MODELLING & SIMULATION OF PROTECTION RELAY OF POWER TRANSFORMER

A Dissertation Submitted in Partial Fulfilment of the Requirements for the Award of the Degree Of

MASTER OF TECHNOLOGY

IN

POWER SYSTEM

Submitted by:

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2021

DECLARATION

I hereby certify that the work which is presented in the Major Project – II entitled "**MODELLING & SIMULATION OF PROTECTION RELAY OF POWER TRANSFORMER**" in fulfilment of the requirement for the award of the Degree of Master of Technology in Power System and submitted to the Department of Electrical Engineering, Delhi Technological University, Delhi is an authentic record of my own, carried out during a period from January to August 2020, under the supervision of Prof. J. N. Rai.

The matter presented in this report has not been submitted by me for the award of any other degree of this or any other Institute/University. The work has been accepted in peer reviewed Scopus indexed conference with the following details:

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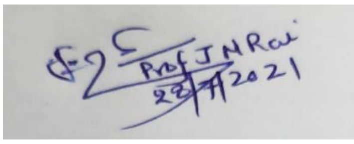
SUPERVISOR CERTIFICATE

This is to certify that the thesis work entitled **“Modelling & Simulation of protection relay of Power Transformer using MATLAB/ SIMULINK”,** submitted by **Ms. Aarti**, Roll No. 2K19/PSY/21, A STUDENT OF Master of Technology in the Department of Electrical Engineering at Delhi Technological University (formerly Delhi College of Engineering), is a work carried out by her under my guidance during 2019-2021 towards the partial fulfilment of the requirement of the award of degree of Master of Technology and is an original contribution with existing knowledge and faithful record of research work carried out by her under my guidance and supervision.

To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.



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In all humility and gratitude, I am overwhelmed to express my gratitude to all those who have assisted me in putting these concepts, much above the level of simplicity, into something solid.

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Date : 28.07.2021 **(AARTI)**

ABSTRACT

In the power system network, the transformer is an essential component. When a distribution or transmission substation is out of operation due to a breakdown, they are more expensive. The transformer's protection is a crucial element in ensuring the system's correct operation. As a result, it is required to investigate the operation of the transformer's protections. We are attempting to mimic the main and backup protection of a transformer in this project. In the study of the impacts of different faults and configurations on the operation of these relays, modelling and investigation of various protection relays is critical.

The first part of this dissertation presents a method to simulate the Overcurrent relay for a transformer. Overcurrent relay is also used to protect transmission and distribution feeders, and bus couplers, among other things. Overcurrent protection can be utilised as the primary or secondary protection.

The second part presents the simulation of differential relay which is used as the main protection of the power transformer. Differential relays are also used to protect bus-bars, generators, small transmission lines and other electrical equipment. Although it can only be used to defend against internal defects and not exterior faults, this relay is the most significant protection.

The current project is about a three-phase transformer with a 250MVA rating and a voltage rating of 735kV/315kV. For the sake of avoiding erroneous results, both relays are modelled individually using generally used MATLAB/SIMULINK software. The simulation is run under a variety of faulty circumstances. Many issues, such as Tap altering, inherent phase-shift of currents in transformer, CT ratio, and non-identical CT, were encountered while simulating the differential and overcurrent relay model. The information comes from a research paper. The settings will then be simulated in MATLAB/Simulink, and the various relays will be simulated according to the accessible panel.

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LIST OF ABBREVIATIONS

CT	Current Transformer
VT/PT	Voltage/ Potential transformer
A/D	Analog to Digital
DSP	Digital Signal Processing
IDMT	Inverse Definite Minimum Time
DMT	Definite Minimum Time
O/C	Overcurrent
E/F	Earth Fault
PS	Plug Setting
TMS	Time Multiplier Setting
SI	Standard Inverse
LLL-G	Three phase to ground
RMS	Root Mean Square
Fcn	Function
Abs	Absolute

CHAPTER - 1

INTRODUCTION

1.1 General:

Differential protection is the most important transformer protection. In contrast to electro-mechanical kinds, which would require numerous relays with interconnections and higher total CT loads, modern relays typically perform all of the required protective functions in a single device. Differential relay protects the transformer from internal faults and not external. Thus, we require protection of transformer in case the differential relay fails and also from any kind of external faults. And thus, Overcurrent relay comes into picture acting as the backup protection for the transformer.

The following are the four types of transformer faults are common:

1. Overcurrent due to overloads and external short circuits
2. Terminal faults
3. Winding faults
4. Incipient faults

All of the aforementioned transformer defects result in mechanical and thermal strains within the transformer winding and connecting terminals. Thermal stresses cause overheating, which affects the transformer's insulation system. Winding issues are caused by deterioration of insulation. Overheating of the transformer can occur when the transformer cooling system fails. As a result, transformer protection methods are essential. An electrical transformer's short circuit current is generally restricted by its reactance, and for low reactance, the short circuit current value might be abnormally large.

Earth faults or inter-turn faults are the most common transformer winding defects. In a transformer, phase to phase winding failures are uncommon. Bushing flash over and faults in tap changer equipment can cause phase faults in an electrical transformer. Whatever the fault, the transformer must be isolated immediately during the fault, or the electrical power system may suffer a serious breakdown.

Internal defects that are not yet dangerous are known as incipient faults. However, if these faults are overlooked and ignored, they may develop into severe problems. Inter-lamination short circuits due to insulation failure between core laminations, oil leakage, and blockage of oil flow channels are the most common problems in this group. All of these faults result in overheating. As a result, for incipient transformer problems, a transformer protection plan is also necessary. An incipient fault could be an earth fault that is very close to the neutral point of the transformer star winding.

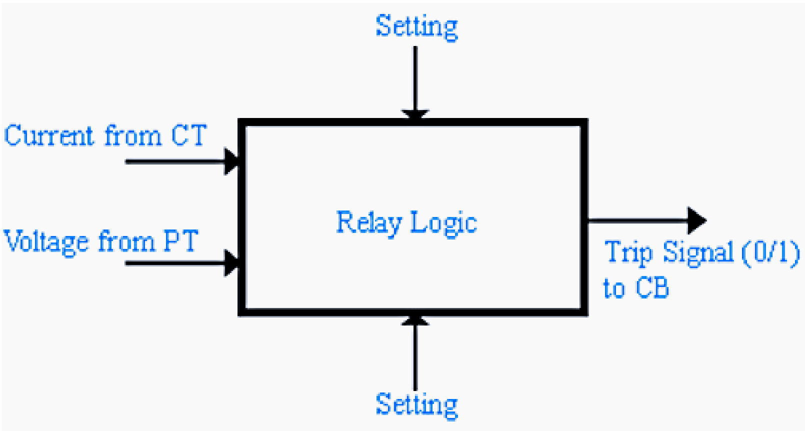


Fig 1.1 Conceptual diagram of Relay

An overcurrent and differential relay for power transformer protection has been created in this thesis work, and the operation of these relays under various faults has been investigated. Differential relays are only employed in the event of an internal fault. A relay is a smart component that processes system inputs and sends out a trip signal whenever a fault is identified within the relay's influence. The conceptual figure of relay is shown in figure 1.1.

To examine the status of the instruments, relay senses current through the current transformer, voltage through the voltage transformer, Voltage transformer is also well-known as potential transformer. Inside this setting we fix the current or voltage value above which relay will operate.

1.2 Evaluation of relay:

There are three different types of relay

1. Electromechanical Relay
2. Solid State Relay
3. Numerical Relay

- **Electromechanical Relay:**

Electromechanical relay are those that use the principle of electromechanical energy conversion for decision making. This relay works in the same way as a switch, which can be either open or closed. When the switch is open, no current flows through the relay, the circuit is open, and the load is unpowered. When the circuit is closed, current flows through the relay, indicating that the circuit is closed and the load is getting power. An electro-magnet is utilised to open and close the relay, which sends a trip signal to the circuit breaker when a problem occurs.

