OF SENIOR PROJECT DESIGN

Project Title: Transformer and Motor Protection Scheme

Student's Name: Bijan Vakilifathi Student's Signature:

Advisor's Name: Dr. Ali Shaban Advisor's Initials: AS Date: February 16, 2015

• 1. Summary of Functional Requirements

The purpose of this project is to integrate a protected system that includes a source, transmission line, transformer, and motors. In the past, Professor Shaban has had Schweitzer Engineering Laboratory's (SEL) protection relays used to trip breakers during harsh conditions on transmission lines (SEL 311), transformers (SEL 587), and motors (SEL 710). The on line diagram includes a source to transmission line to transformer to multiple motors. An important factor with correlating each of these elements occurs between the motors and transformer. If the motor experiences thermal heating or overcurrent the SEL 710 and SEL 587 are programmed to different fault/trip times so there is a possibility of the transformer SEL 710 relay tripping its breaker first. Once this trips all the motors at the end of the transform are failing. This project will include a programmed SEL 710 relay that allows for an isolated trip to the local breaker at the motor to prevent an upstream trip.

• 2. Primary Constraints

With the growth of this project protecting each of the components from all types of faults may prove to be difficult with coordination of the entire distribution system. Programming the relays separately can be done by forcing each of the faults directly through one component. Once the transformer and motor are coordinated together protecting locations above the fault are vital to economic costs. If a fault occurs at the motor the protective relays cannot allow fault current to flow up the system and destroy the transformer, T.L., or source.

• 3. Economic

Power system protection results in the production of revenue found across the United States. For the specific system diagram found in this project factories with anything that uses a motor at the end of the line can use this project. This includes food productions, refineries, power production, and textile productions. If any of these protected systems aren't protected for all types of faults more components of the distribution system may be damaged causing economic troubles for the company. Also, all the time the system is not protected after a fault revenues of the company are impacted dramatically due to no production. These faults can be highly dangerous and can cause damage to the Earth if not handled properly. By providing protection that is reliant and supportive the effect on the environment decreases. Once the system is set up and protected Field Service Engineers will be used to maintain the protected system and fix any damages that may occur during fault times. This life-span sustainability provides assurance to the customers that production will be back up rapidly.

The stakeholders for this product include the people who own the company since they are directly related to the profitability. Also, everyday people who use any of the products listed in the above paragraph (food, gas, clothes) are directly affected if there is a problem with electrical protection. To conclude, I must develop programming techniques for each of the relays that suite each component. The relays must be able to instantaneously, short delay, or long delay trip depending on the type of fault found. If done correctly the goal of our project is to ethically provide safe power protection for future generations and decrease environmental hazards.

• 4. If manufactured on a commercial basis:

Depending on the fiscal year and growth of production industries the number of devices sold could be in the hundreds with warranty coverage and protection layouts. The manufacturing cost all the devices will be around $45,000 and is shown in the costs section of this report. To increase profitability of our company our services will be sold anywhere from $50,000 to $100,000's and increase profit by 100-400% margins. Once the protected system is in place the utility production will be the only cost for the end user depending on amount of unity you plan on producing.

• 5. Environmental

Environmental concerns come with the protected system fail on the industry implemented for. If the fault destroys multiple components there is a possibility for oil spills, arc flash, or waste water failures. This project uses electricity directly to produce a mechanical output in production. Environmental concerns with power production could also come from the excess heat/chemicals that come from the facility. Harnessing this energy to go into a different part of the facility can be done by a local HVAC crew or solar crew.

• **6. Manufacturability**

Manufacturing each of the components can me difficult if dealt with high power distribution parts. Since these components protect higher currents and voltages it is pivotal that the components work correctly. If the breaker doesn't trip or gets stuck there is a higher possibility of arc flash occurring. Also, if there are damages to any of the components in the system the warranty may force the FSE to buy components from outside users. The prices from outside users may be higher compared to in house manufacturing, but producing every power system protection component may not be feasible for a specific corporation.

• **7. Sustainability**

As years go by the power protection may experience wear and tear damage from the types of currents running through each of the devices. The end user can feel comfortable knowing that the company will provide a warranty package that will include manufacturing or device replacement for a certain allocated time of years. The relays can also be upgraded in the future to deal with different kind of currents and provide more fault analysis reports. With the addition of multiple motors at the end of the line the project can be upgraded to multiple production facets for a company. If the company chooses to do this protection coordination must be in place to provide fault protection at each specific motor.

