ASHESI UNIVERSITY

Automated Detection of Faults in Overhead Transmission Lines

CAPSTONE PROJECT

BSc. Electrical and Electronic Engineering

Mary Obutwe Duodu

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ASHESI UNIVERSITY

AUTOMATED DETECTION OF FAULTS IN OVERHEAD TRANSMISSION LINES

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronic Engineering.

Mary Obutwe Duodu

2021

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:

…………………………………………………………………………………………

Candidate's Name:

Mary Obutwe Duodu

Date:

27th April, 2021

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Abstract

Electricity is a significant aspect of our daily lives. social activities and industries heavily depend on electricity to function. Transmission line protection is an essential issue in power system engineering because 85-87% of power system faults occur in transmission lines. Proper detection of various faults which do occur on transmission lines is very important. This project presents an impedance technique to detect and classify the different shunt faults on transmission lines for quick and reliable protection schemes. Discrimination among different types of faults on the transmission lines is achieved by applying evolutionary programming tools. MATLAB software is used to simulate operating and fault conditions on high voltage transmission line, namely single phase to ground fault, line to line fault, double line to ground and three-phase short circuit fault. These faults are isolated from the system using a designed impedance relay and the distance of the fault is calculated and provided. This research project successfully designed a functional and cost effective fault detection prototype and its simulation was also successful.

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Chapter 1: Introduction

1.1 Background

Electrical energy is a convenient form of energy that is used in our world today [1]. The Electric Power System is in many different sections. One is the transmission system, where power is transmitted from generating stations and substations via transmission lines into consumers [2]. Electrical transmission is delivering generated electricity - usually over long distances - to the distribution grid located in populated areas.

The electricity companies are expected to provide the consumer with a continuous and high-quality service at a reasonable cost. From the literature, when designing power transmission systems, electricity companies are expected to follow a set of standard specifications during the planning and construction phases of transmission lines [3]. This is to ensure that natural elements, such as trees, birds, and strong winds, do not interfere with electricity transmission to consumers. From further research, it is identified that faults that occur in power transmission lines are one of the factors that can cause an interruption of power supply [4,5]. Suitable fault diagnosis methods can provide accurate and effective diagnostic information to dispatch operators and help them take necessary measures in fault situation so as to guarantee the secure and stable operation of the Electric power system. Several existing systems can be deployed, but however, they all have their respective limitations for electrical applications [3]. The protective relay is a conventional way through which faults are detected in transmission lines. This method has a setback;

The protective relay does not pinpoint the fault but only identifies the fault [7]. Another method proposed by the literature is using the fuzzy logic controller to detect faults in transmission lines. This method of fault detection is relatively expensive compared to the conventional method of fault detection. It is very complex to achieve and is sometimes used in combination with other methods to improve its accuracy [4]. The above challenges can be combated through automatic detection of faults in transmission lines using impedance method is proposed. This method provides accurate pinpointing of fault location, low cost, and relatively shorter time locating the fault on transmission lines.

1.2 Problem Definition

In recent years, there has been an increasing interest in analysing and detecting faults in transmission lines in various countries [2]. According to [3], faults in transmission lines, when not detected early, causes damage to the power equipment in the power system and at the consumer's end. The impact can bring about a temporary or long-term loss of electric power in an area. Prompt attention to power transmission faults is vital in power systems to avoid harm and instability to the system.

1.3 Objectives of the Project Work

This research project seeks to design an impedance fault technique prototype and simulate the design in MATLAB to automatically detect faults in electrical overhead transmission lines. The specific objectives are listed below;

1. To design a cost-effective and functional fault detection prototype.
2. To model and simulate a power network for fault analysis.

1.4 Expected Outcomes of the Project Work

It is expected that after the completion of this project, the following outcomes will be achieved:

1. A working design of fault detection technique is developed
2. A well-simulated and functional fault detection technique is developed.

1.5 Motivation of Project Topic

Electrical energy is one of the most utilized forms of energy globally, and in Ghana, to be specific. Electricity (energy in general) is an essential promoter of socioeconomic development [5]. This electric energy is transferred from one point to the other through overhead transmission lines. When these transmission lines develop faults and are not detected earlier, it could lead to the destruction of transformers and other power equipment. Aside from the earlier mentioned, faults that are not detected earlier may also lead to power outages in the various communities. Power outages will cause substantial economic loss to the power industry, including sales revenue reduction due to a decline in electricity sales and troubleshooting costs. It could also lead to, for example, traffic confusion, tourists' stagnation, financial transactions interruption, a few but to mention. These reasons motivated the design of a model that will detect faults accurately in these overhead transmission lines to avoid the cost incurred on both the industries and the individuals in the community.

1.6 Research Methodology to be Used

The research methodology to be used in this project includes;

1. Systematic Literature Review
2. Computer modelling and simulation
3. Design and prototyping

1.7 Facilities to be used for the research

1. Library and internet facilities at Ashesi University
2. Simulation Software provided by Ashesi University

3. Electronics Laboratory at Ashesi University

1.8 Scope of Work

The scope of this project encompasses a research about the various ways by which faults are detected in overhead transmission lines and modelling and simulation a power network for fault analysis. It also includes designing and implementing a prototype of a device to detect faults in overhead transmission lines. The prototype is tested and the performance is analysed.

Chapter 2: Literature Review

2.1 Introduction

The electric power system is divided into various sections, the generation subsystem, the transmission subsystem and the distribution subsystem. This capstone project is majorly concerned with identifying, localising, and detecting faults in 161 kV transmission lines for quick and reliable operation of protection schemes. The problem investigated can be categorised under the protection and fault analysis challenges in power systems. This chapter investigates and analyses literature publications on research done on transmission lines protection and fault detection: faults that develop on them and detect those faults. It will then explore literature publications that addressed the challenges, methodology and gaps in the research area.

2.2 Faults in Electric Transmission Lines

It is crucial to understand what these faults are and the scope of occurrences of these faults on transmission to detect faults alone. In the paper [15], a fault is explained as a decrease in the standard insulation strength between phase conductors or between phase conductors and any earthed objects around the conductors, causing any unwanted or unstable condition transmission line. Under safe working conditions, equipment in a power system network operates at standard voltage and current ratings. This implies that, in practice, a fault may not be detectable immediately the insulation of the system fails at any point. It will be detected when the insulation failure results in excess current or decreased impedance between conductors [15]. The increase in current gives an impedance value beneath that of the most negligible load impedance known to the transmission lines. This discovery is crucial in this paper as it informs the researcher when and how to detect a fault. For example, it can be deduced that until an incident causes a short circuit, open circuit or arcing, a fault will not be detected. There are many causes of faults in the power system network, including natural and artificial occurrences. Therefore, in the design of an automated electronic system that detects line faults, the set up must be designed to detect short circuits, open circuit and arcing.

2.2.1 Causes of Transmission Line Faults

Faults on overhead high voltage power transmission lines are due to lightning, fire and pollution. The managing utility has to take the appropriate mitigating action to reduce the recurrence of line faults. This is possible if the exact cause of the fault is known. The causes of these faults are explained below.

Lightening

According to various literature, lightning is the most dangerous form of overvoltage that has perilous impacts on transmission lines. A lightning stroke ending legitimately on phase conductors builds up a too high voltage, which will flash over the conductor's insulation [2]. The main focus is to look at the influence of lightning on transmission lines in power systems and the gaps inline protection against the lightning effect. Lightning has been noted to cause about 25% of power outages on 230 kV to 116 kV transmission lines, particularly in tropical nations with regular lightning [27]. A typical transmission-line design goal is to have an average of less than 0.50 lightning outages per year per 100 miles of transmission. When lightning strikes any of the transmission lines, voltage and current values increase drastically, which may lead to short circuits or open circuit fault lines [21]. Existing protection includes ground wire, line arrester and other surge protection devices that are installed at every pole. Various pieces of literature state that these devices have unpredictable failure states. When surges caused by lightning produce an overcurrent that exceeds protection device limits, they get damaged. The damaged surge protection devices are not replaced in time due to maintenance problems leaving these transmission lines unprotected against lightning faults [26].

Pollution

Insulator pollution is one of the principal issues of high voltage transmission lines. High voltage cables are outdoor; therefore, their performance is usually affected by the different pollution sources they are exposed. The duration in which insulator is subjected to pollutant and the kind of pollutant determines the chance of flashover in insulators of transmission lines [12]. The pollutants carried by wind settles on the insulator surface, and a contaminant layer appears. Rain and fog cause the layer on the surface to dampen, and upon drying, the layer causes an increase in the conductivity of the transmission cable. A more extensive pollutant layer upon heating up can cause insulator flashovers and current leakage. Three main types of pollution can be identified, namely, industrial, desert and marine pollution. Industrial pollutants include chemical substances, dust, carbon, and cement, released into the atmosphere in dry forms that settle on insulator. Marine pollution exists in coastal environments where a conductive layer, due to the salted dew, forms on the surface of the insulator. Desert contamination happens because of a continuous aggregation of dust that settles on insulator surfaces reducing its efficiency [9]. The effect of pollution on the insulators can be resolved through three alternatives: correct election of the insulator type, maintenance of the insulators and elimination of the source of pollution. All the methods mentioned above of elimination, according to [20], are not cost-effective. Due to this, most developing and underdeveloped countries are unable to avoid these faults caused by pollution.

Fires

Wild land fires underneath power lines can cause flashovers which severely affect industries electricity supply. Because of its dielectric properties, air acts as an isolation medium between live conductors and the ground below it. During a fire, the properties of the air change as smoke particles fill the space between the ground and transmission line, which could result in an electrical discharge or flashover to occur [13]. This usually is referred to as a line fault or flashover. Harvesting fires directly beneath high voltage transmission lines are often reported to cause the phase to phase and phase to earth flashovers. The insulation strength of air is decreased by reducing air density due to the temperature increase caused by the fire. The flashover voltage depends on temperature and humidity

2.2.2 Types of Transmission Line Faults

Transmission lines faults can be classified as shunt faults and open circuit faults [4]. Some examples of the shunt faults in transmission lines are; Single-phase-ground short-circuit faults, line to line short-circuit faults and double-line to ground short-circuit faults, three-phase to ground short circuit fault. In an open-circuit fault, all three-phase is simultaneously short-circuited; hence the network remains balanced. This project focuses on unsymmetrical faults; that is, faults that make the system unbalanced. Therefore, open circuit analysis will not be considered.

