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Protective Relaying System for Education

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Abstract

A rapidly growing in power industry requires more reliable operation of power supply that increases complexity of power systems. For attaining this aim new communication solutions and an increased focus on protection may be needed. The power engineering department at IGEE has proposed advanced power systems initiatives to better prepare its students for the power industry field. One of these initiatives is the development of a new laboratory curriculum that uses digital relays to reinforce the fundamental concepts of power system protection. The simple relay protection lab planned at IGEE should include a test bench with distance, over-current and differential relays, and a relay tester that may be used for applying simulated waveforms to the relays.

This project proposes a laboratory protection system fulfilling this task. It presents background on power system protection, modern relay technology, and relay testing, to support the design and practical setup of the protective relaying system.

The report includes a theoretical part describing the components of power system protection, their function, and attributes in order to understand better the importance of power system protection. Three chapters covering the principles of protective relaying functions relevant to the lab are included. They cover the theory of overcurrent, differential and distance protection.

Modeling and simulation can help students to better understand how a relay reacts during a fault or other non-fault disturbances. New design models of overcurrent and differential relay have been implemented in PC using power system simulator PSCAD.

Proposals of lab assignments that can be performed in the protective relaying laboratory are presented at the end, using the designed models and the protective equipment available at the institute and donated for the purpose of this work.

Dedication

I dedicate this modest work

To my idolized Mother, my treasured Father

To my precious Sisters, Uncles, Aunts and Cousins

To every teacher who added something in me from childhood to this day

And to all those who offered me memorable moments

Acknowledgements

The completion of this work could not have been possible without the participation and assistance of so many people whose names may not all be enumerated. Their contributions are sincerely appreciated and gratefully acknowledged.

However, I would like to express appreciation and indebtedness particularly to the following:

IGEE professor Hamid BENTARZI, project supervisor. I am very grateful to him for encouraging me to take on this project. I owe him a very important debt for offering the necessary background and knowledge I needed

Dr. BENTARZI's continual encouragement and support made this project a joy to work on.

IGEE professor Mohamed BOUCHAHDANE donated the equipment necessary for achieving this work. I am deeply grateful for his support, patience, and motivation. Thanks to his generosity, guidance and persistent help this work has been accomplished in time. And without forgetting the power system protection courses taught by him that helped me a lot in this project.

I would like also to show my greatest appreciation to the expert Mr. ABBACI Mohamed for his support and contribution during time of need and for providing me with all the information i needed, without his passionate participation, the results of this thesis could not have been successfully conducted.

To all relatives, parents, family and others who in one way or another shared my support, either morally, financially and physically. Thank you

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List of Abbreviation and Acronyms

ANSI	American National Standards Institute
IEEE	Institute of Electrical and Electronics Engineers
IGEE	Institut De Génie Electrique Et Electronique
IEC	International Electrotechnical Commission
AC	Alternating Current
CB	Circuit Breaker
COMTRADE	Common Format for Transient Data Exchange for Power Systems
CT	Current Transformer
VT	Voltage Transformer
CTR	Current Transformer Ratio
PTR	Power Transformer Ratio
DC	Direct Current
HMI	Human-Machine Interface
SEL	Schweitzer Engineering Laboratories
OC	Overcurrent

Introduction

Protective relays are becoming more advanced to keep up with more complex and integrated power systems. The future of power systems is smart grids, meaning more complex designs, with distributed generation, smart meters and continuous surveillance to ensure optimal operation and power flow at every instant.

The electrical engineers of the future should be educated with this in mind. To enlighten today's and future students about protective relaying, a solid theoretical background part is a fundamental first step. To complement the theory and to better the understanding of the topic, a practical component, to understand how power system protection works in real life, is vital. A protective relay lab can be the foundation of such a practical, hands-on component.

Motivated by the growing demand from the power industry for engineering graduates versed in power systems, as well as a need to provide continuing education opportunities for power engineering students, the Institute of Electrical Engineering and Electronics at Boumerdes University has for a future aim the redesign of its electrical engineering power systems emphasis programs at both the BS and MS levels. The educational goals of the lab are to provide students with hands-on experience with industry protection equipment and software, enhance the classroom-based course curriculum, and acquaint students with industry standards and design practices.

This project is to propose laboratory-scale microprocessor-based relay experiments for students, illustrating the principles of real-time fault protection in radial and bidirectional networks. Student learning outcomes include: applying the fundamental principles of power system protection to detect faults in transformers and transmission lines; comparing experimentally-derived results with expected theoretical circuit performance through post-fault data analysis; developing experience in wiring common circuit connections; understanding the relationship between a relay and a circuit breaker in detecting and clearing faults. This work also lays a foundation for the future development of a microgrid lab in the IGEE power engineering department.

Chapter 1: Protection Student Laboratory

1.1 Customer Needs Assessment

This project directly serves IGEE electrical engineering power students. It arose from the expressed desire of power engineering department to introduce a power systems protection teaching laboratory for graduate power engineering education utilizing protective relaying equipment.

IGEE currently offers a graduate level power systems protection lecture course, EE535 Instrumentation and Protection Systems, to which this project adds an accompanying laboratory component. Curriculum resulting from this project should give students hands-on experience applying the fundamentals of power system protection through microprocessor-based relays. The following section describes the high-level functionality of the proposed student laboratory experiments.

Power system protection rests at the heart of this project. Reference [9] defines the protection as “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”.

The stability of power system was and is still a major concern for electrical engineers, each day; they try to design an ideal power system so it can face the different disturbances that may affect its performances. But, no matter how well designed, faults will always occur and these faults may represent a serious risk to both equipments and personnel. Protective systems were developed so that the power system could operate in a safe manner at all times.

1.2 Protective System

Protection System is a full arrangement of protective equipment and other devices that are required to achieve a specified function based on a protection principle. Its main function is to protect the whole electrical power system (generators, transformers, reactors, lines…) from abnormal conditions such as short circuits, overloads and also equipment failures. This is made by isolating the faulty section from the remaining living system parts [1].

1.3 Protection Requirements

The protection scheme established for this system must recognize to eliminate fault conditions but never interrupt normal circuit operation. This balance in discriminating normal load from fault conditions requires considering the impacts to the system caused by single-line-to-ground, double-line-to-ground, triple-line-to-ground, three-phase, and line-to-line bolted faults. All relays used to detect these faults require coordination so that a relay closer to a fault operates before any of the relays further upstream from the fault location. In order to carry out its duties, protection must have the following qualities:

- Selectivity: To detect and isolate the faulty part only.
- Stability: To leave all healthy circuits intact to ensure continuity of the supply.
- Sensitivity: To detect even the lowest fault, current or system abnormalities, and to operate correctly before the fault causes irreparable damage.
- Speed: To operate speedily when it is called upon to do so, thereby minimizing damage to the surroundings and ensuring safety to equipment as well as to personnel.

To meet all of the above requirements, protection must be reliable which means it must be:

- Dependable: It must trip when called upon to do so.
- Secure: It must not trip when it is not supposed to do [2].

1.4 Protection Equipment

Protection systems consist of components called protection devices. They are installed and connected together with the aims of assets protection, and insurance of continued supply of energy. In any protection system, six essential elements are distinguished.

1.4.1 Current and Voltage Transformers

Current and voltage transformers are continuously used to measure current and voltage signals of the electrical system even under fault conditions. They step these signals down to lower and safe levels so that the relay and other instruments hardware can support them. Besides, they also isolate the relaying system from the primary high voltage system and provide safety to both human being and equipment. The CTs available in the industry can lower the current up to 5 A or 1A, while the voltage transformers lower the voltage to 110V.

1.4.2 Relays

The measured values are converted into analog and/or digital signals and are made to operate the relay. In most of the cases, the relays provide two functions, alarm and trip. They give instructions to open the circuit surrounding the faulty part of the network under faulty conditions. Relays perform also automatic operations, such as auto-reclosing and system restart. Besides, they monitor the equipment which collects the system data for post-event analysis.

1.4.3 Circuit Breakers

The opening of faulty circuits requires some time (in milliseconds), which for a common day life could be insignificant. However, the circuit breakers used to isolate the faulty circuits, are capable of carrying these fault currents until the fault is totally cleared [2]. They are expected to be switched ON with loads and capable of breaking a live circuit under normal switching and fault conditions. The process is realized through the instructions given by the monitoring devices like relays.

The circuit breakers types are determined according to the medium in which the breaker opens and closes. This medium can be oil, air, vacuum or SF6.

Figure 1.1: High Voltage Circuit Breaker from Siemens

1.4.4 Fuses

Fuse is a self-destructing device which carries the currents in a power circuit continuously and it will be melt under abnormal conditions. Fuses are normally independent or stand-alone protective components in an electrical system unlike a circuit breaker, which necessarily requires the support of external components [2].

1.4.5 Reclosers

A recloser is a protection device for electrical distribution networks. It combines a circuit breaker that trips if an overcurrent is detected (indicating a short circuit somewhere in a section of the network), with an electronically-controlled reclosing function that automatically restores power to the affected line if the fault clears itself quickly, which usually happens around 80 percent of the time [4].

1.5 Protective Relays

In order to fulfill the requirements of protection with the optimum speed for the many different configurations, operating conditions and construction features of power systems, it has been necessary to develop many types of relay that respond to various functions of the power system quantities. For example, simple observation of the fault current magnitude may be sufficient in some cases but measurement of power or impedance may be necessary for others. Relays frequently measure complex functions of the system quantities, which may only be readily expressible by mathematical or graphical means.

Relays may be classified according to the technology used:

- Electromechanical
- Static
- Digital
- Numerical

The different types have varying capabilities, according to the limitations of the technology used.

1.5.1 Numerical Relay

Digital relays were developed to create a more advanced technology which is the numerical relays. This type of relay according to the technology uses one or more digital signal processors (DSP) optimized for real-time signal processing, running the mathematical algorithms for the protection functions.

The relay can record parameters with the help of disturbance recorder flexibility as well as other settings, therefore, one relay provides all types of protection functions such as overcurrent or earth faults which are referred to as “relay elements “. Each relay element is in software so with modular hardware the main signal processor can run a vast variety of relay elements [1].

Figure 1.2: SEL-T400L Numerical Relay

1.6 Conclusion

This chapter gives the reader a brief introduction to the protection system and its elements including the importance of using numerical relays regarding their efficiency in providing the protection requirements from selectivity, speed, sensitivity and so on, which makes them the most appropriate relays for protecting human life and expensive devices.

Chapter 2: Protection Equipment Overview

2.1 Protection Equipment Introduction

This project deals with the proposal of a new laboratory curriculum. This chapter introduces the various devices that comprise the protection scheme throughout the various project phases. Information on protection device capabilities and characteristics have been obtained from the company's product literature.

2.2 SEL-221F Numerical Relay

The SEL-221F Relay is a phase and ground distance relay with directional ground, synchronism checking, reclosing and fault locator elements.

It is designed to protect transmission, sub-transmission and distribution lines for all fault types. The following list outlines protective features, performance, and versatility gained when applying this relay to the electrical installations:

- Three zones of phase and ground distance protection.
- A residual time-overcurrent element with selectable curves.
- Instantaneous residual overcurrent element.
- A negative-sequence polarization of ground directional elements.
- A versatile user-programmable logic for outputs and tripping.
- Programmable switch-onto-fault logic.
- Loss-of-potential detection logic.
- Programmable single-shot reclosing with synchronism check and voltage checking.
- Fault locating.
- Metering.
- EIA-232 serial communications ports for local and remote access.
- Automatic self-testing.
- Target indicators for faults and testing [14].

Figure 2.1: SEL-221F Numerical Distance Relay

2.3 The Universal Relay Test Set and Commissioning Tool CMC356

For the purpose of the relay lab, using a relay tester for testing of relays is a safe start. It is a powerful tool capable of doing tests with varying degrees of complexity, which suits a lab with prospective expansions perfectly. An injection test set was generously donated by Mr. Mohamed BOUCHAHDANE for the purpose of achieving this project.

The CMC 356 is an equipment made for testing all generations and types of protection relays. Its powerful six current sources (three-phase mode: up to 64 A / 860 VA per channel) with a great dynamic range, make the unit capable of testing even high-burden electromechanical relays with very high power demands.

The CMC 356 helps commissioning engineers particularly to perform wiring and plausibility checks of current transformers by using a primary injection of high currents from the test set.

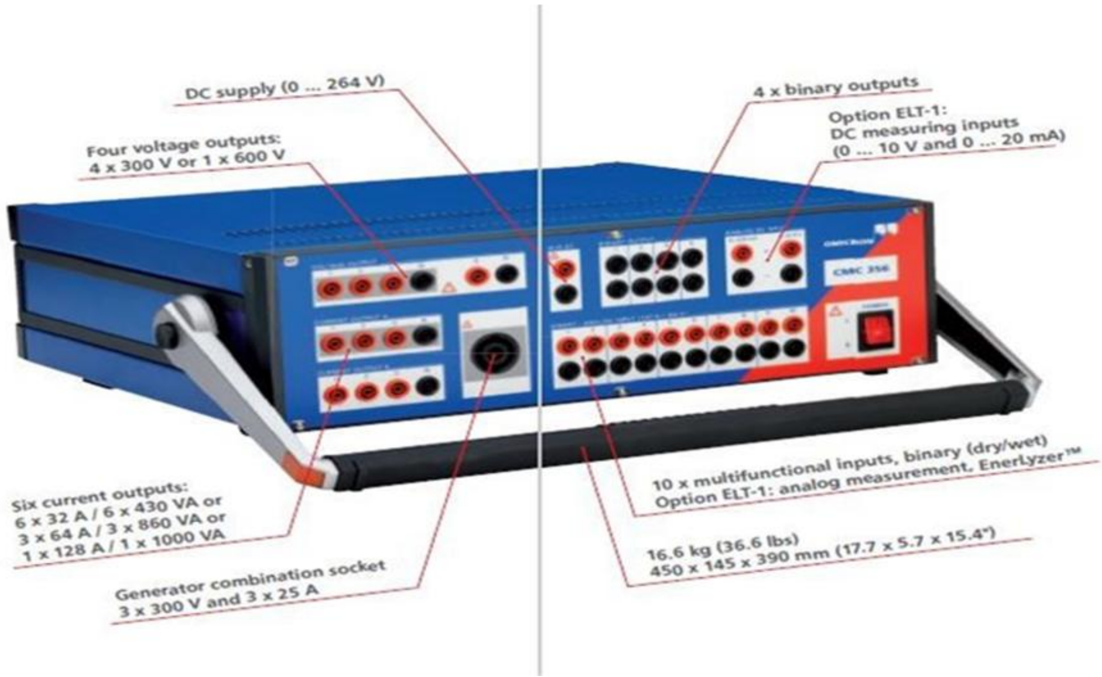

Figure 2.2: Front View of CMC356

The analog test signals are generated digitally using DSP technology. This, in combination with the use of additional error correction algorithms, results in accurate testing signals even at small amplitudes. The six currents and four voltages output channels are continuously and independently adjustable in amplitude, phase, and frequency. All outputs are overload and short-circuit proof and are protected against external high-voltage transient signals and over-temperature.

Up to 12 independent channels with low-level signals are available at the back of the test set, which can be used to test relays having a low-level input facility or to control external amplifier units.

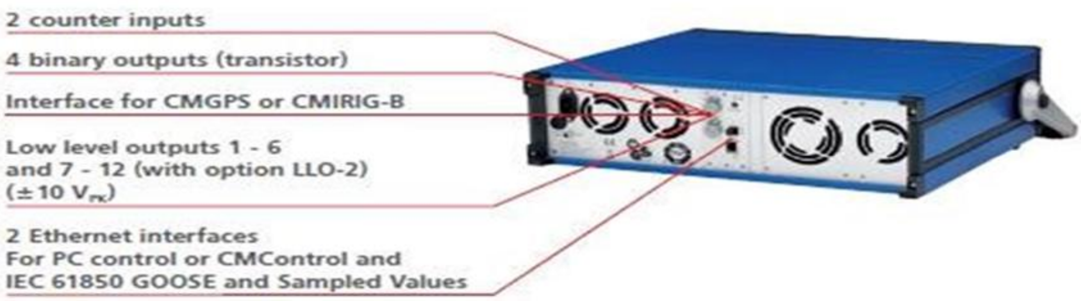

Figure 2.3: Rear View of CMC356

Figure 2.4: SEL 221 Relay and OMICRON CMC 356 Put Together In IGEE Lab Bench

The lab exercises should give students insight into the practical world of power system protection. The exercises should demonstrate the different protection principles and the function of modern relays. Setting parameters for the relays based on calculated values is also an important part. The students should have knowledge of the lab exercise topic before entering the lab. A prelab part is a good way for the students to refresh their knowledge and come prepared to the lab.

It is vital that the scientific assistant and the student assistants are familiar with the software and the different components, most notably the relay and the relay tester. Before the lab session starts the relay should be connected to the lab computer through an Ethernet connection and it should be verified that it is working correctly. This will allow students to get the most out of their session, without spending too much time on practicalities outside the focus of the exercise.

2.4 Experiment 3
SEL-211F Basic Connections and Wiring Check Procedure

This exercise Introduces these equipments to students in a laboratory environment, it has the aim of getting familiar with the SEL 221 relay and the OMICRON test set, this experiment is an exercise of establishing wiring connection and software communication. In the lab exercises, the students face a practical challenge; they are handed a relay, with no cables connected, and have to use the manual and follow the procedure to figure how to connect inputs and outputs. The lab manual guides its performer toward a safe and correct wiring, at the same time, learning how to use the TestUniverse and AcSELerator Quickset software, how to inject correct values and record the relay's results.

2.5 Experiments 4
SEL-211 Relay Configuration and Metering Check Procedure

Lab exercise 4 provides the students with insight on how to configure the relay, change and set parameters relevant to the relay with a metering check procedure that resumes a deeper understanding of the power flow in a power system. Experiments 3 and 4 are shown in appendices C and D respectively.

When designing a university relay lab, it might be a good idea to build the lab gradually, a strategic co-operation with Siemens Algeria and Schweitzer Engineering Laboratories is under establishment for the donation of new relays for the benefit of IGEE students, However, for the time being, the only available relay is a distance relay, a protection laboratory should include the basic protection functions; overcurrent, distance and di erential protection; to cover this and replace the present lack of materials, a desirable good start is to experiment with simulation models proposed and described in the coming chapters.

Chapter 03: Phase Overcurrent Protection

As mentioned earlier, building the lab gradually is desirable. It is therefore important to have a vision for the future expansions and use of the lab. The final outlook for the relay lab may change as it develops. For the present being, in order to understand the functions of relays, for a student of electrical protection, software relay models must be realized, modeling of protective relays offer an economic and feasible alternative to studying the performance of protective relays. This chapter introduces a new software model for overcurrent protection to be introduced as the first experiment in protection laboratory.

3.1 Overcurrent Protection Overview

The function of this protection is to detect single-phase, two-phase or three-phase overcurrents. Protection is activated when one, two or three of the currents concerned rise above the specified setting threshold.

The overcurrent relay uses current inputs from a current transformer and compares the measured values with the pre-set values. If the input current value exceeds the preset value, the relay detects an overcurrent and issues a trip signal to the breaker which opens its contact to disconnect the protected equipment.

When the relay detects a fault, the condition is called fault pickup. The relay can send a trip signal instantaneously after picking up the fault in the case of instantaneous overcurrent relays or it can wait for a specific time before issuing a trip signal in the case of time overcurrent relays. This time delay is also known as the operation time of the relay and is computed by the relay on the basis of the protection algorithm incorporated in the microprocessor [7].

This protection can be time delayed and, in this case, will only be activated if the current monitored rises above the setting threshold for a period of time at least equal to the time delay selected. This delay can be an instantaneous, independent (definite) time or inverse time delay.

3.1.1 Instantaneous:

In such type of relay, there is no intentional time delay provided for operation. The relay sends trip signal immediately to the circuit breaker as soon as the overcurrent has occurred. Instantaneous overcurrent relays are used close to the source where the fault current level is very high and a small delay in sending trip signal can cause big damage to the protected equipment [7].

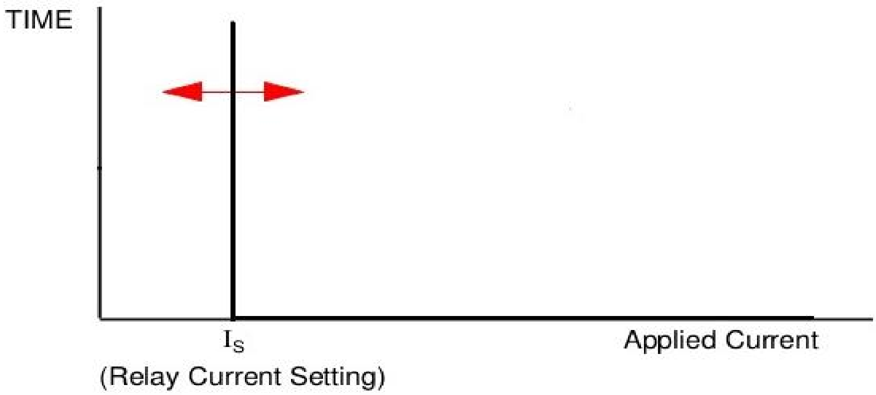

Figure 3.1: Time Versus Current Curve of Instantaneous Overcurrent Relay [11]

Coordination of definite-current relays is based on the fact that the fault current varies with the position of the fault because of the difference in the impedance between the fault and the source. The relay located furthest from the source operates for a low current value. This type of relay is applied to the outgoing feeders.

3.1.2 Definite Time Protection

Definite time overcurrent relay is the most applied type of overcurrent, it has two conditions to operate, first the current must exceed the setting value, and second, the fault must be continuous no less than the time equivalent to the time setting of the relay.

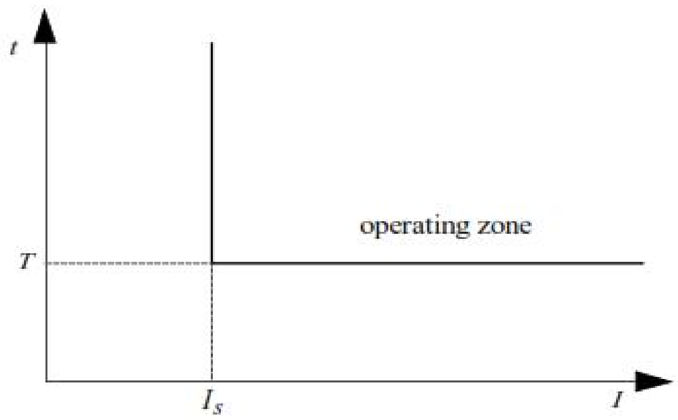

Figure 3.2: Independent Time Delay

I_S: operating current threshold
T: protection operation time delay

The operation of this relay is independent of the current's magnitude above the pickup value, it can be used as:

- Back up protection to differential relay of power transformer with time delay.
- Main protection to outgoing feeders and bus couplers with adjustable time delay setting.
- Back up protection of distance relay of transmission line with time delay (If the distance relay does not detect a line fault and does not trip the breaker, then after a specific time delay, the overcurrent relay will send a trip command to the breaker. In this case, the overcurrent relay is time delayed by a specific time which is just greater than the normal operating time of the distance relay plus the breaker operation time [7].)

3.1.3 Inverse Definite Minimum Time (IDMT)

This type of relay has an inverse time characteristic. This means that the relay operating time is inversely proportional to the fault current. So, high currents will operate overcurrent relay faster than lower ones. The characteristics of an IDMT overcurrent relay depend on the type of standard selected for the relay operation. These standards can be ANSI, IEEE, lAC or user defined. The relay calculates the operation time by using the characteristic curves and their corresponding parameters [7]. IDMT relay gives inverse time current characteristics at lower values of fault current and definite time characteristics at higher values. Based on the Inverness it has three different types [8].

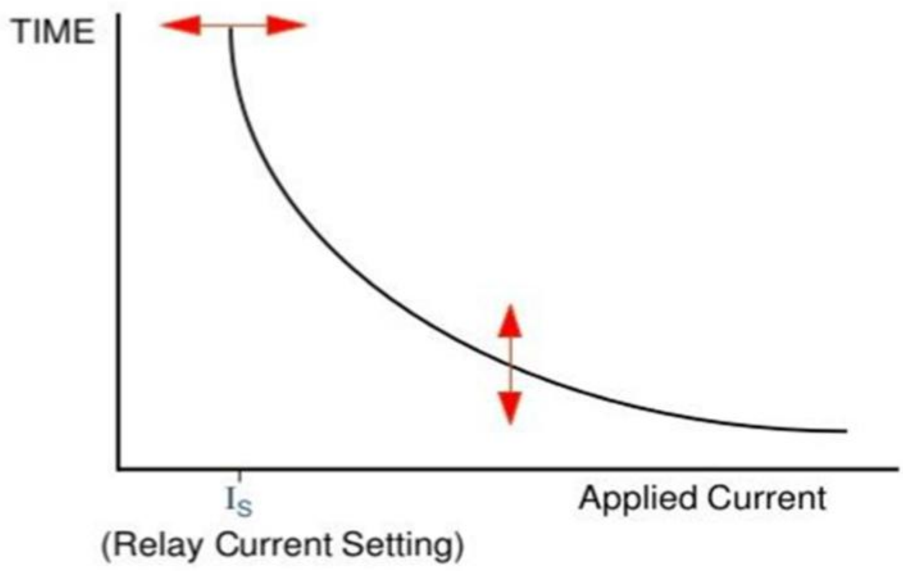

Figure 3.3: Time Versus Current Curve for IDMT Overcurrent Relay [11]

Inverse time protection operation is defined by standards IEC 60255-3 and BS 142. These standards define several types of inverse time protection that are distinguished by the gradient of their curves: standard inverse, very inverse or extremely inverse time protection.

3.1.4 Normal Inverse

This type is used when Fault Current is dependent on the generation of fault not fault location and it has a relatively small change in time per unit of change of current. Its operating time's accuracy may range from 5 to 7.5% of the nominal operating time as specified in the relevant norms. The uncertainty of the operating time and the necessary operating time may require a grading margin of 0.4 to 0.5 seconds. Normal Inverse Time Overcurrent Relay is used in utility and industrial circuits [8].

3.1.5 Very Inverse

Very inverse overcurrent relays are particularly suitable if there is a substantial reduction of fault current as the distance from the power source increases, i.e. there is a substantial increase in fault impedance. The grading margin may be reduced to a value in the range from 0.3 to 0.4 seconds when they are used [8]. This type has more inverse characteristics than that of IDMT. It can be used when the fault current is dependent on fault location.

3.1.6 Extremely Inverse

With this characteristic, the operation time is approximately inversely proportional to the square of the applied current. This makes it suitable for the protection of distribution feeder circuits in which the feeder is subjected to peak currents on switching in, as would be the case on a power circuit supplying refrigerators, pumps, water heaters and so on, which remain connected even after a prolonged interruption of supply. This type has more inverse characteristics than that of IDMT and very inverse overcurrent relay [8]. It is also used for the protection of alternators, transformers, expensive cables, the protection of machines against overheating and when fault current is dependent on fault location.

3.1.7 Long Time Inverse

The main application of long time overcurrent relays is as backup earth fault protection.

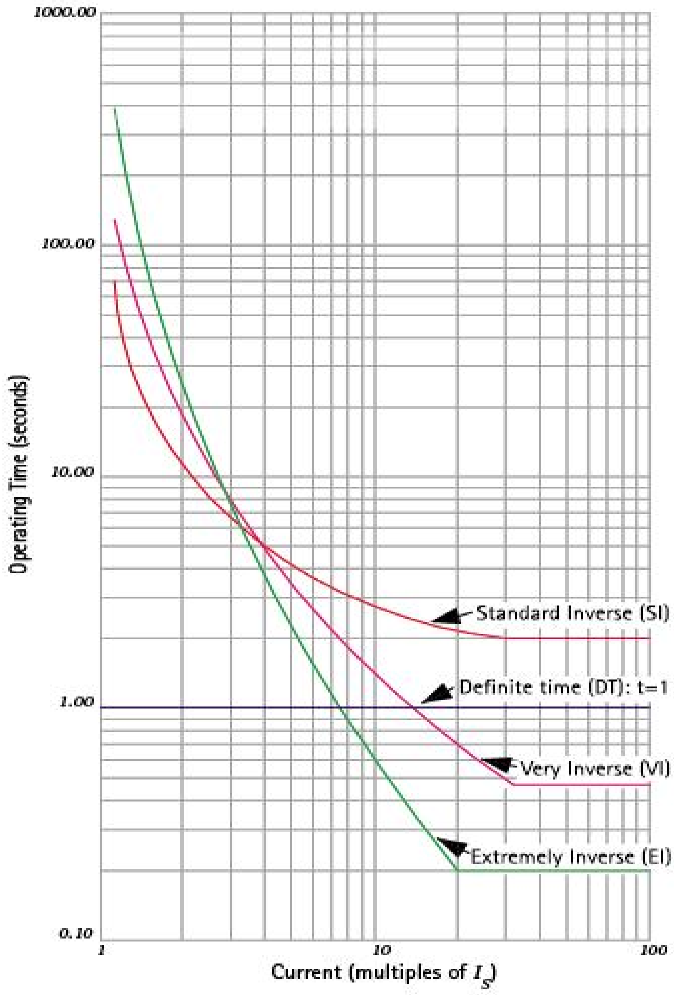

Figure 3.4: IEC 60255 Characteristics of IDMT Relay [1]

3.2 Application of Over Current Relay

- Used against overloads and short circuits in stator windings of motors.
- Used at power transformer locations for external fault back-up protection.
- For ground backup protection on most lines having pilot relaying for primary protection.