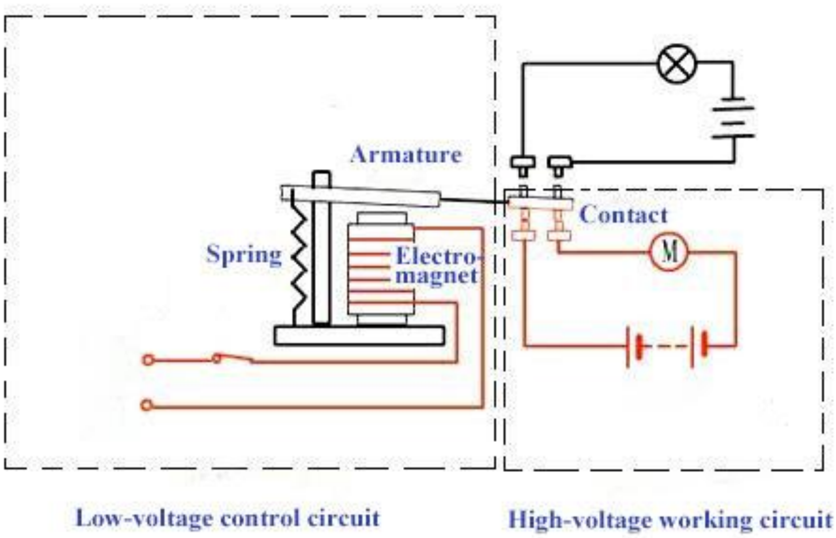


Fig 1.2 Electromechanical relay working principle

The electromechanical relay is used to separate alternating current and direct current circuits, as well as to prevent interference between electronic control and power circuits. Low starting cost, contacts that can switch between ac and dc, and great resistance to voltage transients are some of the benefits.

- **Solid State Relay:**

These relays were developed following the invention of transistors, operation amplifiers, and other electronic components. Many components, such as comparators, make up solid state relays. The flexibility of these relays is greater than that of electromechanical relays. The best feature of these relays is that they contain a self-checking feature, which allows the relay to monitor its own health and send an alarm if any of its components are damaged. There are a few more benefits, such as reduced panel spacing and minimal burden.

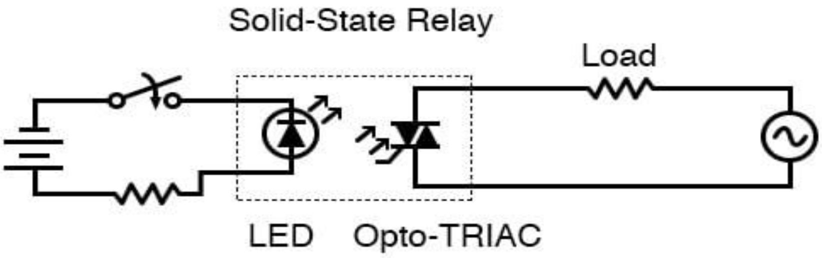


Fig 1.3 Solid state Relay block diagram

- **Numerical Relay:**

A communication relay can be made more adaptable by allowing it to adapt to changing device or scheme conditions. A differential protection relay, for example, may respond to changes in transformer tap. The overcurrent relay can acclimatise to various loading conditions. A numerical relay is a technique that can be used in both the present and the future.

Figure 1.4 depicts the numerical relay block diagram. There is an analogue to digital (A/D) converter that converts analogue voltages and currents derived from the secondary sides of voltage and current transformers to digital voltages and currents.

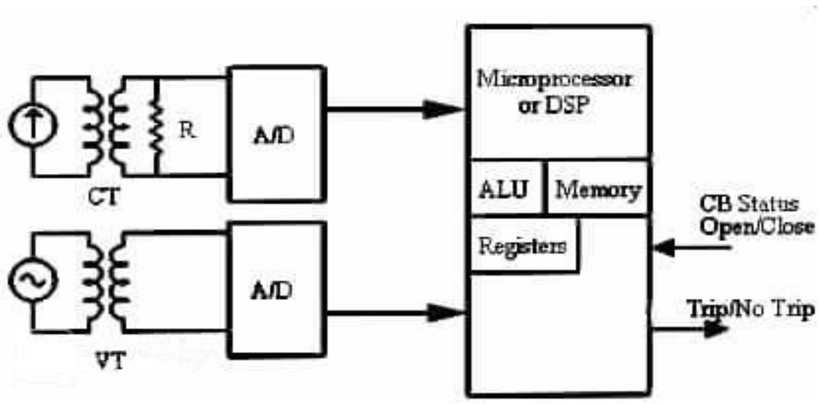


Fig 1.4 Numerical relay block diagram.

These voltage and current samples are fed into a microprocessor or digital signal processor, where the logic part replicates voltage and current signals and determines whether or not there is a problem. If a fault is discovered, the circuit breaker will get a trip signal. Significant relaying logic can be made flexible in numerical relay. The type of microprocessor utilised determines the difference between numerical and digital relays. Digital signal processors (DSP) cards, which include dedicated microprocessors expressly intended to do digital signal processing, are found in numerical relays.

1.3 Type of protective scheme:

A protective scheme is used to protect an instrument or a component of the system. One or more relays of the same or different types can be utilised in a single protective scheme. The following are some of the most frequent protection schemes:

a) Overcurrent protection

b) Distance protection

c) Differential protection

- **Over Current Protection:**

This system is based on the intuition that short circuits cause current to rise significantly above the load current. Within this protection scheme, there are two settings: time setting and plug setting. The operating time of the relay is determined by the time setting, and the relay operation is determined by the plug setting. Fig 1.5 show a radial distribution system with a single source. Only one side of the feeder is supplied with fault current. The system shows that:

i. To relay R1, both downstream faults F1 and F2 are visible, allowing IF1 and IF2 to pass via R1's current transformer.

ii. To relay R2, fault F1 is not seen as an upstream fault; only F2 is seen. This is because no IF1 components pass through R2's current transformer. As a result, selectivity comes naturally. The amount of the fault current is the single factor that influences the relay decision. This type of security is referred to as a non-directional relay.

Fig 1.5 Radial distribution system diagram

- **Distance Relay:**

Consider a simple radial system with a single source of power. Let's take a look at the sending end's apparent impedance (V/I). When the system is unloaded, I=0, and the apparent impedances perceived by the relay are infinite. When the system is loaded, the apparent impedances are reduced to finite values (Zl+Zline), where Z1 represents the load and Zline represents the line impedance. The relay drop to m*Zline in the presence of a defect at a per-unit distance, 'm, as illustrated in fig 1.6, indicates impedance.

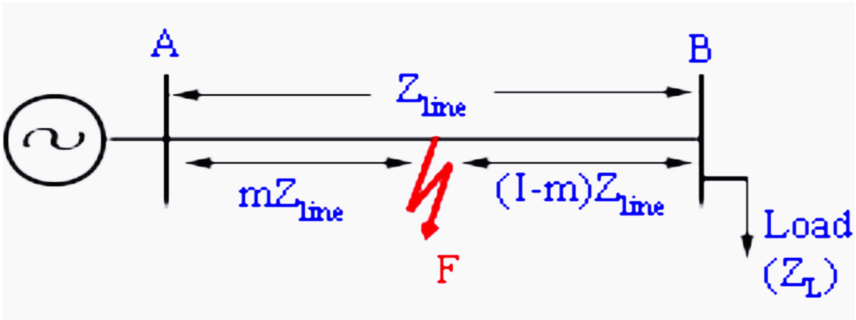


Fig 1.6 fault in a transmission line diagram

The basic principle of distance relay is that in the case of a line fault, the real impedance perceived by the relay, which is defined as the ratio of phase voltages to line currents of a transmission line (Zapp), decreases dramatically. The distance relay compares this ratio to the transmission line's positive sequence impedance (Z1). It indicates a flaw if the fraction Zapp /Z1 is less than unity. This ratio also reflects the distance between the relay and the issue. The distance protection is naturally directed because the impedance is a complex quantity. The forward direction is represented by the first quadrant, which contains the impedance of the transmission line to be protected. However, if only magnitude information is used, non – directional impedance relay results. Fig 1.7 and 1.8 shows a characteristic of an 'impedance relay' and 'mho relay'.