Single-phase-to- ground short-circuit faults

This type of fault is the most common type of fault in transmission line systems. This is because it has been estimated to account for about 75% of faults in transmission lines systems. This kind of fault occurs when any of the lines comes into contact with the ground resulting in heavy flow of current to ground from the failed phase. *figure. 2.1* shows the description of this type of fault. Suppose the phase *a* is connected to ground at the fault point *f* as shown in a figure below. I_a, I_b and I_c are the current and V_a, V_b and V_c are the voltage across the three phase line a, b and c respectively. The fault impedance of the line is Z_f. The current in the healthy phases will be zero since they will be open circuited and the current in the faulted line will be given by the voltage in the faulted line divided by the faulted impedance as shown in equation (1) and demonstrated in the figure 2.1 below.

$$I_c = \frac{V_C}{Z_f} \quad while\ I_a = I_b = 0 \quad (1)$$

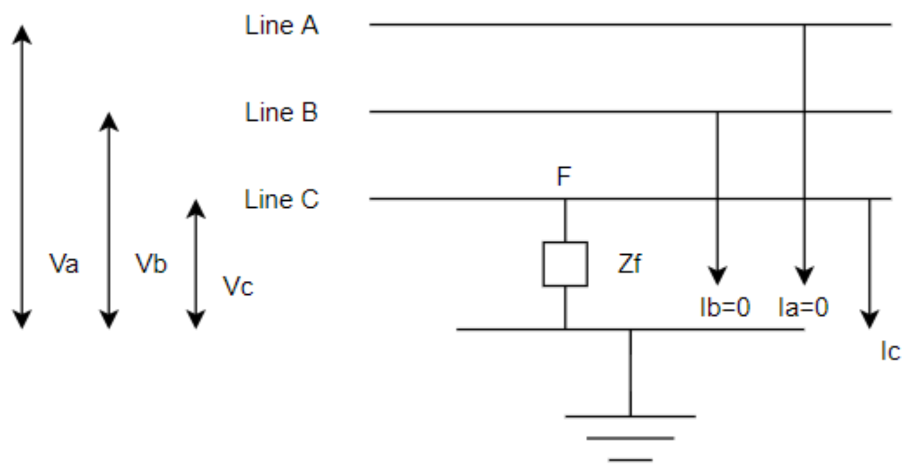

Figure 2.1 A diagram of Line to ground Fault

Line-to-line short-circuit faults

The second most occurring type of shunt faults is the Line-to-Line fault (LL). This is said to occur when two transmission lines are short-circuited. It has been found to cause about 15 to 20 % of line faults. The current in the healthy cable gets to zero while the current in the faulted line b will be the negative of the current in the other unhealthy line. Mathematically, $I_c = 0$, while $I_b = -I_a$. The difference in voltage in the two faulted lines is equal to the product of fault impedance and current through any of the faulted lines.

Figure2.2 illustrates double line to ground fault and equation (2) below demonstrates the voltage in the faulted line.

$$V_c - V_a = Z_f(I_b). \qquad (2)$$

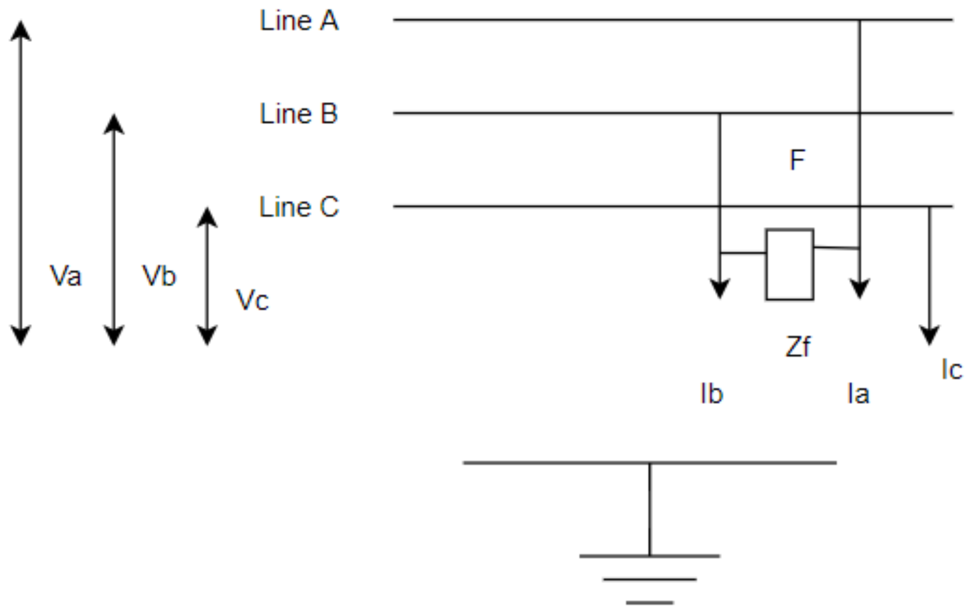

Figure 2.2 A diagram of Line to Line Fault

Double Line-to-ground short-circuit faults

This type of fault occurs when two phases or lines in the three phase transmission line is connected to ground. This can be cause by for example falling trees or a lightning strike as mentioned earlier in this literature. In this case, fault current will flow from the line to the ground within the involved phases, say, Phase B and Phase C. During this type of fault, $I_a = 0$, while $I_b = I_c$ and the voltage is given in equation (3) and illustrated in *figure 2.3.*

$$V_c - V_b = Z_f(I_b + I_c). \qquad (3)$$

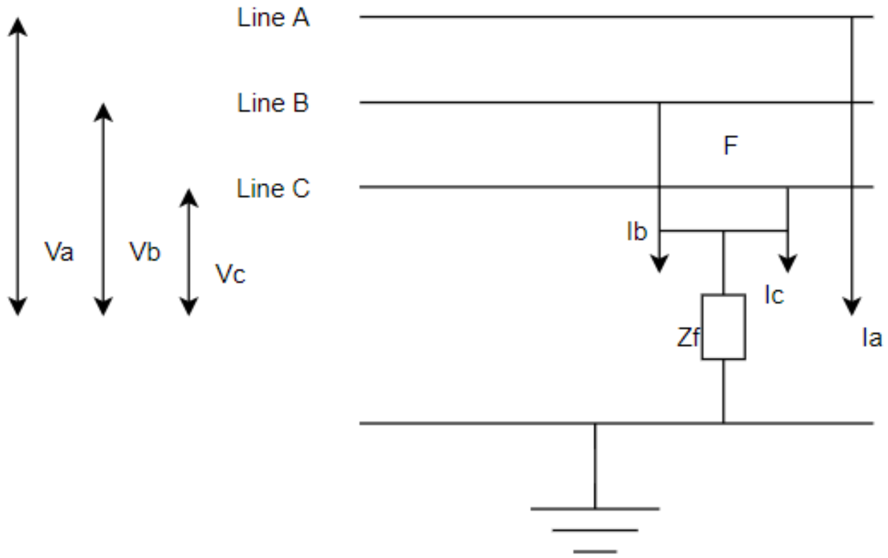

Figure 2.3 A diagram of Double-Line to ground Fault

2.3 Methods for Fault Detection in Electrical Transmission Lines

A variety of fault location schemes have been developed over the years. Typical systems include impedance-based locators or those measuring the impedance seen by one or both ends of the transmission line and travelling wave-based locators.

2.3.1 Impedance and Fundamental Frequency Component Based Methods

The use of fundamental-frequency voltages and currents at the terminals of the line appears to be the simplest approach to finding faults in transmission lines. It is usually considered that the calculation of the impedance of the faulty line is equivalent to the distance of the fault [11]. This method is very simple, and economical in terms of implementation.

2.3.2 Travelling Wave Based Methods

This method of fault detection takes into consideration the voltage and current waves that is travelling at the speed of light from the location of the fault to the terminals of the lines [14]. The main idea behind this approach is based on the relation between the forward and reverse travelling waves in the transmission lines. The first few travelling waves of the current and voltage at where the locator is installed is used to determine the fault position [16]. This method is considered more accurate than the method of using the fundamental frequency components for fault detection but it requires high sampling rate. It is however more complex and expensive. It has also proven to be insensitive to fault type and power frequency phenomena such as current transformer saturation. Travelling waves method also has the problems with distinguishing between travelling waves reflected from faults and from the remote ends of the transmission lines [16] [7].

2.3.3 Artificial Intelligence (AI)

Research continue to seek a more accurate approach for detecting faults in power systems. A new technique has been discovered using knowledge-based artificial intelligence methods including artificial neural networks(ANN) and fuzzy-logic systems to locate faults in transmission lines [13]. An ANN is a set of elementary neurons that are connected together in different architectures organized in layers that are biologically inspired. The artificial neural network(ANN) have to be trained with numerous actual cases [13]. It therefore concurrently compares the information it obtains from the transmission lines to the cases that has been input into it. When there is an abnormality it will then classify it as a fault.

2.4 Protections in Electrical Transmission Lines

Blackburn defines protection as ‘‘the science, skill, and art of applying and setting relays and/or fuses to provide maximum sensitivity to faults and undesirable conditions, but to avoid their operation on all permissible or tolerable conditions [27]”. In every power system it is desirable that only the faulted equipment or transmission lines are isolated so that the unfaulted part of the system can still supply power to the loads. This literature will discuss three main ways of transmission line protection.

2.4.1 Transmission Lines Protection using Distance Relays

A *protective relay* is a piece of preventive equipment with a priority to isolate system fault or eliminate abnormal conditions in the power system [28]. Therefore, a distance protection relay is a name given to any protective device whose action depends on the distance of the feeding point to the fault. The operation time of a distance relay is the ratio of voltage to current, the impedance. It is a double actuating quantity relay; one of the coils is energized by voltage while the current energizes the other. The distance relay is given a set value of impedance, and the relay operates only when the impedance obtained from the transmission lines falls below the set value. During a three-phase fault, the magnitude of current increases while the voltage near the fault point decreases [27]. This type of protection is shown in figure 2.4. It has the advantage of having a high fault clearing speed and can also be used for both phase and ground faults.