- Distribution Protection: Overcurrent relaying is very well suited to distribution system protection for the following reasons:
  - It is basically simple and inexpensive.
  - It is possible to use a set of two OC relays for protection against interphase faults and a separate overcurrent relay for ground faults [8].

3.3 Overcurrent Protection Model

Relay models have been long used in a variety of tasks, such as designing new relaying algorithms, optimizing relay settings. Electric power utilities use computer-based relay models to confirm how the relay would perform during systems disturbances and normal operating conditions and to make the necessary corrective adjustment on the relay settings. It is seen, then, that for the better comprehension of a student to the overcurrent relay, the implementation, simulation and testing is to be done on two steps, the first to be a work on a model, the second is a hardware hands-on experiment.

The principles of operation and application procedures of overcurrent have been presented above. The concept of a generalized numerical relay, whose structure is constituted by the typical operational modules and functions of modern digital and numerical relays, has been introduced.

For this purpose, an overcurrent protection design model is proposed in the coming section. The proposed relay model and tools required are summarized into the flowchart in figure 3.5. The design was performed on PSCAD software.

3.3.1 PSCAD

PSCAD (Power Systems Computer Aided Design) is a powerful and flexible graphical user interface to the world-renowned, EMTDC (Electromagnetic Transient Simulation Engine). PSCAD enables the user to schematically construct a circuit, run a simulation, analyze the results, and manage the data in a completely integrated, graphical environment. Online plotting functions, controls and meters are also included, enabling the user to alter system parameters during a simulation run, and thereby view the effects while the simulation is in progress.

Because this modeling is meant to be for laboratory learning purposes, PSCAD is the appropriate tool for a simplified scheme for better and faster learning, this is due to the fact that PSCAD comes complete with a library of pre-programmed and tested simulation models, ranging from simple passive elements and control functions to more complex models, such as electric machines and transmission lines and cables. If a required model does not exist, PSCAD provides avenues for building custom models. For example, custom models may be constructed by piecing together existing models to form a module, or by constructing rudimentary models from scratch in a flexible design environment.

The following are some common models found in the PSCAD master library:

- Resistors, inductors, capacitors.
- Mutually coupled windings, such as transformers.
- Frequency-dependent transmission lines and cables (including the most accurate time-domain line model in the world).
- Current and voltage sources.
- Switches and breakers.
- Protection and relaying.
- Diodes, thyristors and GTOs.
- Analog and digital control functions.
- AC and DC machines, exciters, governors, stabilizers and inertial models.
- Meters and measuring functions.
- Generic DC and AC controls.
- Wind source, turbines and governors.

3.4 Proposed Protection Model and Tools Required

The methodology for modeling overcurrent numerical protection is proposed in the coming section. The proposed protection system model designing methodology is shown in figure 3.5.

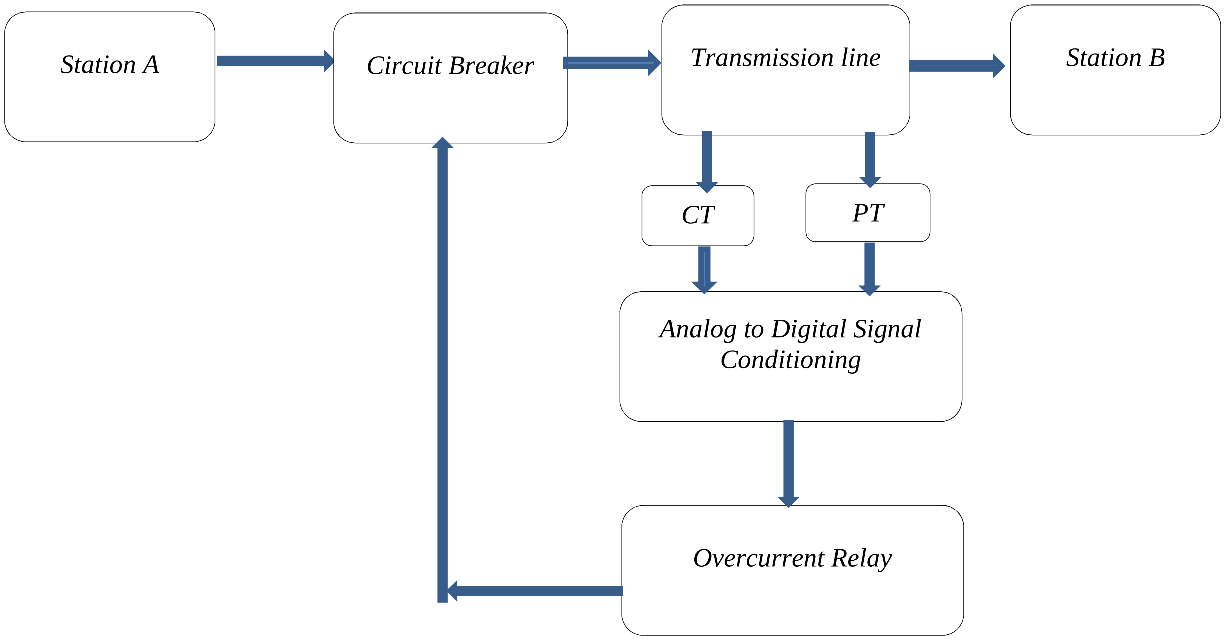

Figure 3.5: The General Block Diagram of The Proposed Protection Scheme

3.4.1 Signal Conditioning Circuit:

Fast Fourier transform (FFT)

An online Fast Fourier Transform (FFT), can determine the harmonic magnitude and phase of the input signal as a function of time. The input signals first sampled before they are decomposed into harmonic constituents.

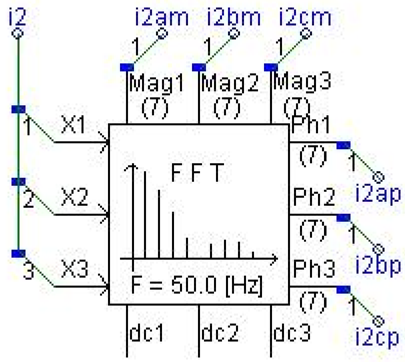

Figure 3.6: FFT Block

For two stations two FFT models were used in order to process the three-phase analog signals coming from both sources.

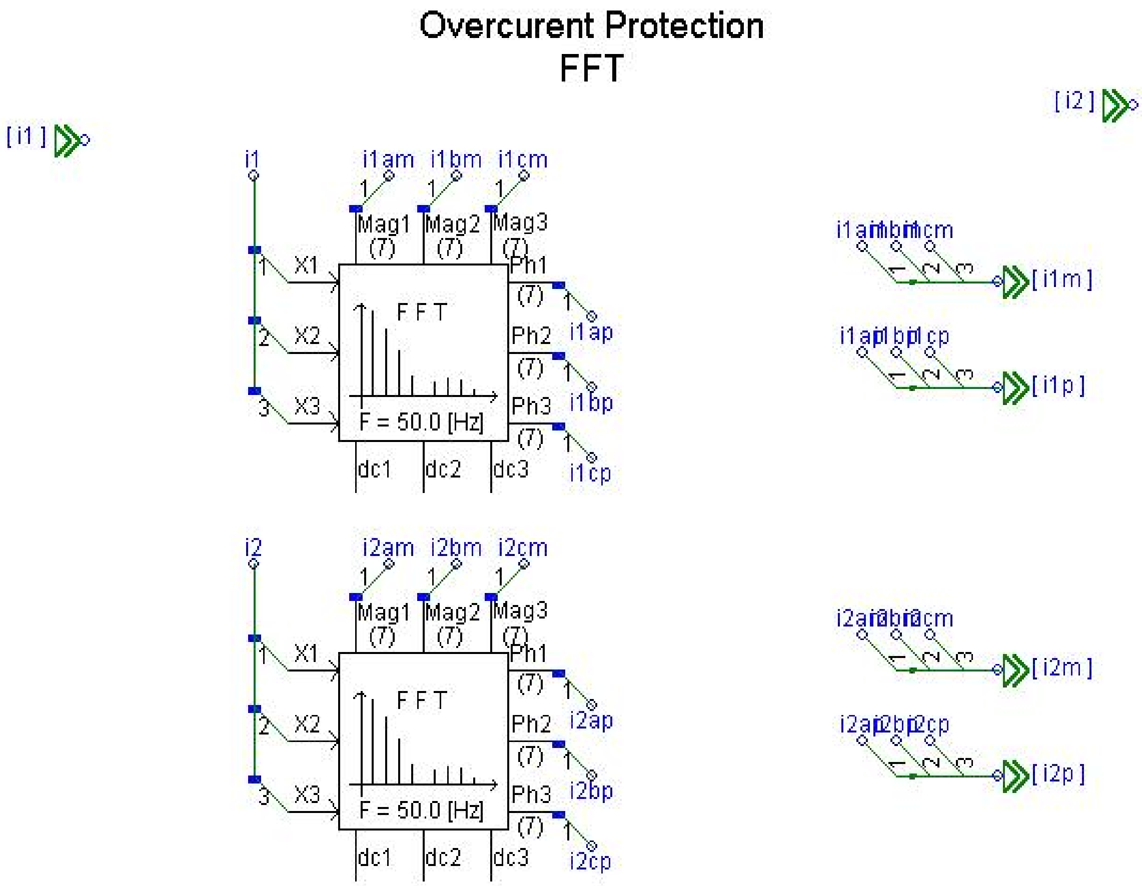

Figure 3.7: Signal Sampling Block Diagram

3.4.2 Overcurrent Relaying Circuit:

The PSCAD software provides ready blocks, pre-programmed and tested simulation models for overcurrent relays, two types of overcurrent relays were proposed in this simulation: IDMT inverse time overcurrent relay for station A and definite time overcurrent relay for station B

Figure 3.8: Overcurrent Relay Models

Signal conditioning and overcurrent relay circuits were arranged in blackbox modules for clearer interface with the front plane.

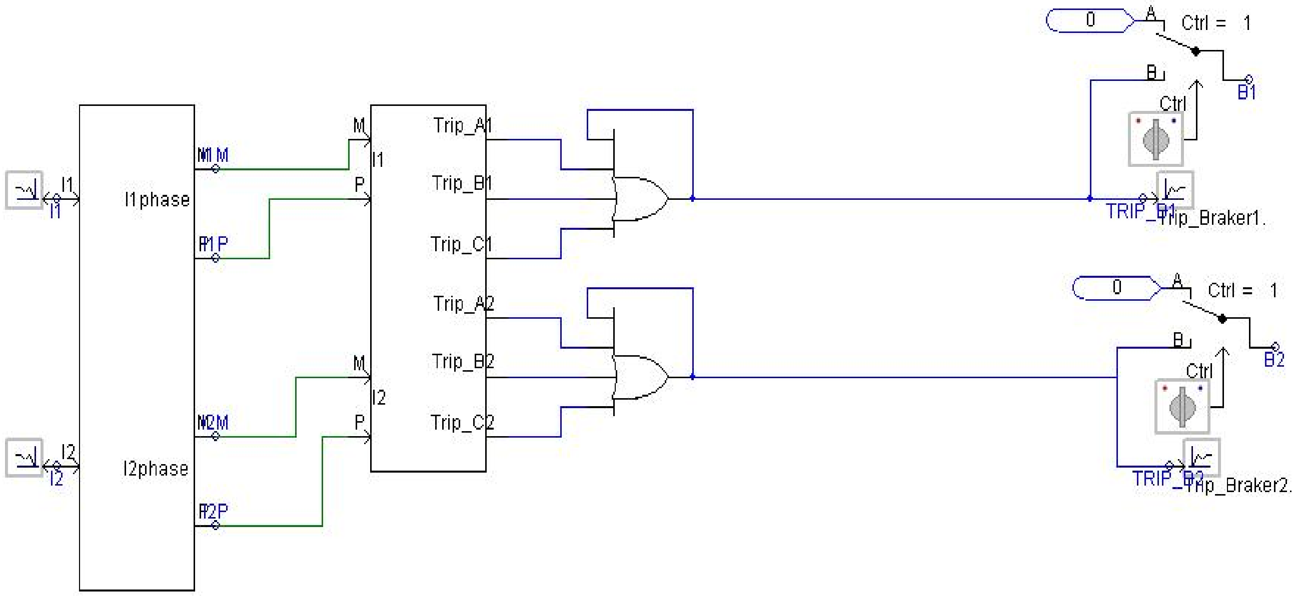

Figure 3.9: Conditioning and Relays Circuit Blackbox Diagram

3.4.3 Front Panel Block Diagram Construction:

Using the provided pre-programmed models for electrical components, the following diagram was constructed:

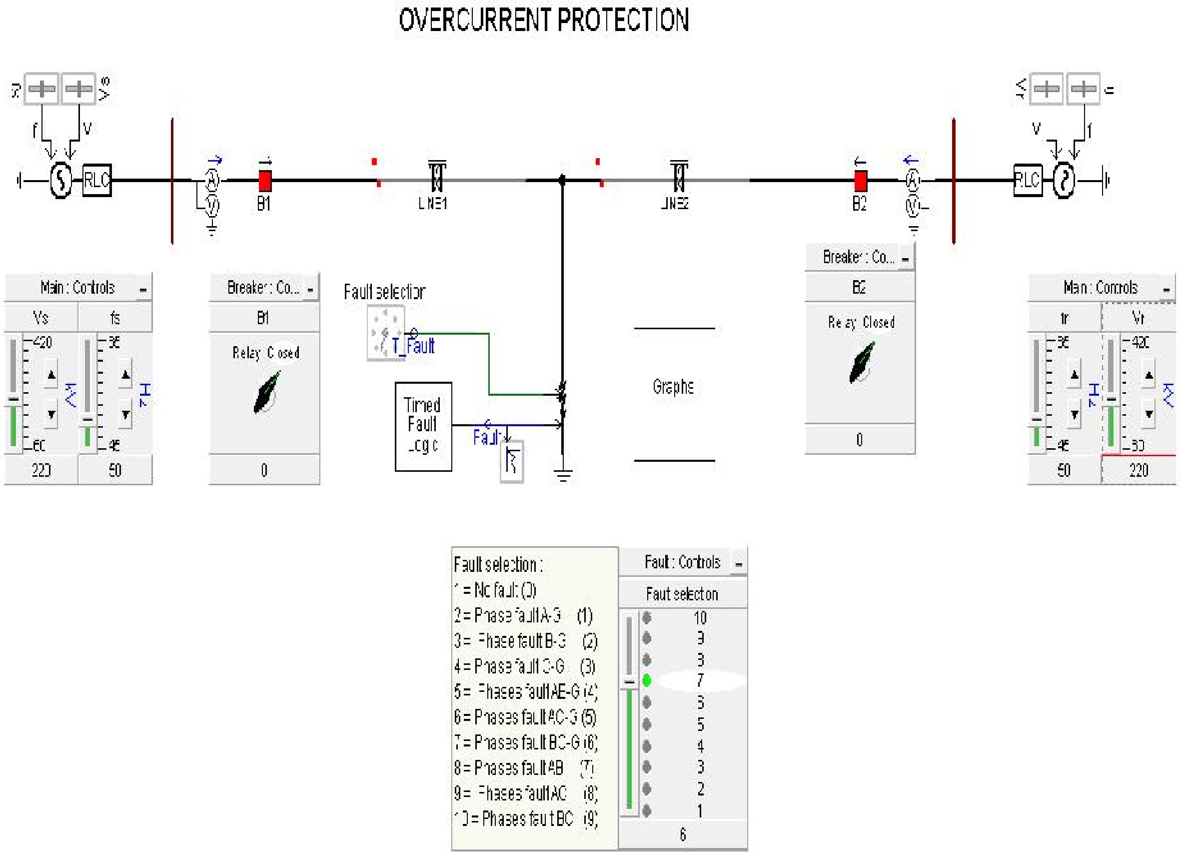

Figure 3.10: Overcurrent Protection Front Panel

The front panel provides easy understanding and simple interface aimed to give the user control of the inputs and all the same provides general insight into the protection scheme.

It is used to enter visualize the line construction. It allows to select fault type, circuit breaker trip, it displays and allows to adjust the amplitude and frequency of the balanced three phase voltages and currents. Graphs display the three phase currents of both stations and record simulation results and system behavior to fault conditions.

The choice of PSCAD is due to the fact that it is an electrical simulator which shows in simple way how the electrical systems will behave and the results that can be obtained from them. it has all the subparts an electrical engineer needs starting from machine to renewable energy. It is best suitable for academic learning purposes.

3.5 Laboratory Experiment 1

Found in appendix A, it is a laboratory exercise for students, designed to use the PSCAD Simulator and the overcurrent protection model presented in the previous section. It serves the goal of demonstrating and comparing the behavior of IDMT and independent time overcurrent relay for different types of faults between interconnected systems.

Chapter 4: Differential Protection

4.1 Differential Protection Overview

Differential protection, as its name implies, compares the currents entering and leaving the protected zone and operates when the differential between these currents exceeds a pre-determined magnitude [2]. If the current entering the protected zone is not equal to the current leaving this zone, the current differences at the ends of the protected zone give the fault current measurement (see Figure 4.1)

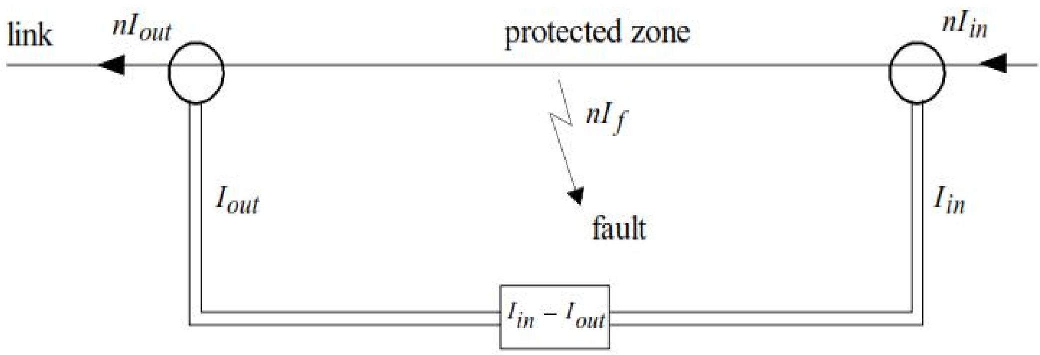

Figure 4.1: Block Diagram of Differential Protection [10]

$I_{in} - I_{out} = I_f$: Fault current measurement

I_{in}: Measurement of the current entering the protected zone

I_{out}: Measurement of the current leaving the protected zone

n: CT transformation ratio

4.1.1 Balanced Circulating Current System

The principle is shown in Figure 4.2. The CTs are connected in series and the secondary current circulates between them. The relay is connected across the midpoint thus the voltage across the relay is theoretically nil, therefore no current through the relay and hence no operation for any faults outside the protected zone. Similarly, under normal conditions, the currents leaving zone A and B are equal, making the relay to be inactive by the current balance.

Under internal fault conditions (i.e. between the CTs at end A and B) relay operates. This is due to the direction of current reversing at end B making the fault current to flow from B to A instead of the normal A to B condition in the earlier figure [2].

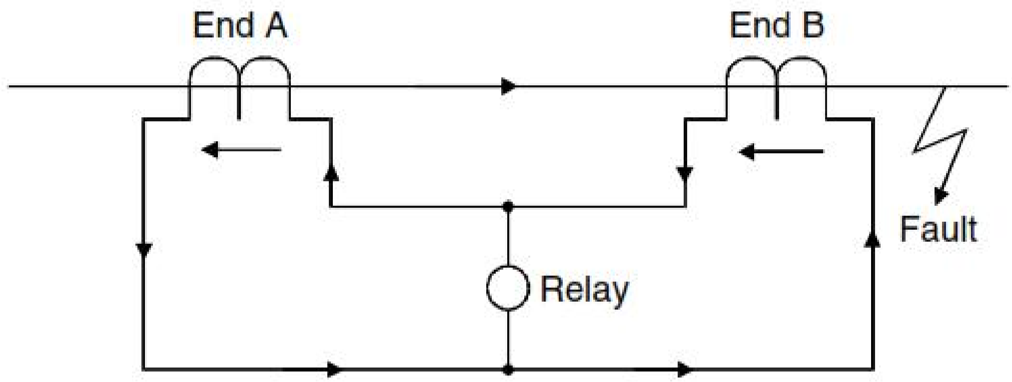

Figure 4.2: Balanced circulating current system, external fault (stable)

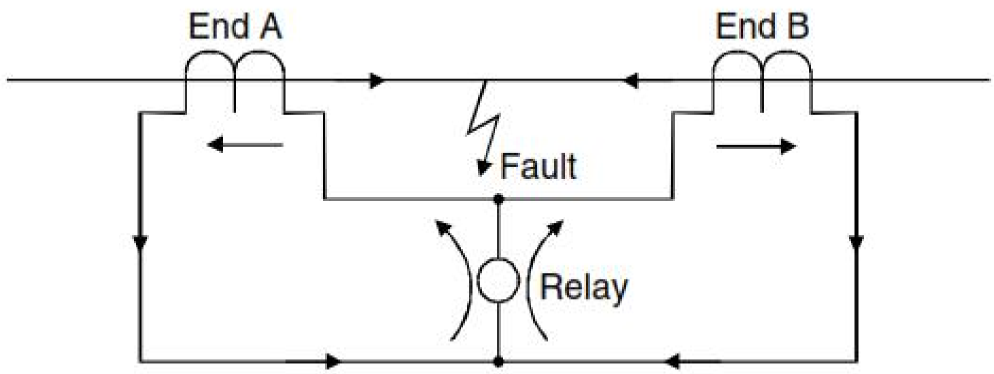

Figure 4.3: Balanced circulating current system, internal fault (operate)

The current transformers are assumed identical and are assumed to share the burden equally between the two ends. However, it is not always possible to have identical CTs and to have the relay at a location equidistant from the two end CTs. It is a normal practice to add a resistor in series with the relay to balance the unbalance created by the unequal nature of burden between the two end circuits. This resistor is named as 'stabilizing resistance'.

4.2 Transformer Differential Protection (ANSI code 87 T)

Generally differential protection is provided in the electrical power transformer rated more than 5MVA. The differential protection of transformer has many advantages over other schemes of protection.

Transformer differential protection protects against short-circuits between turns of a winding and between windings that correspond to phase-to-phase or three phase type short circuits.

Transformer differential protection operates very quickly, roughly 30 ms, which allows any transformer deterioration in the event of a short-circuit between windings to be avoided.

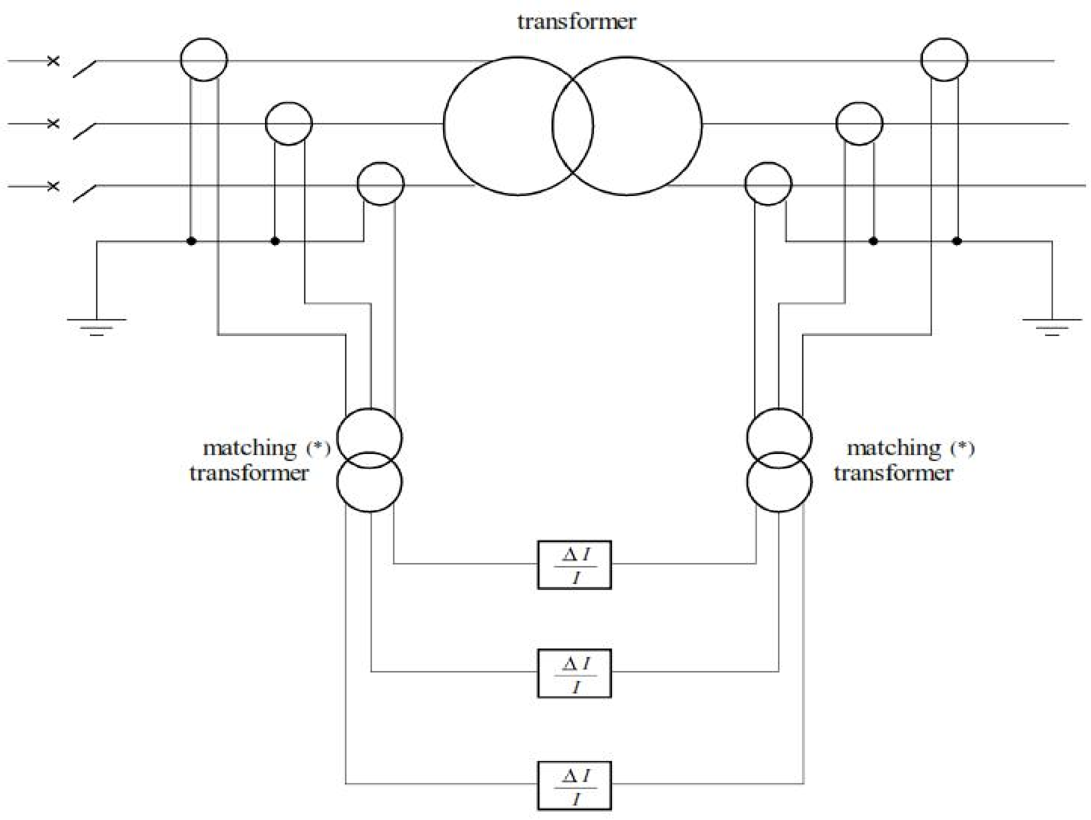

Figure 4.4: Transformer Differential Protection Block Diagram[10]

4.2.1 Differential Protection Scheme in A Power Transformer

The principle of differential protection scheme is one simple conceptual technique. The differential relay actually compares between primary current and secondary current of power transformer, if any unbalance found in between primary and secondary currents the relay will actuate and inter trip both the primary and secondary circuit breaker of the transformer.

Transformers cannot be differentially protected using high impedance differential protection for phase-to-phase short-circuit due to the natural differential currents that occur:

- The transformer inrush currents. The operating speed required means that a time delay longer than the duration of this current cannot be used (several tenths of a second).
- The action of the on-load tap changer causes a differential current.
- The characteristics of transformer differential protection are related to the transformer specifications:
- Transformation ratio between the current entering and the current leaving .
- primary and secondary coupling method.
- inrush current.
- permanent magnetizing current [10].

In the case of the transformer which has primary rated current Ip and secondary current Is. An installed CT of ratio Ip/1 A at the primary side and similarly, CT of ratio Is/1 A at the secondary side of the transformer. The secondaries of these both CTs are connected together in such a manner that secondary currents of both CTs will oppose each other.

In other words, the secondaries of both CTs should be connected to the same current coil of a differential relay in such an opposite manner that there will be no resultant current in that coil in a normal working condition of the transformer. But if any major fault occurs inside the transformer due to which the normal ratio of the transformer disturbed then the secondary current of both transformers will not remain the same and one resultant current will flow through the current coil of the differential relay, which will actuate the relay and inter trip both the primary and secondary circuit breakers. To correct phase shift of current because of star-delta connection of transformer winding in the case of a three-phase transformer, the current transformer secondaries should be connected in delta and star as shown in figure 4.5 [4].

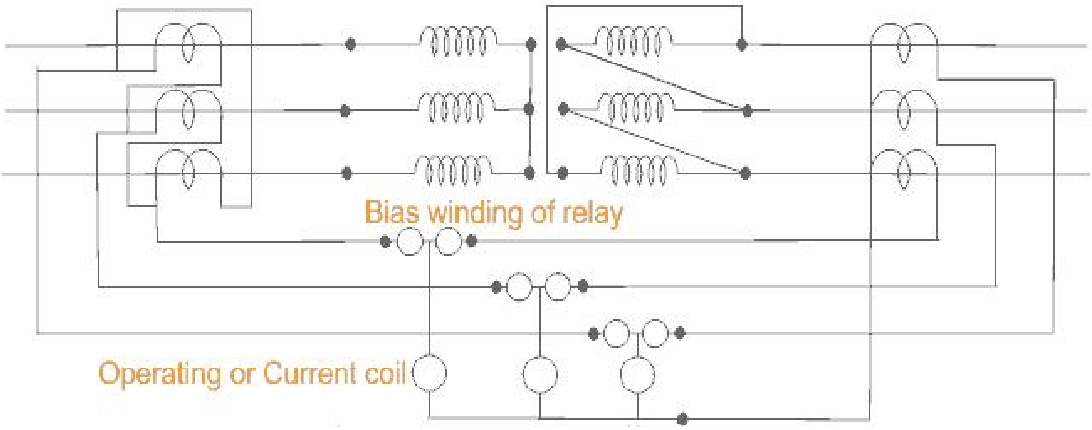

Figure 4.5: Schematic Diagram of Differential Protection Scheme

At maximum through fault current, the spill output produced by the small percentage unbalance may be substantial. Therefore, differential protection of transformer should be provided with a proportional bias of an amount which exceeds in effect the maximum ratio deviation.