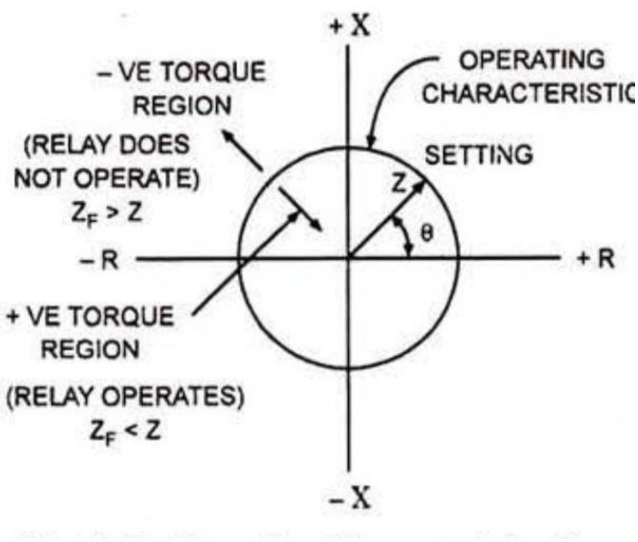


Fig. 1.7: Impedance relay characteristics on R-X diagram

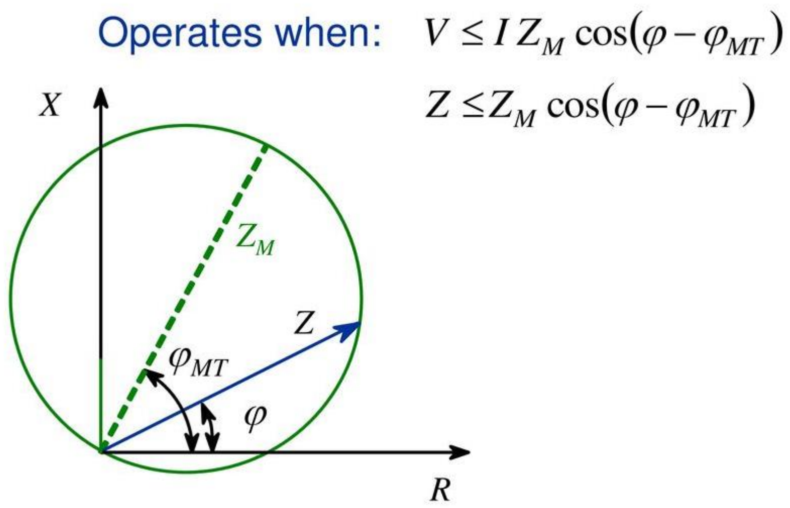


Fig. 1.8: Mho relay characteristics on R-X diagram

- **Differential relay:**

Consider the use of an ideal transformer in place of the protected equipment, as shown in figure 1.9 with the CT connections. Let's pretend that the primary winding has a current rating of 100 amps and the secondary winding has a current rating of 1000 amps to demonstrate the principle. If we employ 100:5 and 1000:5 CT in the primary and secondary windings, the scaled CT currents will match in magnitude under normal (no fault) operating conditions. By carefully connecting the major and secondary CTs while paying attention to the dots (polarity marking).

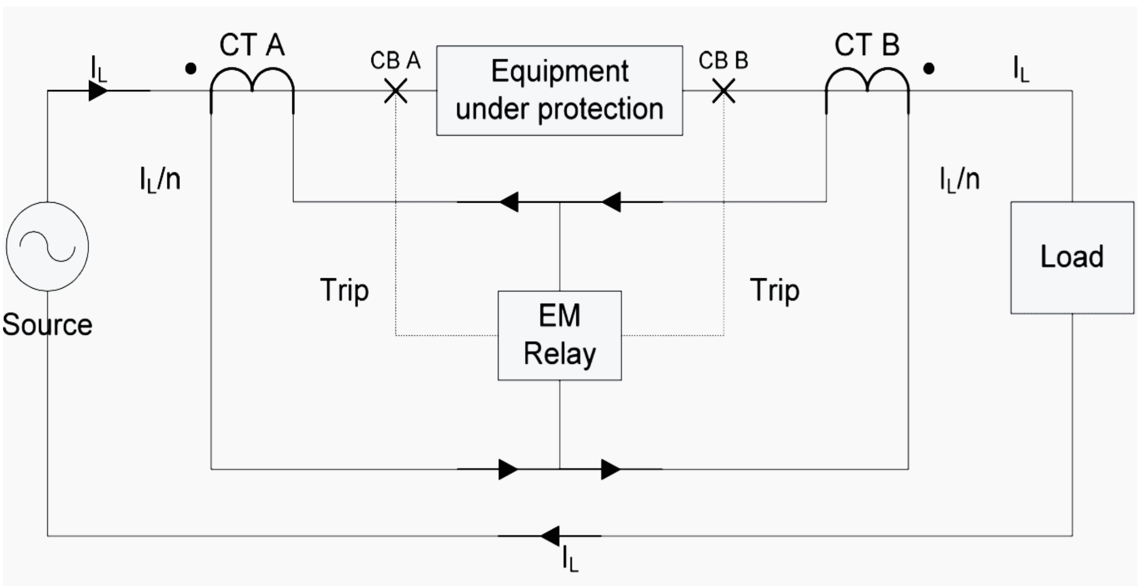


Fig 1.9: Differential protection scheme

The current transformer is linked to both sides of the equipment in this diagram. As a result, the current entering must equal the current exiting. I1-I2 should be 0 in this protection strategy. If the difference exceeds a particular threshold, the relay will send a trip signal to the circuit breaker, which will remove the damaged component from the circuit's healthy section.

Figure 1.10 shows the operating characteristic of I-bias vs. I-diff with internal faults indicating operating region and external faults indicating restraining region. This differential relay work for only internal faults not for external faults. In practice, the transformer is not ideal as there is the magnetization current or (no load) current present. Thus, a differential current always flows through over- current relay.

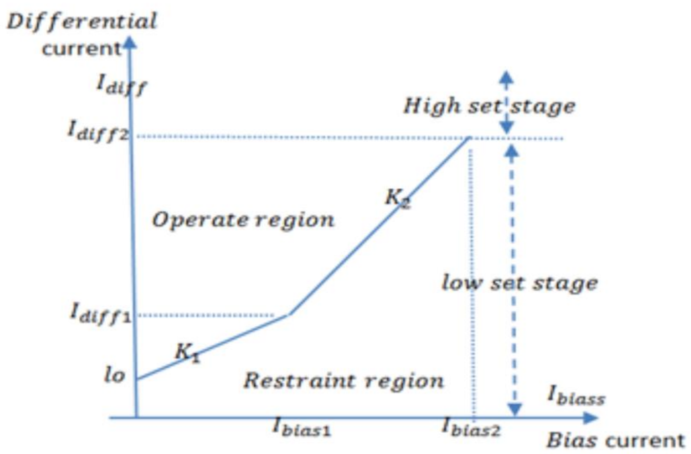


Fig 1.10: Differential Relay Characteristics

1.4 Relay performance and relay technology:

The following characteristics are related with a good performance of a relay in the power system:

- **a.** Necessities of speed in relaying
- **b.** Speed vs. Accuracy conflict

Necessities of speed in relaying:

A malfunctioning part should be cleaned as soon as possible to maximise safety and prevent equipment damage and system instability. This means that the relay should make a judgement rapidly and the circuit breaker should operate immediately. A rapid circuit breaker should typically function in two cycles. One cycle is an acceptable time estimate for determining the presence of a defect. This implies that main protection has a three-cycle fault clearance time.

If a five-cycle circuit breaker is employed, however, the fault clearing duration climbs to six cycles.

Speed vs. Accuracy conflict:

Quickness can be an offer to disaster. The consequences of quick tripping decisions are:

- Nuisance tripping
- Tripping for faults outside the relay jurisdiction.

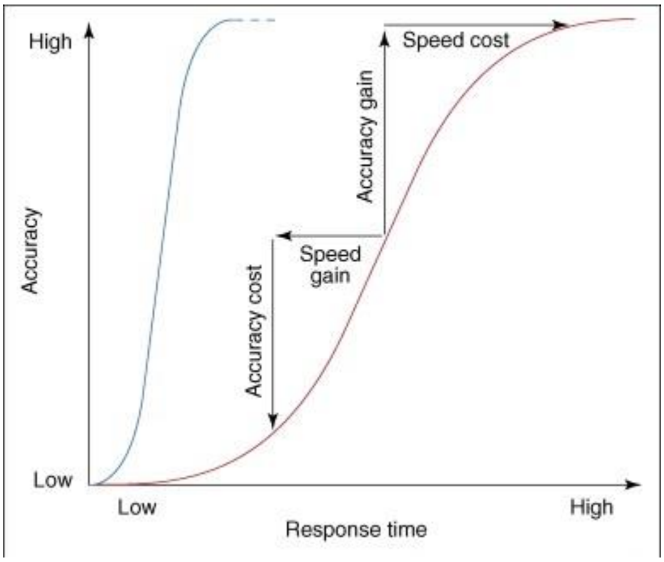


Fig 1.11 Conceptual illustration of speed Vs accuracy conflict diagram

Nuisance or unpleasant tripping refers to tripping for no apparent cause, such as an overcurrent relay tripping on load. As a result of unnecessarily lost service, it loses faith in the relaying process. The healthy half of the circuit, on the other hand, loses service unnecessarily if the relay trips due to difficulties outside the relay's control. It's worth remembering that speed and accuracy can work in both directions. High-speed systems are less accurate simply because they have a less amount of data to work with when making decisions. As a result, the protection engineer must find a middle ground between these two diametrically opposed demands.