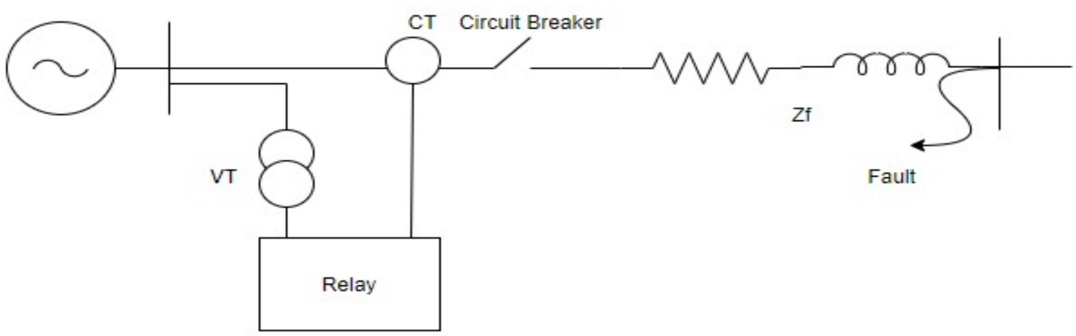

Figure 2.4 A diagram illustrating line protection using distance relay.

2.4.2 Transmission Lines Protection using Over current Relays

This is the simplest way of protecting a line and is, therefore, widely used in power systems. Overcurrent relay protection owes its application because the fault current in the event of a short circuit will raise the current in the transmission line to a value greater than the specified adjustable relay current magnitude, called the pickup current [27]. When the input current of the relay is greater than the pickup current, the relay contacts close instantaneously to energize the circuit breaker trip coil. Time-delay overcurrent relays also respond to the magnitude of their input current, but with an intentional time delay. The time depends on the input current of the time overcurrent relay. If the input current is a significant multiple of the pickup current, the relay operates on a small time interval. The overcurrent protection is mainly provided at the supply end of the line.

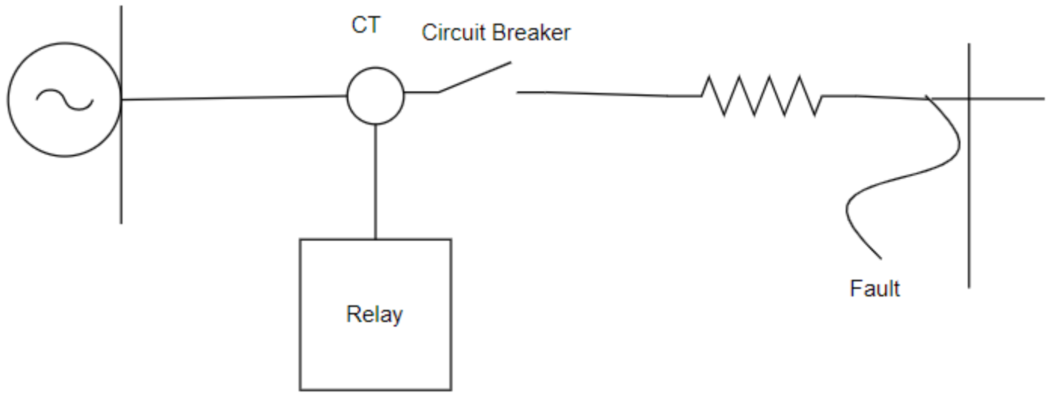

Figure 2.5 A diagram illustrating line protection using over current relay

2.4.3 Transmission Lines Protection using Differential Relays

Differential Relays are commonly known for being used to protect generators, buses and generators [27]. It provides sensitivity, selectivity and security. It is a relay that operates on the phase difference of two or more electrical quantities. Consider the comparison of input current flow in the transmission line with the output current. If the magnitude of input current is more than the output current of the relay it is said that a fault has occurred. For Bus protection using differential relay, three relays will be needed, one for each phase. Triggering any of the relays caused all three relays to be open thus isolating all the three phases from the system. In the *figure2.6* below, when there is no internal fault, the total current is zero hence the relay does not operate but when there is a fault the total current fault triggers the relays and the entire three phase is isolated from the transmission system.

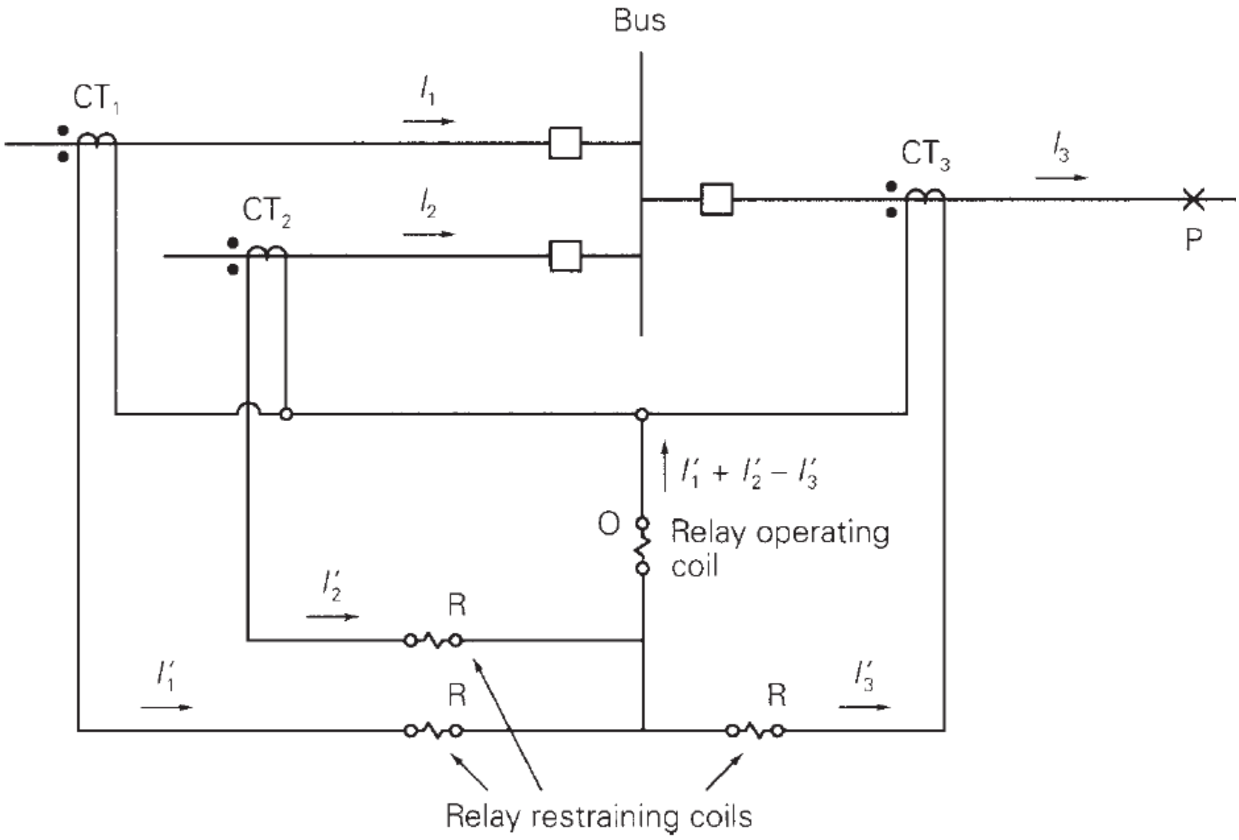

Figure 2.6 A diagram illustrating line protection using differential relay

2.5 Related Works on Electric fault Detection in Transmission lines

In this paper [29], a technique of identification and classification of faults on transmission line has been proposed. The main objective of this literature was to discriminate among different types of faults on the transmission lines through the application of wavelet transform. The method utilizes wavelet transforms to extract the transient energy from current and voltage samples extracted from the fault point. The wavelet transforms algorithm is based mainly on calculating the RMS value of transient energy of pre-fault and post-fault signals of the three-line currents and three-line voltages. This extracted information from the fault points then serves as input to a Support vector machine for training. According to the literature, the proposed scheme has the advantage of being free from many difficulties that traditional neural networks approaches, such as generalization. In section 2.3 of this chapter, various methods for fault detection. The proposed method of fault detection in this chapter can be classified under the use of travelling waves for fault detection.

In contrast, the proposed method in this project is the impedance method of fault detection. Although the wavelet transform approach in this literature was quite successful in determining that there is a fault, it had the disadvantage of locating the exact location of a fault. It could not perform classification of fault on a series compensated line because it required that a few more features or inputs are added for the SVM training [30]. Also proposed another technique of fault detection using Artificial Neural Network-based six-phase transmission line fault detector and fault classifier. The literature's main objective is to stimulate and protect the six-phase transmission line against any ground faults.

A 765kV, 6 phase transmission line of 100km length is simulated for different system conditions and parameters. The algorithm in such a way that the fundamental components of six-phase voltages and currents at one end only are collected using voltage and current transformers. Remote end data are not required. The Simulation results show that single phase-to-ground faults can be correctly detected and classified within one cycle from the inception of the fault. Although the neural-network-based approach has been quite successful in determining the correct fault type, the main disadvantage of this approach, according to the literature, is that it is very complicated, expensive and time-consuming. It requires a considerable amount of training effort for good performance, especially under a wide variation of operating conditions such as system loading level and fault. Moreover, another disadvantage of the neural-network-based algorithms is that the training may not converge in some cases. The starting point is chosen at random and can end up at a local minimum.

[31] This literature considers a one-terminal fault location system for transmission lines. An impedance-travelling wave assembled algorithm, which combines the measurement impedance method with the travelling wave method, is presented. This literature proves that the measurement impedance method guarantees reliability, especially when the fault point is near the detective bus and has optimum accuracy when it is far from the detective bus. Results of the simulation test proved that assembled algorithm proposed is correct. Travelling wave velocity has no relation with fault accuracy and can be corrected to its actual velocity online. However, in the worst situation, the measurement impedance method can still guarantee reliability despite that the travelling wave method is no available. They, therefore, concluded that the combination method might be helpful but implementing a design that has just the measurement impedance method will be a much more straightforward and cost-effective method of fault detection in transmission lines.