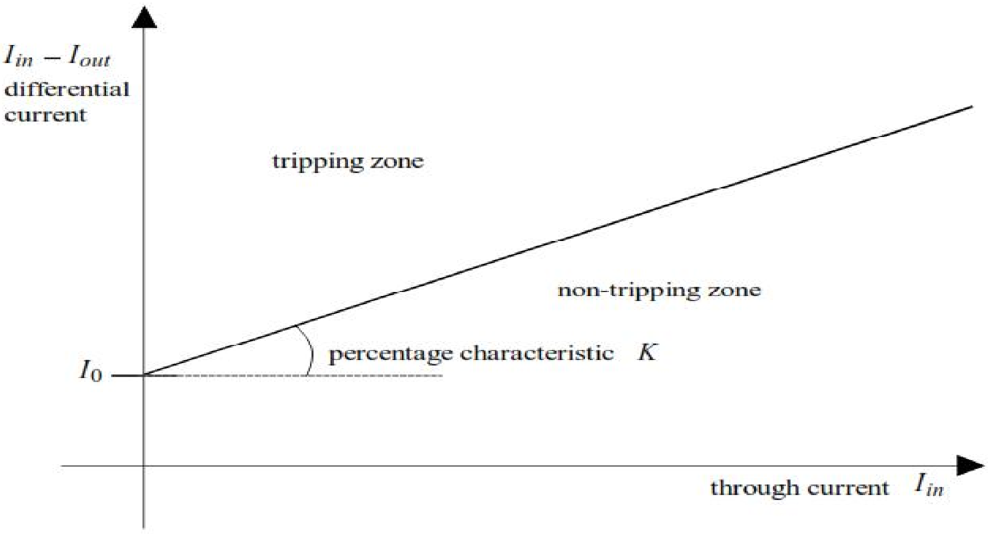

Figure 4.6: Transformer Differential Protection Tripping Curve [10]

In order to prevent tripping upon occurrence of high fault currents of external origin, biased differential protection devices are used. This is because of:

- The differential current due to the on-load tap changer.

- The current transformer measurement errors, as for pilot wire differential protection for cables or lines.

Protection is activated when $I_{in} - I_{out} > K \frac{I_{in+} I_{out}}{2}$ (see figure 4.6).

4.3 Transformer Differential Protection Model In PSCAD

A transformer differential protection design model is proposed in the coming section for a better understanding of the differential relay, simulation and testing is to be performed on PSCAD software.

4.3.1 Dual Slope Current Differential Relays

A ready pre-programmed simulation model of dual slope current differential relay is used, one for each phase, to protect the three-phase transformer.

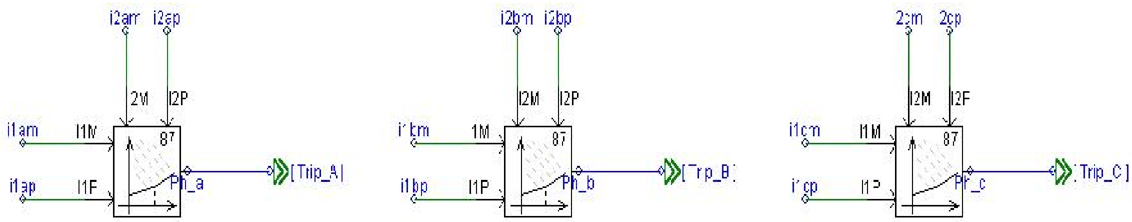

Figure 4.7: Current Differential Relays Blocks

Input signal processing module and current differential relays circuits were arranged in blackbox modules for clearer interface with the front plane, followed by the tripping and reclosing logic diagram of breakers 1 and 2.

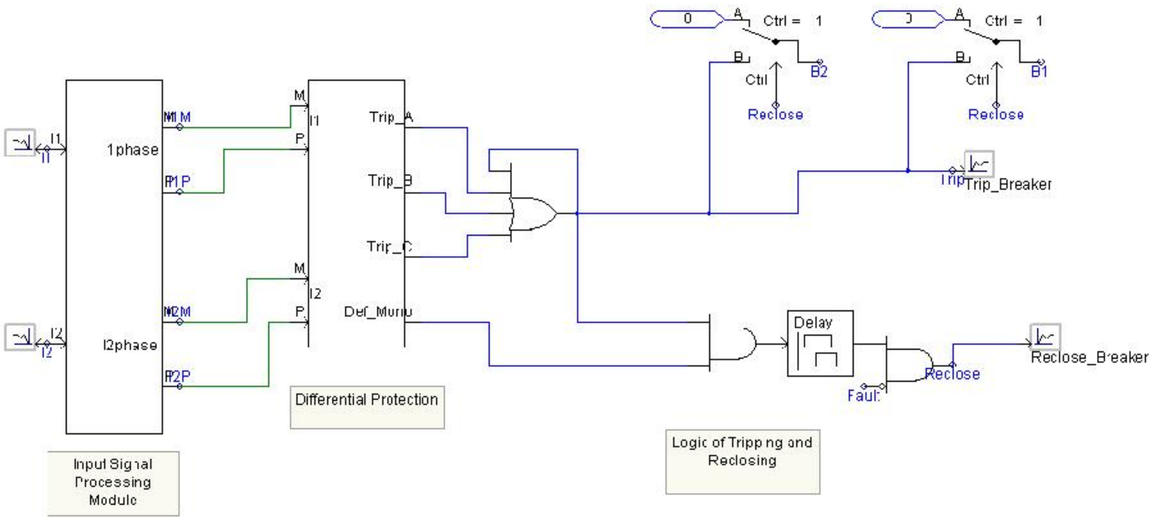

Figure 4.8: Differential Protection Signal Processing Blackbox Diagram

4.3.2 Front Panel Block Construction

As was expressed in the previous chapter, the front panel provides easy understanding and simple interface aimed to give the user control of the inputs and all the same provides general insight into the protection scheme.

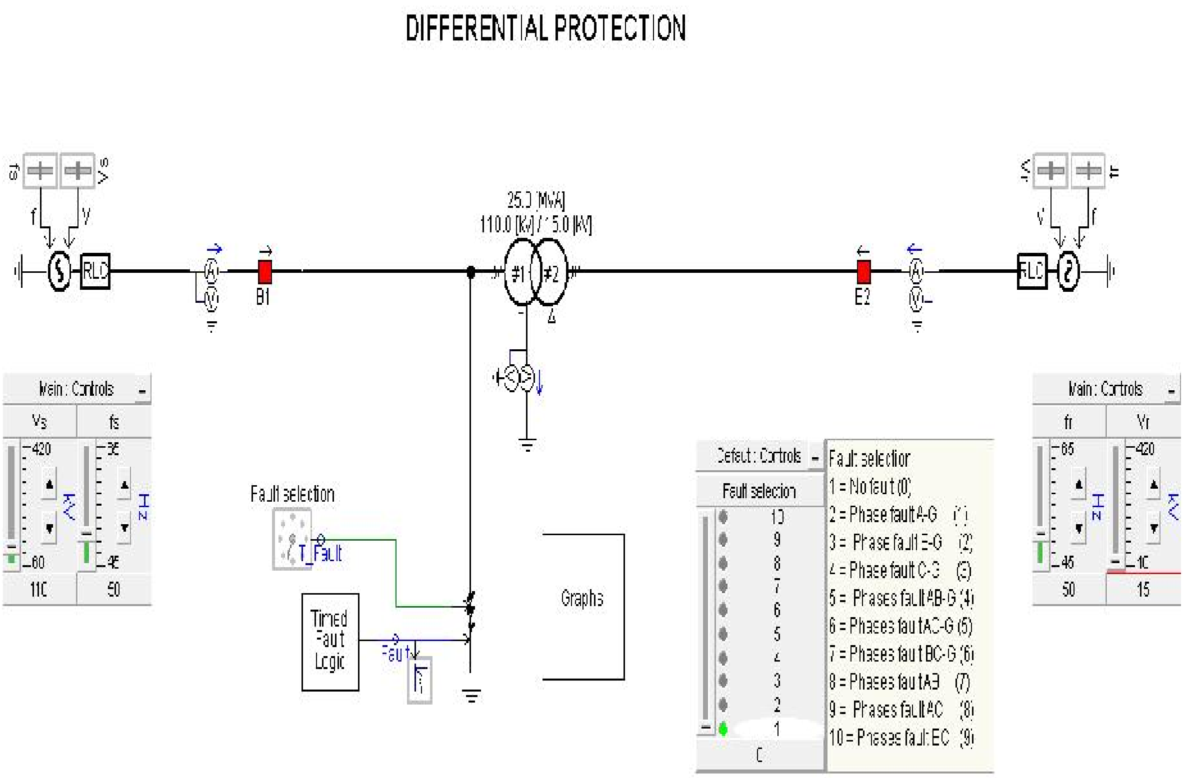

Figure 4.9: Transformer Differential Protection System Model

This model consists of a Y-Δ 25MVA – 110kV/15kV three phase transformer protected with dual slope differential relays that operates on two circuit breakers, Breaker 1 and breaker 2.

The control panels of the model allow to select fault type, it displays and adjusts the amplitude and frequency of the balanced three phase voltages and currents.

Graphs display the three phase currents of both sides of the transformer and record simulation results and system behavior to fault conditions.

.

4.4 Laboratory Experiment 2: Transformer Differential Protection

This laboratory experiment, found in Appendix B, carries the idea of selection of dual slope differential relay parameters for various faulty conditions on the system. The differential protection of power transformer is a unit protection scheme. The protective scheme should operate only for the internal fault, and it must be insensitive for any fault outside the zone of protection. That means the protection scheme should not operate for any external through fault and the magnetizing inrush current due to energization of the transformer under no load condition and also due to external fault removal.

Fast Fourier Transform technique is used to provide the operating quantity for the dual slope differential relay. The simulation for Y-Δ connection of transformer is made using PSCAD software.

Chapter 5: Distance Protection

5.1 Introduction:

Overcurrent protection scheme is a simple protection scheme, consequently, its accuracy is not very high. It is comparatively cheap as non-directional protection does not require VT. However, it is not suitable for protection of meshed transmission systems where selectivity and sensitivity requirements are more stringent. Overcurrent protection is also not a feasible option if fault current and load currents are comparable. Distance protection scheme provides both 'higher' sensitivity and selectivity.

Distance protection provides more accurate as more information is used for decision taking. It is a directional protection, i.e. it responds to the phase angle of current with respect to voltage phasor. Distance protection is fast and accurate and ensures backup protection. It is primarily used in transmission line protection. Also, it can be applied to generator backup, loss of field and transformer protection.

Distance protection relay is the name given to the protection, whose action depends on the distance of the feeding point to the fault. The time of operation of such protection is a function of the ratio of voltage and current, i.e., impedance. This impedance between the relay and the fault depends on the electrical distance between them. The principal types of distance relays is impedance relays, reactance relays and the mho relays. Distance protection relay principle differs from other forms of protection because their performance does not depend on the magnitude of the current or voltage in the protective circuit but it depends on the ratio of these two quantities [13].

The relay operates only when the ratio of voltage and current falls below a set value. During the fault the magnitude of current increases and the voltage at the fault point decreases. The ratio of the current and voltage is measured at the point of the current and potential transformer. The voltage at potential transformer region depends on the distance between the PT and the fault.

If the fault is nearer, measured voltage is lesser, and if the fault is farther, measured voltage is more. Hence, assuming constant fault impedance each value of the ratio of voltage and current measured from relay location comparable to the distance between the relaying point and fault point along the line. Hence such protection is called the distance protection or impedance protection.

Distance relays are used for both phase fault and ground fault protection, and they provide higher speed for clearing the fault. It is also independent of changes in the magnitude of the short circuits, current and hence they are not much affected by the change in the generation capacity and the system configuration. Thus, they eliminate long clearing times for the fault near the power sources required by overcurrent relay if used for this purpose [13].

5.2 Application of Distance Protection Relay

Distance protection relay is widely spread employed for the protection of high-voltage AC transmission line and distribution lines. It has replaced the overcurrent protection because of the following reasons.

- It provides faster protection as compared to overcurrent relay.
- It has a permanent setting without the need for readjustments.
- Direct protection relay has less effect of an amount of generation and fault levels.
- Their fault current magnitude permits the high line loading.

Distance protection schemes are commonly employed for providing the primary or main protection and backup protection for AC transmission line and distribution line against three-phase faults, phase-to-phase faults, and phase-to-ground faults [13].

5.3 Principles of Distance Relays

Since the impedance of a transmission line is proportional to its length, for distance measurement it is appropriate to use a relay capable of measuring the impedance of a line up to a predetermined point (the reach point). Such a relay is described as a distance relay and is designed to operate only for faults occurring between the relay location and the selected reach point, thus giving discrimination for faults that may occur in different line sections.

The basic principle of distance protection involves the division of the voltage at the relaying point by the measured current. The apparent impedance so calculated is compared with the reach point impedance. If the measured impedance is less than the reach point impedance, it is assumed that a fault exists on the line between the relay and the reach point.

The reach point of a relay is the point along the line impedance locus that is intersected by the boundary characteristic of the relay. Since this is dependent on the ratio of voltage and current and the phase angle between them, it may be plotted on an R/X diagram. The loci of power system impedances as seen by the relay during faults, power swings and load variations may be plotted on the same diagram and in this manner the performance of the relay in the presence of system faults and disturbances may be studied [1].

5.4 Mho Distance Protection Overview

Distance relays use voltage and current measurements to detect fault conditions. These relays have fixed zones of protection that generally do not vary much in response to changes in loading conditions, which allows them to employ higher sensitivity than overcurrent relays in detecting faults [6].

Distance relays often protect transmission lines, which have known impedances based on the conductor characteristics. Typical three-phase mho distance relays operate using the characteristic illustrated in Figure 5.1. A circle passing through the origin of the R-X plane defines the boundary between the operating and non-operating regions of the relay. This circle defines a baseline impedance, often representative of some percentage of a transmission line's impedance. A reach point on the circumference of the circle, often along a line taken at about 75° above the positive R-axis, shows this baseline.

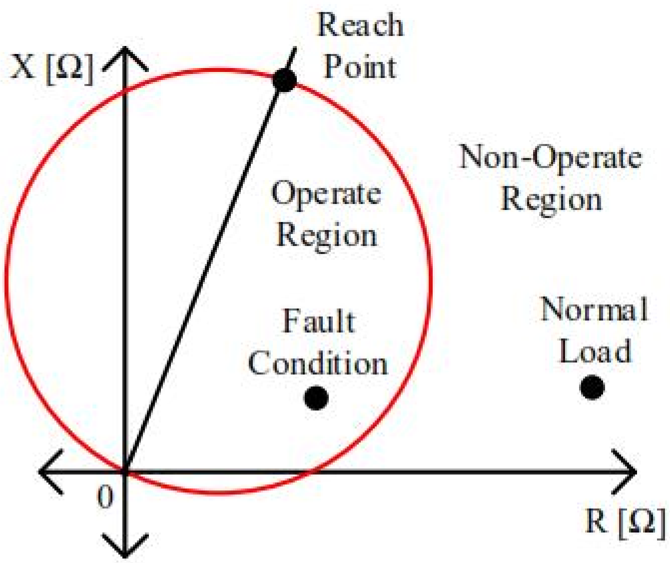

Figure 5.1: Typical Mho Distance Characteristic

Local ground faults cause decrease in voltage (closer to ground potential) and increase in current (due to a reduced-impedance path available to ground). This condition decreases the impedance measured by the relay and moves the operating point on the R-X plane closer to the origin, the point of minimum impedance. Faults outside the defined distance covered by the relay cause the impedance measured by the relay (based on the measured voltage and current) to decrease, but not by enough to come inside the circle.

Faults inside the defined distance cause a greater drop in impedance, bringing the operating point inside the circle. The larger impedance drop alerts the relay to the fault, leading the relay to trip for the fault condition. Calculating impedance in this way allows a distance relay to distinguish between internal and external faults.

Correct coordination of the distance relays is achieved by having an instantaneous directional zone 1 protection and one or two more time-delayed zones. A transmission line has a resistance and reactance proportional to its length, which also defines its own characteristic angle. It can therefore be represented on an R/X diagram as shown in figure 5.1.

5.4.1 Zone 1 Protection

The relay characteristic has also been added, from which it will be noted that the reach of the measuring element has been set at approximately 80% of the line length (see Figure 5.2). This 'under-reach' setting has been purposely chosen to avoid over-reaching into the next line section to ensure sound selectivity, for the following reasons:

• It is not practical to accurately measure the impedance of a transmission line, which could be very long (say 100 km). Survey lengths are normally used and these could have errors up to 10%.

• Errors are also present in the current and voltage transformers, not to mention the possible transient performance of these items.

• Manufacturing tolerances on the relay's ability to measure accurately, etc [2].

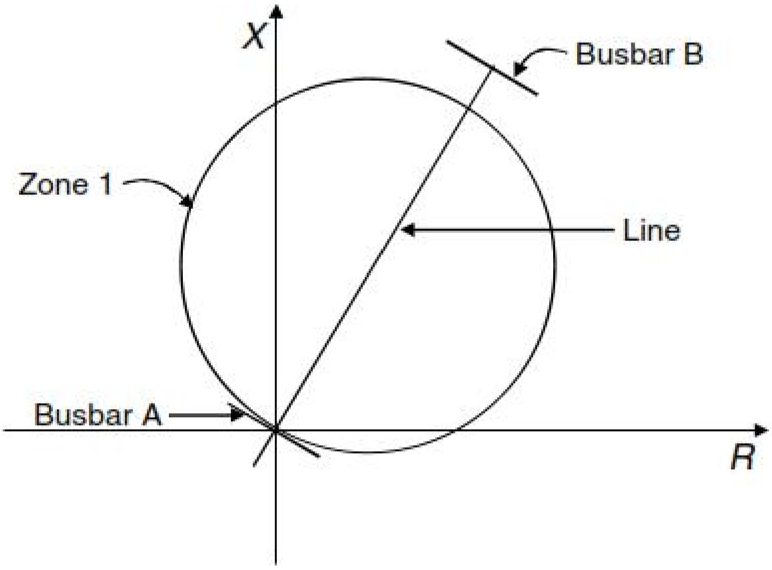

Figure 5.2: Zone 1 Mho Characteristic

This measuring element is known as zone 1 of the distance relay and is instantaneous in operation.

5.4.2 Zone 2 Protection

To cover the remaining 20% of the line length, a second measuring element can be fitted, set to over-reach the line, but it must be time delayed by 0.5 s to provide the necessary coordination with the downstream relay. This measuring element is known as zone 2. It not only covers the remaining 20% of the line but also provides backup for the next line section should this fail to trip for whatever reason.

5.4.3 Zone 3 Protection

A third zone is invariably added as a starter element and this takes the form of an offset mho characteristic. This offset provides a closing-onto-fault feature, as the mho elements may not operate for this condition due to the complete collapse of voltage for the nearby fault. The short backward reach also provides local backup for a busbar fault.

The zone 3 element also has another very useful function. As a starter it can be used to switch the zone 1 element to zone 2, reach after say 0.5 s, thereby saving the installation of a second independent zone 2 measuring element so reducing its cost (see Figure 5.3) [2].

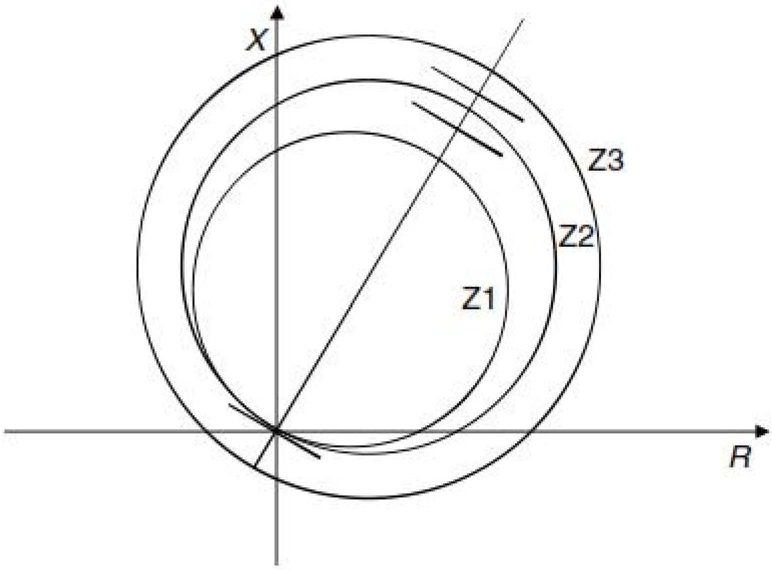

Figure 5.3: Three-Zone MHO Characteristics

5.5 Laboratory Experiment 5

SEL 221 Setting and Testing Phase Distance Elements & Interpreting Event Records

The objective of this experiment is to set and test phase distance elements on SEL-221 relay, students will configure the relay according to calculated pre-lab values. Fault currents will be injected using the CMC 356 test set to observe and examine the phase distance elements on SEL 221.

This experiment is inspired by the work done by reference [18], it adapts the existing relay at IGEE (SEL 221) to the exercise provided.

Experiment 5 is found in Appendix E.

Conclusion

A protective relaying laboratory consisting of modern relays is an essential component to educate students in the field of power system protection. The relay lab should function as an arena to demonstrate protection principles and practical challenges. Further developing of the lab to include newer multifunctional relays is vital, as this is important for the future of power system protection.

Certain challenges that occurred during this project correspond to relatively simple misunderstandings in operating the equipment. For example, during a great period, difficulties were encountered in extracting event reports from the SEL 221, this was due to the fact that being an old version relay, it is not compatible with present software available for users. Another is the availability of the relay tester at the institute which could not be achieved without the charitable donation previously mentioned in chapter 2.

Students should be educated with knowledge of the possibilities within modern relay technology. After graduation, they can contribute to a shift in protection strategies within utility companies to meet the demands for power system protection in the future. Using an injection test set as a testing tool for the relay lab is a good, versatile and flexible solution. It is easy to use for the beginner, while having advanced features for the more advanced user. A new relay tester should be acquired by IGEE, as well as new protective relays to create opportunities for future senior projects and master's theses.

Power system analysis software such as PSCAD and ETAP presents opportunities for future groups to analyze transient and steady-state imbalances in the system, further work can be done to create more ready models for the students to benefit from.

If utilized properly the relay lab can contribute to increased interest and knowledge of power system protection among students at IGEE for many years to come. Educating future engineers with this knowledge is important for the protection and reliability of future power systems. If the lab is well maintained and expanded to keep up with trends in the field it could last many years.

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Appendices

Appendix A

University of M'hamed BOUGARA Boumerdes
Institute of Electrical Engineering and Electronics
Control and Power Department

Experiment # 1
Overcurrent Protection Modeling Using PSCAD Simulator

Learning outcome

- To use and understand an overcurrent protection model in PSCAD power system simulator and gain an understanding of the impact of both IDMT and independent time overcurrent relays on power system protection.
- To compare the different types of characteristics of inverse time overcurrent relay.

Apparatus

- PSCAD Simulator.
- Computer.

Background

Power system simulators are mathematical models of the electric system. They use an iterative method to simultaneously solve a large matrix of complex numbers, which numerically represent the power system for a set of initial conditions. They are often accompanied by a graphical interface which allows the user to 'see' the numerical results they produce.

Simple Guide to Using PSCAD/EMTDC

1) Launch PSCAD (student version) from Start Menu.

2) Creating a new project:

Click on **File/New/Case**: A new project entitled 'noname' appears in the left workspace window, indicating that a new project is created.

3) Setting active project: In the workspace window, right click on the title of an inactive project and select **Set as active.**

4) Saving active project: Click on **File/Save Active Project.** Select an appropriate folder and save the project as ‘Lab1’ or any other name.

5) Adding components to a project: Double click on master library in left top workspace. Navigate to the area containing desired component. Right click on component and select **Copy**. Open the project where you wish to add the component (double click on ‘project name’), right click over blank area and select **Paste**. (Note: There are many other ways to add a component to a project)

6) Setting Properties: To set the properties double click on any component and change the parameters.

At the top of the parameter dialog is a drop list, which contains list of all parameter dialog pages. If only one page exists, then the drop list will be disabled. For e.g. if you double click on resistor, it will ask for only resistance value.

7) Making connections between components: Click **Wire Mode** button in the main toolbar. Move the mouse pointer onto the project page.

The mouse pointer will have turned into a pencil, which indicates you are in Wire mode. To draw a wire, move the cursor to the node where you want the line to start and left click. Move the cursor to where you want the line to end and right-click to complete the wire. Multi-segment Wires may be built by continuing to left click at different points. To turn off Wire Mode, press **Esc** key.

8) Measurement: To measure currents and voltages **ammeter** and **voltmeter** are provided on the toolbar on the right. Ammeter should be connected in series.

To plot currents and voltages use **output channel** and **data signal label** on the toolbar. The **output channel** parameter dialog gives title, unit, scale factor and min/max limits.
9) Adding a Graph Frame: Right click on the Output Channel component. Select **Input/Output Reference/Add Overlay Graph with Signal.** This will create a new

graph frame, overlay graph and a curve simultaneously. For adding more graphs on same graph frame, right click on graph frame and click **Add Overlay Graph (Analog).** This will add another graph on same frame. To put a curve on this graph Ctrl+click on output channel and drag it on the graph.

The curve corresponding to that output channel will be added on to the graph. When you run the simulation, curves will be automatically plotted on this graph.

Press **Y** and **X** buttons to see complete curve (zoom out).

10) Setting time step and simulation time: Right click on blank space in the project, select **Project Settings**. In runtime tab you can set simulation time, time step and plot step.

11) To simulate the project: Click on **Build/Run.**

Procedure

1. Start PSCAD and open project **OVERCURRENT PROTECTION**, it represents a network of two sources with RLC impedance and a transmission line protected by two overcurrent relays at both stations A and B.

At station A the protection is an inverse time overcurrent relay with inverse time characteristic, while at station B an independent time overcurrent relay is used (see figure 3.11).

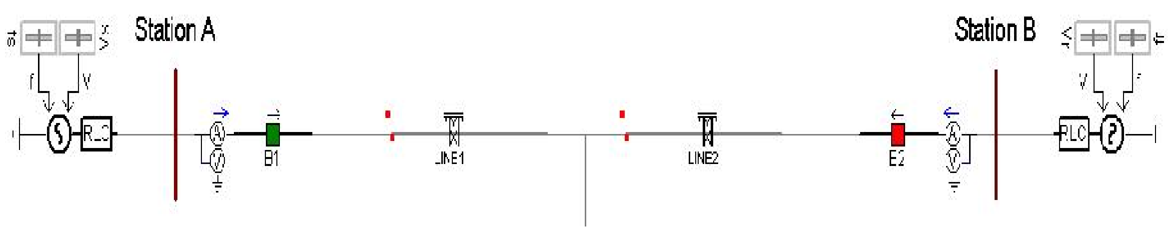

Figure 3.11: Overcurrent System Model

2. Using the mouse, click on the blackbox named **Overcurrent Relays** to see the protection configuration for each station, the relay can be configured by accessing the relay parameters→ right click on the relay-→ go to **Edit parameters**, by the same manner you can change the parameters of the RLC impedance and the timed fault logic which is initially set to start from 0.2s to 1.5 s.

3. Start with V=220 kV, f=50 Hz, R=50ohm and H=138mH on both stations.

4.a. From the parameters window of the overcurrent relay go to **Main→ Data entry format→** chose **Automatic_Standard**, from **Automatic data entry_standart** you can modify the type of curve standard, set it as IEEE std.C37.112 and the type of characteristic as moderately inverse for phase a relay, set pickup up current to be 0.3.

4.b. For relays of station B (independent time relays), set the delay time to 2s.