CHAPTER-2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, many research papers and work related to Protection of Power transformer are reviewed. The review work is done for the following areas-

i. Overcurrent and Earth fault relay
ii. Differential relay

2.2 LITERATURE SURVEY

Since relays are utilised in so many applications, there has been a lot of evolution in the industry. They're commonly used for transformer, generator, and bus-bar protection, among other things. As the need for power grows in people's lives, the complexity of the power system grows as well. As a result, the possibilities of a failure causing a loss of power as well as damage to the entire system's equipment are increased. As a result, understanding the relay, its operation, setup, and location in the system, among other things, is critical. For both overcurrent and differential relay, a three-phase power transformer with all conceivable faults is studied in my system. For development of my project "Modelling and simulation of Protection relay of power transformer" I have used MATLAB SIMULINK software.

2.2.1 Overcurrent and Earth Fault relay

Nur Hazwani Hussin [6] used MATLAB-SIMULINK to model an inverse time overcurrent relay. This proposed model was evaluated for L-G and L-L faults in a transmission network for phase and earth relay with various fault sites. The paper explains how to operate with an overcurrent relay and simplifies its modelling so that it may be simply applied to different curves or applications.

Multiple studies have been conducted to model and simulate protection relays using MATLAB-SIMULINK software, such as [15], which used the software Inverse Definite Minimum Time (IDMT) to model an overcurrent relay utilising a digital signal processor (DSP)[7].

Electrical utilities are looking for sustainable alternatives to enhance generating capacity without putting additional burden on system infrastructure as a result of rising consumer energy demand. Distributed energy resources (DERs) that deliver power to load demand on a local level, eliminating the need for increasing grid generation capacity, are one of the emerging options capable of achieving this [22]. This research presents a unique technique for mitigating distributed generation (DG) effects on existing radial distribution network fuse-recloser protection architecture [5][10][17]. Multiple in-depth time domain simulations are performed in the framework of this article to determine the efficacy of the proposed strategy in reducing the impact of DG sources on existing overcurrent protection infrastructure.

Electricity is one of the most essential resources for modern survival. Other sources of generation [25] are getting increasingly popular as the need for energy continues to rise. Integrating such sources into the grid necessitates planning for their protection as well as the grid's. Simulink was also used to model an overcurrent relay for a photovoltaic (PV) irrigation system [9]. The constructed model was tested in both normal and abnormal settings, including starting the motor.

Relays in an adaptive protection coordination scheme should respond to changing system conditions and modify new settings in response to new prevalent conditions like operational or topological changes. In distribution networks with distributed generators, adaptive relaying helps to improve the sensitivity and selectivity of protective coordination mechanisms (DGs) [4][13]. Due to the unnecessary activation of any backup relay, improper coordination can lead the system to disconnect a larger amount of the system. As a result, the amount of energy not supplied (ENS) in the network rises, lowering system reliability [8][27].

2.2.2 Differential Relay

Adel Aktaibi [28] MATLAB-SIMULINK is used to create a differential protection model for the power transformer. The simulation of a differential relay for power transformer protection is discussed in this study. This implementation is demonstrated in detail. This simulation has been tested in a variety of scenarios, and the results are all satisfactory.

B.Vahidi [29] used MATLAB-SIMULINK to create a simulation of a digital differential relay for power transformer protection. Outside and in current faults are detected in this system. This is best suited for the safety of all important parts of the plant, as it has a fast tripping facility with complete selectivity. In this study, a method for using MATLAB-SIMULINK to set up a relay in a laboratory is described. This work presents a MATLAB-SIMULINK-based model for simulating the relay and determining its performance during internal fault protection in transformers.

Nikhil Paliwal [11], MATLAB- SIMULINK & fuggy- logic analysis of modern digital differential relay protection for the power transformer. The analysis of a digital differential protection relay for a power transformer is described in this work. The electrical power system's efficient and nonviolent operation necessitates complete protection. This protective relay prevents tripping during external faults or magnetising inrush and allows for quick tripping during power transformer internal problems. The main goal of this work is to analyse a digital differential relay during external and internal failures and to properly trigger the relay with fault judgement.

Adel Aktaibi [14] uses a fourier transformer to construct a differential relay utilising a software design technique for power transformer protection. Inside the article, a digital differential relay software is built to simulate the problem of an internal malfunction in an electrical power transformer. This increases the comprehension power of the digital differential relay, which protects the transformer by judiciously distinguishing between fault current and inrush current without blocking the relay during power transformer energization and avoiding tripping during the tape changer process. The MATLAB-SIMULINK environment was used to create this digital differential relay.

Using MATLAB-SUIMLINK, Kadri kadriu [23] created the differential protection relay mis-operation during dynamic processes of faults in the secondary protection circuit of the relay. When a short circuit occurs on the secondary circuit side, differential current rises to a large level. The current value is determined by the location of the faults, the power of the circuit loop, and the relay's protection. If there is no energetic process in the power system under normal circumstances, this differential current is insufficient for the relay to operate. As a result, this issue relates to instances in which a short circuit develops in the secondary circuits and the power transformer's neutral point is grounded. The numerical relay of type "MICOM" (ALSTOM) is utilised as a model in this paper.

Using Fourier algorithm analysis, Ivi Hrrmanto [30] constructed the isolated digital protection relay of the three phase power transformer. The hardware and software model of the relay are described in detail in this publication. Separate protection for the high impedence primary and secondary ground faults is provided by a differential protection relay with a second-harmonic limitation for the magnetising inrush and a fifth-harmonic limitation for over-excitation circumstances. A data gathering board and a digital processing board based on the ThIS3'70E15 processor make up the relay hardware.

The dynamic performance of a differential relay system is built using MATLAB-SIMULINK [20]. The established modelling makes it easier to test the power differential relay's energetic behaviour under quick system transients. For this, several outputs were recorded for various operating settings in order to show the most important simulation themes, such as load angle, active and reactive power difference, and power through.

In [12] an attempt to increase the sensitivity of power transformer differential protection while also increasing its security. This research presents a novel adaptive protection criterion that allows us to self-regulate the parameters of relay characteristics (e.g. restraint current and restraint coefficient in the slope characteristic at the knee point) based on transformer working conditions. This relay is used to detect both internal and exterior defects.

CHAPTER- 3

THEORY

3.1 OVER-CURRENT AND EARTH FAULT RELAY

An electrical transformer's protection in the case of a power outage is simple. Over Current and Earth Fault protection safeguard against external short circuits and excessive overloads. These over current and earth fault relays could be of the Inverse Definite Minimum Time (IDMT) or Definite Time types (DMT). IDMT relays are often attached to the transformer's in-feed side.

On larger transformers with standard circuit breaker control, overcurrent relays are employed. Over current relays can't tell the difference between an external short circuit, an overloaded transformer, and a transformer with internal defects. Backup protection, such as over current and earth fault protection linked to the transformer's in-feed side, will work in the event of any of the following faults. The current and time parameters, as well as the relay's characteristic curve, determine the operation.