• **8. Ethical**

Ethically the system must be protected fully to comply with IEEE health and safety codes. When dealing with high power production there is a set of IEEE standards that must be complied with in order to let a project be fully executed across its lifespan. Also, since the type of production the user may be implementing may be hazardous to the environment if not handled correctly. It is up to our protective system to keep production running and not let any hazardous materials escape confined, protected, environments.

An ethical study outside of the IEEE standards includes ethical egoism. At times to work on the senior project the user may want to run the system without properly addressing safety measures. Since this system is dealing with high voltage and current the user will need to have at least one other person in the room to call authorities if an injury takes place. At times people will think about their time and want to deal with the system and making a simple change, but they will have to wait for another person to come to the lab.

• **9. Health and Safety**
Within the IEEE standards all components found in the system must be protected to match health and safety codes. These health codes provide verification to our customers that arc flash and components will not cause any dangerous collateral damage to the surrounding environment. When dealing with repairs or warranties the entire system from the source down must be shut off to provide a safe working environment for each of the field service engineers.

• **10. Social and Political**
Stakeholders are the people who own the production company that uses this type of system. With any damage to the system the production stops immediately causing the customer to lose production and revenues. With multiple motors tied to the end of the line there is a necessity to stop the fault at the specific motor so other generation can still occur. Also, the people who use any of the products from the production companies are affected if there is impedance to the system. The benefits of our system provides a safely protected distribution system where each component is programmed specifically to handle multiple types of faults. With faults occurring due to human error we provide a warranty package for our customers that will provide component installation in less than 48 hours at a premium price.

• **11. Development**
Using the IEEE website to review articles and different health and safety codes provided details on how a power distribution system is protect in industry. I learned about how system coordination works with multiple different types of components in a system along with programming various types of relays at different levels of a distribution system. Below are the resources I used from patents, data sheets, IEEE journals/articles, books, and patents. These helped depict a picture of my project at a component level while I learned to integrate all parts for a final product.

[1] SEL-710 Motor Protection Relay, SEL, Pullman, WA, 2011, pp. 01-10

[2] SEL-587 Current Differential Relay, SEL, Pullman, WA, 2011, pp. 01-12

[3] J Duncan Glover, “Fault Analysis,” in Power System Analysis and Design, 5th ed. Stamford, CT: Cengage Learning, 2012, Ch. 9

[4] S. Lotfifard, J. Faiz, M. Kezunovic, "Detection of Symmetrical Faults by Distance Relays during Power Swings," IEEE Transactions on Power Delivery, Vol. 25, No. 1, pp. 81-87, January 2010.

[5] C. Pang, M. Kezunovic, "Fast Distance Relay Scheme for Detecting Symmetrical Fault During Power Swing," IEEE Transactions on Power Delivery (Accepted, In Press).

[6] B. Kasztenny, M. Kezunovic, “Digital Relays Improve Protection of Large Power Transformer,” IEEE Computer Applications in Power, Vol. 11, No. 4, pp.39-45, October 1998

[7] M. Kezunovic, “A Survey of Engineering Tools for Protective Relaying,” ELECTRA, No. 225, pp 26-30, 2006

[8] Murty V. V. S. Yalla, David C. Vescovi, Thomas R. Beckwith, “Multifunction protective relay system,” U.S. Patent 5224011 A, Jun, 29, 1993.

[9] Cortlandt Warringto Albert Rus, “Electrical protective relay systems,” U.S. Patent 3048744 A, Aug, 7, 1962.

[10] Nikoli Tesla, “Electro-magnetic motor,” U.S. Patent 381968 A, May, 1, 1888.

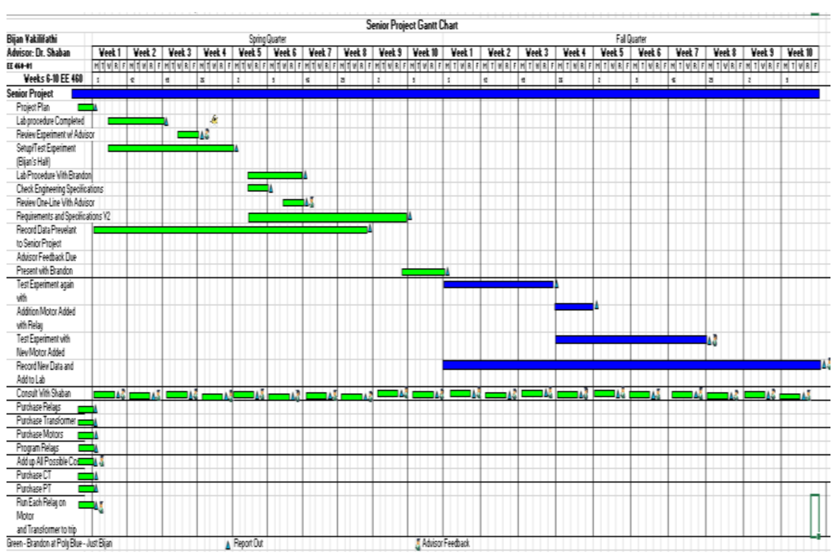


FIGURE 24

ESTIMATED GANTT CHART DESCRIBE PROJECT PROCESS.