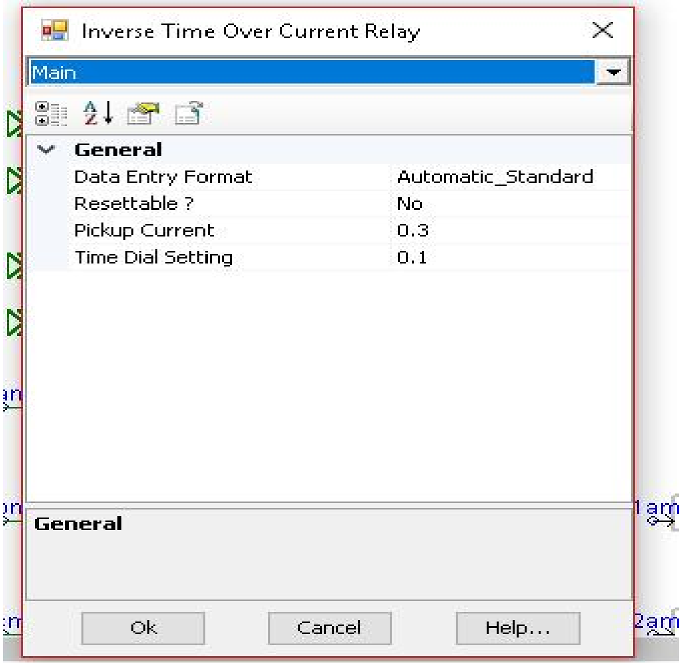

Figure 3.12: Inverse Time Relay Parameters Window

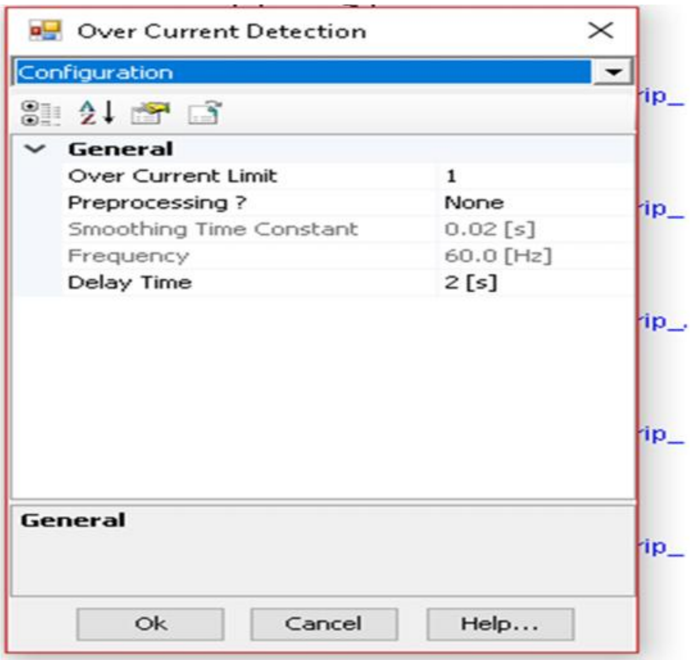

Figure 3.13: Independent Time Relay Parameters Window

5. Select the fault (2): Phase fault A-G.

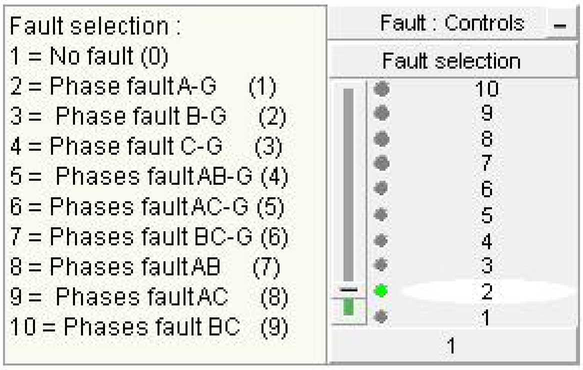

Figure 3.14: Phase Fault A-G Selection Window

6. To simulate the project, click on Run simulation.

7. To see the results, click on Graphs, Record the results of the simulation.

8. Repeat the same procedure for phase fault A-G with standard inverse, very inverse, extremely inverse and long time back up and for pickup current of 0.6 and 0.9, record your results each time. Examine the results and fill the table with tripping times recorded, what do you conclude?

Table 1: Tripping Times for Different Types of Characteristics

Type of characteristic	Pickup current 0.9	Pickup current 0.6	Pickup current 0.3
Moderately inverse	0.64 s	0.47 s	0.37 s
Inverse	1.08 s	0.55 s	0.33 s
Very inverse	1.06 s	0.56 s	0.32 s
Extremely inverse	1.41 s	0.65 s	0.319 s
Long time backup	1.42 s	0.66 s	0.31 s

Results

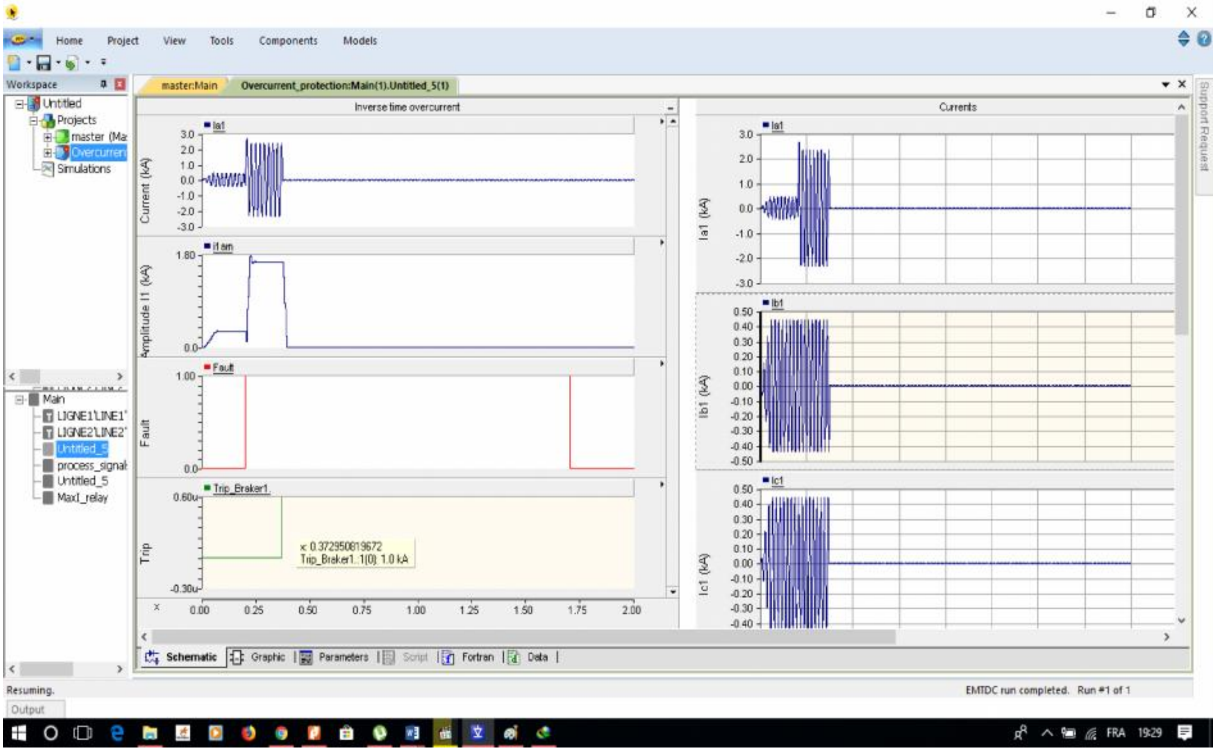

Figure 3.15: Moderately Inverse Characteristic Simulation Graphs

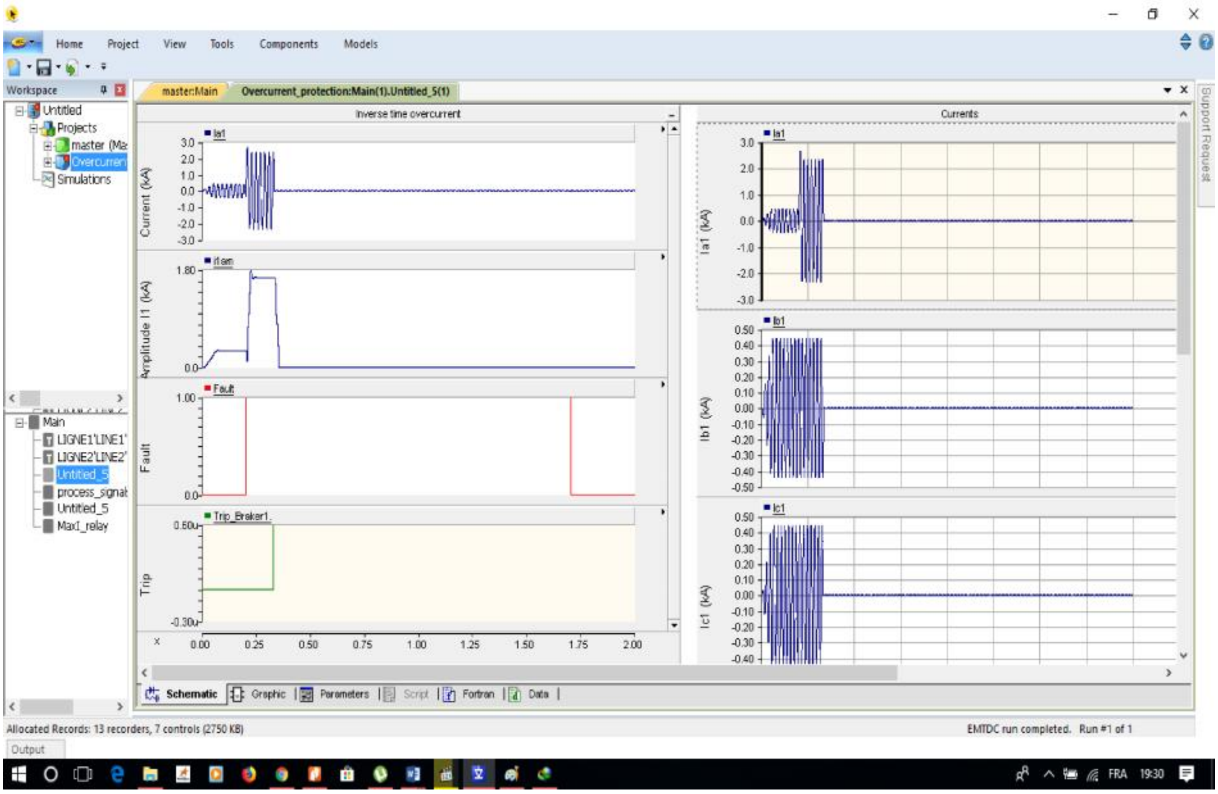

Figure 3.16: Standard Inverse Characteristic Simulation Graphs

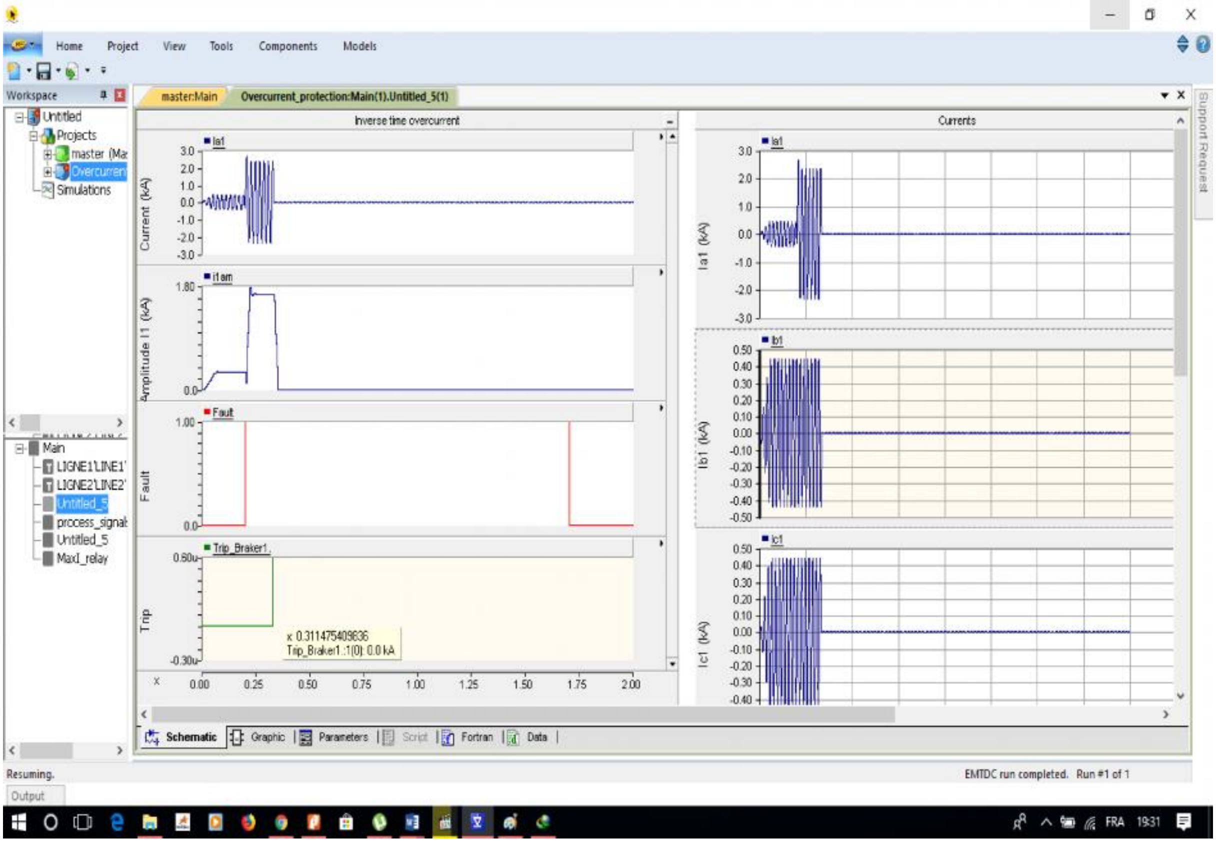

Figure 3.17: Very Inverse Characteristic Simulation Graphs

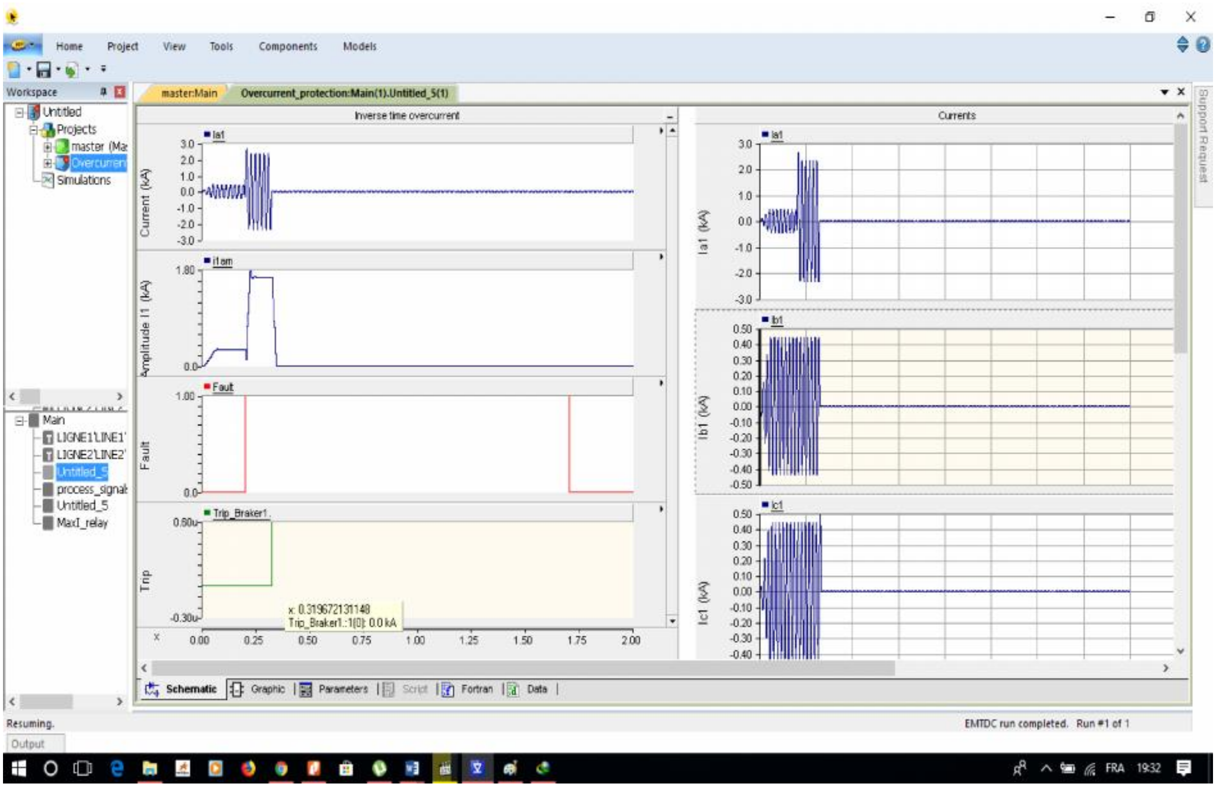

Figure 3.18: Extremely Inverse Characteristic Simulation Graphs

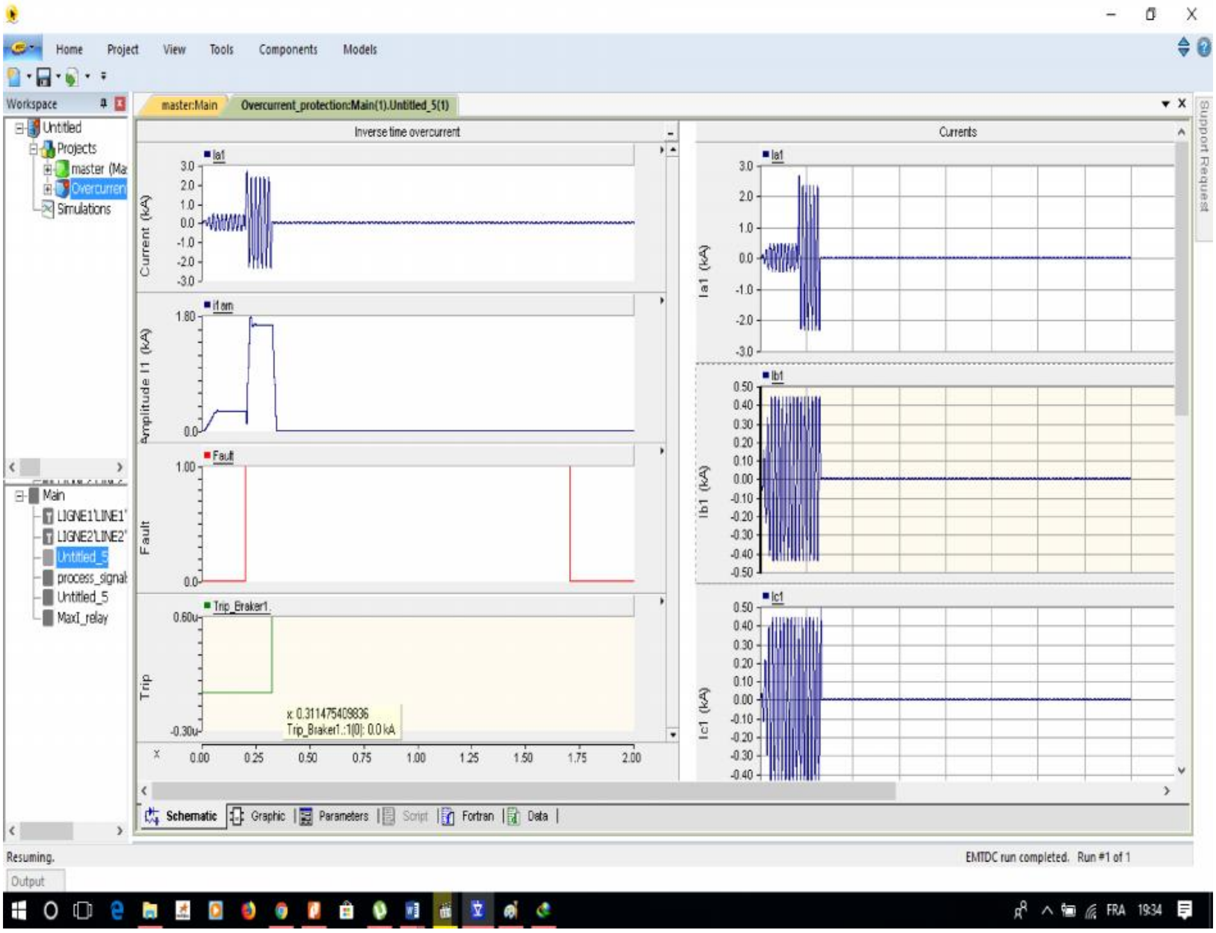

Figure 3.19: Long Time Backup Characteristic Simulation Graphs

The simulation results and table 1 describe the time taken to detect and isolate the fault for different types of characteristics going from moderately inverse to long time backup, the tripping time increases for high fault currents and decreases for lower fault currents which corresponds to the graph of IDMT relay characteristics (see figure 3.4).

Appendix B

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Institute of Electrical Engineering and Electronics
Control and Power Department

Experiment #2
Transformer Differential Protection

Learning Outcomes

- To use and understand the differential protection scheme of power transformer.
- To compare and study various faulty conditions on the system.

Background

The basic operating principle of differential protection is to calculate the difference between the current entering and leaving the protected zone. There is a phenomenon that occurred during removal of external through fault or due to energization of the transformer under no load condition named magnetizing inrush current. The differential protection scheme should remain insensitive for such magnetizing inrush current. The differential relay should not operate for the external/through fault. The differential protection of power transformer is a unit protection scheme. The protective scheme should operate only for the internal fault, and it must be insensitive for any fault outside the zone of protection.

The protection operates when the differential current exceeds the set bias threshold value. For external faults, the differential current should be zero, but error caused by the CT saturation and CT ration error leads to non-zero value. To prevent maloperation the operating threshold is raised by increasing the relay setting [17].

Maloperation of the differential protection of power transformer may occur due to Magnetizing inrush current, CT saturation and Through Fault Inrush. Among all these three; magnetizing inrush results during excitation of Transformer under no load condition. It can also come in to picture during the energization of parallelly connected power transformer. For this setting of 4 relay parameter is very important: i.e.

(1) Differential Current Threshold: Is1

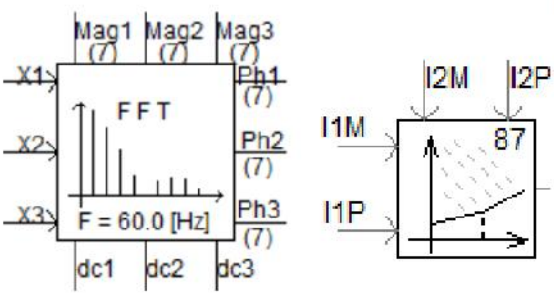
(2) Lower Percentage Bias Setting: K_1

(3) Bias current threshold: Is2

(4) Higher Percentage bias setting: K_2

Fast Fourier Transform:

Fast Fourier Transform technique is used for preventing the maloperation. The secondary current signals from the CTs are sampled at a regular interval. This is an online Fast Fourier Transform (FFT), which can determine the harmonic magnitude and phase of the input signal as a function of time. The input signals first sampled before they are decomposed into harmonic constituents. PSCAD software includes the online FFT block which is shown below.



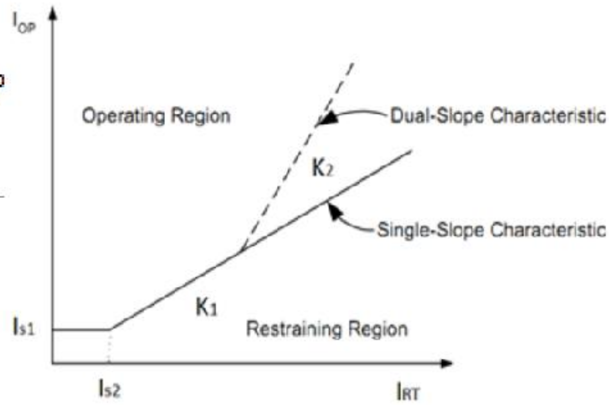


Figure 4.10: FFT Block in PSCAD

Figure 4.11: Dual-Slope Differential Relay characteristic

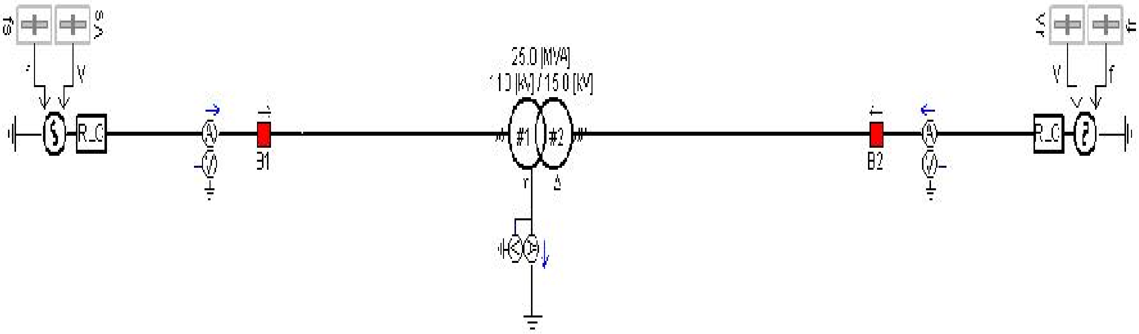


Figure 4.12: System Model

T/F: 25 MVA, 110/15KV, Y-Δ / **Primary CT1**: 1/200 (Turns ratio)

Secondary CT2: 1/1000 (Turns ratio)

Prelab

Effective setting of the four basic parameters of the dual slope differential relay will prevent any maloperation of the differential protection scheme. FFT is used to provide the different harmonic content in the supply signal.

At any instance on secondary current waveform at CT secondary side we can calculate the value of the four relay parameter mentioned above.

Setting and configuration of the dual slope differential relay

I_s1: The basic differential current setting

K_1: The lower percentage bias setting

I_S2: The bias current threshold setting

K_2: The higher percentage bias setting

Primary side:

- Calculate the primary current of the transformer under normal condition:

$\mathbf{I_{ap1}}$ = -132 A

- Calculate the secondary current of CT 1:

$\mathbf{I_{ap2}} = I_{ap1} * \frac{N_1}{N_2} = -132\ A * \frac{1}{200} = -0.66$

Secondary side:

- Calculate the secondary current of the transformer under normal condition:

$\mathbf{I_{as1}}$ = 962.3 A

- Calculate the secondary current of CT 2:

$\mathbf{I_{as2}} = I_{as1} * \frac{N_1}{N_2} = 962.3\ A * \frac{1}{1000} = 0.96$

Calculate the lower percentage bias setting (slope **K_1**):

$$\boldsymbol{I_{Diff}} = |\ I_{ap2} + I_{as2}| = |(-0.66) + 0.96| = 0.3$$

$$\boldsymbol{I_{Bias}} = \frac{I_{ap2} + I_{as2}}{2} = \frac{0.66 + 0.96}{2} = 0.81$$

$$\boldsymbol{K_1} = \frac{I_{Diff}}{I_{Bias}} = \frac{0.3}{0.81} = 0.37 = 37\%$$

.

Setting K_2:

Slope K_2 will be selected based on the relay operating criterion given for the dual slope relay. To provide safe operation of differential relay the differential current threshold is to be raised under no-load condition, but care must be taken for the relay sensitivity for internal fault. The second slope K_2 is selected based on the CT saturation possibility, let it be $\mathbf{K_2 = 0.5}$ for the purpose of this experiment.

Procedure

1. Start PSCAD and open project **TR_ Diff_Protection**, it represents the system presented above. A dual slope differential relay is used to protect the transformer from internal faults.
2. **Relay configuration**: Using the mouse, click on the blackbox named **Differential Protection** to see the protection configuration for each side of the transformer, the relay can be configured by accessing the relay parameters → right click on the relay, go to **Edit parameters**, by the same manner you can change the parameters, insert the value of $\mathbf{K_1}$ (The lower percentage bias setting) found in prelab calculation and 0.5 for $\mathbf{K_2}$.