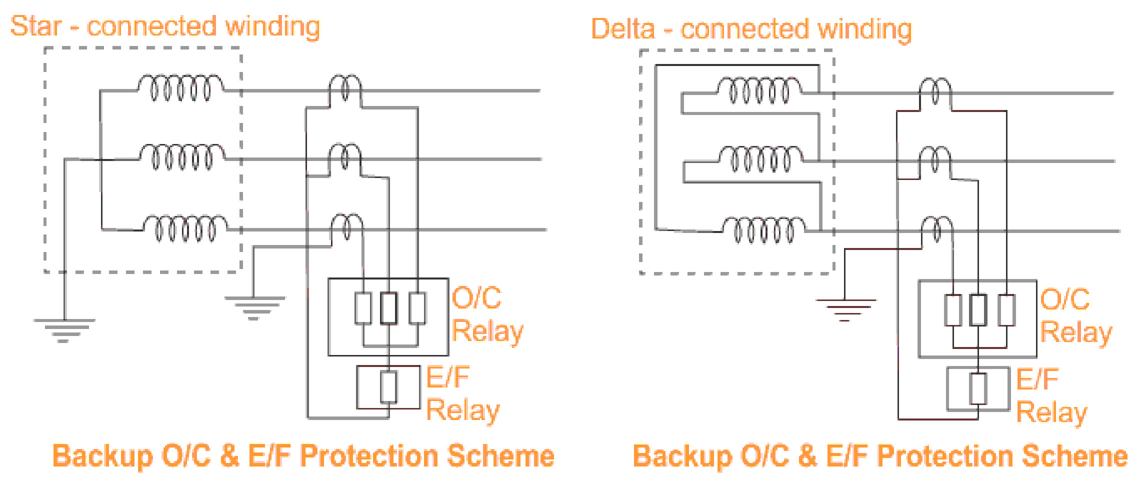


Fig: 3.1: Schematic Diagram of O/C and E/F Protection

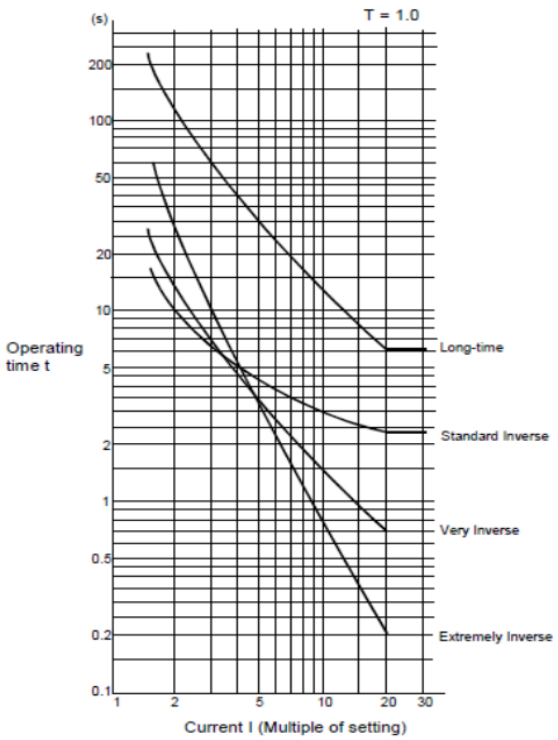
Figure 3.2 shows the characteristics of the inverse time overcurrent relay. The figure shows four curves, each of which can be written as an equation to compute the operating time. Table I displays the operating time equations that depict the inverse time overcurrent relay's characteristic curves. The long duration inverse curve takes the longest to operate for the same multiples of current setting, while the extremely inverse curve takes the shortest. Eq. (1) represents the current setting (or pickup current) for each curve.

$$Ip = PS * CT_{sec} \tag{1}$$

Where;

PS = Plug Setting (% or pu)

CT_{sec} = Rated Secondary Current of Current Transformer (CT) in Ampere (A).



Type of curve	Equation for operating time (s)
Long time inverse	$t_{op} = TMSx \dfrac{120}{\left(\frac{I_f}{I_p}\right) - 1}$
Standard inverse	$t_{op} = TMSx \dfrac{0.14}{\left(\frac{I_f}{I_p}\right)^{0.02} - 1}$
Very inverse	$t_{op} = TMSx \dfrac{13.5}{\left(\frac{I_f}{I_p}\right) - 1}$
Extremely inverse	$t_{op} = TMSx \dfrac{80}{\left(\frac{I_f}{I_p}\right)^{2} - 1}$

Fig: 3.2: (a) Characteristics of inverse time OC relay; (b) Operating time equations table

The TMS for both phase and earth faults are set to the same value. In the table showing Operating time Equations of the different curve the variables are as follows:

top = Operating Time (s)

TMS = Time Multiplier Setting (% or pu)

If = Fault Current (A)

Ip = Current Setting or Pickup Current (A)

In this model, only Standard Inverse (SI) curve is used to detect phase and earth faults. However, the model can easily be extended to other types of curve.

$$t_{op} = TMSx \frac{0.14}{\left({}^{I_f}/_{I_p} \right)^{0.02} - 1}$$

3.1.1 Main Component Rating for O/C & E/F relay:

The transformer used in the simulation is of 735kV/315kV, 250MVA rating. The load considered is resistive with 175MW active power. The Source voltage is taken to be 735kV. Network frequency is 50Hz. The PS parameters for phase and earth faults are different where PS for phase fault normally set higher than full load current while PS for earth fault normally set lower than full load current to detect high impedance fault when involving ground fault which normally undetected by phase overcurrent relay.

Table 3.1. Transformer and Relay setting parameters for O/C and E/F relay

Parameters	Values
Source Short Circuit Level (VA)	500,000,000
X/R Ratio	5
Source VLL (V)	735,000
Transformer MVA rating	250
Transformer Voltage rating (KV)	735/315
Transformer vector group	Yg-yg
Line CT Ratio	1200/1 A
Plug Setting (PS) for Phase	1.2
Time Multiplier Setting (TMS) for Phase	0.35
Plug Setting (PS) for Earth	0.4
Time Multiplier Setting (TMS) for Earth	0.35
Network Frequency (Hz)	50
Type of Curve	Standard Inverse
Load Active Power (W)	175,000,000

3.1.2 Modelling and Simulation

The general model for the network and relay was constructed using Matlab/Simulink software, as shown in Figure 3.3. The chosen network is a three-phase transformer with one end linked to a Thevenin equivalent three-phase power source and the other to a three-phase load.

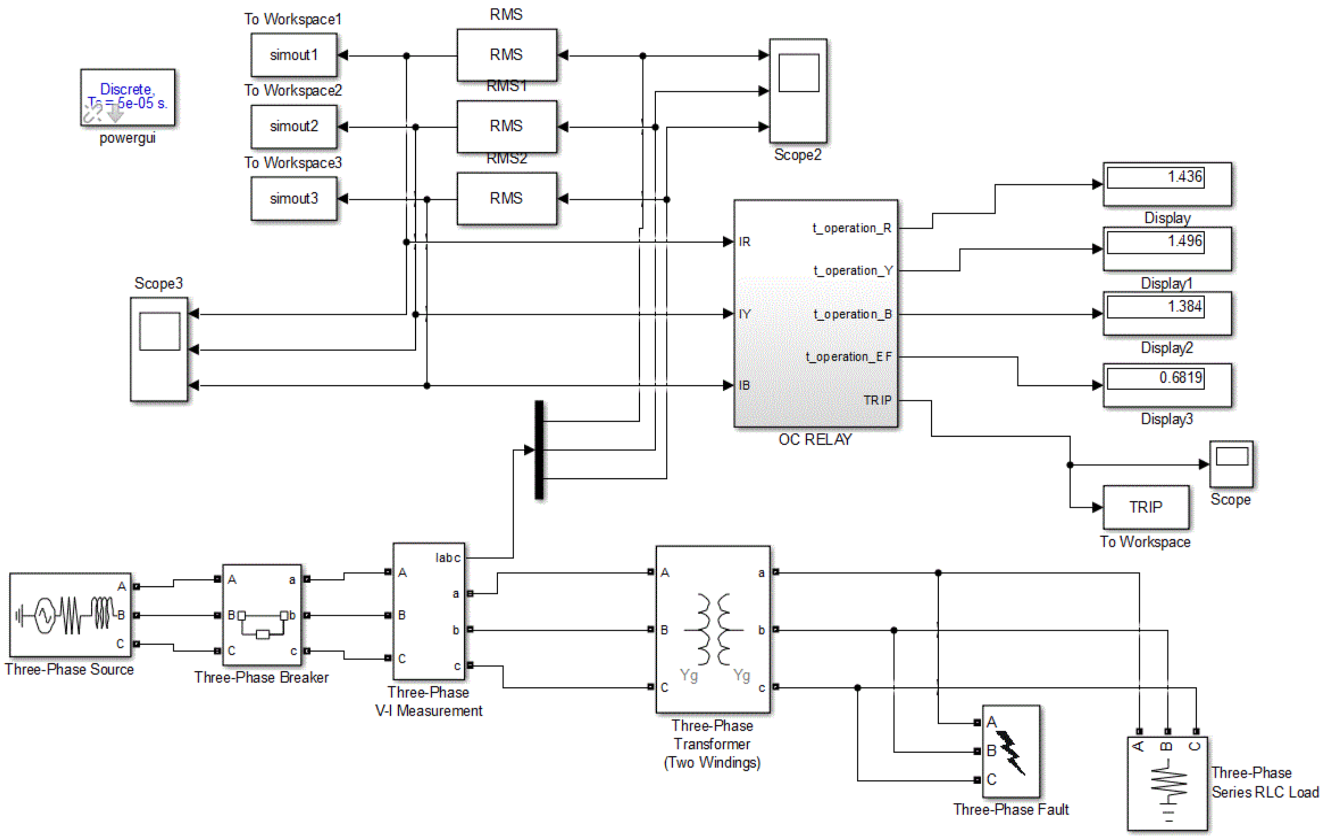


Fig: 3.3: Simulation Model of O/C and E/F protection of transformer

Figure 3.4 depicts the blocks that make up the OC Relay Subsystem. To compute the operating time and deliver the trip signal, each phase and earth subsystem has its own curve. The input to the EF subsystem is the phasor summation of red, yellow, and blue currents, with residual or imbalanced current flow to the earth if there is a ground fault. This will not occur in the case of a phase-to-phase fault. When the current to a subsystem from any phase or the earth is higher than other subsystems, it will deliver the trip signal faster. This is why all of the trip signals are gated with a ‘OR'. Depending on the value of fault current entering them, all phases and earth subsystems will calculate the operation time.