References

Data Sheets
[1] SEL-710 Motor Protection Relay, SEL, Pullman, WA, 2011, pp. 01-10
[2] SEL-587 Current Differential Relay, SEL, Pullman, WA, 2011, pp. 01-12

Books
[3] J Duncan Glover, “Fault Analysis,” in Power System Analysis and Design, 5th ed. Stamford, CT: Cengage Learning, 2012, Ch. 9

IEEE Journal
[4] Corulli, Ozro. Motor Protection Lab Experiment Using SEL-710. Motor Protection Lab Experiment Using SEL-710. Cal Poly SLO, Dec. 2013. Web. Mar. 2016.

[5] C. Pang, M. Kezunovic, "Fast Distance Relay Scheme for Detecting Symmetrical Fault During Power Swing," IEEE Transactions on Power Delivery (Accepted, In Press).
[6] B. Kasztenny, M. Kezunovic, “Digital Relays Improve Protection of Large Power Transformer,” IEEE Computer Applications in Power, Vol. 11, No. 4, pp.39-45, October 1998
[7] M. Kezunovic, “A Survey of Engineering Tools for Protective Relaying,” ELECTRA, No. 225, pp 26-30, 2006

Patent
[8] Murty V. V. S. Yalla, David C. Vescovi, Thomas R. Beckwith, “Multifunction protective relay system,” U.S. Patent 5224011 A, Jun, 29, 1993.
[9] Cortlandt Warringto Albert Rus, “Electrical protective relay systems,” U.S. Patent 3048744 A, Aug, 7, 1962.
[10] Nikoli Tesla, “Electro-magnetic motor,” U.S. Patent 381968 A, May, 1, 1888.