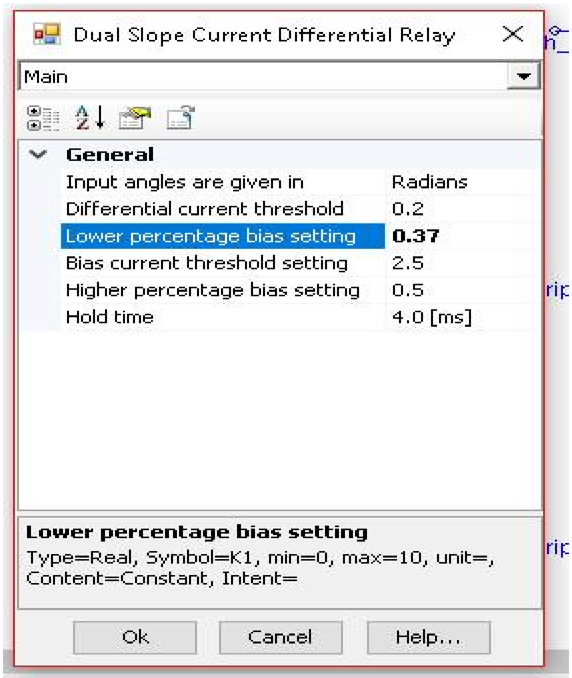


Figure 4.13: Differential Relay Parameters Setting

3. Start with Vs=110 kV, Vr = 15 kV, f=50 Hz.

4. Select the fault (2): Phase fault A-G.

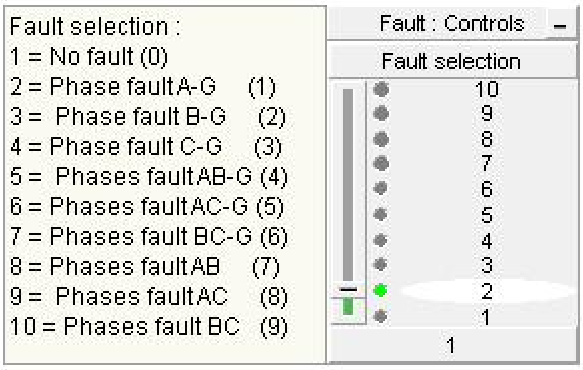


Figure 4.14: Phase Fault A-G Selection Window

5. Run Simulation, click on Run.

6. Click on Graphs, Record the results of the simulation.

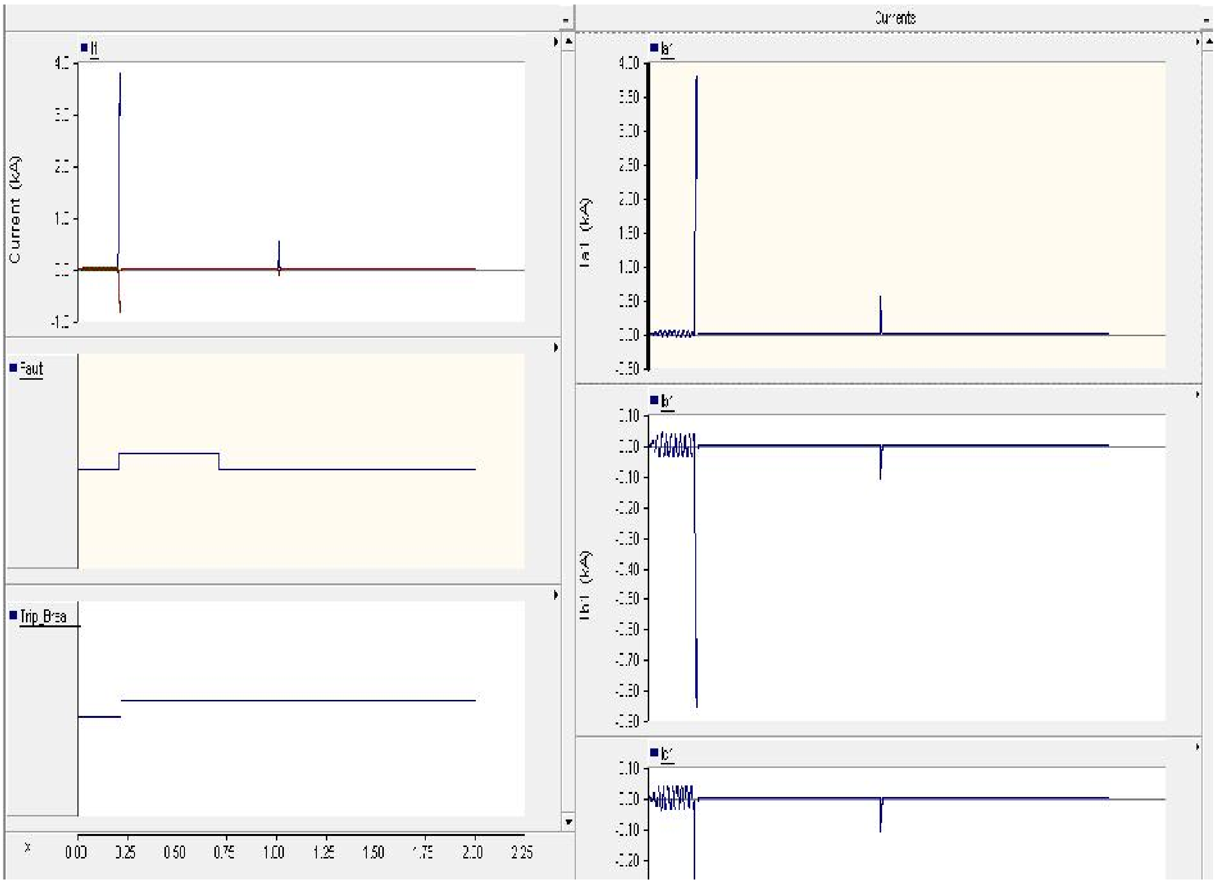


Figure 4.15: Internal Phase Fault A-G Simulation Result

7. Open project **TR_Diff_protection_external**, it represents the same system presented above. A dual slope differential relay is used to protect the transformer from external faults.

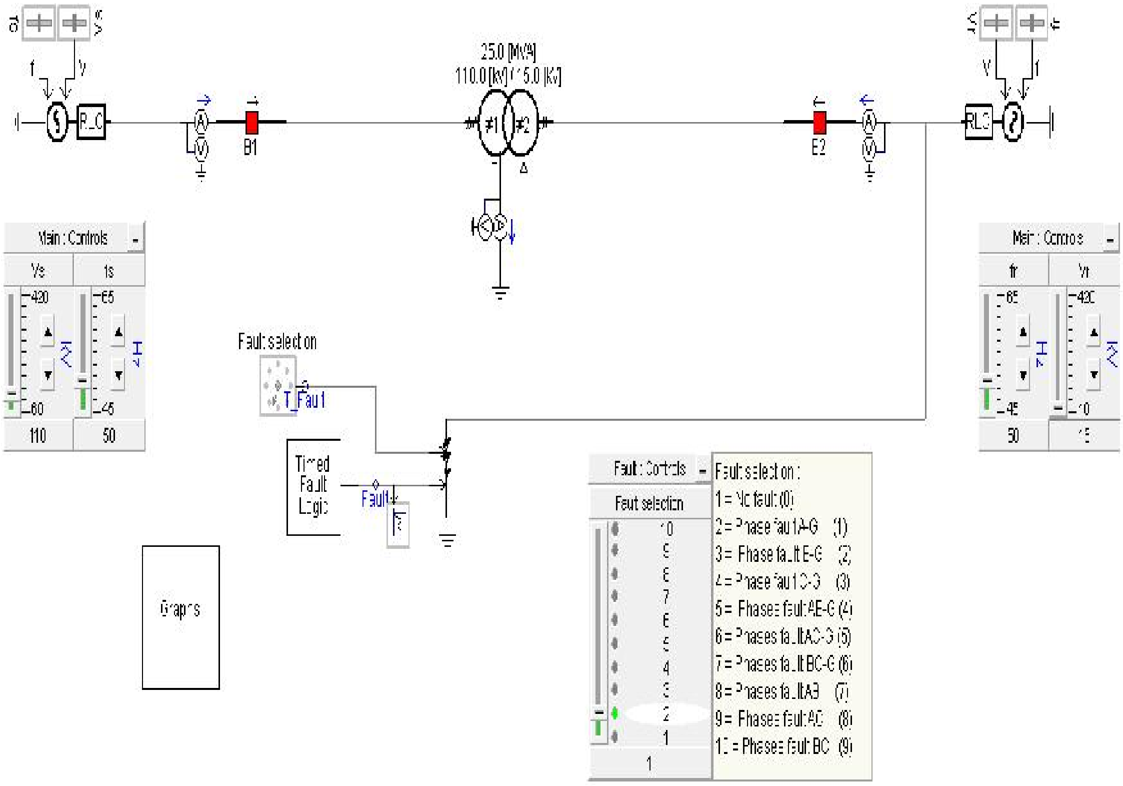


Figure 4.16: External Fault Transformer Protection System Model

8. Repeat the same procedure for phase fault A-G, Phase fault B-G and Phases fault BC-G, record your results each time.

9. Discuss the behavior of the differential protection to internal and external faults.

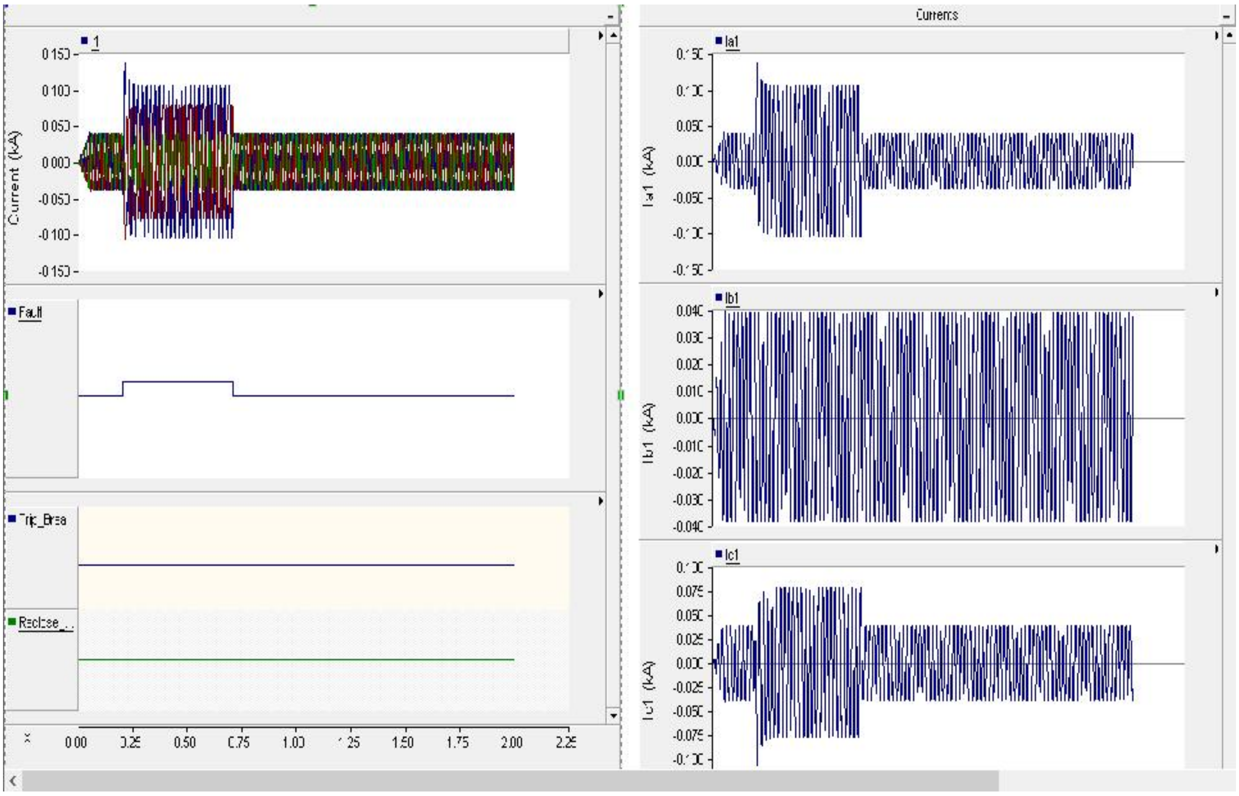


Figure 4.17: External Phase Fault A-G Simulation Results

Results analysis: An immediate trip is recorded for the internal fault simulation for all fault types, while for external fault, no fault is detected by the relay, hence, no tripping.

Comparison of currents:

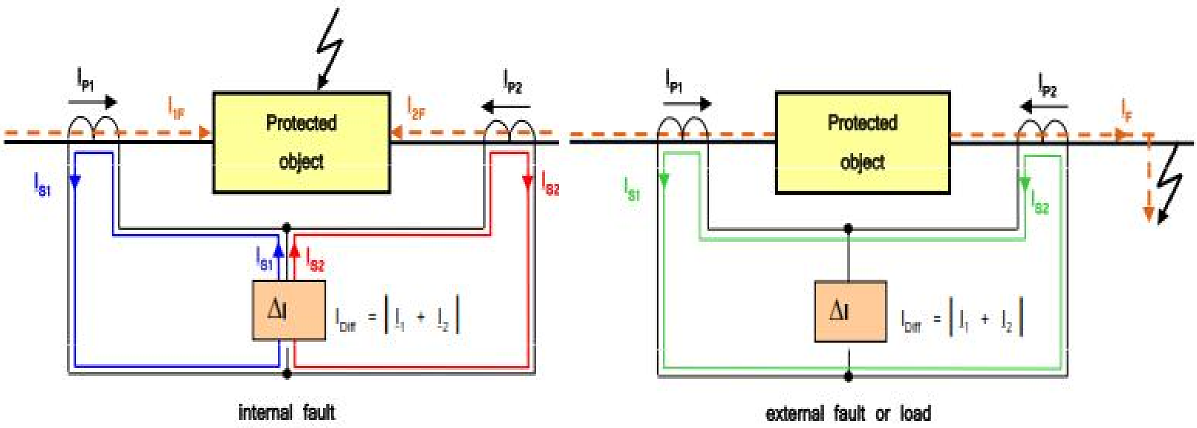


Figure 4.18: Internal and External Fault Comparison

Internal fault:

$\underline{I}_{P1} = \underline{I}_{1F}$

$\underline{I}_{P2} = \underline{I}_{2F}$

$I_{Diff} = |\underline{I}_{P1} + \underline{I}_{P2}| = |\underline{I}_{1F} + \underline{I}_{2F}|$

→ Tripping

External fault:

$\underline{I}_{P1} = \underline{I}_{F}$

$\underline{I}_{P2} = -\underline{I}_{F}$

$I_{Diff} = |\underline{I}_{P1} + \underline{I}_{P2}| = |\underline{I}_{F} - \underline{I}_{F}| = 0$

→ No tripping

Appendix C

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Experiment #3
SEL-211F Basic Connections and Wiring Check Procedure

Learning Outcomes

- Get familiar with the concept of a protective relay and an injection test set and how to connect them.
- Understand the power flow direction concept.

Equipment

- SEL 221F relay.
- OMICRON CMC356 injection test set.
- Bag of Banana-Banana Short leads (3x).
- Banana-Banana or Banana-Spade leads (30x).
- Computer with AcSELerator QuickSet Software.
- Computer with OMICRON TestUniverse software.

Background

Relays are frequently found devices in high voltage or medium voltage power system. Their main duty is to isolate a faulty section within few cycles but by ensuring minimum interruption to healthy sections. Therefore, an ideal relay is a unit which would act by compromising costs of damage to imperfect section and cost interfere the perfect.

With usage, the connections of relay get deteriorated or contaminated with carbon particles, etc. Therefore, it is the interest of both the end user as well the manufacturer to check the behavior of relay after time intervals, that is relay testing.

A computer program is used to test a relay function. A computer-aided relay testing is best suitable for modern microprocessor relays that cannot be tested with slow speed of amplifier injection.

And since the type of tests, test procedure, frequency etc. are decided by the computer, tester need not be an expert. In an automated testing we need an amplifier to apply 3 phase currents and voltages to the relay.

Over the time relay technology has evolved so has the testing. Many manufacturers have developed a variety of computer-aided testing systems for testing the latest microprocessor biased relays, such as the CMC 356 test set, and as the most used one in our country for its high accuracy and the ability of testing many relay functions in a single module, moreover, it confirms to the IEC60255-151 measuring relay and protective equipment standards.

Equipment Used

SEL 221 Relay

The SEL-221F is designed to protect transmission, sub-transmission, and distribution lines for all fault types. The relay has three zones of phase-to-phase and phase-to-ground mho distance elements with independent timers. Distance elements are polarized using positive-sequence memory voltage.

SEL 221F generates an eleven-cycle event report after each fault, or upon command. The report provides four cycles of pre-fault data and seven cycles of fault data. The data includes voltages, currents, relay elements, and relay inputs and outputs. The report also shows the calculated fault location, time and date of event, and relay settings. This information simplifies post-fault analysis and improves understanding of protective scheme operation.

OMICRON Test Set CMC 356

The OMICRON test set CMC 356 is a universal test set that is used all around the world to test relays' operation. The test set has six current and four voltage output channels which are continuously and independently adjustable in amplitude, phase and frequency. All outputs are overload and short-circuit proof and are protected against external high-voltage transient signals and over-temperature. The test set also has digital 10 input and 4 output ports.

The analog test signals are generated digitally using DSP technology. This, in combination with the use of additional error correction algorithms, results in accurate testing signals even at small amplitudes.

The output channels are continuously and independently adjustable in amplitude, phase and frequency. All outputs are overload and short-circuit proof and are protected against external high-voltage transient signals and over-temperature. The signals injected to the relay can be specified through the pc software Test Universe.

Figure 2.5: Injection Test Set OMICRON CMC 356

Procedure

1. Starting with a disconnected test set and a disconnected relay, perform the following tasks:

2. Set up the communication between SEL 221 relay and Acselerator software using EIA-232 serial communications cable.

On the QuickSet main window, open the Communication Parameters window (Communications, Parameters) to define and create a communication link with the 221.

Enter the following information for a Serial Active Connection Type:

a. Device: COM1: Communications Port
b. SEL Bluetooth Device: Unchecked
c. Data Speed:9600
d. Data Bits: 8
e. Stop Bits: 2
f. Parity: None
g. RTS/CTS: Off

h. DTR: On
i. XON/XOFF: On
j. RTS: N/A (On)
k. Level 1 Password (Default OTTER)
l. Level 2 Password (Default TAIL)

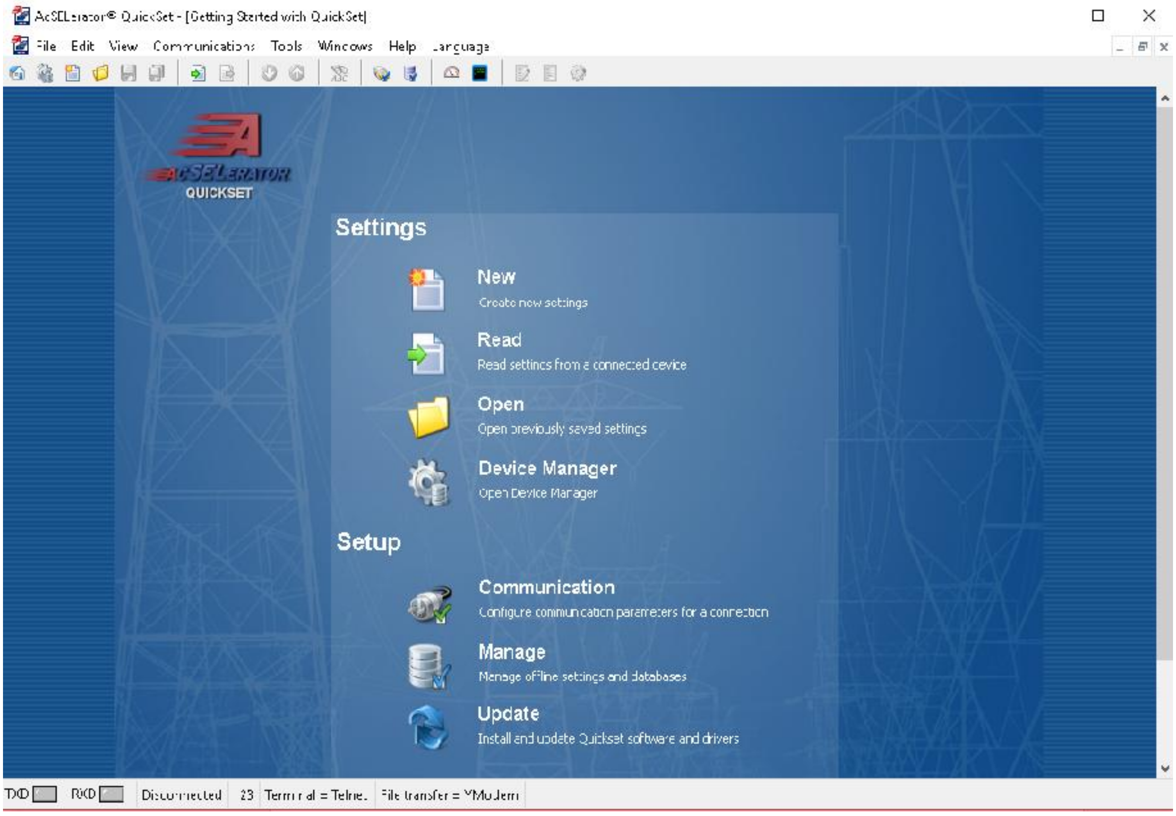

Figure 2.6: QuickSet Main Window

m. Click **Apply** at the bottom of the Communication Parameters window. Then click Ok. If the computer successfully connects to the relay, the connection status in the lower-left corner of the QuickSet main window should say “Connected.”

3. Set up communication between the CMC 356 and TestUniverse software using RJ45 serial communication cable.

- Once the cable is plugged the test set will automatically connect to TestUniverse showing the following window.

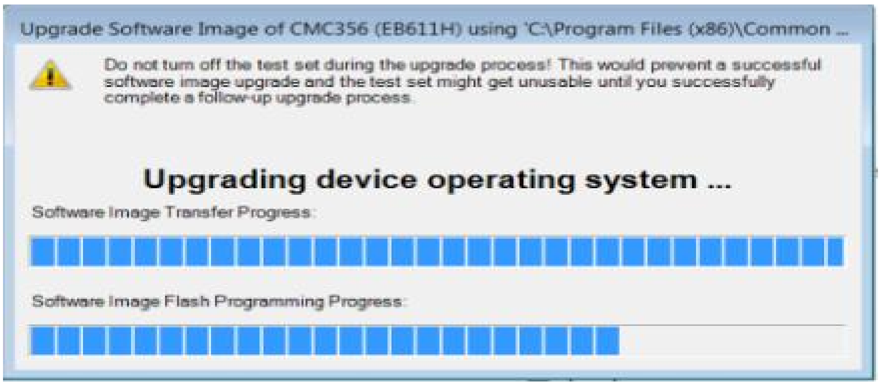

Figure 2.7: CMC 356 Communication Setup Window

4. Connect 3-Φ voltages from the test set voltage analog outputs to the relay.
5. Connect 3-Φ currents from the test set current analog outputs to the relay.
6. Power up the relay and the test set.

Figure 2.8: Front View of CMC 356 With Voltage and Current Outputs Connected

Figure 2.9: Rear View of SEL 221F Relay with Voltage and Currents Inputs Connected

Figure 2.10: The Experimental Setup for Experiment 1

7. Using Quick CMC, apply the following values to inject the analog signals from the OMICRON test set to the assigned relay.

- Open TestUniverse → QuickCMC → From the window of analog outputs select **Direct** and apply the following values:

Table 2: Values for Wire Checking Injection

V L1-E	10.00 V	0.00	60.000 Hz
V L2-E	20.00 V	-120.00	60.000 Hz
V L3-E	30.00 V	120.00	60.000 HZ
I L1	1.000 A	0.00	60.000 HZ
I L2	2.000 A	-120.00	60.000 HZ
I L3	3.000 A	120.00	60.000 HZ

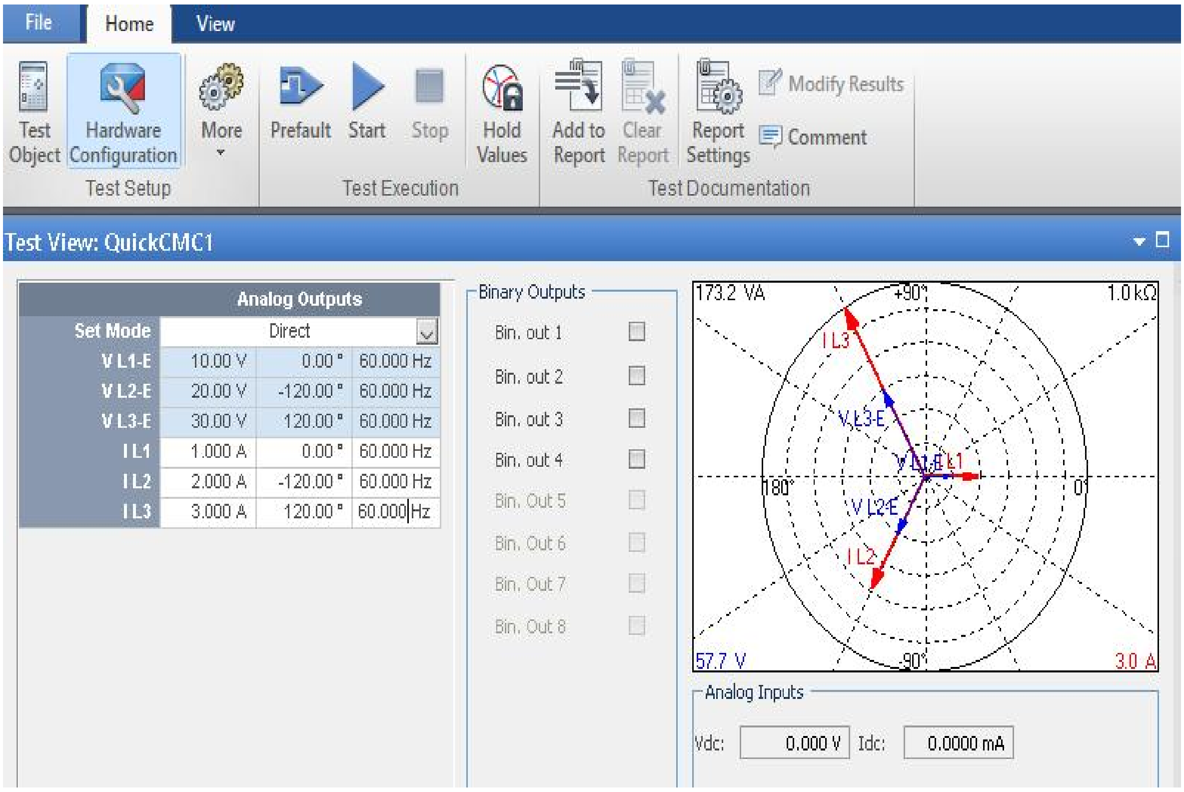

Figure 2.11: Test Execution Window

8. Once the values set click on **Star**t to begin the injection.

9. Check if the wiring is correct: On AcSELerator QuickSet, go to **Communications → Terminal →** on the terminal window type in the command **Meter** then observe the inputs recorded by the relay.

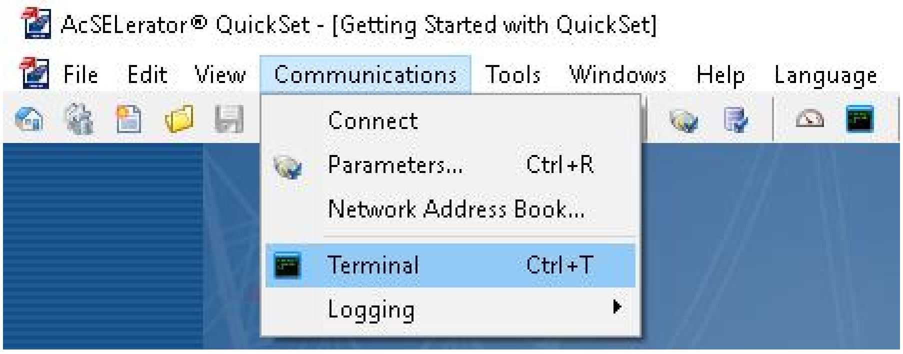

Figure 2.12: Communications Window

10. Knowing that the relay is assigned a PT ratio of 2000 and CT ratio of 200, What are the values expected for Va, Vb, Vc, Ia, Ib and Ic, for the wiring to be correct he values must correspond to those injected by the CMC356 ?

Calculation

Table 3 lists the secondary values of voltages and currents injected to the relay and the calculated primary values needed to check the wiring order.