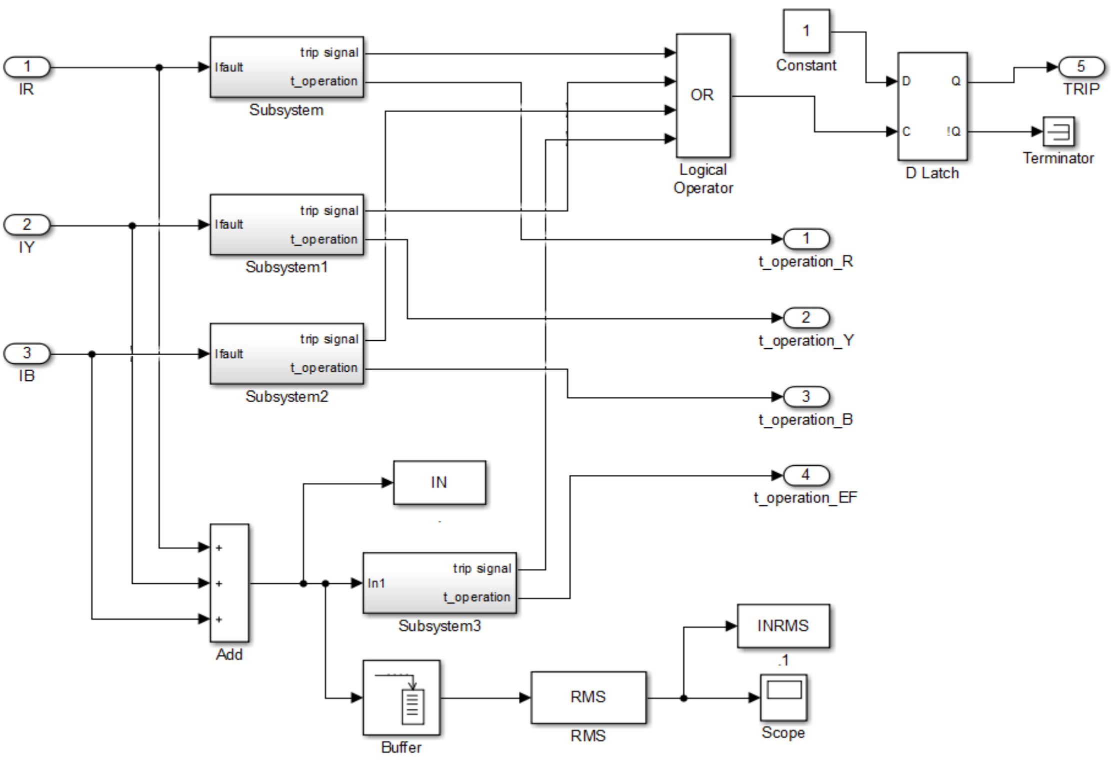


Fig 3.4: O/C Relay subsystem

The blocks inside each phase and earth subsystem are depicted in Figure 3.5. The equation for the SI curve is represented by all of these blocks. The timer will only start when the fault current is greater than the pickup current, as can be observed. The trip signal will be delivered when the timer has elapsed (more than) the calculated operation time.

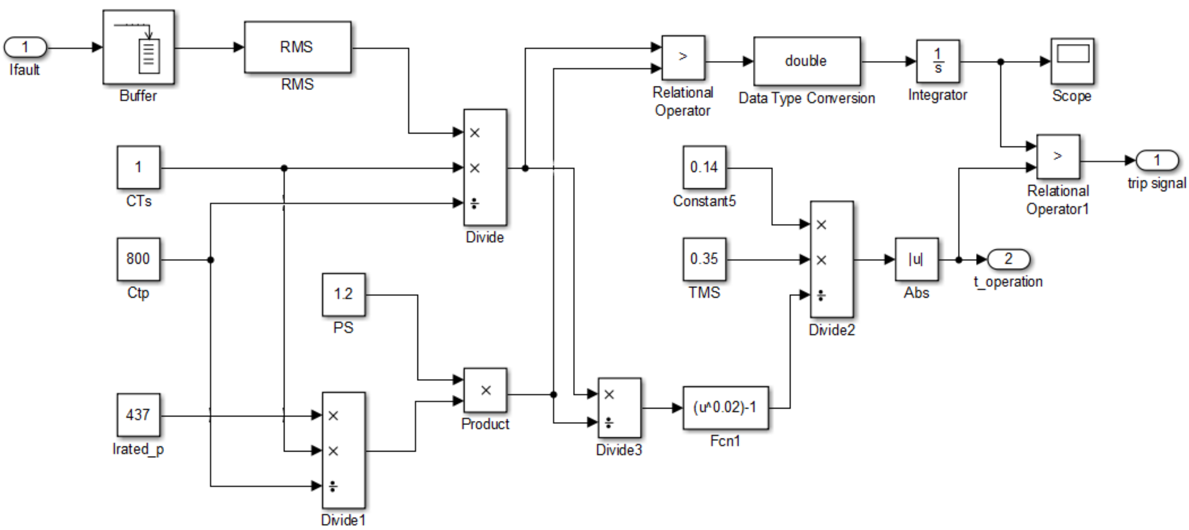


Fig 3.5. Phases and Earth Subsystems

3.2 DIFFERENTIAL RELAY-

This relay is based on the principle that output power of power transformer is equal to the input power. In the normal condition, no current flows in the differential current coil. But when there is a fault then there is flow of current in the operating coil. The relay gives the trip signal to the circuit breaker. Then circuit breaker opens its contacts and removes the faulty part from the healthy part. So, differential relay compares the primary side current and the secondary side current of the power transformer. By using the current transformers on both sides of the power transformer, we change the current on both side of the power transformer equal for relay during no fault. The polarity of CTs must be selected as there will be no flow of current in the primary relay in normal condition and external fault conditions. The rating of the CTs must be selected carefully so that this should match with power transformer then secondary side of the CTs will be equal. But there is a lot of problem like the CT ratios available in the market is of standard rating only. Therefore, the turns ratio of the secondary side CT is $\frac{1}{N_2}$ and the turns ratio of the primary side current transformer is $\frac{1}{N_1}$. The secondary current of the current transformer located on the primary side of the transformer is

$$I_1 = \frac{I_p}{N_1} \qquad 3.1$$

Where:

I_p: power transformer primary side current

I_1: CT1secondary side current

N_1: number of turns of the CT1 on the secondary side

In the same way, the secondary of the CT located on secondary side of the power transformer

$$I_2 = \frac{I_s}{N_2} \qquad 3.2$$

Where:

I_s: power transformer secondary side current

I_2: CT2 secondary side current

N_2: number of turns of the CT2 on the secondary side

Differential current flowing is $I_d = I_1 - I_2$

From equations 3.2 and equation 3.1, the differential current flowing in the operating coil is

$$I_d = \frac{I_p}{N_1} - \frac{I_s}{N_2} \qquad 3.3$$

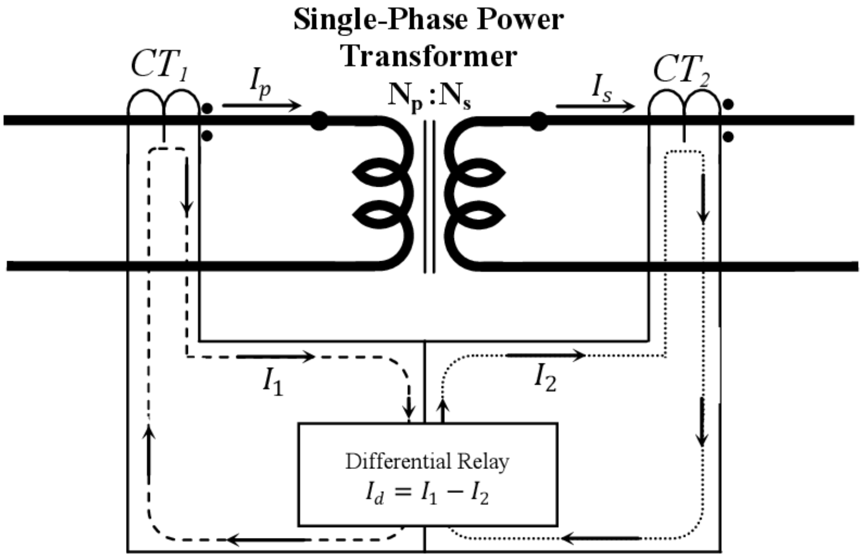


Fig 3.6: Differential Protection of Transformer

There is no internal fault then, $I_1$and I_2 are supposed to be equal in magnitude but opposite in direction to that I_d will be zero as shown in the figure 3.7.the power transformer secondary side and primary side current are related to each other as show in equation 3.4

$$\frac{I_p}{I_s} = \frac{N_s}{N_p} \qquad 3.4$$

Where:

N_p and N_s : power transformer primary and secondary side turns

$\frac{N_s}{N_p}$: power transformer transformation ratio.