Chapter 3: Design Methodology

3.1 Introduction

The aim of this project is to design a device that will protect transmission lines against overcurrent and overvoltage as well as have the capabilities of fault identification, localization and detection of faults in 161 kV transmission lines subsystem of the power system. To do this a proof of concept design would be developed and simulated in MATLAB/SIMULINK. In this chapter, the design requirements of the proposed system will be discussed. It will detail the system, user, and environmental requirements of the system and surrounding. These requirements will influence the design and selection of materials for the proposed system.

3.2 System Requirements and Architecture

The requirements will be taken from the user's perspective, that of the environment, and the system itself. This will help in creating a system that achieves the desired basic task. The main users for the proposed system will be electrical engineers who work on transmission lines.

Table 3.1 shows the system requirements and their respective justifications for the prototype of the automatic fault detection device.

Table 3.1: System requirements for the protype of automatic fault detection device

No.	System Requirement	Justification
1	Main power supply from power grid	It is an efficient and reliable source of power
2	An efficient fault detection block that supports sensors and instrumentation devices.	It serves as the brain of the entire system and its efficiency impacts the entire system
3	Instrumentation information data should be checked instantaneously and sent to fault detection block	This is to make sure that a fault is detected in time at the same time.
4	Technique should be able to calculate fault distance and classify the kind of fault	This is to make it easy for electrical crew to solve any issues of blackouts within the shortest possible time.
6	Should be low-cost	To make it easy to use

The system to be built will be separated into the electrical phase, and programming phase. The electrical phase includes all the necessary circuit designs needed to achieve the specified tasks while the programming phase will include the control logic that will be implemented in coding the electronic system.

3.3 Design Components

In order to fully meet the requirements of this project, the following components need to be used. They are, Three Phase AC power source, Impedance Relays, Bulbs, Circuit Breaker, Display, current transformers, voltage transformers, microcontroller, Rectifiers.

3.4 Functional Block Diagram of Design

The hardware components of this project consist of a power source a current and voltage sensor connected to the transmission lines and connected to a distance relay and then to fault detection block.

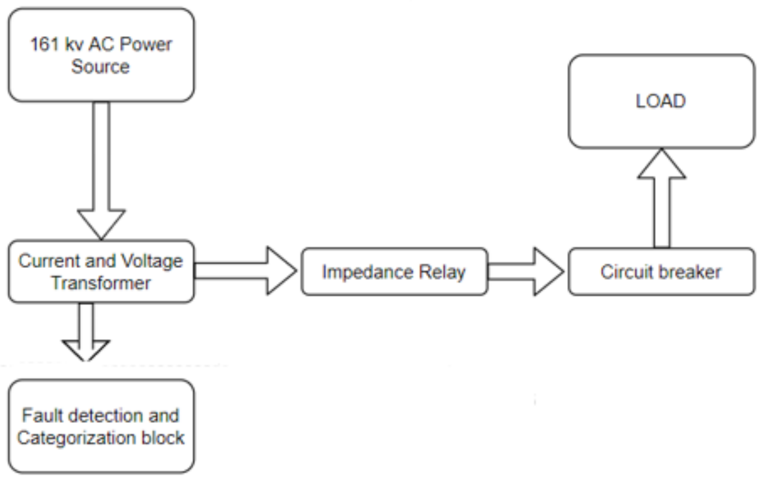

Figure 3.1: Function Block Diagram of Design

3.4.1 Current transformer

Current transformers reduce high voltage currents to a much lower value and provide a convenient way of safely monitoring the actual electrical current flowing in an alternating current transmission line. Current transformers can reduce or "step-down" current levels from thousands of amperes down to a standard output of a known ratio to 1 Amp. In this projected the current sensor would feed the distance relay with current reading in the transmission lines and will also feed the microcontroller with the current values so that the fault can be classified and transmitted to control room. For a transmission line of 100 km in distance assumed in this project, the current transformer will be stepping the current down from 31.5 kA to 1A.

Figure 3.2: Current Transformer

3.4.2 Voltage transformer

Power voltage transformers are connected to the high voltage overhead line to provide power at low voltage. Due to this direct connection to the transmission line, the reliability of Power voltage transformers is extremely high. In this design three single phase voltage transformers will be utilised. For this design, the voltage transformer will be rated 161kv at the primary side 93 kV at the secondary side. The output of each transformer will be fed to the impedance relay and to the microcontroller.

Figure 3.3: Voltage Transformer

3.4.3 Microcontroller Atmega328

The microcontroller chosen for this project is one of the latest products from microchip Atmel. It was picked for the project because it has significant features like low prices, wide range of application, high quality, and easy availability []. It served as the brain of design. It contained a set of programming codes which have been stored in the EEPROM which enabled it to classify the fault type based on the voltage and current values. Based on the code, the microcontroller compares these values to see whether they are within the range required. If the voltage and current values are out of range as compared to the reference, it gives an indication of a fault. The microcontroller also calculates the fault distance, relative to the device based on an impedance-based algorithm and then relays this information to the modem for transmission.

Figure 3.4: Microcontroller Atmega328

3.4.4 LCD

An LCD is an electronic display module that uses liquid crystal to produce a visible image. In this project design, the 6x2 LCD is connected to the microcontroller to display the status of the various phases. 31

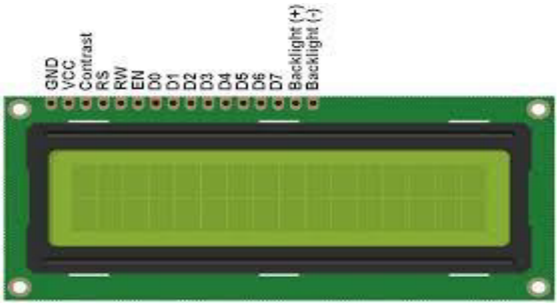

Figure 3.5: LCD

3.4.5 Circuit Breaker

Circuit breakers are regulatory devices for overcurrent protection: overloads and short circuits. Their function is to act when a fault is detected to cut off the electricity supply of the installation and allow its restoration when the anomaly has been solved. In this design it will be used alongside a relay to cut off the transmission lines when a short circuit occurs and will be rated 161 kv and having a reclosing time of 0-0.3 sec.

Figure 3.6: Circuit Breaker

3.4.6 Impedance Relay

An impedance relay is a voltage restrained overcurrent relay. The relay measures impedance up to the point of fault and gives tripping command if this impedance is less than the relay setting Z. Relay setting Z is known as replica impedance and it is proportional to the set impedance, that is impedance up to the reach of the relay. The relay is used to monitors continuously the line current (I) through current transformer and the bus voltage (V) through voltage transformer and trips the circuit breaker when the V/I ratio falls below the set value.

Figure 3.7: Impedance Relay

3.5 Circuit Diagram

The circuit diagram for the transmission line fault detection and protection was designed using Autodesk Eagle software. Figure 3.18 shows the various connections between the components listed in Section 3.4.

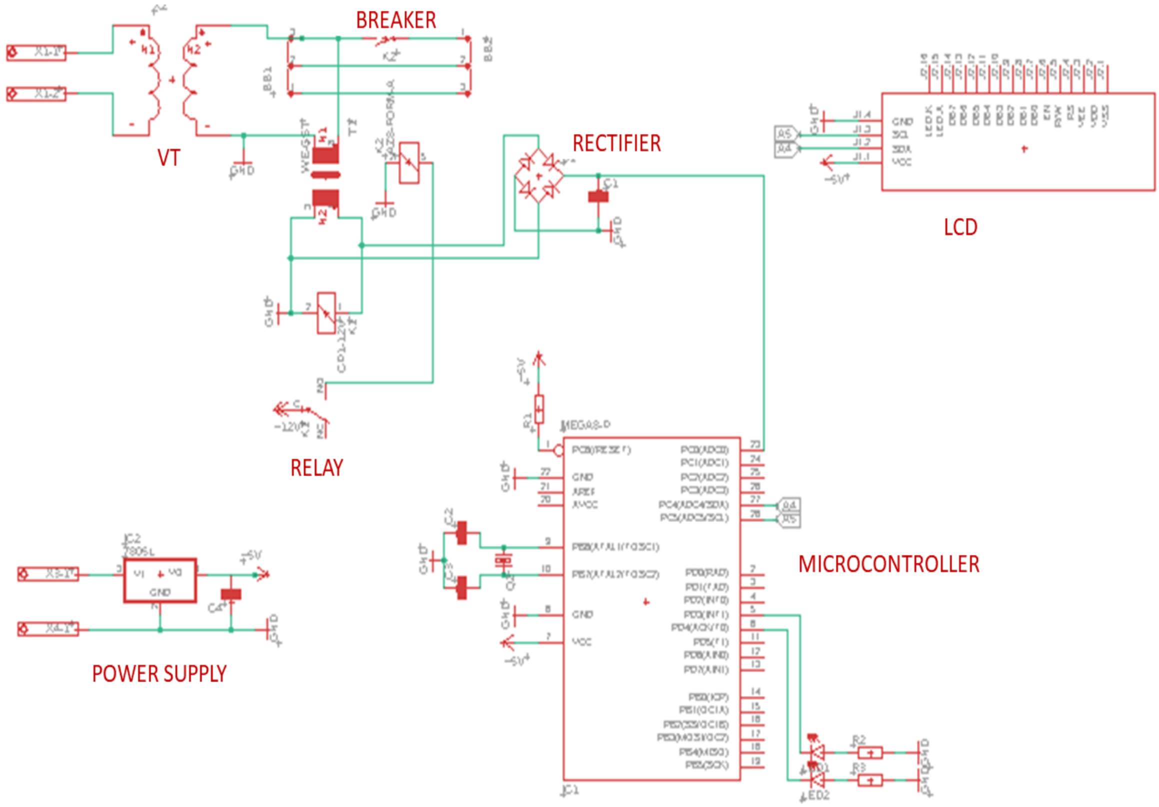

Figure 3.8: Single Line Circuit Diagram for Design

3.5.1 Software Design

The software design of this project includes the programming of an at the fault detection block which serves as the brain for the entire design. The programming of the components and microcontroller was done using multitasking in MATLAB. This is to allow the different components to function concurrently. The entire system is automated. The fault detection block derives its data from voltage and current transformers and gives outputs to the various actuators.