Panel Pin Layout for SEL Relays

Front- and Rear-Panel Diagrams

Induction Motor Protection Relay

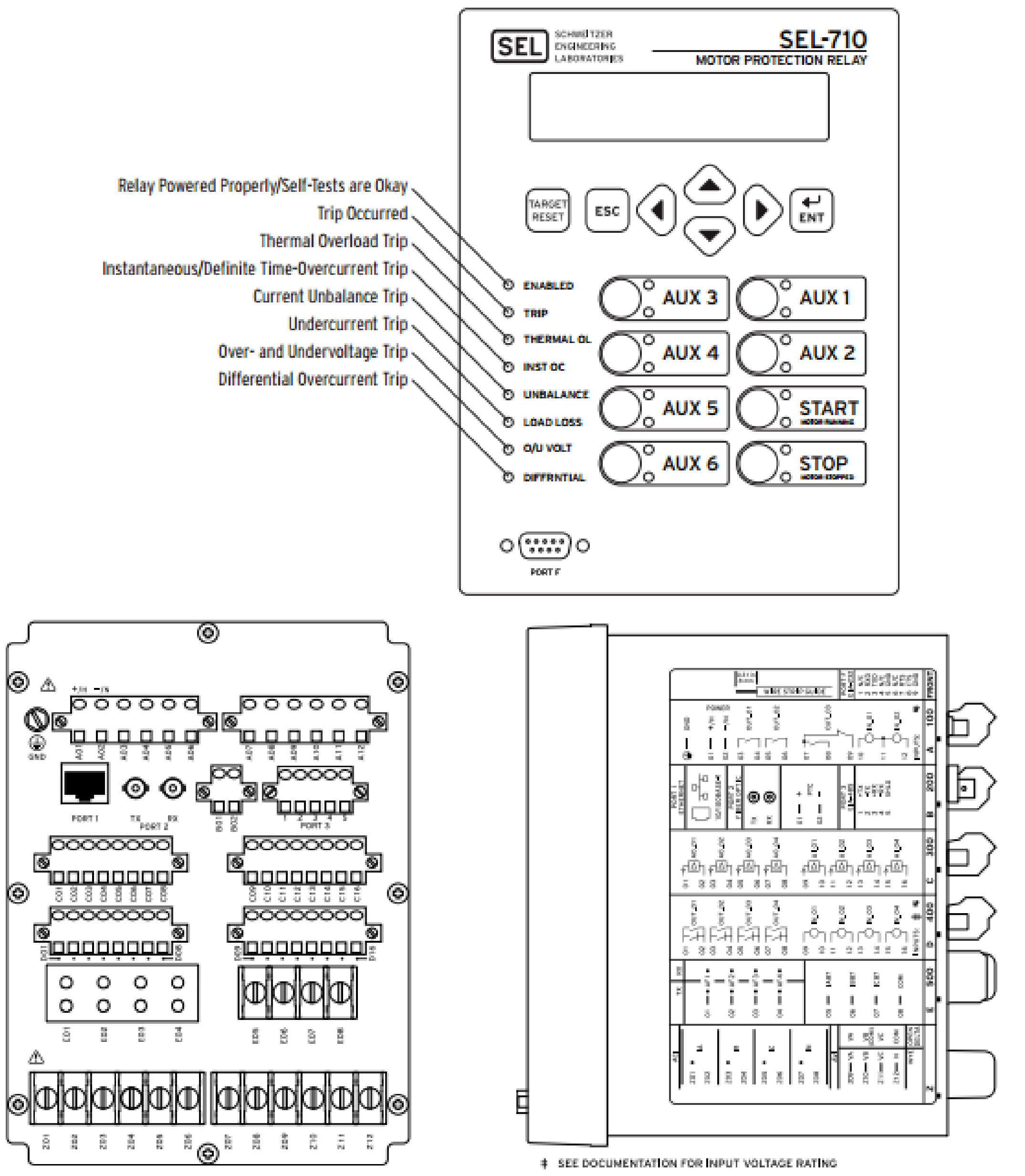


Figure 18 Single Copper Ethernet, Fiber-Optic Serial, EIA-485 Communications, PTC, 4 AI/4 AO, Fast Hybrid 4DI/4DO and 4 Arc Flash/Differential Option (MOT: 0710S0E1A6XCA74851300)

FIGURE 25

SEL 710 FRONT, BACK, AND SIDE PIN LAYOUT.

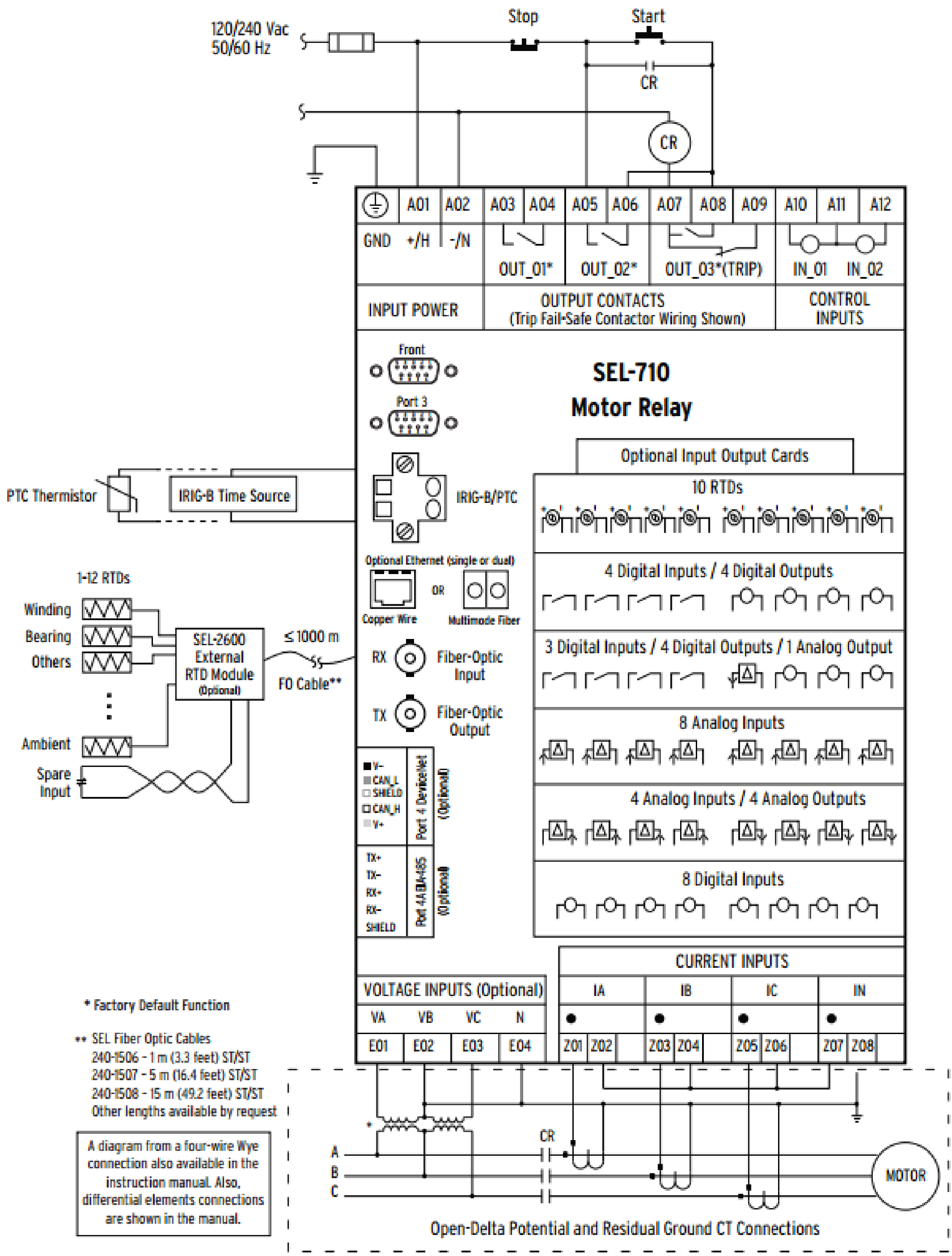
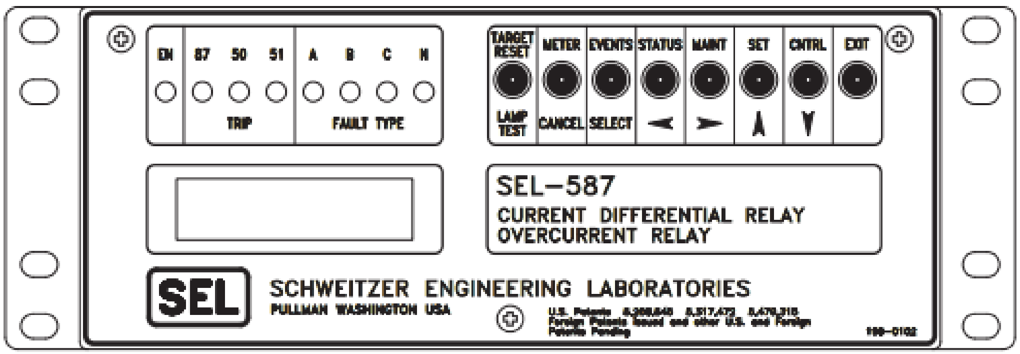