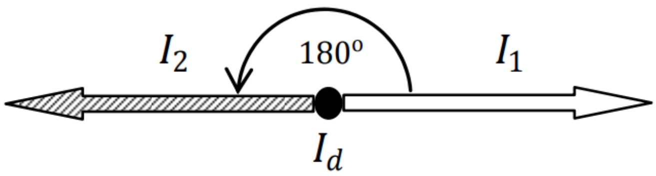


Fig 3.7: CTs secondary current are equal in magnitude and opposite in direction

Suppose there is any internal is the protective zone, then $\boldsymbol{I_1}$and $\boldsymbol{I_2}$are not equal. So there will be current flow and $\boldsymbol{I_d}$ current has some value through which relay will be operate as shown in fig 3.8.

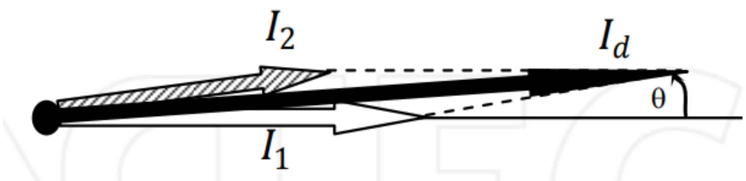


Fig 3.8: Secondary current of CTs are not equal

The $\boldsymbol{I_d}$ =$\boldsymbol{I_d}$<θ, which will flow in operating coil so that relay gives the signal to circuit breaker which isolate the faulty part from healthy part of circuit.

By equation 3.4

$$\boldsymbol{I_s = \frac{N_p}{N_s} * I_p} \qquad 3.5$$

Using 3.3 and 3.5 equation,

$$\boldsymbol{I_d = \frac{I_p}{N_1} - \frac{(\frac{N_p}{N_s})*I_p}{N_2}} \qquad 3.6$$

$$\boldsymbol{I_d = \frac{I_p}{N_1}(1 - \frac{N_p/N_s}{N_2/N_1})} \qquad 3.7$$

$$\gamma = \boldsymbol{(1 - \frac{N_p/N_s}{N_2/N_1})} \qquad 3.8$$

From above equation it is very clear that γ must be equal to zero for make $\boldsymbol{I_d}$=0

$$\boldsymbol{(1 - \frac{N_p/N_s}{N_2/N_1})=0} \qquad 3.9$$

$$\frac{N_2}{N_1} = \frac{N_p}{N_s} \qquad 3.10$$

This equation 3.10 given circumstances for safety of a differential relay, which means the reciprocal of the ratio of the secondary side turns of the CTs must equal to the turn ratio of the power transformer.

The figure 3.9 shows the Differential protection scheme for 3 phase transformer with bias/ restraining coil winding of the relay. To correct phase shift of current because of star-delta connection of transformer winding in the case of three-phase transformer, the current transformer secondaries should be connected in delta and star as shown here.

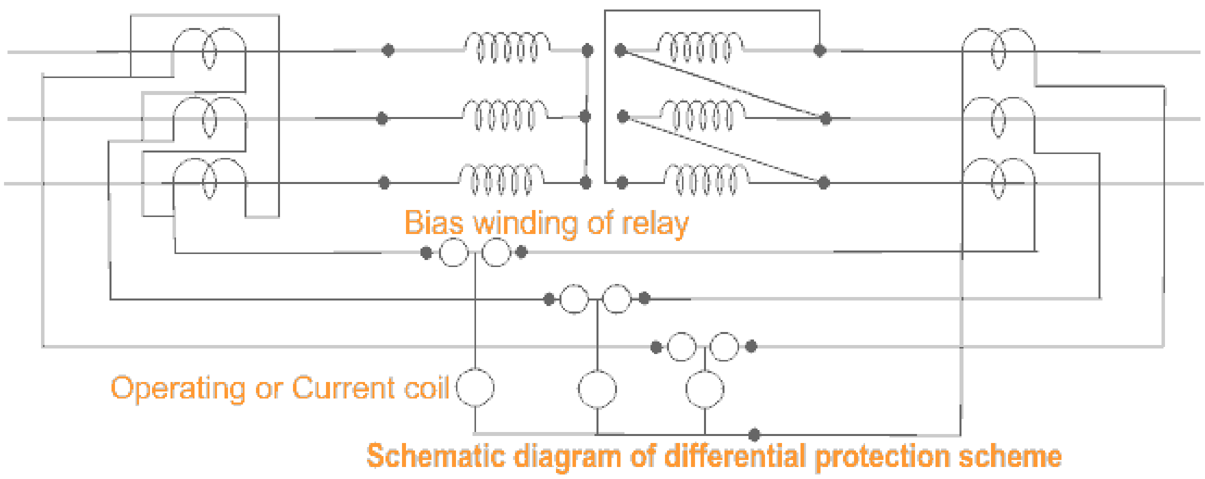


Fig: 3.9- Differential protection Scheme for 3 phase transformer

3.2.1 Current Transformer

Current and voltage signals are used in almost all electrical measurements and relaying decisions. Real-world signals (feeder or transmission line currents) and bus voltages must be scaled to a lower level before being fed to the relays since relaying gear works with a smaller range of current (in Amperes, not kA) and voltage (in volts, not kV). Current and potential transformers are in charge of this task (CTs and PTs). The relaying system for the actual power apparatus is likewise electrically isolated by CTs and PTs. Electrical separation from the primary voltage ensures the safety of both human and machine personnel. CTs and PTs are hence the relay's sensors. CT and PT serve as the protection system's "ears" and "eyes." They pay attention to and monitor everything that happens in the outside world. The relay is the brain that interprets these impulses and sends out decision commands to circuit breakers, alarms, and other devices.

A CT's equivalent circuit is quite similar to that of a normal transformer (fig 3.10). A key distinction is that, although ordinary power transformers are excited by a voltage source, current transformers are excited by a current source. The CT's primary winding is linked to the transmission line in series. The load on the secondary side of the relaying burden, as well as the resistance of the lead wire.

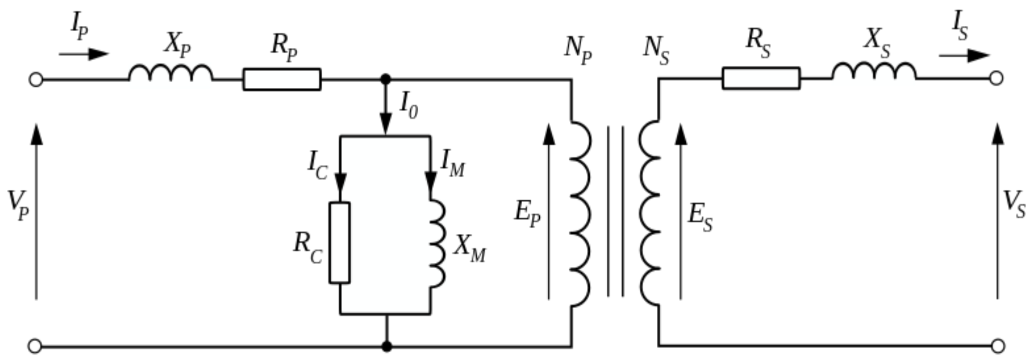


Fig 3.10: Equivalent circuit of transformer

Total load in ohms that is introduced by CT in series with the transmission line is insignificant and hence, the connection of the CT does not alter current in the feeder on the power apparatus at all. Hence from modelling perspective it is reasonable to assume that CT primary is connected to a current source. Therefore, the CT equivalent circuit will look as shown in fig 3.11. the remaining steps in modelling are as follows:

As impedance in series with the current source can be neglected, we can neglect the primary winding resistance and leakage reactance in CT modelling.