Figure 3.4.14 shows the flowchart for the operation of the Fault Detection Block.

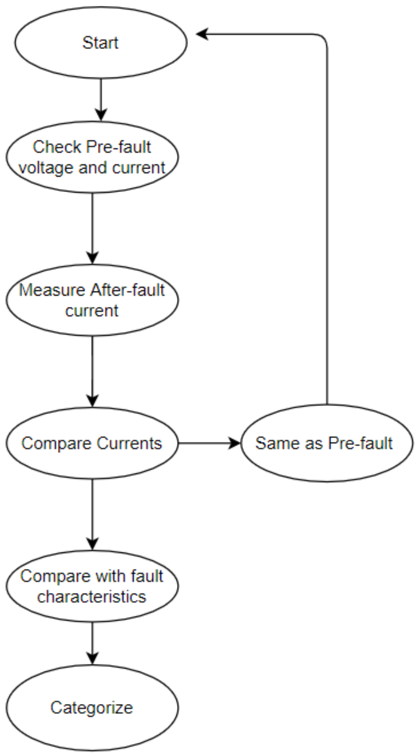

Figure 3.9 Flow Chat for Software Design

Chapter 4: Modelling and Simulation of the Design

4.1 Introduction

This chapter presents the simulation model for the project design. The MATLAB simulation blocks are stated as well as the methods for the simulation

4.2 Simulation Block Components

In order to fully meet the requirements of this project, the following components need to be used in the simulation process. MATLAB three- phase power source, Impedance relays block, three phase series load, Circuit Breaker, Display, impedance calculation subsystem, current transformers, voltage transformers, fault detection block, average voltage and current measurement subsystem.

4.3 Results of Hardware simulation

The hardware component of the simulation consists of the power source, the instrumentation transformers, scopes and displays. The Instrumentation transformers were connected to the relay and the fault detection block. After simulation, it was observed that each transformer generated data and each relay was able to reflect the necessary changes based on transformer input, all while in automatic control mode. The detection block was also able to detect the fault and categorise the faults accordingly. Figure 4.1 shows the hardware set up for the fault detection technique.

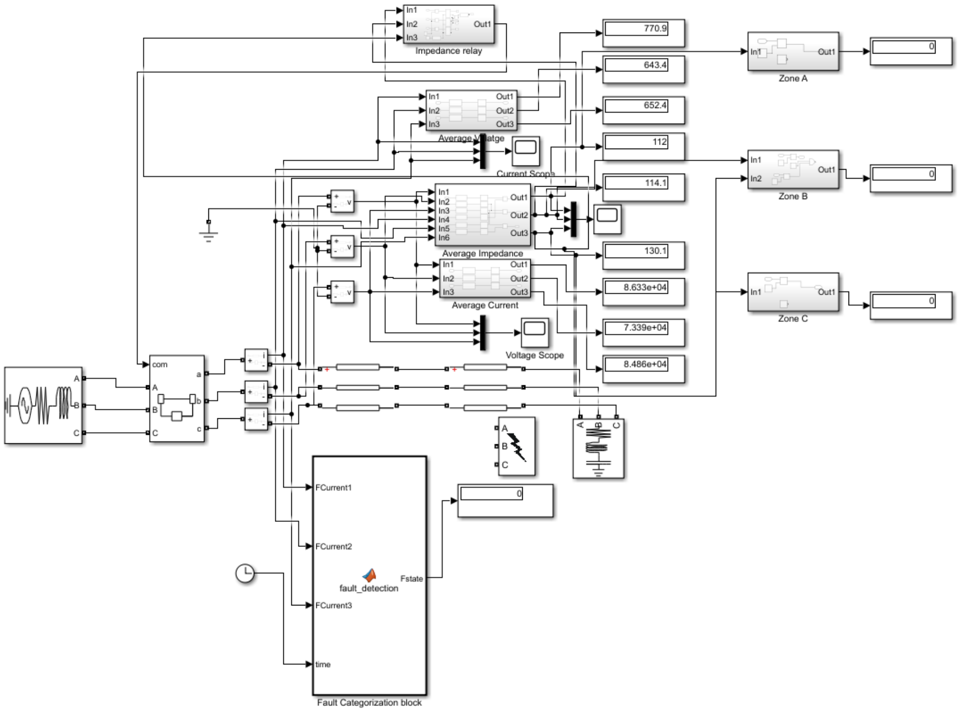

Figure 4.1: Hardware Simulation Results

4.4 Transmission Line Modelling

The power system designed for the research project consists of a 161 kV three-phase generator to two 100 km long transmission line. A circuit breaker was connected in series with the transmission line. The load end consists of a 100 MW of load connected to the system. The voltage and current waveforms have been observed under different fault conditions, namely, three-phase, double line to ground and single line to ground faults. The impedance (R-X) plots for different faults and different distances between relay location and the occurrence of a fault (10 km, 30 km, 100 km) have also been plotted. The magnitude of various line parameters used in the simulation model is given in the table below.

Table 4.1: Transmission Model Line Parameters

No.	Transmission Line Parameter	Value
1	Length of transmission line	100 km
2	Nominal frequency	50 Hz
3	Line Resistance (R1=R2)	0.01273 Ω/Km.
4	Line Inductance (L1=L2)	0.9337×10-3 H/Km.
5	Line Capacitance (C1=C2)	12.74×10-9 F/km.
6	Zero Sequence Resistance (R0)	0.3868 Ω/Km.
7	Zero Sequence Inductance (L0)	4.1264×10-3 H/km
8	Zero Sequence capacitance (C0)	7.751×10-9 F/km.
9	Total Positive Sequence Impedance (Z1)	29.6 <87.51
10	Total Zero Sequence Impedance (Z0)	135 < 75.38

4.5 Methods

The design of the simulation for this project requires that components of the software designs work hand in hand to make sure the entire design is working efficiently. The microcontroller being the brain and centre of the design is represented by the Fault detection block in Simulink. The entire system is automated. The transmission lines with will be made using conductors to carry the electricity. The current transformer and voltage transformers are attached to the terminals of each of the conductor cables. It will be measuring the voltages and currents from the transmission line. The output of the voltage and current sensors will be fed into an impedance relay and will also be connected to the fault detection. When the ratio of voltage to current readings from the transformers exceed the set impedance limit of the relay, the relay coils will be energised to trip the circuit breaker. In doing so the faulty transmission lines will be isolated from the rest of the transmission system.

The fault detection block receives the values check whether the voltage and current are within ranges. If it is not within range, the fault classification block classifies the fault, calculate the fault distance show which area the fault is located with the help of the impedance relay and displays the results on the display.

4.6 Impedance calculations

The algorithm that was used to calculate the various fault impedance is given in the table 3.1 below.

Table 4:2: Impedance calculation Algorithm

Fault Type	**Algorithm**
AB or ABG	(Va-Vb)/(Ia-Ib)
BC or BCG	(Vb-Vc)/(Ib-Ic)
(AC or ACG	(Va-Vc)/(Ia-Ic)
AG	Va/(Ia+3*K0*I0)
BG	Vb/(Ib+3*K0*I0)
CG	Vc/(Ic+3*K0*I0)
ABC or ABCG	(Va/Ia) or (Vb/Ib) or (Vc/Ic)

Here A, B, C represents the faulty phase of the system and G represents the ground fault
Where,
Va= Voltage in A-phase
Vb= Voltage in B-phase
Vc= Voltage in C-phase
Ia= Current in A-phase
Ib= Current in B-phase
Ic= Current in C-phase
I0= zero sequence current

$I0= (Ia+Ib+Ic)/3$ (1)
$K0= (Z0-Z1)/3*Z1$ (2)
Where,
K0= residual compensation factor
Z0= zero sequence impedance
Z1= positive sequence impedance

4.7 Relay Modelling

In this subsystem of the simulation model, the mean value of impedance is obtained by dividing the mean value of voltage by the mean value of current of the respective phases. The output of the average impedance subsystem is fed into the isolation subsystem of the impedance relay subsystem. The isolation block is designed so that whenever the impedance of the fault line is decreased below a prespecified value, the relay circuit senses the fault and gives a signal to the circuit breaker to open the line.

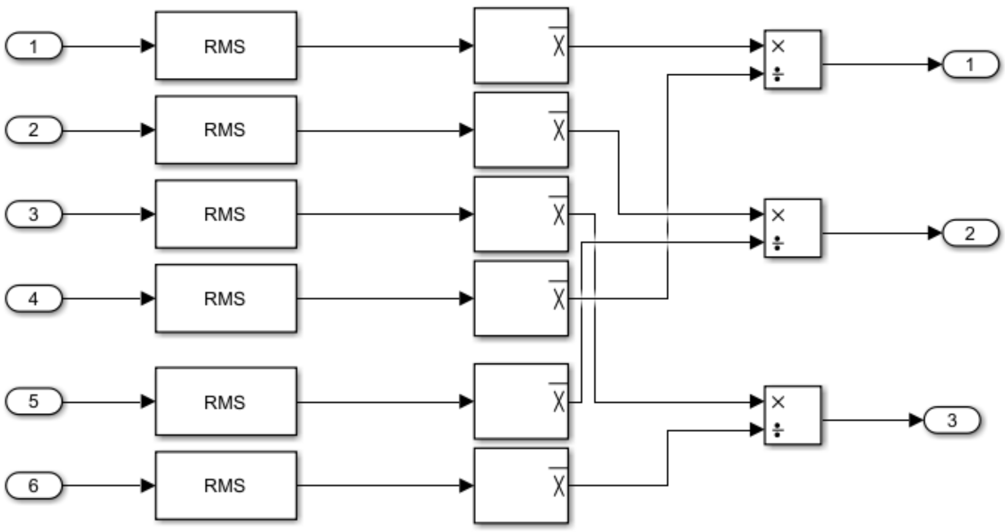

Figure 4.2: Average Impedance Calculator

Chapter 5: Results and Discussions

5.1 Introduction

This chapter presents the results from the simulation of the fault detection technique in MATLAB Simulink. These results are grouped in three. First of all, we will discuss the results from the fault analysis of the various shunt fault. The results from the distance calculations will also be shown as well as the categorization results.