Table 3: Wiring Checking Voltage and Current Calculations

	Secondary value	PT/CT ratio	Primary value
V L1-E (Va)	10.00 V	2000	20 kV
V L2-E (Vb)	20.00 V	2000	40 kV
V L3-E (Vc)	30.00 V	2000	60 kV
I L1 (Ia)	1.000 A	200	200 A
I L2 (Ib)	2.000 A	200	400 A
I L3 (Ic)	3.000 A	200	600 A

Results

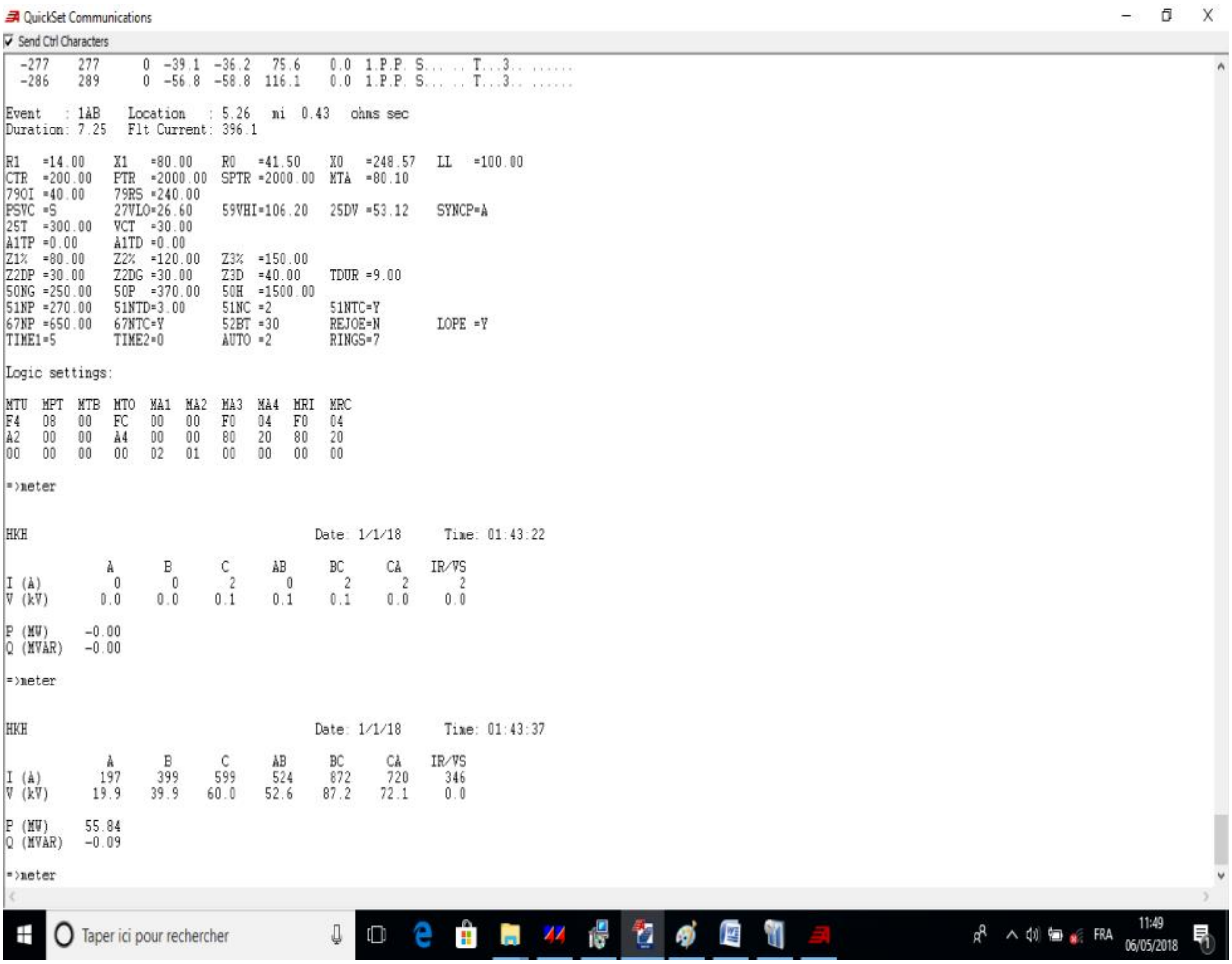

Figure 2.13: Meter Command Report Window

The primary values recorded by the relay correspond to the ones calculated, this coherence indicates a correct wiring.

Appendix D

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Experiment #4

SEL-211 Relay Configuration and Metering Check Procedure

Learning Outcomes

- Learn how to properly set SEL 221 relay and the test set.
- Understand the power flow direction concept.

Equipment

- SEL 221F relay
- OMICRON CMC356 injection test set
- Bag of Banana-Banana Short Leads (3x) *
- Banana-Banana or Banana-Spade Leads (30x)
- Computer with AcSELerator QuickSet Software
- Computer with OMICRON TestUniverse software

Prelab

1. Assume that the full load ratings of the transmission lines of Table 1 are equal to their CTRs. For example, if the CTR is 3000/5, then the transmission line full loading is 3000A.

2. Use the given information as shown in Table 3, calculate the secondary phasor values of the balanced three-phase systems as follows:

a. Va-N, Vb-N, Vc-N

b. Ia, Ib, Ic

3. Calculate the primary three phase values of S, MW, MVAR

Table 4: Relay Configuration and Power Flow Direction

NO	Voltage Level	VT Ratio	CT Ratio	% Power Factor	Line loading = % of Full Load	Direction of MW Flow
1	600kV	4000/1	3000/5	87 Lag	96%	Out of terminal
2	181kV	1500/1	3000/5	84 Lag	85%	Into terminal
3	400kV	4000/1	2500/5	93 Lead	92%	Out of terminal
4	500kV	4000/1	3000/5	87 Lag	95%	Into terminal

Calculations

Table 4 describes the primary values for the four cases that needed to be simulated in this experiment. Table 5 is the calculated secondary values for the four cases. Table 6 shows the calculated primary power values that will be compared later with relay's measurements.

Secondary voltages and currents

Table 5: Calculated Values for Secondary Voltages and Currents

Case	Va	Vb	Vc	Ia	Ib	Ic
1	86.60∠0°	86.60∠240°	86.60∠120°	4.8∠ − 29.5°	4.8∠210.46°	4.8 ∠90.46°
2	69.67∠0°	69.67∠240°	69.67∠120°	4.25∠147.14°	4.25∠207.14°	4.25 ∠267.14°
3	57.73∠0°	57.73∠240°	57.73∠120°	4.6 ∠21.56°	4.6 ∠261.56°	4.6 ∠141.56°
4	72.16∠0°	72.16∠240°	72.16∠120°	4.75 ∠150.46°	4.75 ∠210.46°	4.75 ∠270.46°

Primary MVA, MW and MVAR

Table 6: Calculated Values for Primary MVA, MW and MVAR

Case	MVA	MW	MVAR	Direction of Power Flow
1	2992.98	2603.89	1475.663	Out of terminal
2	799.43	671.52	433.7601	Into terminal
3	1593.49	1481.95	585.57	Out of terminal
4	2468.17	2147.30	1216.88	Into terminal

Procedure

Starting with a disconnected test set and a disconnected relay, perform the following tasks:

1. Set up the communication between SEL 221 relay and AcSELerator software using EIA-232 serial communications cable (follow procedure in experiment 1).
2. Set up communication between the CMC 356 and Test Universe using RJ45 serial communication cable (follow procedure in experiment 1).
3. Connect 3-Φ voltages from the test set voltage analog outputs to the relay (Va, Vb, Vc).
4. Connect 3-Φ currents from the test set current analog outputs to the relay (Ia, Ib, Ic).
5. Power up the relay.
6. Power up the test set.
7. Begin with case 01: On the main window of AcSELerator QuickSet go to **Read → Read settings from a connected device → Enter device part number →** Once the settings window is open insert CT ratio of 3000:5 (600:1) and VT ratio of 4000:1 into SEL-221F relay.

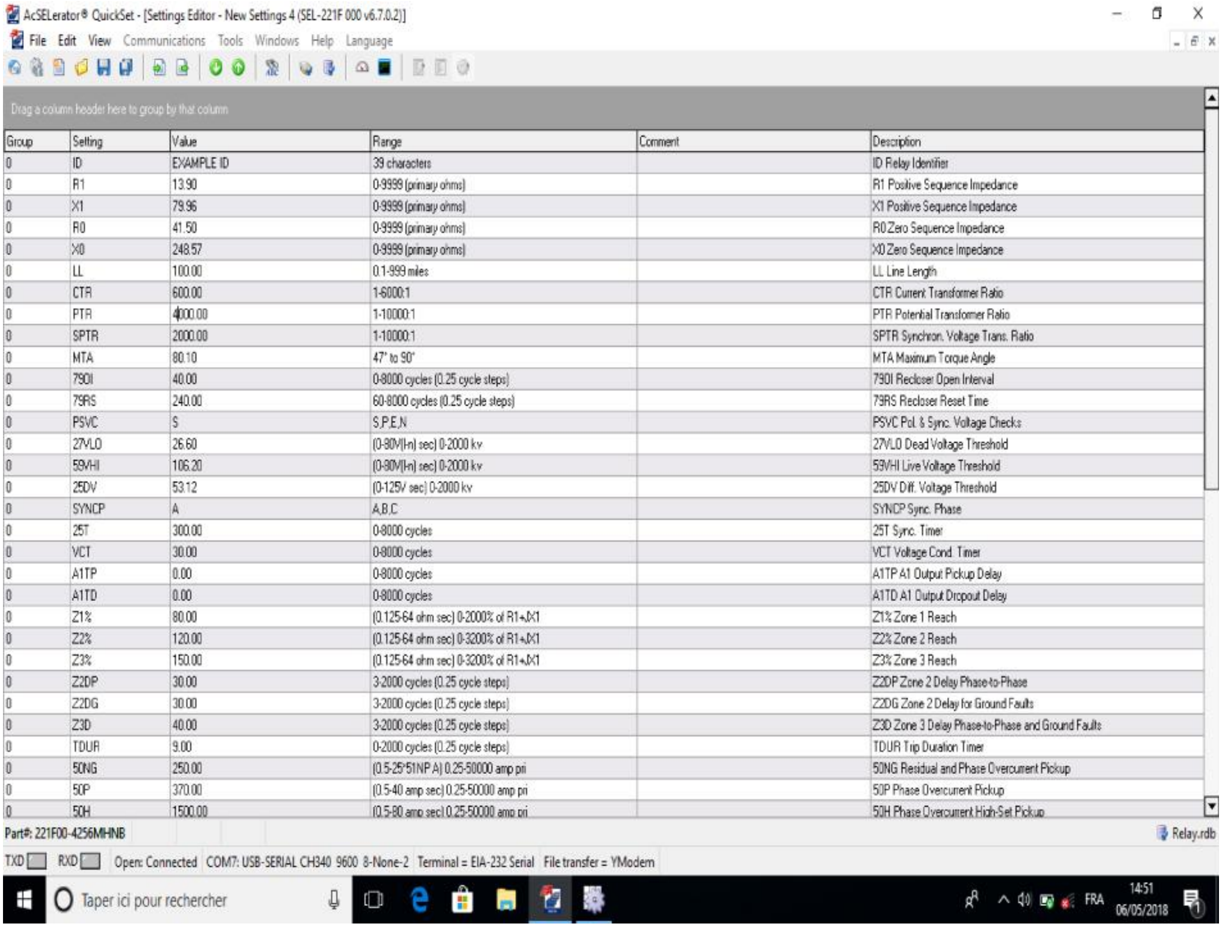

Figure 2.14: SEL 221 Settings Editor

8. Send modified settings to relay.

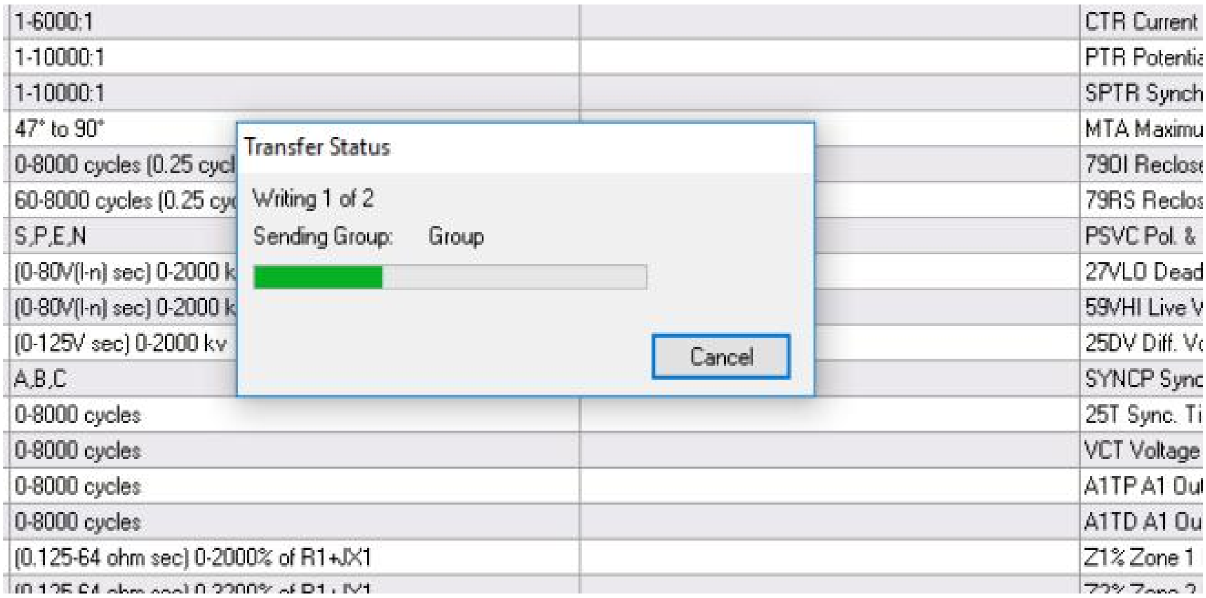

Figure 2.15: Send Modified Settings to SEL 221

9. Open TestUniverse → Quick CMC → From the window of analog outputs select **Direct** and apply the values calculated for case 01 to inject the analog signals from the OMICRON test set to the assigned relay.

10. Display metering values: On AcSELerator QuickSet, go to Communications → **Terminal** → on the terminal window type in the command **Meter** then observe the inputs recorded by the relay.

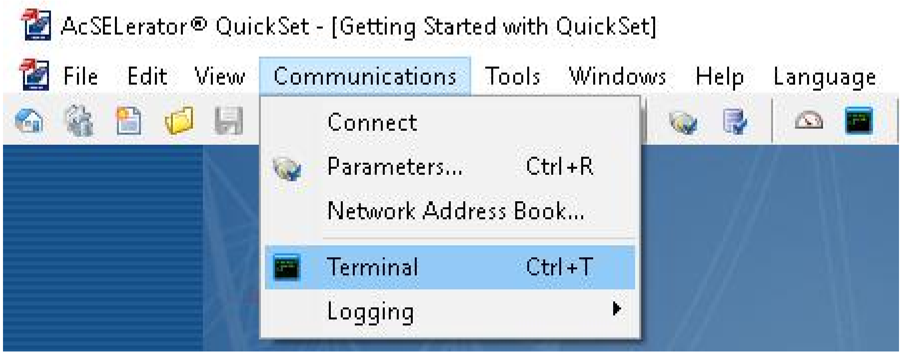

Figure 2.16: Communication Window

Case 01

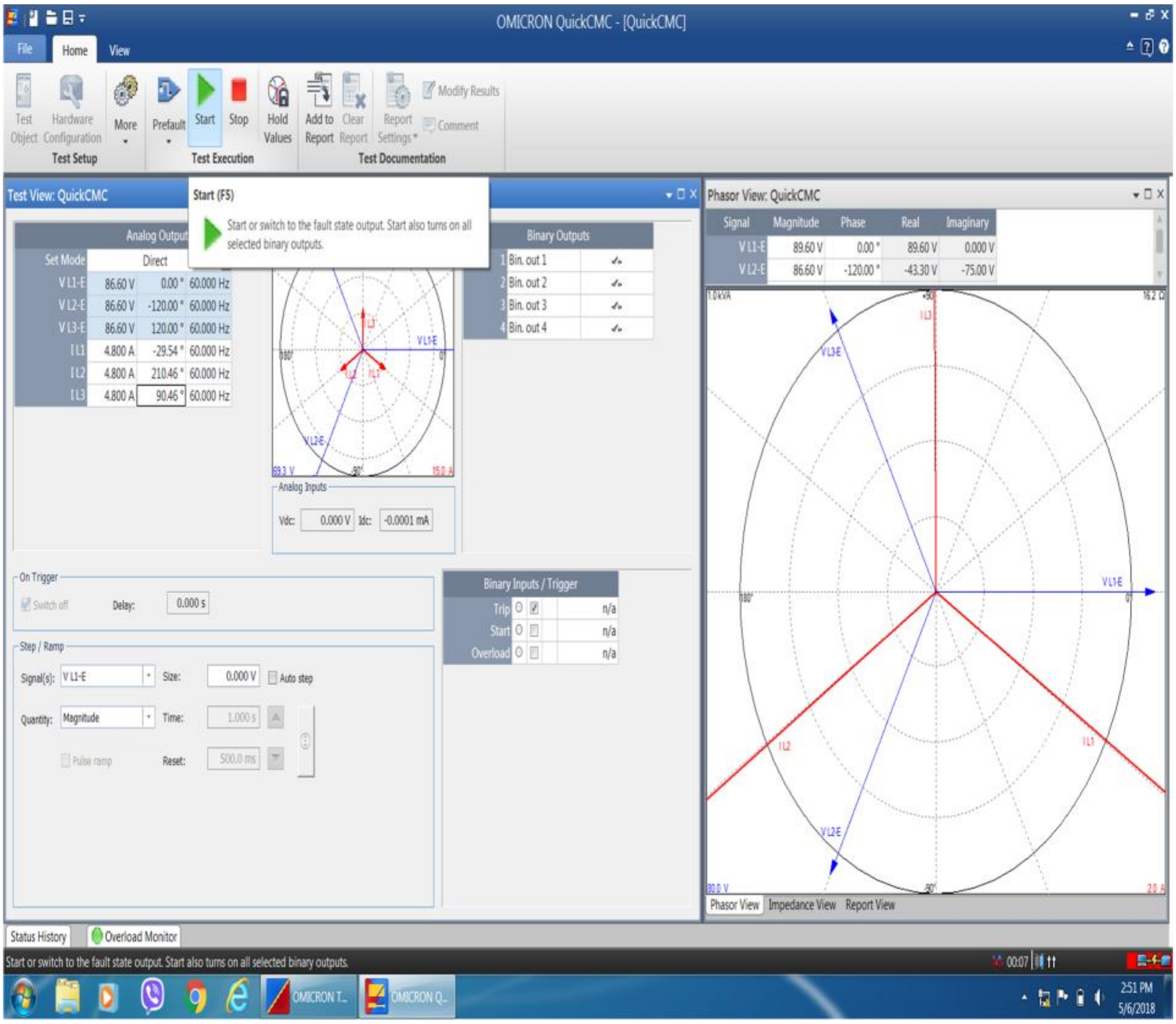

Figure 2.17: Case 01 Values Injection Execution

No	Va	Vb	Vc	Ia	Ib	Ic
1	86.60□0°	86.60□240°	86.60□120°	4.8□ − 29.54°	4.8□210.46°	4.8 □90.46°

Case	MVA	MW	MVAR	Direction of power flow
1	2992.98	2603.89	1475.663	Out of terminal

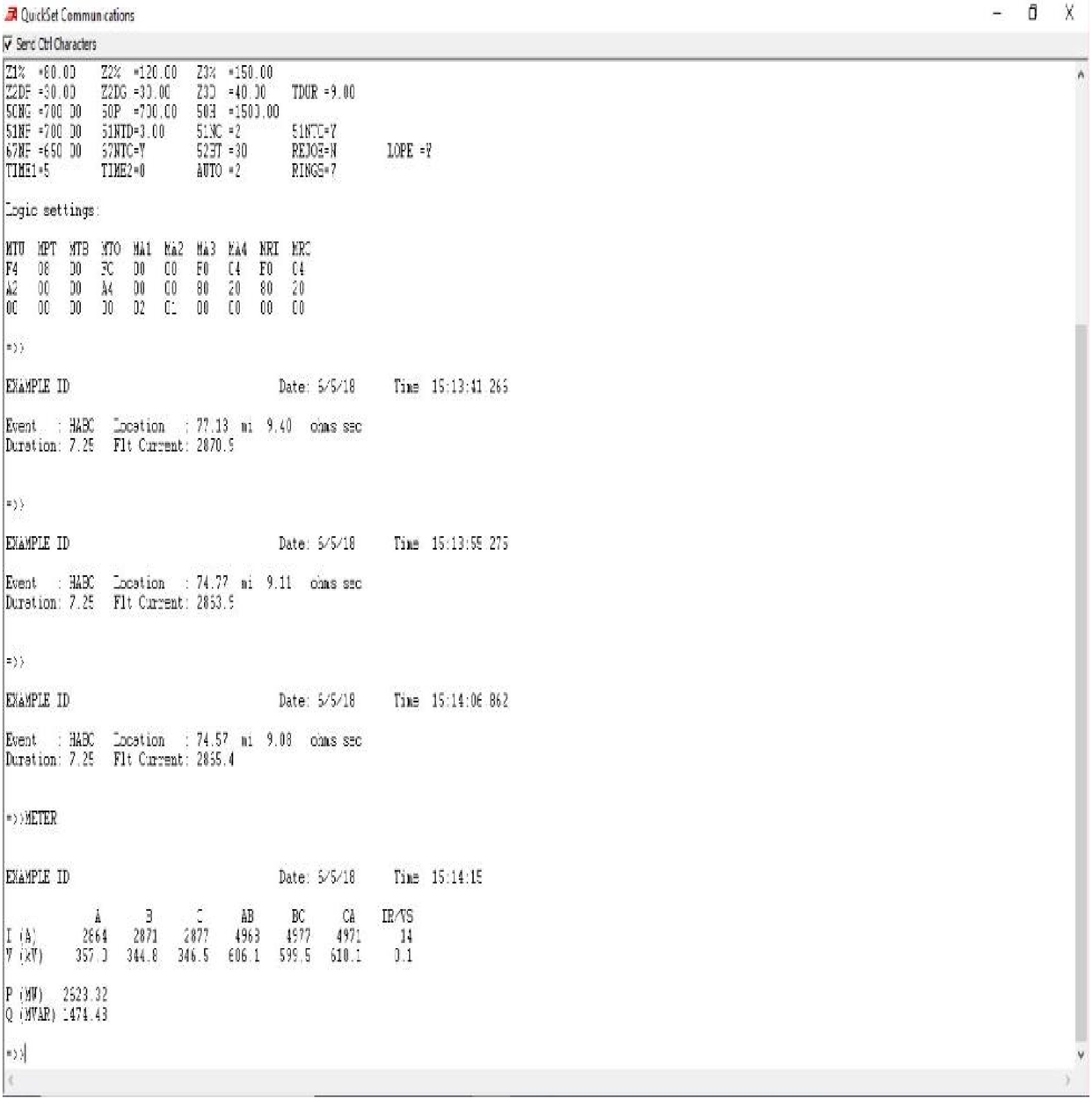

Figure 2.18: Case 01 Meter Values

Case 02

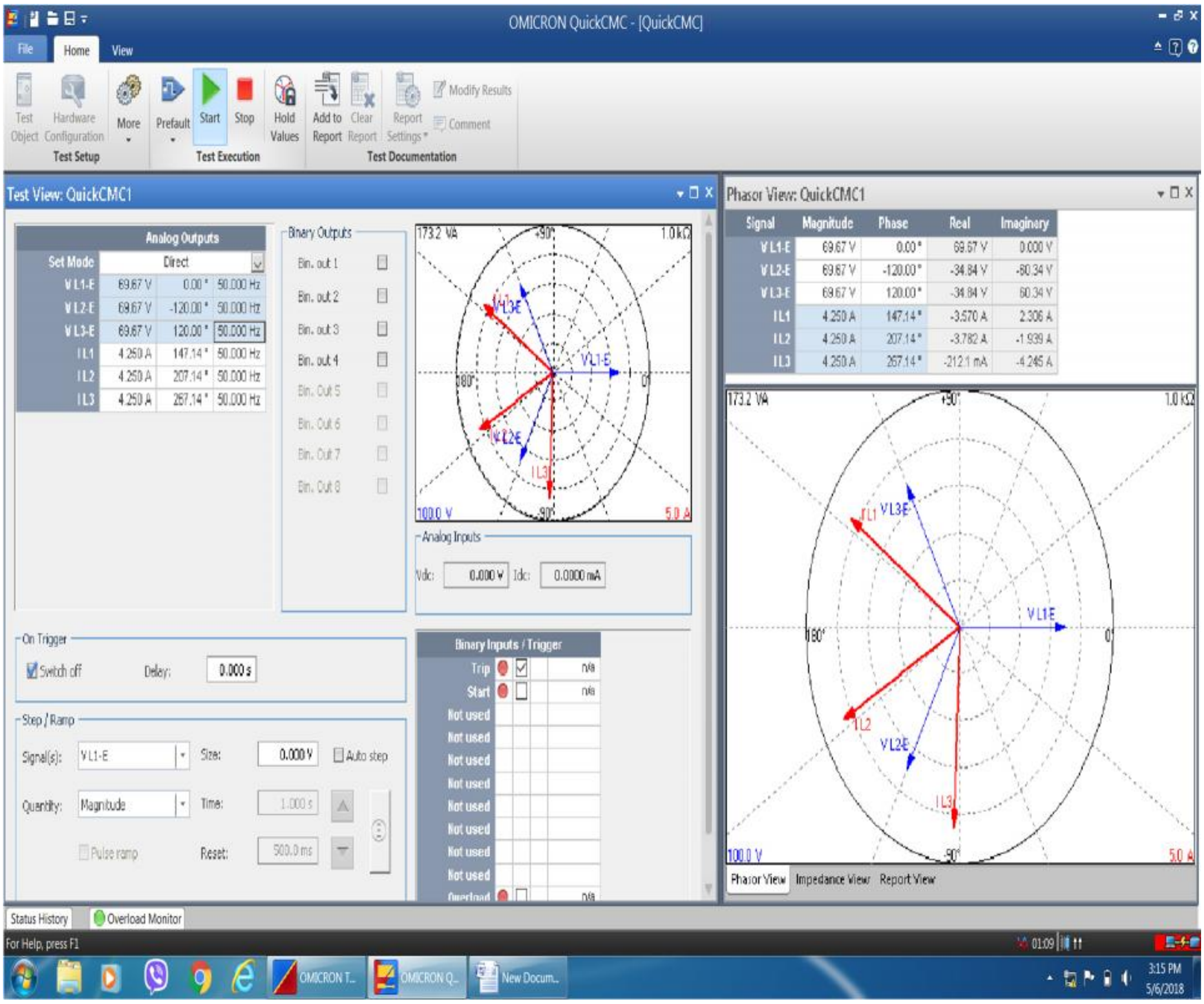

Figure 2.19: Case 02 Values Injection Execution

Case	Va	Vb	Vc	Ia	Ib	Ic
2	69.67□0°	69.67□240°	69.67□120°	4.25□147.14°	4.25□207.14°	4.25 □267.14°