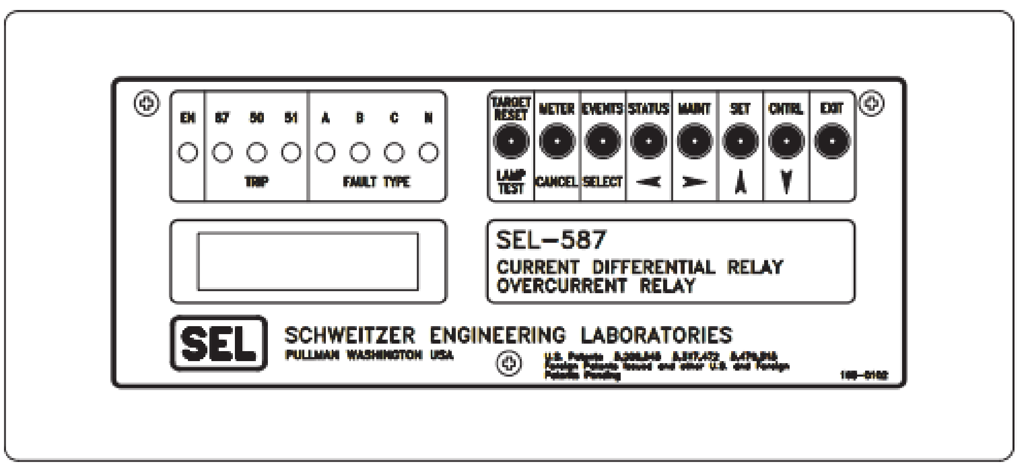
FIGURE 26

SEL 710 INTERIOR PIN LAYOUT.