5.2 Results of Fault Analysis

The main faults that were investigated in this project was single-line-to-ground fault, double-line-to-ground fault, three-phase-line-to-ground fault and line-line faults. A transmission line system was created in MATLAB. A three-phase source was connected a distributed parameter line of 100km each and a load with Q equals 100VA was also applied. A three phase fault was applied and the various faults were analysed. From figure4.1 below, it can be observed that when there is no fault, the voltage in the system is almost around 151 kv and the nominal transmission line current is 1.4 kA. After simulating to obtain the pre-fault voltage and current, a fault was applied to the system to the system and the results were analysed.

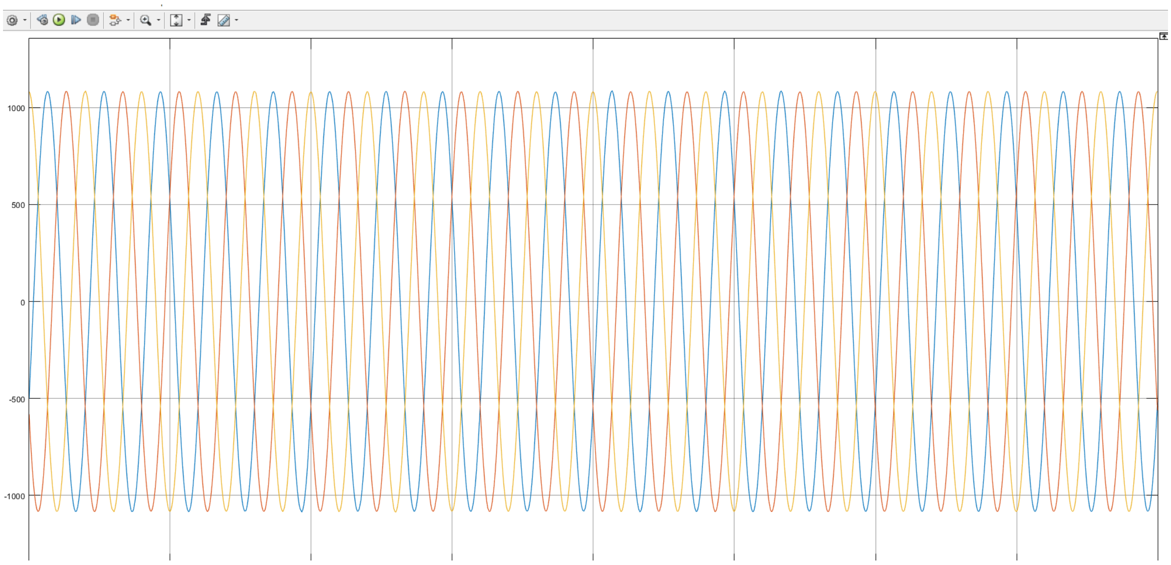

Figure 5.1: Transmission line Current Graph with no fault

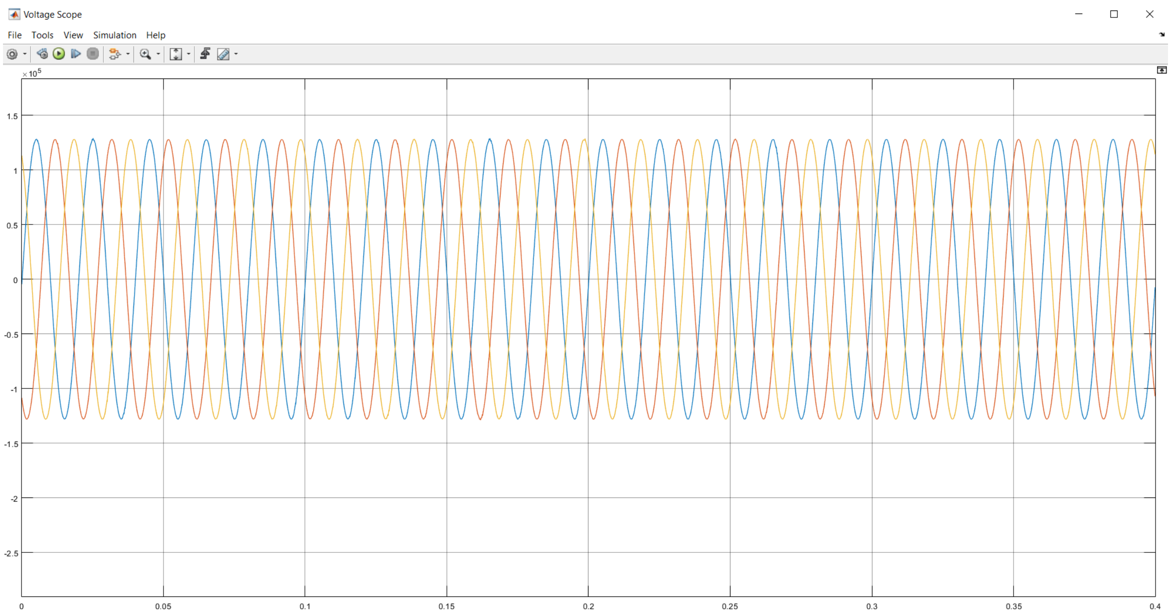

Figure 5.2: Voltage Graph with no fault

5.2.1 Single-Line to Ground Fault

A single to line fault was applied to the transmission lines and the outputs of the voltage and current measuring block was observed. From *figure 4.4* it can be observed that the current output of the transmission line in the phase *a* (the faulted line) drastically increased. The normal current of the transmission line as shown is *figure 4.2* was 1.4 kA. But after single line to ground was applied to the line A, the maximum current observed was approximately, 4 KA. However, the current in the healthy lines remained within the normal current range of 1.4 kA. *Figure 4.4* bellow illustrates the current output for a single-line-to-ground fault(SLG).

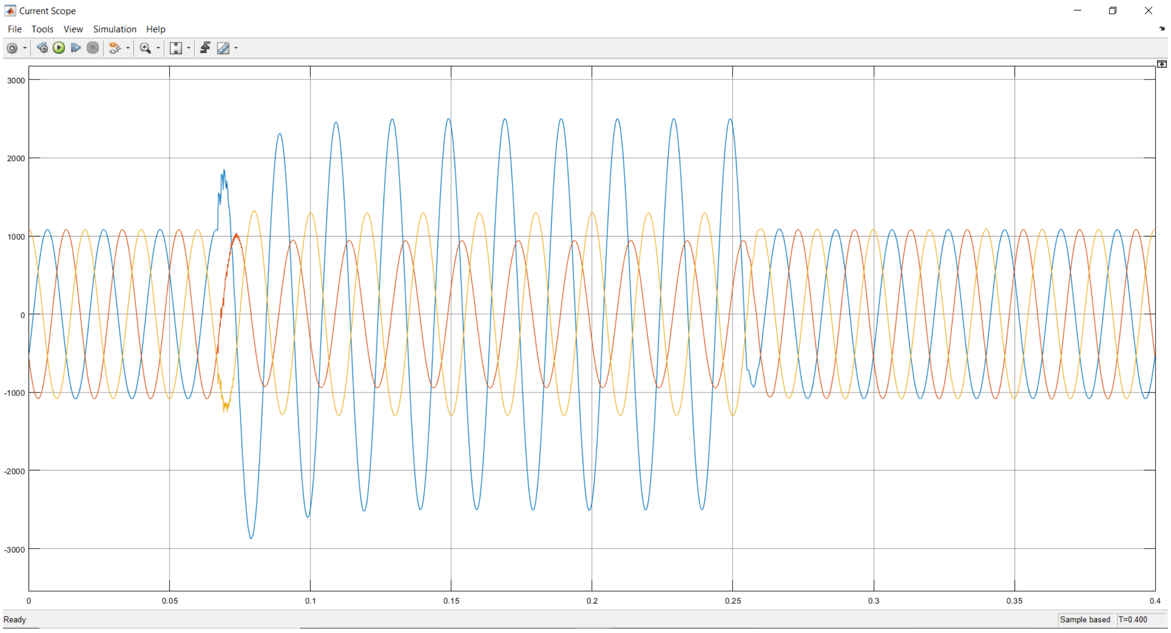

Figure 5.3: Current Output for a SLG fault

5.2.3 Double-Line to Ground Fault

A double to line fault was then applied to the transmission lines and the outputs of the voltage and current measuring block was observed. From *figure 4.5* it can be observed that the current output of the transmission line in the phase *a and phase b* (the faulted lines) drastically increased to about 6 KA. On the other hand, the current in the healthy line remained within the normal current range of 1.4 kA. *Figure 4.5* bellow illustrates the current output for a double-line-to-ground fault(DLG).