Case	MVA	MW	MVAR	Direction of power flow
2	799.43	671.52	433.7601	Into terminal

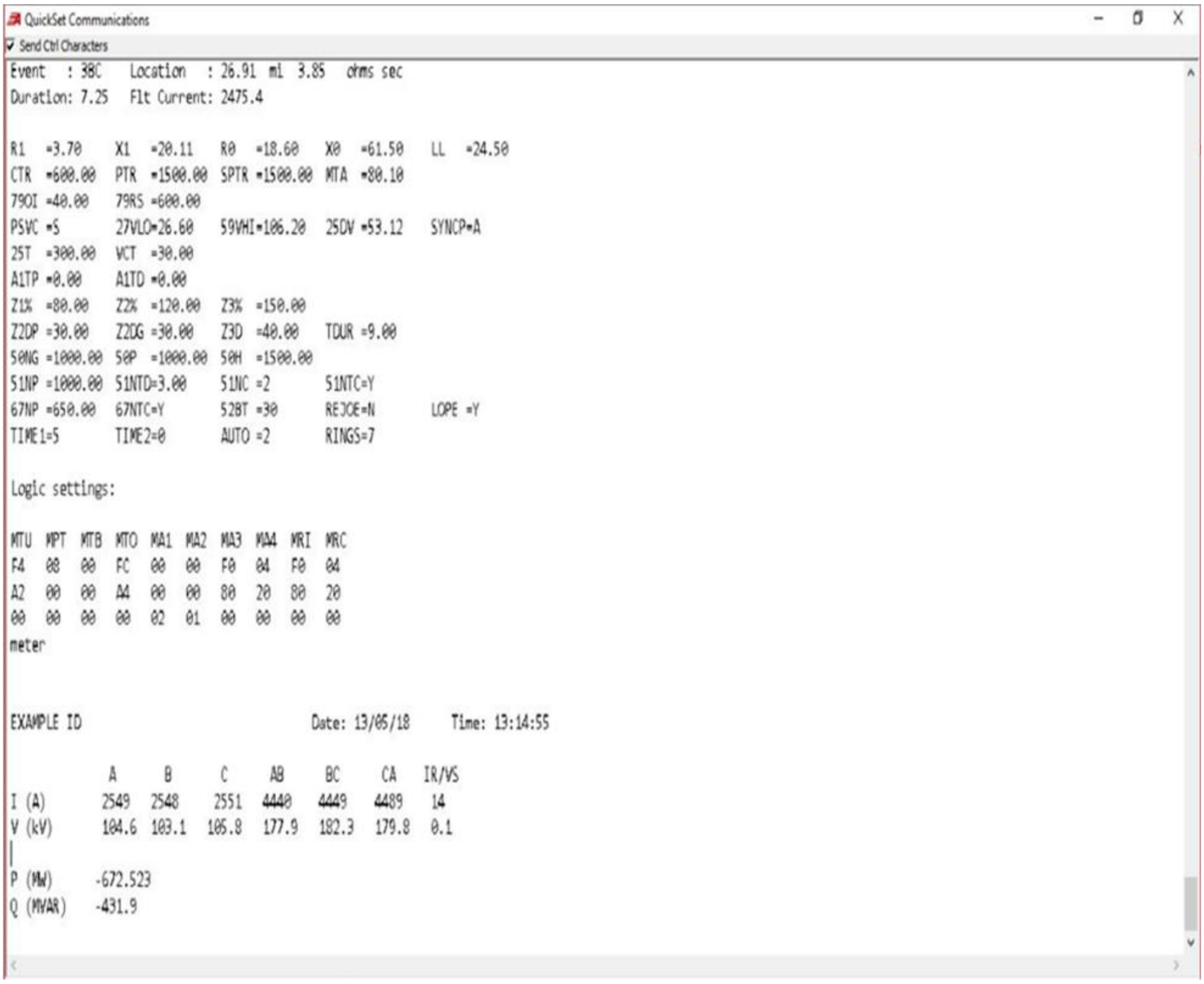

Figure 2.20: Case 02 Meter Values

Case 03

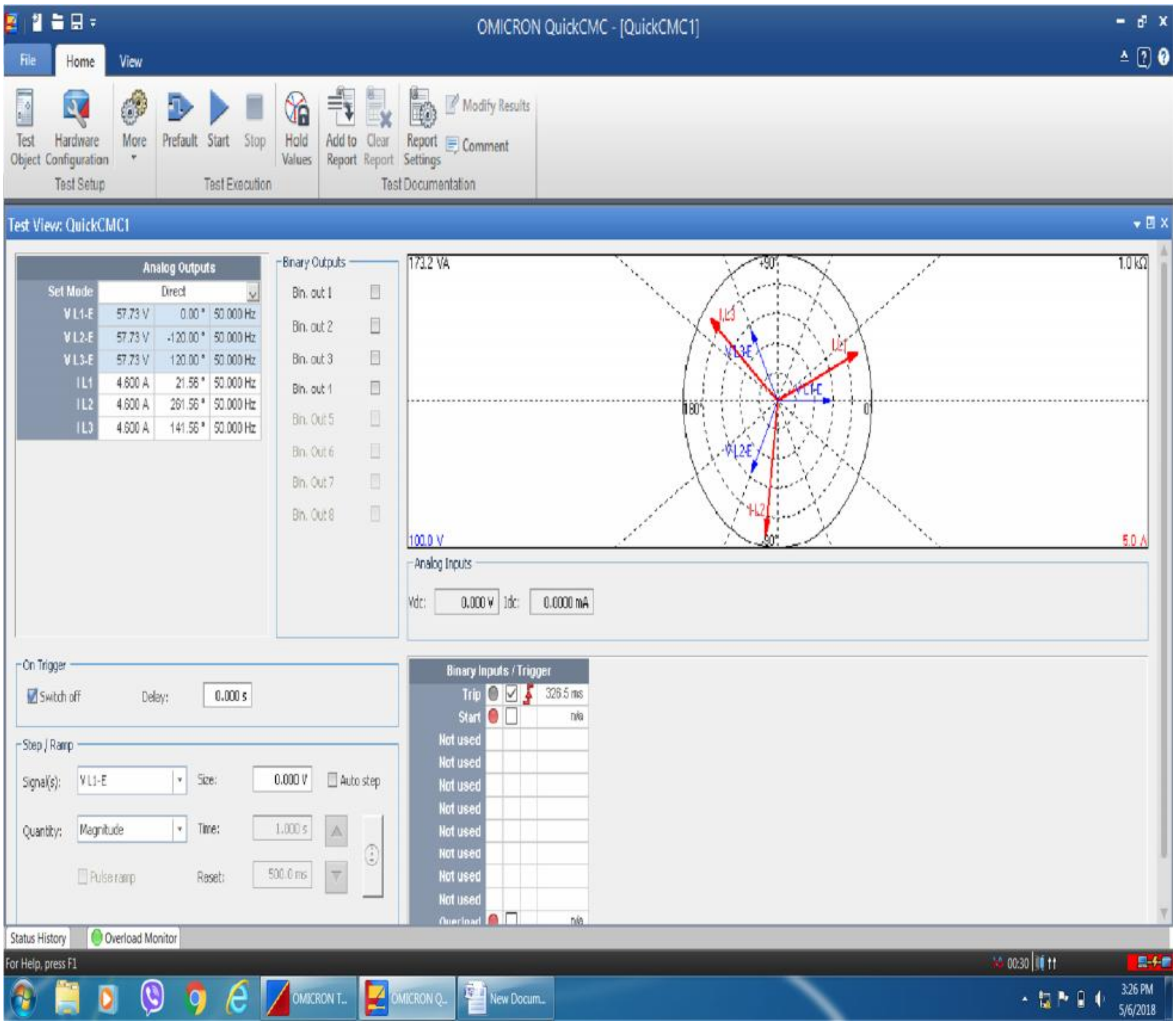

Figure 2.21: Case 03 Values Injection Execution

Case	Va	Vb	Vc	Ia	Ib	Ic
3	57.73∠0°	57.73∠240°	57.73∠120°	4.6 ∠21.56°	4.6 ∠261.56°	4.6 ∠141.56°

Case	MVA	MW	MVAR	Direction of power flow
3	1593.49	1481.95	585.57	Out of terminal

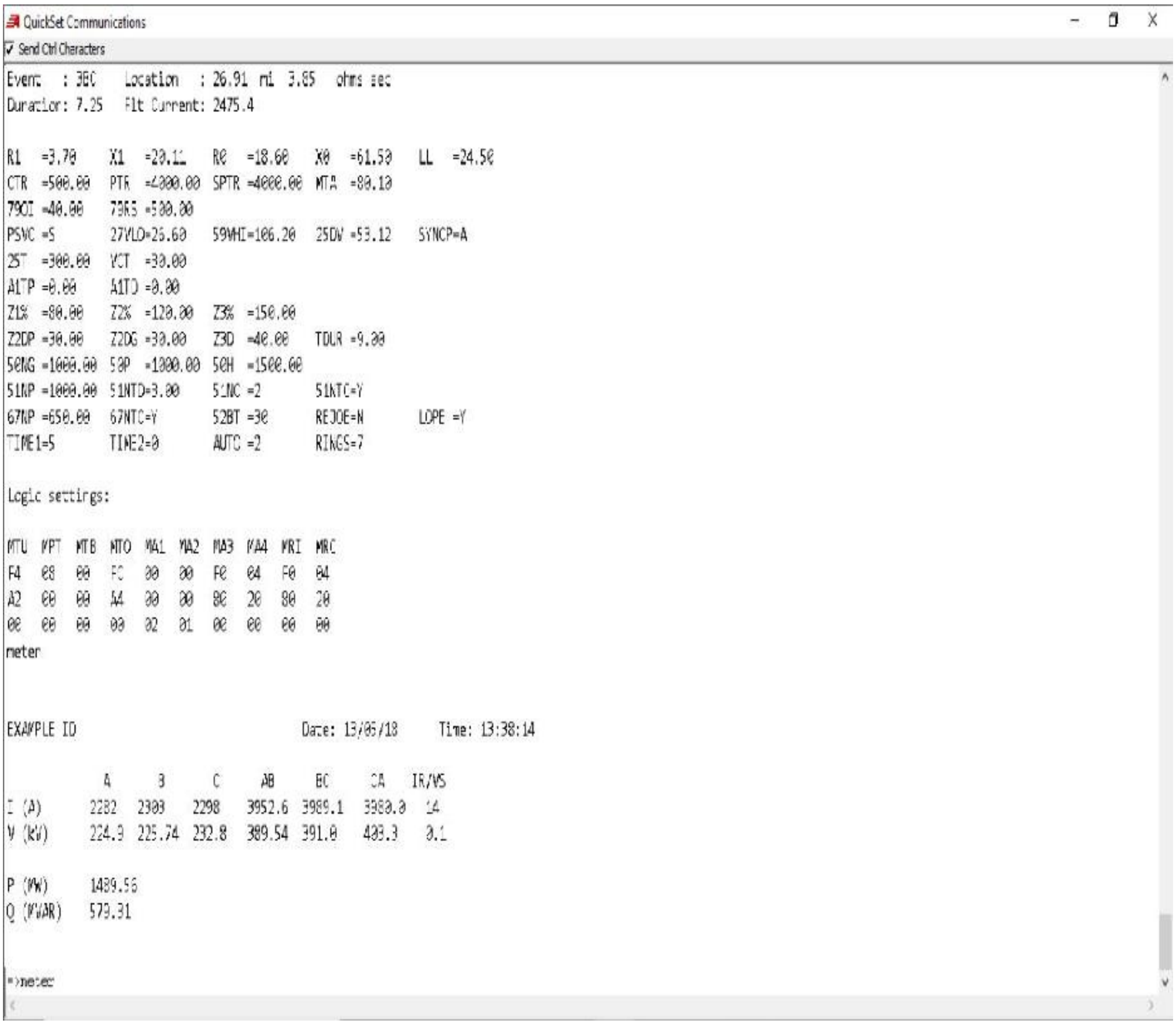

Figure 2.22: Case 03 Meter Values

Case 04

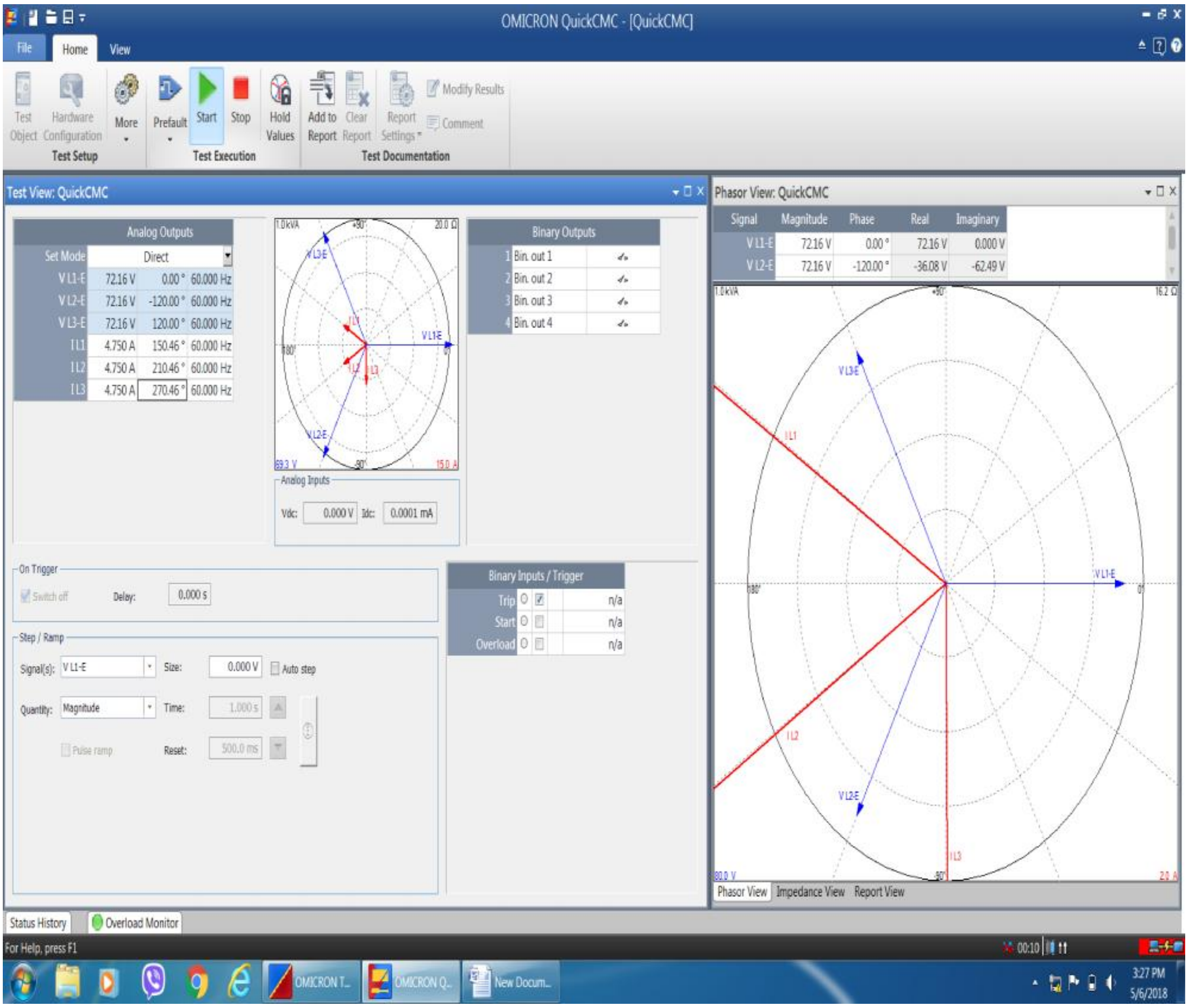

Figure 2.23: Case 03 Values Injection Execution

Case	Va	Vb	Vc	Ia	Ib	Ic
4	72.16□0°	72.16□240°	72.16□120°	4.75 □150.46°	4.75 □210.46°	4.75 □270.46°

Case	MVA	MW	MVAR	Direction of power flow
4	2468.17	2147.30	1216.88	Into terminal

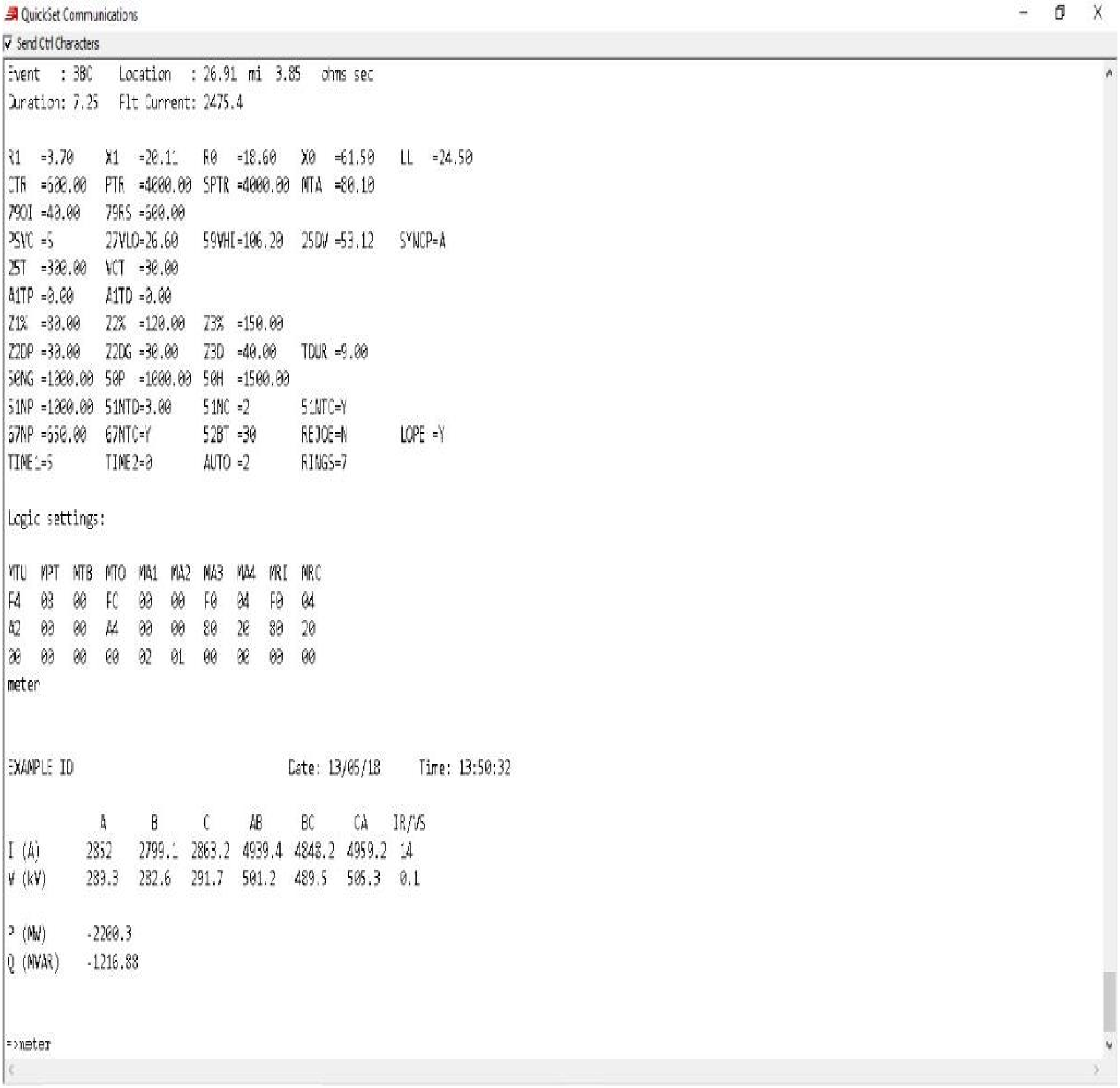

Figure 2.24: Case 04 Meter Values

All power flows' direction, obtained from the relay, were consistent with calculations.

Appendix E

University of M'hamed BOUGARA Boumerdes
Institute of Electrical Engineering and Electronics
Control and Power Department

Experiment #5
SEL 221 Setting and Testing Phase Distance Elements and Interpreting Event Records

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Learning outcome

The objective of this experiment is to set and test phase distance elements on SEL-221F relay.

Equipment

- SEL 221F relay
- OMICRON CMC 356 injection test set
- Bag of Banana-Banana Short Leads (3x)
- Banana-Banana or Banana-Spade Leads (30x)
- Computer with AcSELerator QuickSet Software
- Computer with OMICRON TestUniverse software

Prelab

Assume the following data:

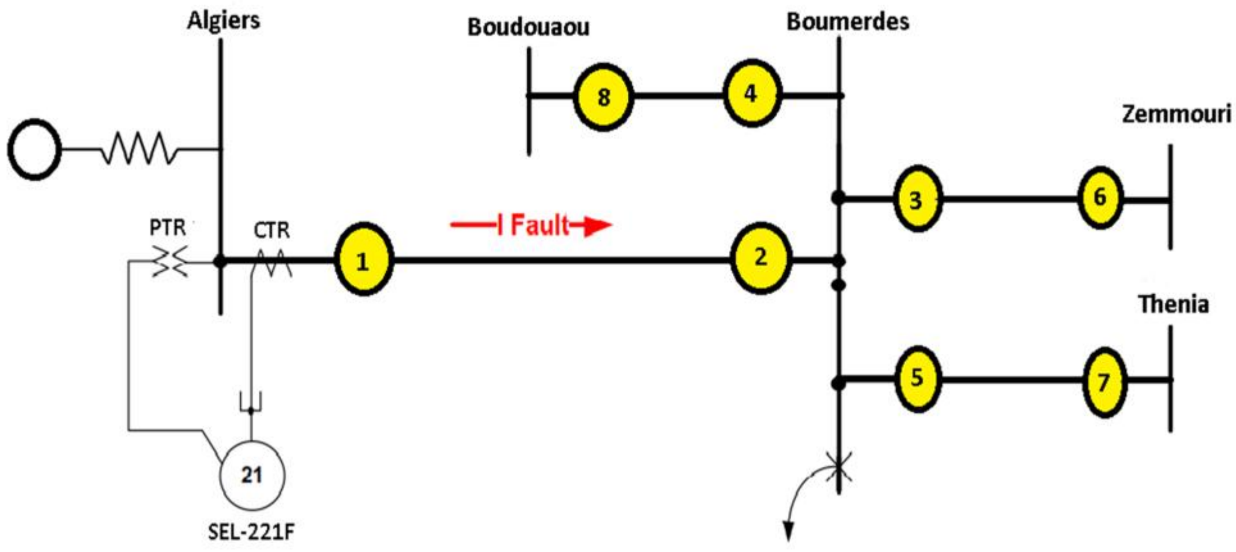


Figure 5.4: Algiers Boumerdes Single Line Network Diagram

- All zone 1 phase distance elements at Boumerdes substation are set at 80% of their lines and to operate with no time delay.
- Zone 2 of phase distance elements at Boumerdes substation are set to operate in 30 cycles
- Assume that there are no in-feed (no source or generation) at Zemmouri, Boudouaou and Thenia substations.

- System voltage: 161kV, 100MVA Base
- $Z_{Base} = \frac{kV_{L-L}^{2}}{MVA_{3-\phi}}$
- $Z\Omega = Z_{Per\,unit} * Z_{Base}$

Thevenin equivalent impedance at Algiers bus in percent:

- %Z+ = 0.526+j3.899 primary
- %Z0 = 0.524+j3.83 primary

Relay data: (SEL-221F relay): Line impedance in percent for the Algiers-Boumerdes 161-kV line

- Available CTR = 1200-5, 2000-5, 3000-5 / PTR = 1400-1
- % Z+ of line Algiers-Boumerdes =1.43+ j7.76 primary in percent
- %Z0 of line Algiers-Boumerdes =7.2+ j23.74 primary in percent

Neighboring line data:

Line impedance in percent for the Boumerdes-Zemouri 161-kV line:

- % Z+ of line Boumerdes-Zemouri =1.34+J6.59 primary in percent
- %Z0 of line Boumerdes-Zemouri =6.48+ j 21.08 primary in percent

Line impedance in percent for the Boumerdes-Boudouaou 161-kV line:

- % Z+ of line Boumerdes-Boudouaou =0.54+J 2.54 primary in percent
- %Z0 of line Boumerdes-Boudouaou =2.67+ j 8.5 primary in percent

Line impedance in percent for the Boumerdes-Thenia 161-kV line:

- % Z+ of line Boumerdes-Thenia =0.546+J 2.54 primary in percent
- %Z0 of line Boumerdes-Thenia =2.873+ j 7.997primary in percent

Step 1

Calculate z1 and z2 mho phase distance elements for the relay at Algiers substation that is used to protect the Algiers Boumerdes 164 kV line.

1. Calculate the following line data for line Algiers-Boumerdes 161-kV line:

a. Z+ line = ______________ primary ohms

b. Z0 line = ______________ primary ohms

c. Line length = 24.5 miles

2. Select an appropriate CTR to make sure that your secondary fault currents will not exceed 12.5A for OMICRON test set.

3. Perform the following calculations:

a. Set the reach for zone 1 mho phase distance

b. Set an operating time for the Z1P element

c. Set the reach for zone 2 mho phase distance

d. Set an operating time for the Z2P element

4. **Fill in the following data:**

	Primary Ohms	**Secondary Ohms**	**Operating Time in Cycles**	**SEL Relay Setting Parameter**	**SEL Relay Word Bit**
Z1P					
Z2P					

Step 2 : Test Z1 and Z2 Mho phase distance element

(Limit the test current to 12.5A or less)

1) Calculate the fault currents that the relay at Algiers substation sees for the following faults:

a. B-C fault on 80% of Algiers-Boumerdes 161-kV line

b. C-A fault at the remote bus at Boumerdes substation

Procedure

1. Starting with a disconnected test set and a disconnected relay, perform the following tasks:

2. Set up the communication between SEL 221 relay and AcSELerator software using EIA-232 serial communications cable (follow procedure in experiment 1).

3. Set up communication between the CMC 356 and Test Universe using RJ45 serial communication cable (follow procedure in experiment 1).

4. Connect 3-Φ voltages from the test set voltage analog outputs to the relay (Va, Vb, Vc)

5. Connect 3-Φ currents from the test set current analog outputs to the relay (Ia, Ib, Ic)

6. Power up the relay and the test set.

Figure 5.5: Experimental Setup of Experiment 5

a. On the main window of Quickset go to **Read → Read settings from a connected device** → Enter device part number → Insert line length, line positive and zero impedance, zone1 and zone2 parameters found in calculations, along with 0 cycle and 30 cycle time delay respectively.

b. Insert CT ratio of 240:1 and VT ratio of 1400: 1 into SEL-221F relay.