Relay Front Panel, Rack-Mount Version (Half Rack Width)

13044a

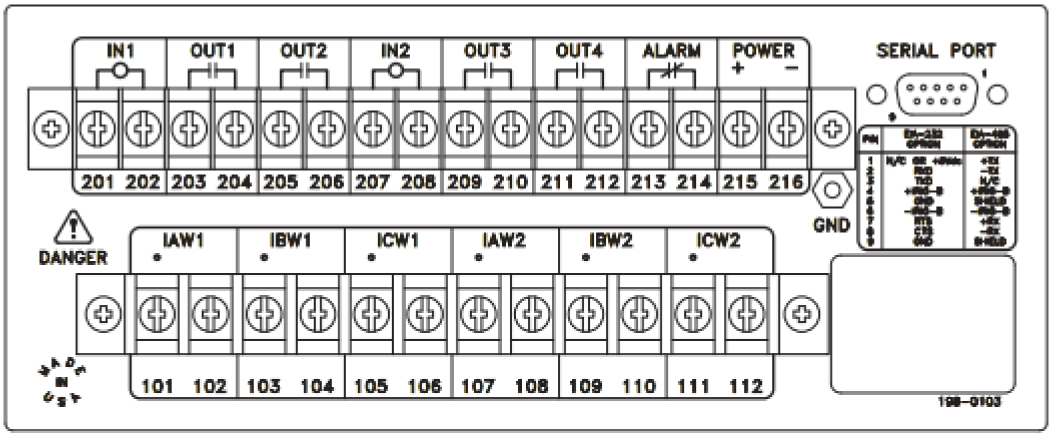


Relay Front Panel, Panel-Mount Version

13046a

FIGURE 27

SEL 587 FRONT PANEL PIN LAYOUT.



Relay Rear Panel, Conventional Terminal Blocks Version

i3043a

FIGURE 28
SEL 587 REAR PANEL PIN LAYOUT.