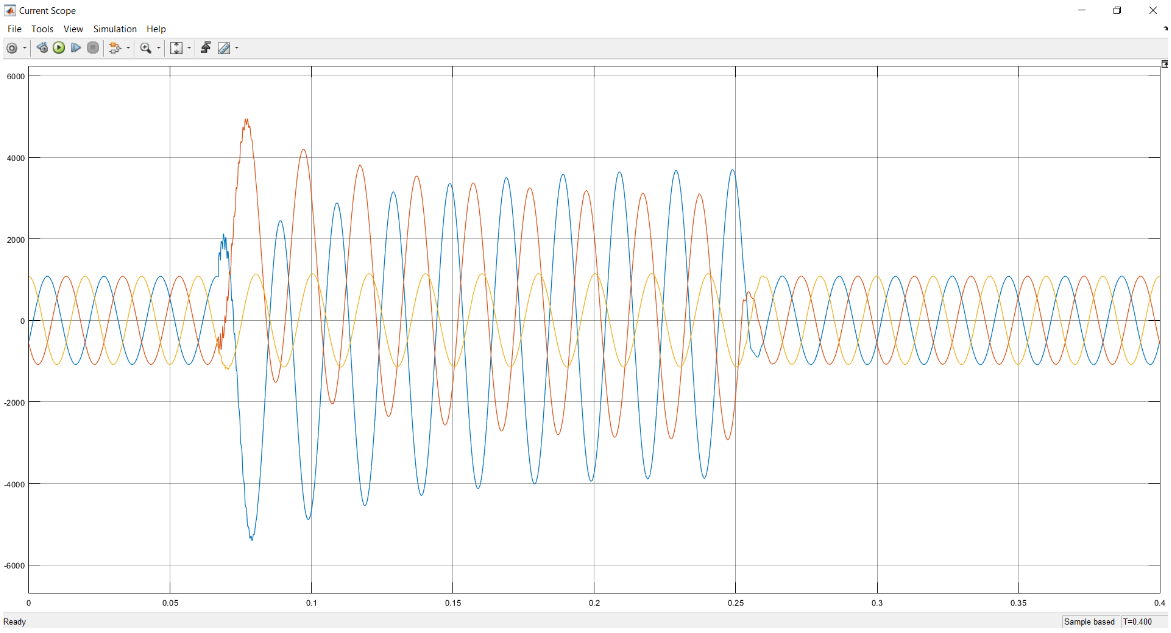

Figure 5.4: Current Output for a DLG fault

5.2.4 Three-Line to Ground Fault

A three phase line to ground fault was applied to the transmission lines and the outputs of the voltage and current measuring block was observed. From *figure 4.6* it can be observed that the current output of the transmission line in the phase *a and phase b and phase c* (the faulted lines) drastically increased to about 7 KA. It can therefore be concluded that three phase to ground fault is the most sever shunt fault in transmission lines system *Figure 4.6* bellow illustrates the current output for a double-line-to-ground fault(DLG).

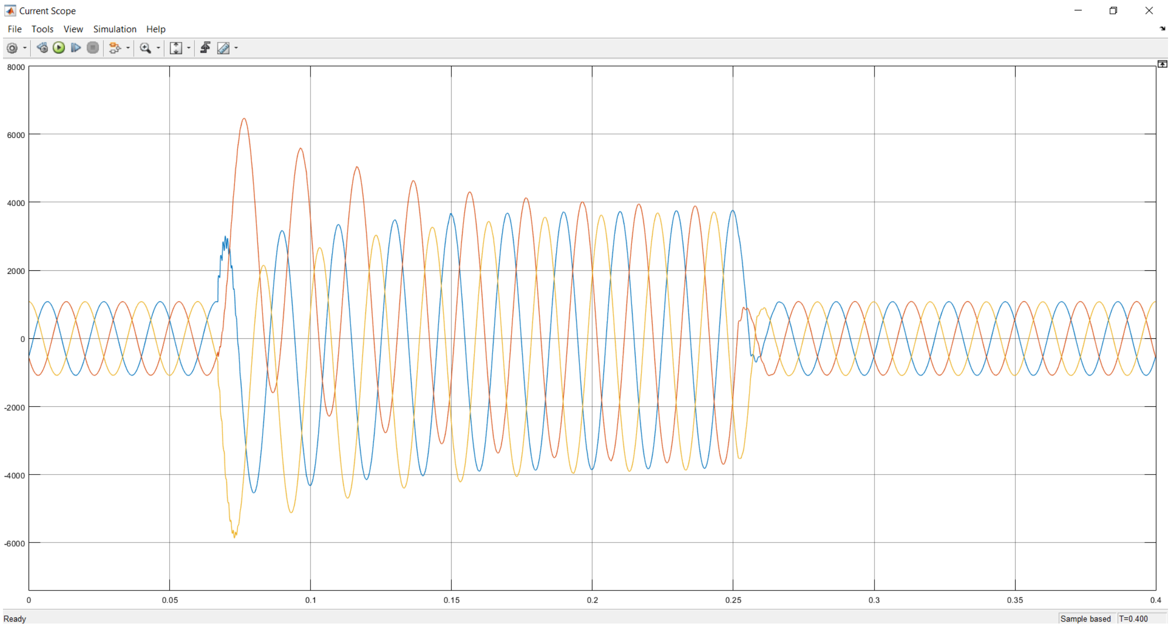

Figure 5.5: Current Output for a Three Phase to Ground Fault

5.2.5 Line-Line Fault

A Line-Line fault between phase *a* and phase *b* fault was applied to the transmission lines and the outputs of the voltage and current measuring block was observed. From *figure 4.8* it can be observed that the current output of the transmission line in the phase *a and phase b* the faulted lines) drastically increased to about 7 KA. It can be observed that Line to Line behaves similarly to two line to ground fault.

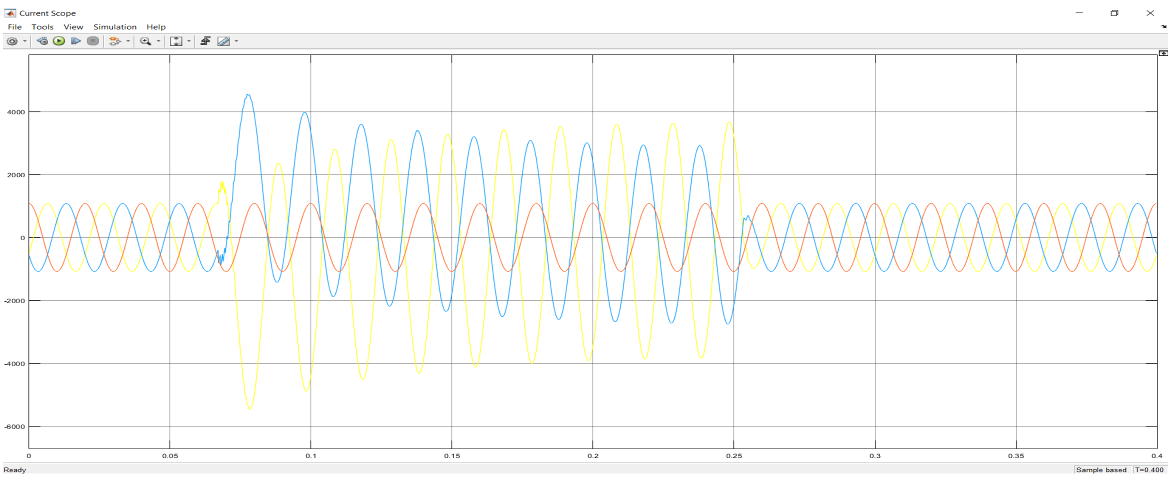

Figure 5.6: Current Output for a Line-Line Fault

5.3 Results of Fault Isolation and Protection Using Impedance Relay

There are four subsystems in the Simulink model. In the first subsystem average value of voltage is calculated and an output was given. In the second subsystem average value of current is calculated and the output given. The output of the average voltage and current serves as the input for the third subsystem. In the third subsystem average value of impedance is measured. The impedance subsystem then serves as the input to the relay subsystem. The Relay model works hand in hand with the circuit breaker. The relay is designed such that whenever the impedance of the fault line is decreased below a prespecified value (125 in this design), the relay circuit senses the fault and gives a signal to the circuit breaker to open the line.