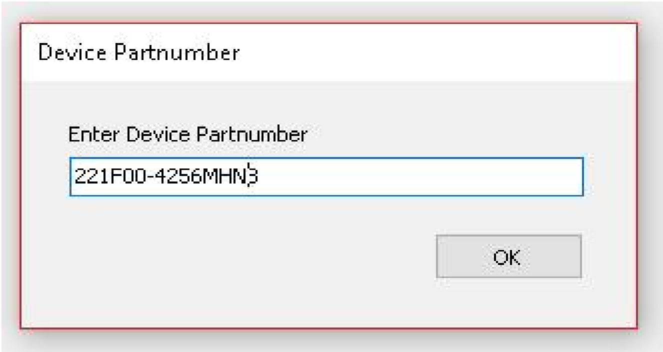
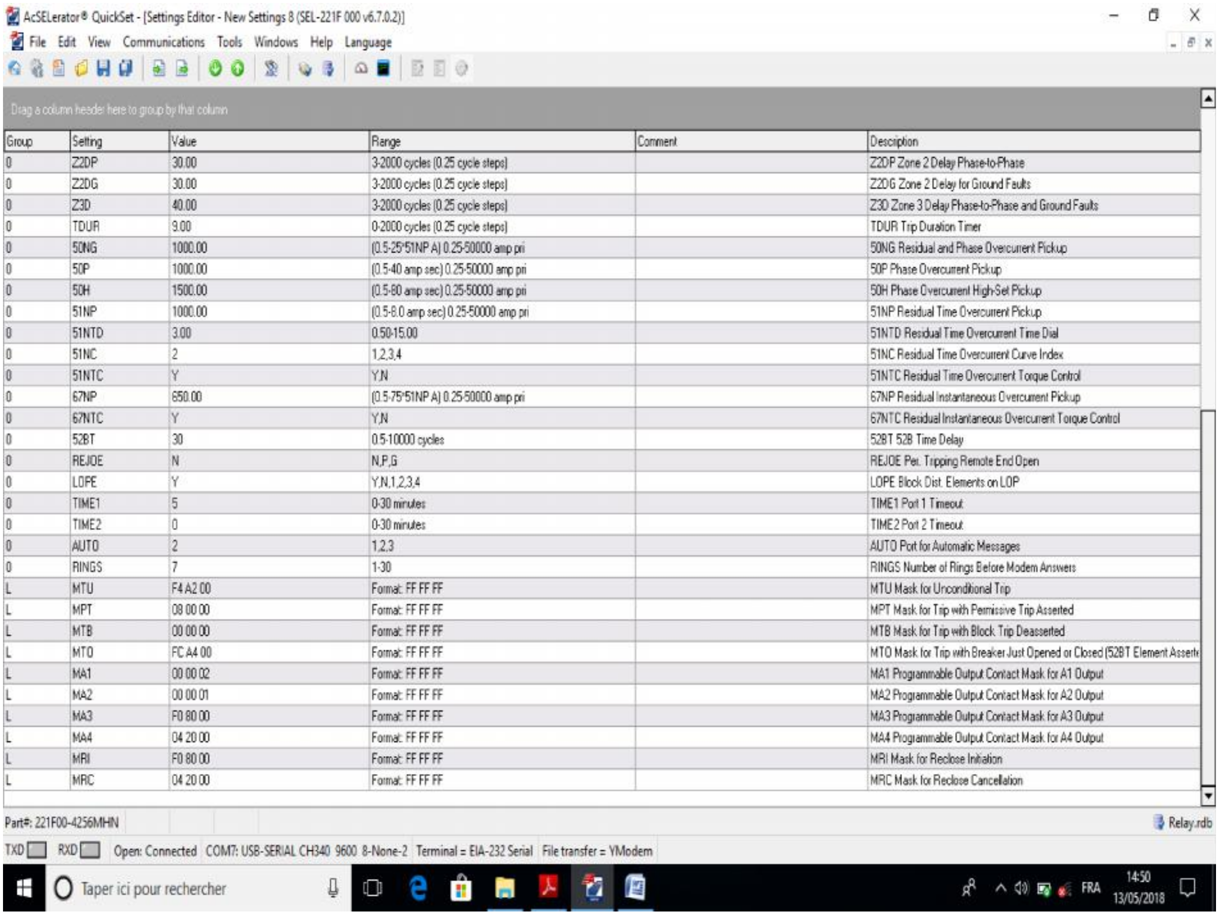
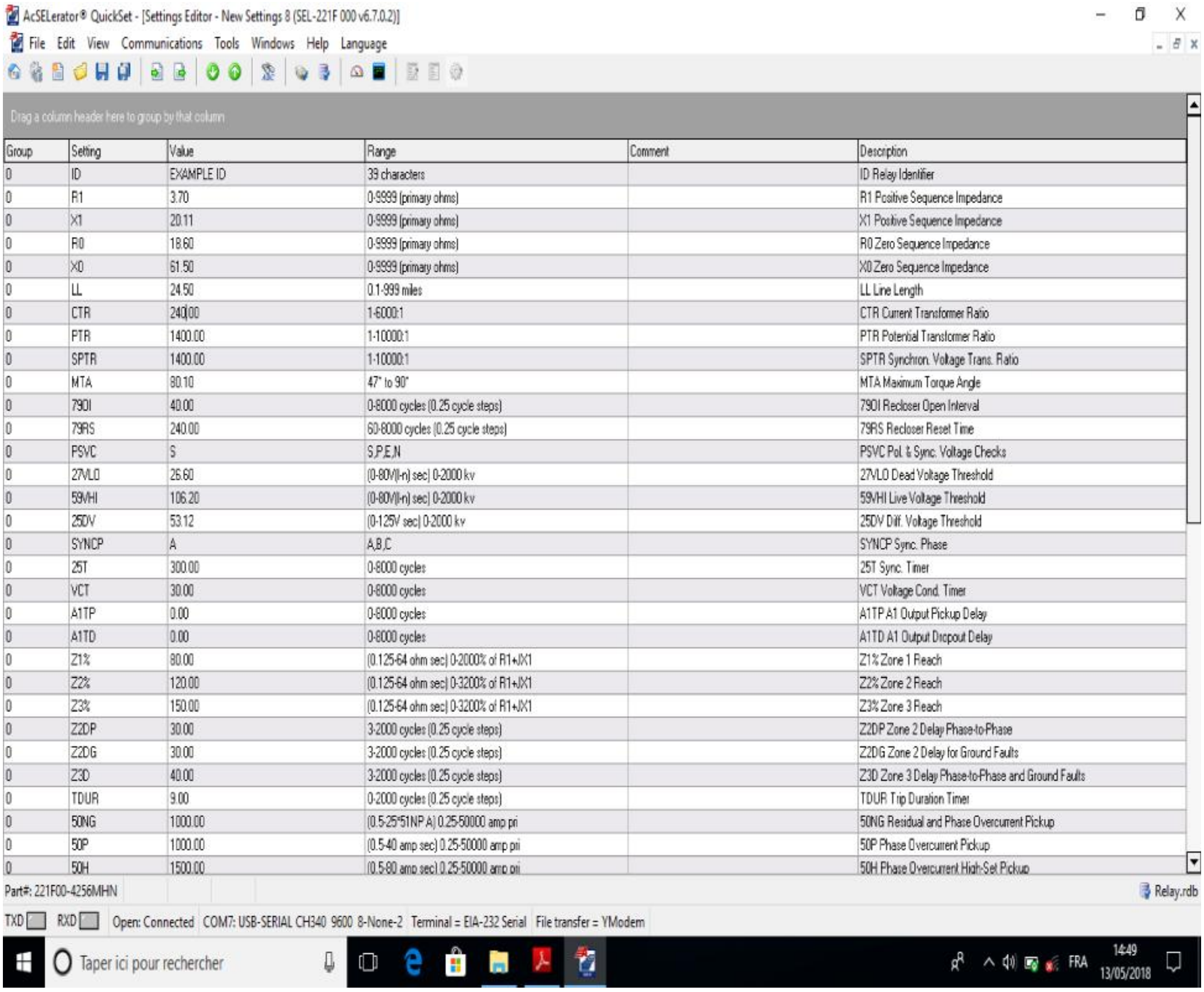


Figure 5.6: Device Part Number Inserting



Group	Setting	Value	Range	Comment	Description
0	Z2DP	30.00	3-2000 cycles (0.25 cycle steps)		Z2DP Zone 2 Delay Phase-to-Phase
0	Z2DG	30.00	3-2000 cycles (0.25 cycle steps)		Z2DG Zone 2 Delay for Ground Faults
0	Z3D	40.00	3-2000 cycles (0.25 cycle steps)		Z3D Zone 3 Delay Phase-to-Phase and Ground Faults
0	TDUR	9.00	0-2000 cycles (0.25 cycle steps)		TDUR Trip Duration Timer
0	50NG	1000.00	(0.5-25*51NP A) 0.25-50000 amp pri		50NG Residual and Phase Overcurrent Pickup
0	50P	1000.00	(0.5-40 amp sec) 0.25-50000 amp pri		50P Phase Overcurrent Pickup
0	50H	1500.00	(0.5-80 amp sec) 0.25-50000 amp pri		50H Phase Overcurrent High-Set Pickup
0	51NP	1000.00	(0.5-8.0 amp sec) 0.25-50000 amp pri		51NP Residual Time Overcurrent Pickup
0	51NTD	3.00	0.50-15.00		51NTD Residual Time Overcurrent Time Dial
0	51NC	2	1,2,3,4		51NC Residual Time Overcurrent Curve Index
0	51NTC	Y	Y,N		51NTC Residual Time Overcurrent Torque Control
0	67NP	650.00	(0.5-75*51NP A) 0.25-50000 amp pri		67NP Residual Instantaneous Overcurrent Pickup
0	67NTC	Y	Y,N		67NTC Residual Instantaneous Overcurrent Torque Control
0	52BT	30	0.5-10000 cycles		52BT 52B Time Delay
0	REJOE	N	N,P,G		REJOE Per. Tripping Remote End Open
0	LOPE	Y	Y,N,1,2,3,4		LOPE Block Dist. Elements on LOP
0	TIME1	5	0-30 minutes		TIME1 Port 1 Timeout
0	TIME2	0	0-30 minutes		TIME2 Port 2 Timeout
0	AUTO	2	1,2,3		AUTO Port for Automatic Messages
0	RINGS	7	1-30		RINGS Number of Rings Before Modem Answers
L	MTU	F4 A2 00	Format: FF FF FF		MTU Mask for Unconditional Trip
L	MPT	08 00 00	Format: FF FF FF		MPT Mask for Trip with Permissive Trip Asserted
L	MTB	00 00 00	Format: FF FF FF		MTB Mask for Trip with Block Trip Deasserted
L	MTO	FC A4 00	Format: FF FF FF		MTO Mask for Trip with Breaker Just Opened or Closed (52BT Element Asserte
L	MA1	00 00 02	Format: FF FF FF		MA1 Programmable Output Contact Mask for A1 Output
L	MA2	00 00 01	Format: FF FF FF		MA2 Programmable Output Contact Mask for A2 Output
L	MA3	F0 80 00	Format: FF FF FF		MA3 Programmable Output Contact Mask for A3 Output
L	MA4	04 20 00	Format: FF FF FF		MA4 Programmable Output Contact Mask for A4 Output
L	MRI	F0 80 00	Format: FF FF FF		MRI Mask for Reclose Initiation
L	MRC	04 20 00	Format: FF FF FF		MRC Mask for Reclose Cancellation

Figure 5.7: Setting Line Parameters and Zones Reach



Group	Setting	Value	Range	Comment	Description
0	ID	EXAMPLE ID	39 characters		ID Relay Identifier
0	R1	3.70	0-9999 (primary ohms)		R1 Positive Sequence Impedance
0	X1	20.11	0-9999 (primary ohms)		X1 Positive Sequence Impedance
0	R0	18.60	0-9999 (primary ohms)		R0 Zero Sequence Impedance
0	X0	61.50	0-9999 (primary ohms)		X0 Zero Sequence Impedance
0	LL	24.50	0.1-999 miles		LL Line Length
0	CTR	240.00	1-6000:1		CTR Current Transformer Ratio
0	PTR	1400.00	1-10000:1		PTR Potential Transformer Ratio
0	SPTR	1400.00	1-10000:1		SPTR Synchron. Voltage Trans. Ratio
0	MTA	80.10	47° to 90°		MTA Maximum Torque Angle
0	79OI	40.00	0-8000 cycles (0.25 cycle steps)		79OI Recloser Open Interval
0	79RS	240.00	60-8000 cycles (0.25 cycle steps)		79RS Recloser Reset Time
0	PSVC	S	S,P,E,N		PSVC Pol. & Sync. Voltage Checks
0	27VLO	26.60	(0-80V(l-n) sec) 0-2000 kv		27VLO Dead Voltage Threshold
0	59VHI	106.20	(0-80V(l-n) sec) 0-2000 kv		59VHI Live Voltage Threshold
0	25DV	53.12	(0-125V sec) 0-2000 kv		25DV Diff. Voltage Threshold
0	SYNCP	A	A,B,C		SYNCP Sync. Phase
0	25T	300.00	0-8000 cycles		25T Sync. Timer
0	VCT	30.00	0-8000 cycles		VCT Voltage Cond. Timer
0	A1TP	0.00	0-8000 cycles		A1TP A1 Output Pickup Delay
0	A1TD	0.00	0-8000 cycles		A1TD A1 Output Dropout Delay
0	Z1%	80.00	(0.125-64 ohm sec) 0-2000% of R1+jX1		Z1% Zone 1 Reach
0	Z2%	120.00	(0.125-64 ohm sec) 0-3200% of R1+jX1		Z2% Zone 2 Reach
0	Z3%	150.00	(0.125-64 ohm sec) 0-3200% of R1+jX1		Z3% Zone 3 Reach
0	Z2DP	30.00	3-2000 cycles (0.25 cycle steps)		Z2DP Zone 2 Delay Phase-to-Phase
0	Z2DG	30.00	3-2000 cycles (0.25 cycle steps)		Z2DG Zone 2 Delay for Ground Faults
0	Z3D	40.00	3-2000 cycles (0.25 cycle steps)		Z3D Zone 3 Delay Phase-to-Phase and Ground Faults
0	TDUR	9.00	0-2000 cycles (0.25 cycle steps)		TDUR Trip Duration Timer
0	50NG	1000.00	(0.5-25*51NP A) 0.25-50000 amp pri		50NG Residual and Phase Overcurrent Pickup
0	50P	1000.00	(0.5-40 amp sec) 0.25-50000 amp pri		50P Phase Overcurrent Pickup
0	50H	1500.00	(0.5-80 amp sec) 0.25-50000 amp pri		50H Phase Overcurrent High-Set Pickup

Figure 5.8: Setting Zones Time Delays in Cycles

7. On QuickCMC, go to **Parameters →Test object → Device → Edit**, insert primary and secondary voltage levels.

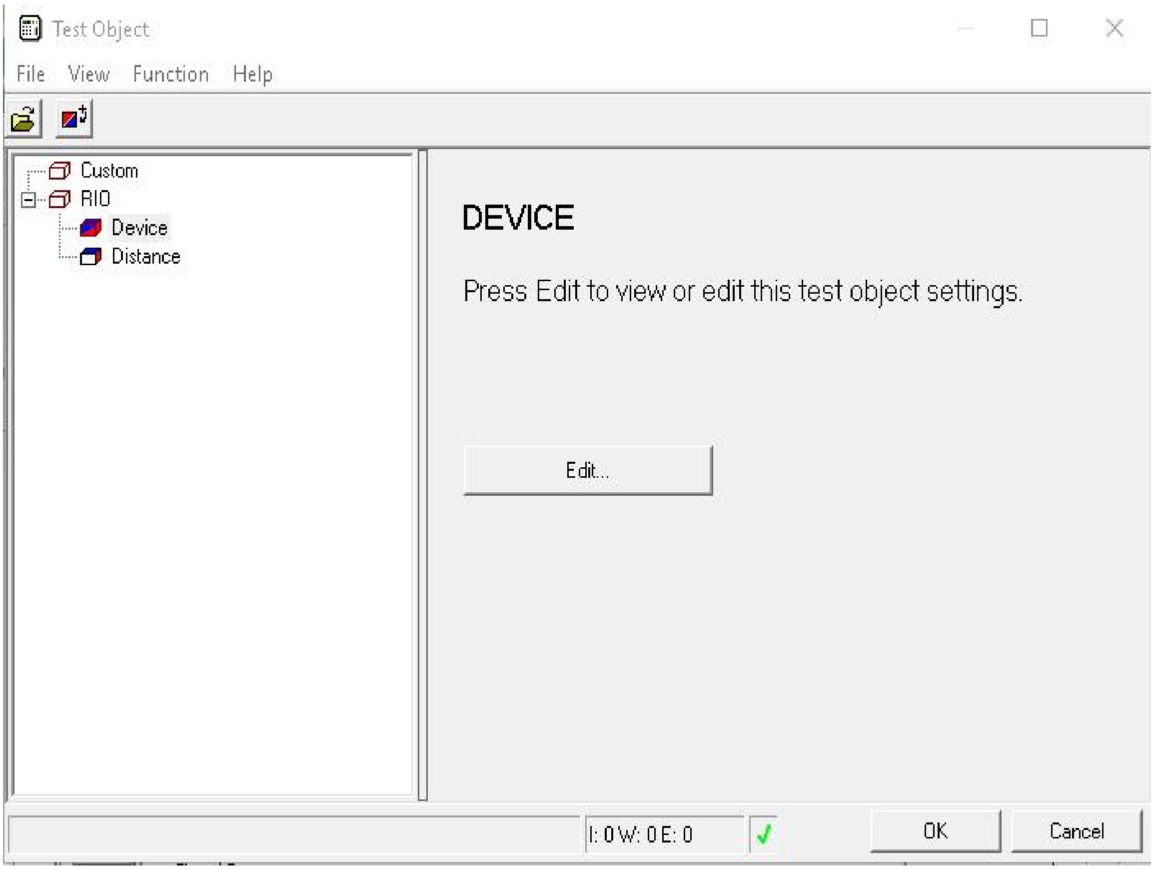


Figure 5.9: QuickCMC Test Object Window

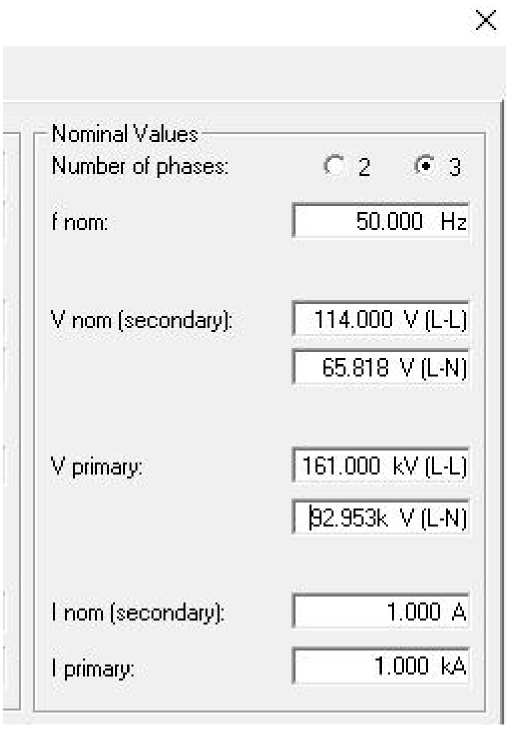


Figure 5.10: Voltage Levels Set on QuickCMC

8. On the same test object window, click on **Distance → Edit**, insert line parameters

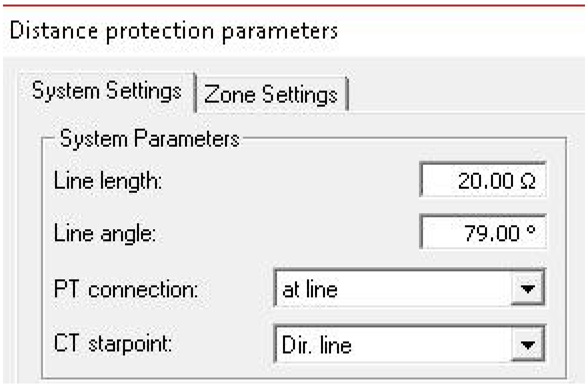


Figure 5.11: Distance Protection Parameters Set on Quick CMC

9. Inject the secondary values calculated in step 1 to the relay (same procedure as experiment 1) and monitor the results using terminal window.

10. Record relay behavior to the injection.

Prelab Calculations

Step 1

Z1 and Z2, mho phase distance elements for the relay at Algiers substation, were calculated to be used to protect the Algiers-Boumerdes 161-kV line.

1. Calculate the following line data for Line Algiers-Boumerdes 161-kV line:

a. Z+ line = $\frac{(1.43+j7.76)}{100} \times \frac{161^2}{100} = (3.7 + j20.11)$ primary ohms or $20\angle 79°$ primary ohms

b. Z0 line = $\frac{(7.2+j23.74)}{100} \times \frac{161^2}{100} = (18.6 + j61.5)$ primary ohms or $64\angle 73°$ primary ohms

c. Line length = 24.5 miles

2. Performing the following calculations

a. Set the reach for zone 1 mho phase distance:

$$Z+ \text{ line secondary} = 20\angle 79° \times \frac{240}{1400} = 3.428\angle 79°$$

$$Reach\ for\ zone\ 1\ mho\ phase\ distance = 3.428\angle 79° \times 0.8 = 2.74\angle 79°$$

b. Set an operating time for the Z1P element: 0 cycles.

c. Set the reach for zone 2 mho phase distance

Reach for zone 2 mho phase distance = $3.428\angle 79^\circ \times 1.2 = 4.11\angle 79^\circ$

d. Set an operating time for the Z2P element: 30 cycles.

Table 7: Zones 1 and 2 Parameters

	Primary Ohms	Secondary Ohms	Operating Time in Cycles	SEL Relay Setting Parameter	SEL Relay Word Bit
Z1P	$20\angle 79^\circ \times 0.8 = 16\angle 79^\circ$	$2.74\angle 79^\circ$	0	2.74	Z1P
Z2P	$20\angle 79^\circ \times 1.2 = 24\angle 79^\circ$	$4.11\angle 79^\circ$	30	4.11	Z2PT

Step 2: Testing Z1 and Z2 Mho Phase Distance Element

1) Calculate the fault currents that the relay at Algiers substation sees for the following faults:

A. B-C fault on 80% of Algiers-Boumerdes 161-kV line.

B. C-A fault at the remote bus at Boumerdes Substation.

a. B-C fault on 80% of Algiers-Boumerdes 161-kV line :

The Matlab code shown in appendix F was used to obtain the following results:

Table 8: Case 01 Secondary Values

Secondary line currents. A	**Secondary phase voltages. Volt**
$0\angle 0^\circ$ $12.6317\angle -170.61^\circ$ $12.6317\angle 9.38^\circ$	$66.3953\angle 0^\circ$ $49.0001\angle -133.69^\circ$ $48.1047\angle 132.57^\circ$

Table 9: Case 01 Primary Values

Primary line currents. A	**Primary phase voltages. KV**
$0\angle 0^\circ$ $3031.6\angle -170.61^\circ$ $3031.6\angle 9.38^\circ$	$161\angle 0^\circ$ $118.82\angle -133.69^\circ$ $116.65\angle 132.57^\circ$

b. C-A fault at the remote bus at Boumerdes Substation

Table 10: Case 02 Secondary Values

Secondary line currents. A	**Secondary phase voltages. Volt**
10.9457□9.523° 0□0° 10.9457□ − 170.47°	50.3410□ 130.33° 66.3953□ − 0° 51.1452□ − 131.38°

Table 11: Case 02 Primary Values

Primary line currents. A	**Primary phase voltages. KV**
2627□9.38° 0□0° 2627□ − 170.61°	122.07□130.33° 161□0° 124.02□ − 131.38°

Case 01

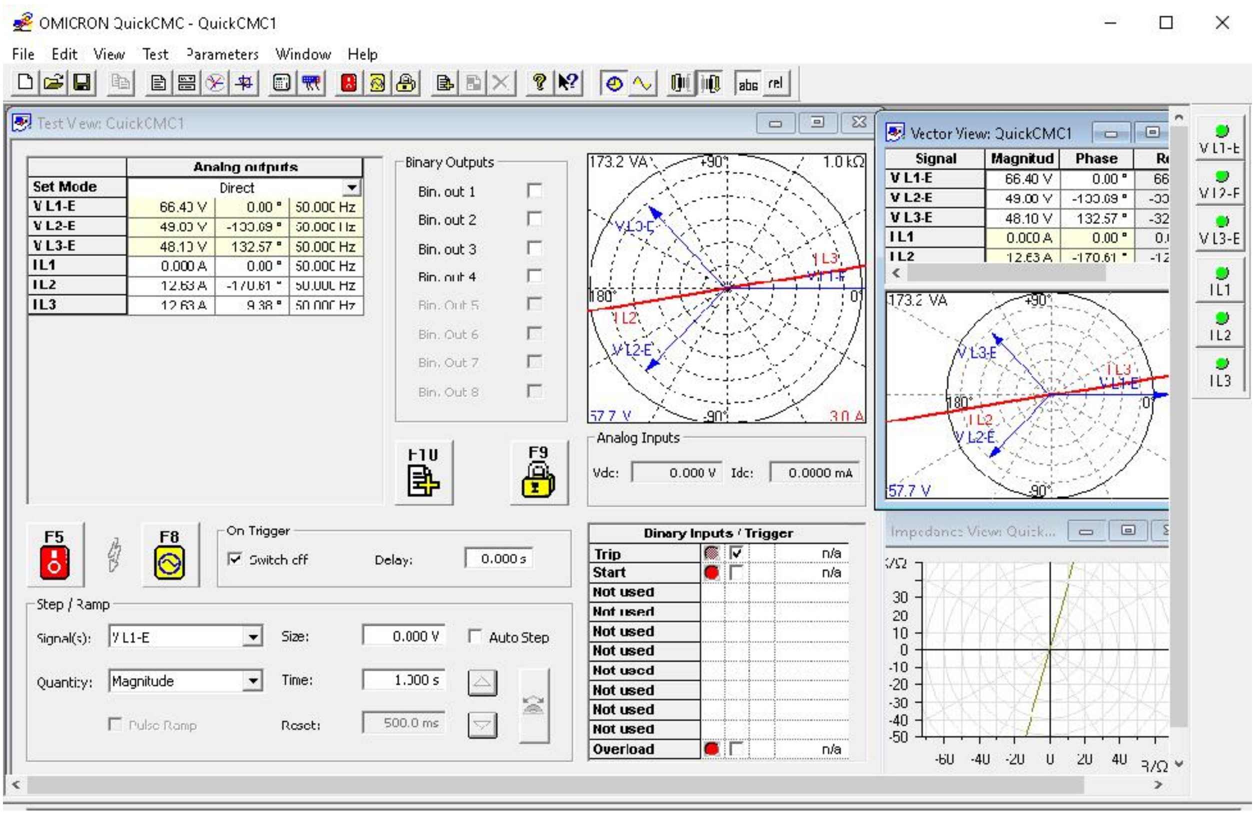


Figure 5.12: Case 1 Injections Window

Figure 5.13: SEL 221 Tripping In Zone 1

The secondary values shown in Table 8 were injected using OMICRON CMC356 to the relay. Figure 5.12 shows the interface of the OMICRON QuickCMC. Figure 5.13 shows the front panel of the SEL 221 displaying a zone 1 tripping indicating a test pass.

Before moving to the next, the reset button on the relay is pressed to clear the HMI and begin case 02 injections as shown below.

Figure 5.14: Resetting the Relay

Case 02

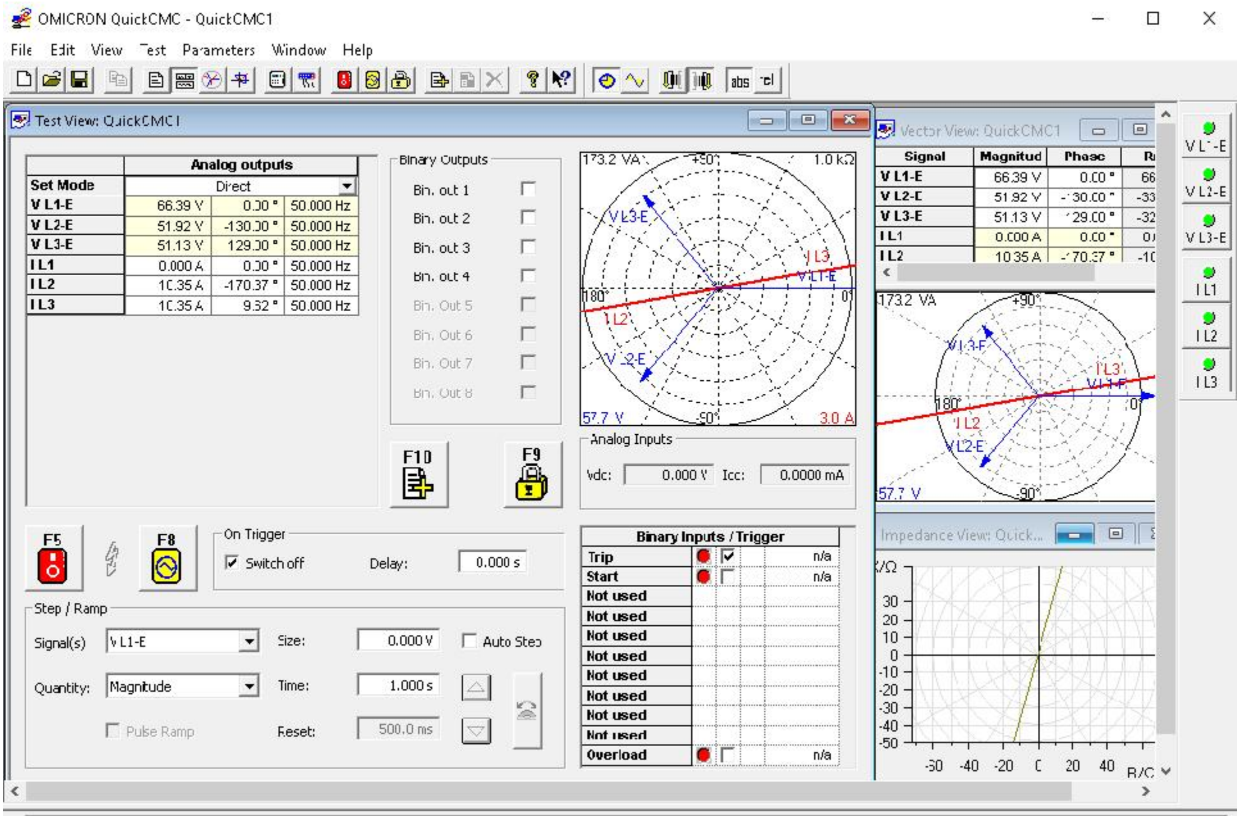


Figure 5.15: Case 2 Injections Window

Figure 5.16: SEL 221 Tripping in Zone 1 for Case 02 Fault

Figure 5.15 represents the QuickCMC window with injection values of case 02, the result of the test is shown in figure 5.16, the same results obtained from case 01, the relay indicates a trip in zone 01.

Normally, both cases are zone 02 faults, unfortunately, this could not be achieved due a missing fault recording configuration function inside the relay related to the communication scheme, the relay is performing zone 1 acceleration trip due to an overreach in zone 01, it is suspected that directional comparison blocking scheme is activated by the manufacturer.

Appendix F

```
clc
a=exp(i*120/180*pi);
Ibase=100000/sqrt(3)/161;
Zbase=161^2/100;
T=[1 1 1; 1 a^2 a ; 1 a a^2];
Z1=(1.43+7.76i)/100;
Zbase=161^2/100;
Zs=(0.526+3.899i)/100;
Zbravo_charlie=(1.34+6.59i)/100;
%==================================================
%case1:B-C fault at 80%.
I1=1/(2*(Zs+0.8*Z1));
I2=-I1;
I0=0;
I=[I0; I1; I2];

I=T*I*Ibase;
Imag1=abs(I)/240
Iangle1=angle(I)*180/pi

V1=1-I1*Zs;
V2=-I2*Zs;
V0=0;
V=[V0;V1;V2];
V=T*V;

Vmag1=(161000/sqrt(3)*abs(V))/1400
Vangle1=angle(V)*180/pi
%==================================================
%case2:C-A fault at 100%.
I1=1/(2*(Zs+Z1));
I2=-I1;
I=[I0; I1; I2];

I=T*I*Ibase;
Imag2=abs(I)/240
Iangle2=angle(I)*180/pi

V1=1-I1*Zs;
V2=-I2*Zs;
V0=0;
V=[V0;V1;V2];
V=T*V;
Vmag2=(161000/sqrt(3)*abs(V))/1400
Vangle2=angle(V)*180/pi
%==================================================
```