Functional Overview

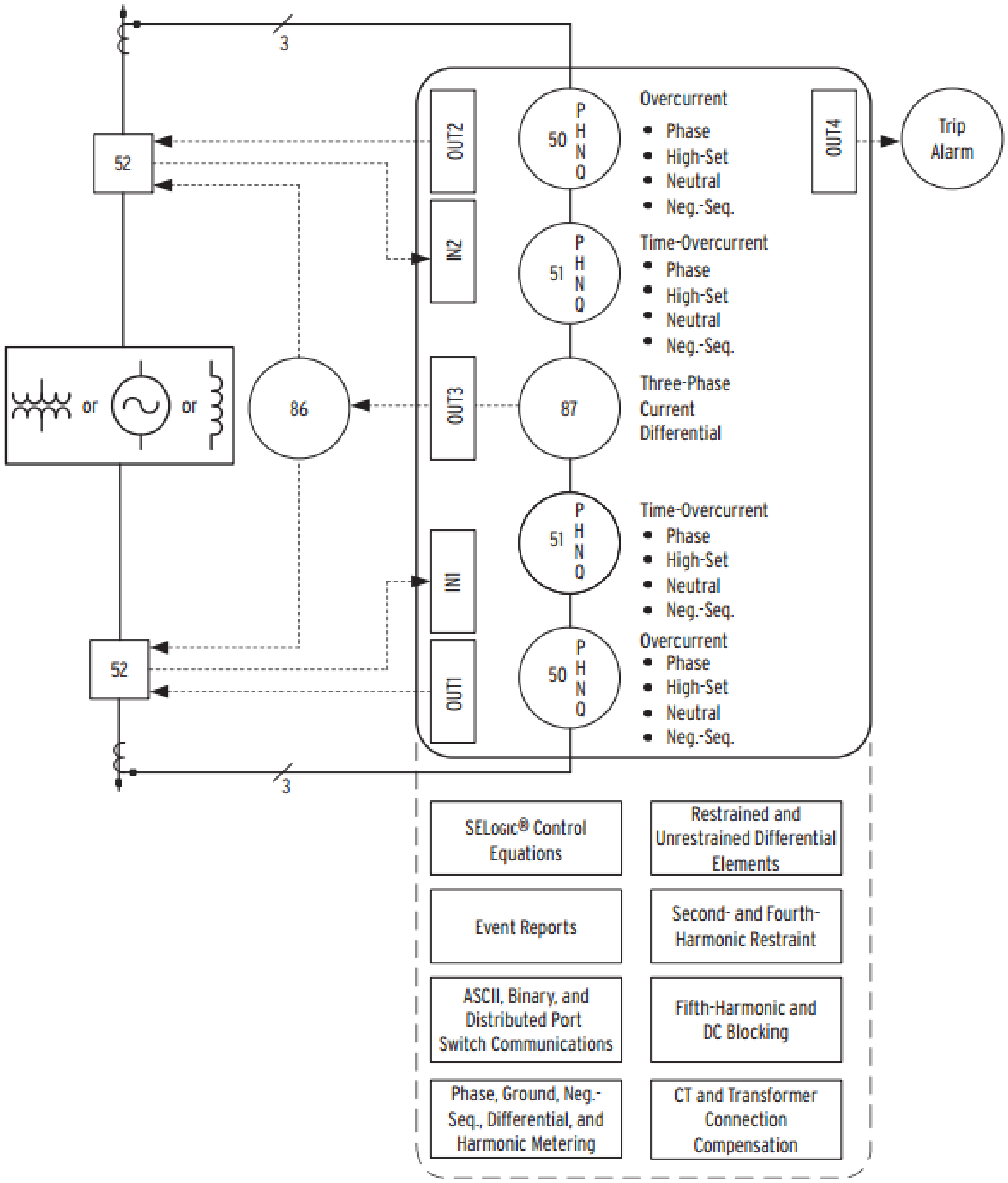
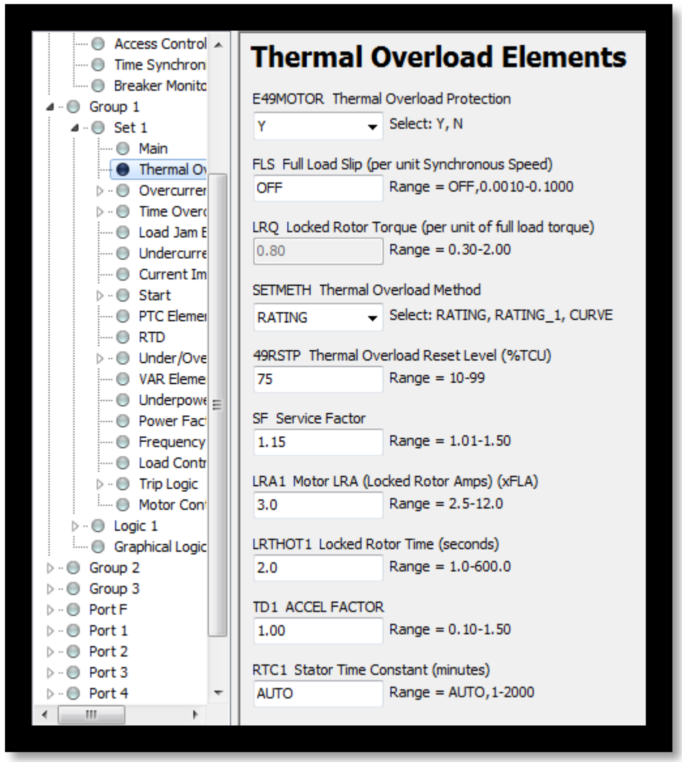
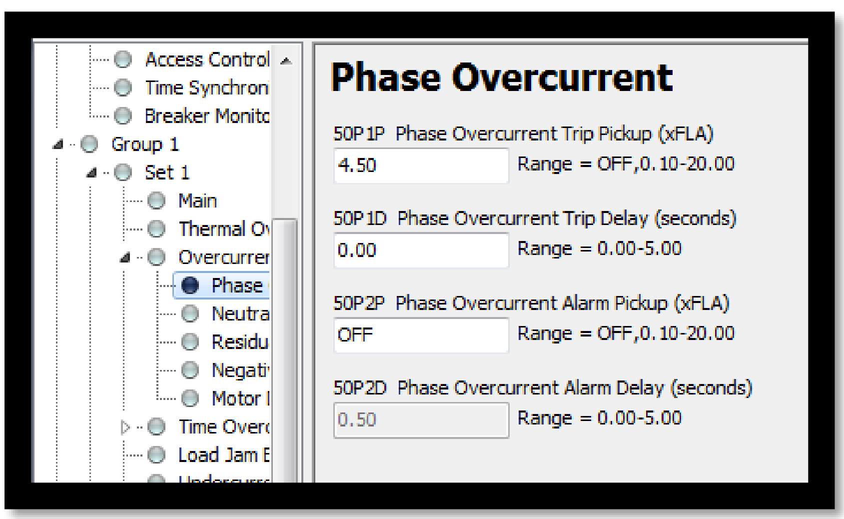
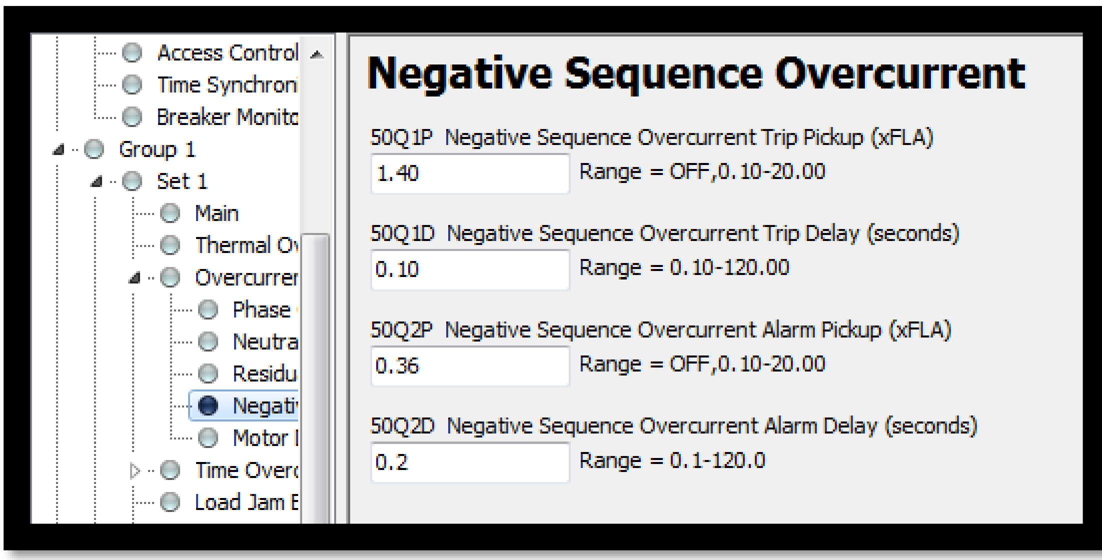