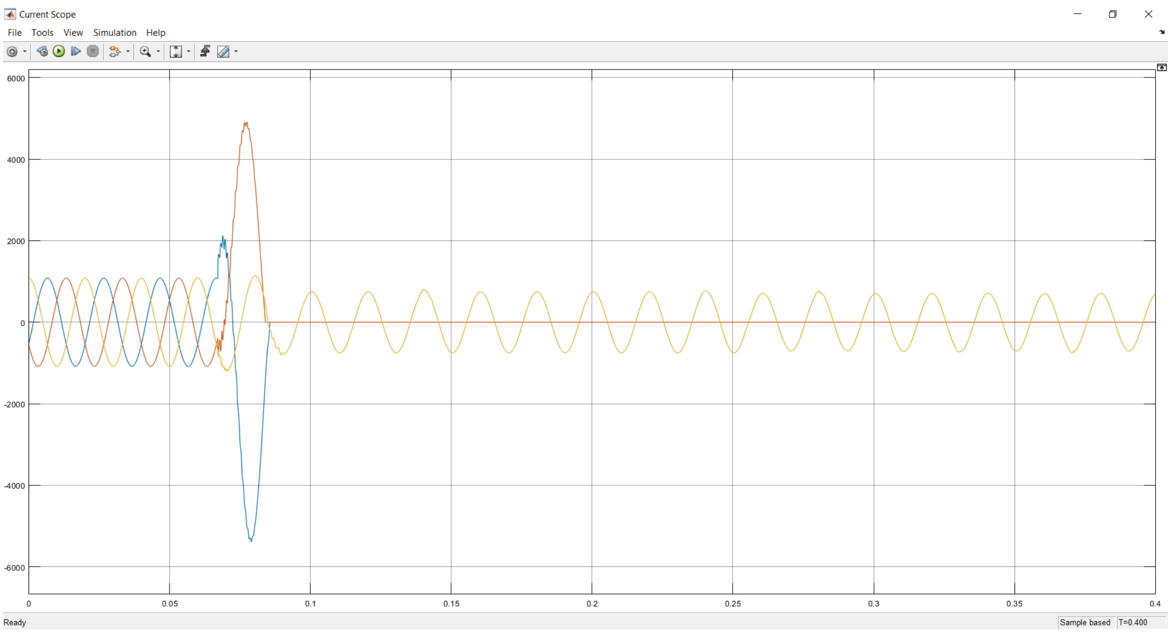

Figure 5.7: Current Output Showing isolation for a DLG Fault

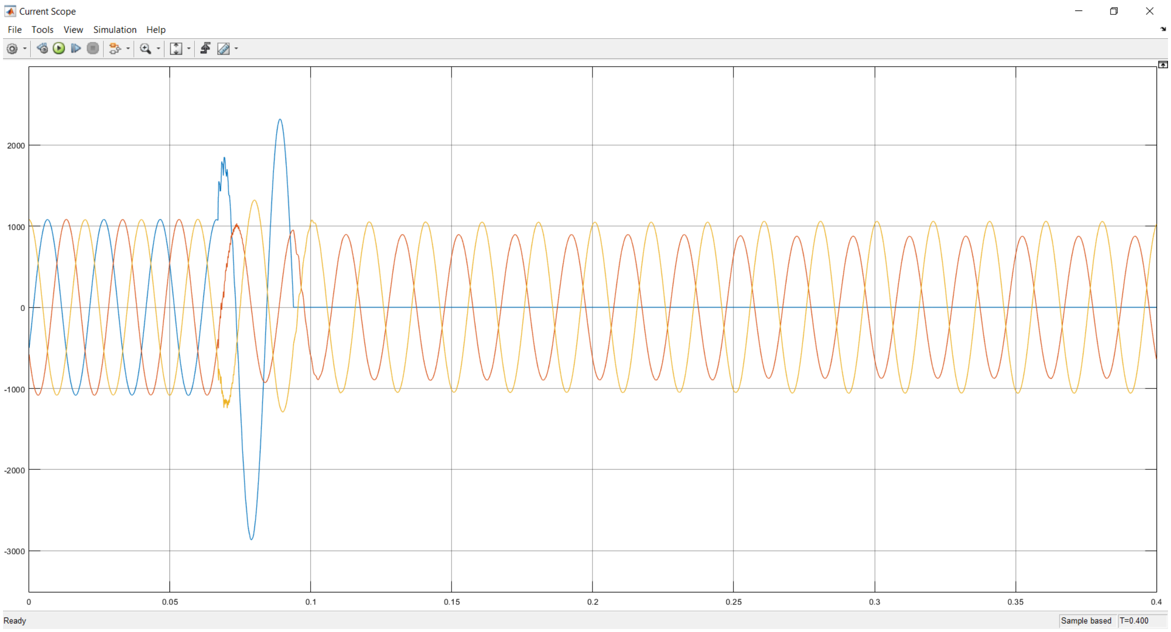

Figure 5.8: Current Output Showing isolation for a SLG Fault

The distance relay is also designed to give a three zone protection. This zone protection is to help detect the distance at which the fault occurred. In this project the three zones are described as zone ‘A’; a fault which occurred at the generation side of the transmission system. Zone ‘B’; Zone B means that the fault occurred on the transmission line 30km from generation and the last zone ‘C’ means that the fault occurred on the transmission line 100km from generation. When the fault is applied at the generating side i.e. at zone ‘A’ only the relay circuit designed inside the subsystem4 will activate so that only the first display will show ‘1’. Whenever only the first display shows ‘1’, it means that the fault is occurred at zone ‘A’. When the fault is applied at zone ‘B’, the relay circuit designed inside both subsystem4 and subsystem5 will activate so that only first and second displays will show ‘1’. Whenever first display and second display shows ‘1’, it means that the fault is occurred at zone ‘B’. Similarly, when the fault is applied at a point near to load point, that is, at zone ‘C’, all the three displays show a ‘1’.

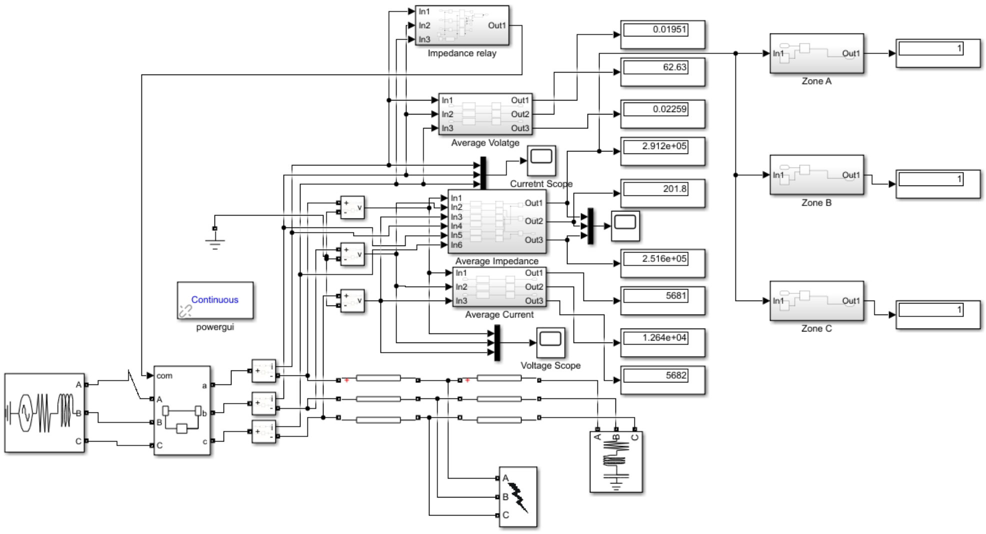

Figure 5.9: Diagram illustrating Fault Detection in Zone C

5.4 Results of Fault Categorization

The fault categorization block took its input from the current transformer. Each of the fault has a unique characteristic. Based on the expected characteristics, a MATLAB code was written and binary codes were assigned to categorise each of the faults. A '100' output from the fault categorization block indicates that the fault is a SLG fault. A '110' output from the fault categorization block indicates that the fault is a DLG fault. A '111' output from the fault categorization block indicates that the fault is a three phase to ground fault. Lastly, A '101' output from the fault categorization block indicates that the fault is a L-L fault.

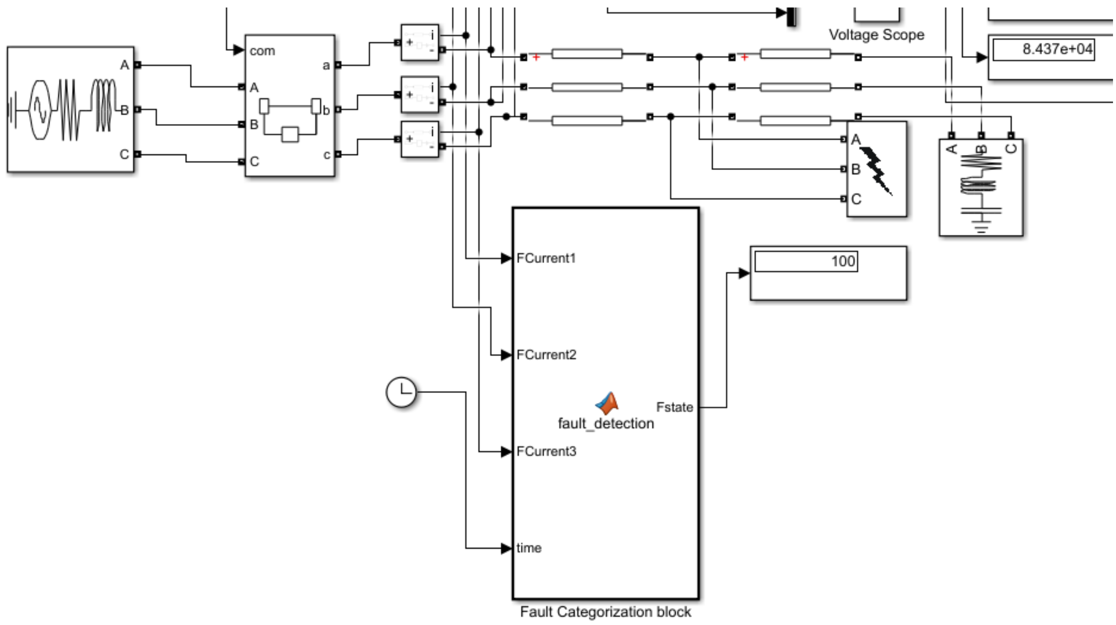

Figure 5.10: Diagram illustrating SLG Fault Categorization

5.5 Results from Statistical Analysis

After simulation, statistical analysis was performed on the system to determine its accuracy and responsiveness. Comparative analysis was performed on the response times for detecting and categorizing the fault as well as the time it takes to isolate the system. The test for accuracy involved observing the accuracy of categorizing the faults.

5.5.1 Test for Responsiveness

The project was tested for the response time it takes the system to detect and isolate the fault. After a few observations it can be concluded it takes about 0.01s for the system to isolate the faulted line. The relay was also able to coordinate the circuit breaker such that it only isolates the faulted line.

5.5.2 Test for Accuracy

The test for accuracy was performed by carrying out test runs for fault categorization block and examining whether the output was accurate. For fault block was able accurately distinguish between the three ground faults. That is to say that it could accurately tell a SLG from a DLG fault. It was also tested whether it was able to detect a line to line fault from a single line fault and it categorized it accurately. The relay was also tested to see if was able to accurately detect the fault zone. The results showed that the relay can accurately give and approximation of the distance where the fault occurred.

Chapter 6: Conclusion, Limitations and Future Work

6.1 Conclusion

The research project successfully designed a cost-effective and functional fault detection prototype, the simulation which was in three parts was also successfully achieved. Firstly, the system could detect all the four types of shunt faults. That is engineers will be able to detect and analyse the four types of shunt fault. Secondly, An impedance relay was successfully created and could accurately isolate the faulted lines in time before any of the power systems components gets damaged. Lastly the project also successfully and accurately categorised and displayed all for types of shunt faults occurring on the transmission lines system. A full working model can be developed from this design to be used to detect and categorize faults in GRIDCO company of Ghana.

6.2 Limitations

As the project progressed, the level of knowledge acquired for designing the project improved hence it was necessary to learn new concepts. There was also budget constraint for the model. The project involves high voltage and high current which means that the cost of the components would exceed $50. Therefore, the project had to be limited to simulations. The simulations came with its constraints. Components such as the microcontroller and GSM module could not be used. The displays could only display digits hence the output of the fault categorization block was limited to producing binary values to represent the different types of faults. Lastly, simulation time of more than 10s took a while to display due to software lags hence, a simulation time of only 10s was displayed.

6.3 Future Works

Further analysis can be carried out so that a specific fault distance can be produced. Also in situations where impedance relays cannot be used a digital overcurrent relay can be explored.

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