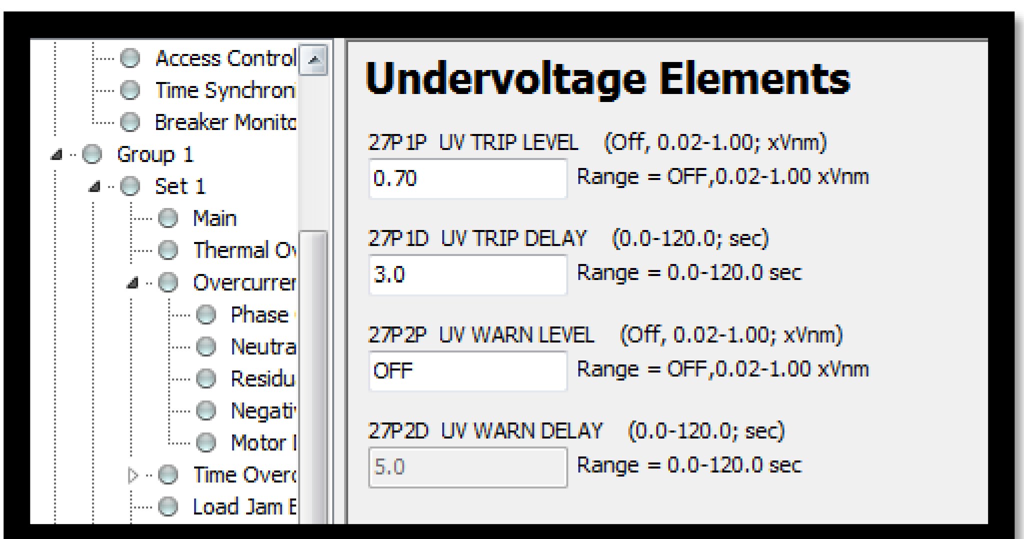
FIGURE 29
SEL 587 FUNCTIONAL OVERVIEW.

Fault Settings






Access Control
Time Synchron
Breaker Monito
Group 1
Set 1
Main
Thermal O
Overcurren
Phase
Neutra
Residu
Negati
Motor I
Time Overc
Load Jam E
Negative Sequence Overcurrent
50Q1P Negative Sequence Overcurrent Trip Pickup (xFLA)
1.40
Range = OFF,0.10-20.00
50Q1D Negative Sequence Overcurrent Trip Delay (seconds)
0.10
Range = 0.10-120.00
50Q2P Negative Sequence Overcurrent Alarm Pickup (xFLA)
0.36
Range = OFF,0.10-20.00
50Q2D Negative Sequence Overcurrent Alarm Delay (seconds)
0.2
Range = 0.1-120.0


Access Control
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Set 1
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Phase
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Residu
Negati
Motor I
Time Overc
Load Jam E
Undervoltage Elements
27P1P UV TRIP LEVEL (Off, 0.02-1.00; xVnm)
0.70
Range = OFF,0.02-1.00 xVnm
27P1D UV TRIP DELAY (0.0-120.0; sec)
3.0
Range = 0.0-120.0 sec
27P2P UV WARN LEVEL (Off, 0.02-1.00; xVnm)
OFF
Range = OFF,0.02-1.00 xVnm
27P2D UV WARN DELAY (0.0-120.0; sec)
5.0
Range = 0.0-120.0 sec