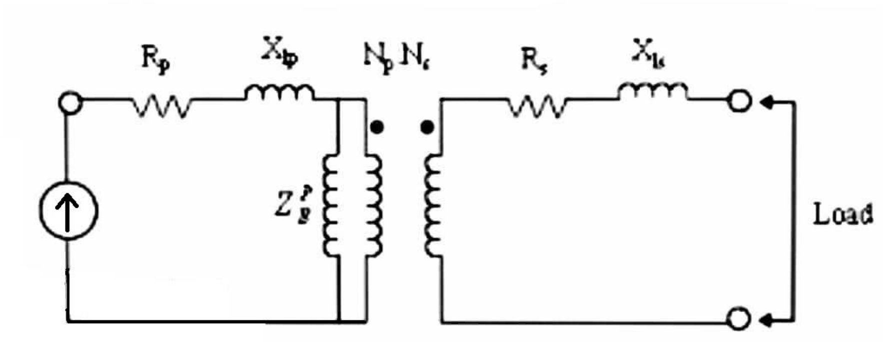


Fig 3.11: Modelling of CT

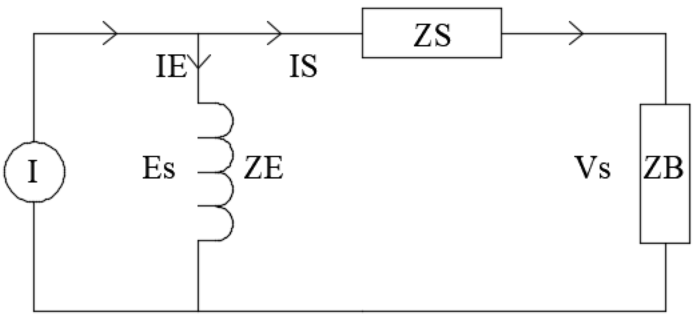


Fig 3.12: Final Equivalent circuit of CT

Simplify the equivalent circuit of a CT by transferring the current source (through the ideal transformer) to the secondary side. Thus, the equivalent circuit of the CT is as shown in fig 3.12.

3.2.2 Main Components rating

1. Power transformer
2. Differential relay
3. Current transformer
4. Induction load

1.) Power transformer_ the rating of power transformer are as follows:

Nominal power (MVA)	250
Frequency (Hz)	50
Voltages (KV)	735/315

2.) Current transformer (CTs)_the rating of CTs are follows:

Nominal power (VA)	250
Frequency (Hz)	50
CT_1 turns	5/3000
CT_2 turns	5/4200

3.) **Differential relay-**

I_1-I_2 ≥ K(I_1+I_2)/2 3.11

K = Nr/No 3.12

No (operating coil) = 1mH

Nr (restraining coil) = 0.5mH

By putting in equation (3.12), we get

K=0.5

Where there is no fault, maximum current flows in coils are I_1=4.3A, I_2=4.28A. By putting in equation (3.11), we get

I_1-I_2 ≥ 2.15A

So, when I_1-I_2 ≥ 2.15A then relay will be operated. Otherwise, relay will not be operated.

4.) **Load** – the load we are using is induction motor load.

R = 1850 ohm L=3.68H

After converting these value to active and reactive power

P+j*Q = 50+j*37.5

So that, P=50MW, Q=37.5 MVAr

In figure 3.13 shown, we are considering that power is coming from the power stations which is our electrical source and we are stepping down the voltage for industrial use. We will connect the CTs with power transformer both secondary and primary side. Therefore, if we connect the secondary winding of CTs on each side is star, then the current we not match up & I_d or spill current would result when there is no internal fault.

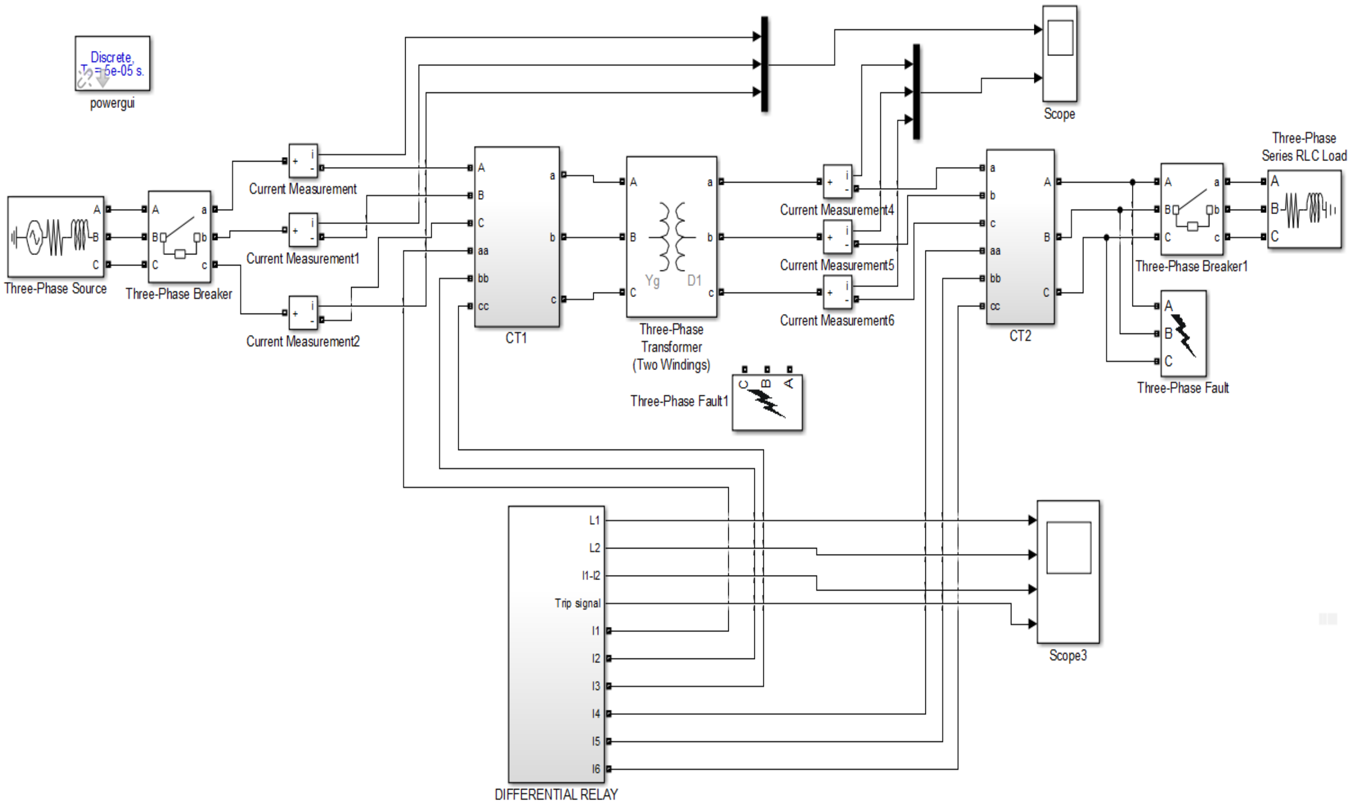


Fig 3.13: Simulation Model of Percentage Differential Protection Relay

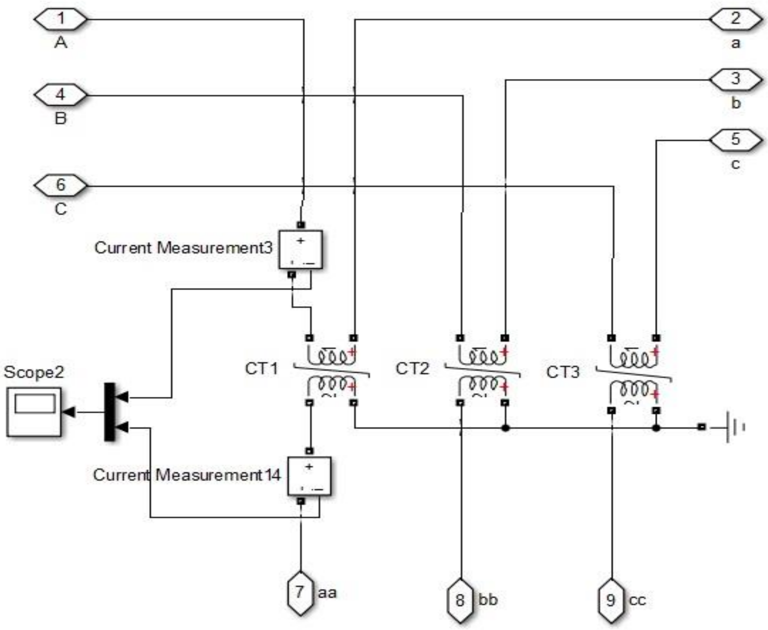


Fig 3.14: Current Transformer Block

We observe, that if the secondary winding of CTs on the star side are connected in delta, then the line currents would exactly match with the secondary current of CTs on the delta side, provided that these are connected in star. So operating coil current will be zero then and there exists no fault. This relay will not be operated when there is an external fault (fault outside the protective zone). If current is above a certain level, then relay will give trip signal and circuit breaker will open its contacts and remove the faulty part from healthy part. The load we are using is the induction motor type load. There are two conditions arises that relay will operate or not. In the no fault or external fault relay will not be operate, but when there is internal fault relay will absolutely work.

In the figure 3.15 shows differential relay, where we have used inductor for restraining and operating coil.

$$I_1 - I_2 \geq K(I_1 + I_2)/2$$

K=Nr/No

Nr= Restraining coil

No= Operating coil

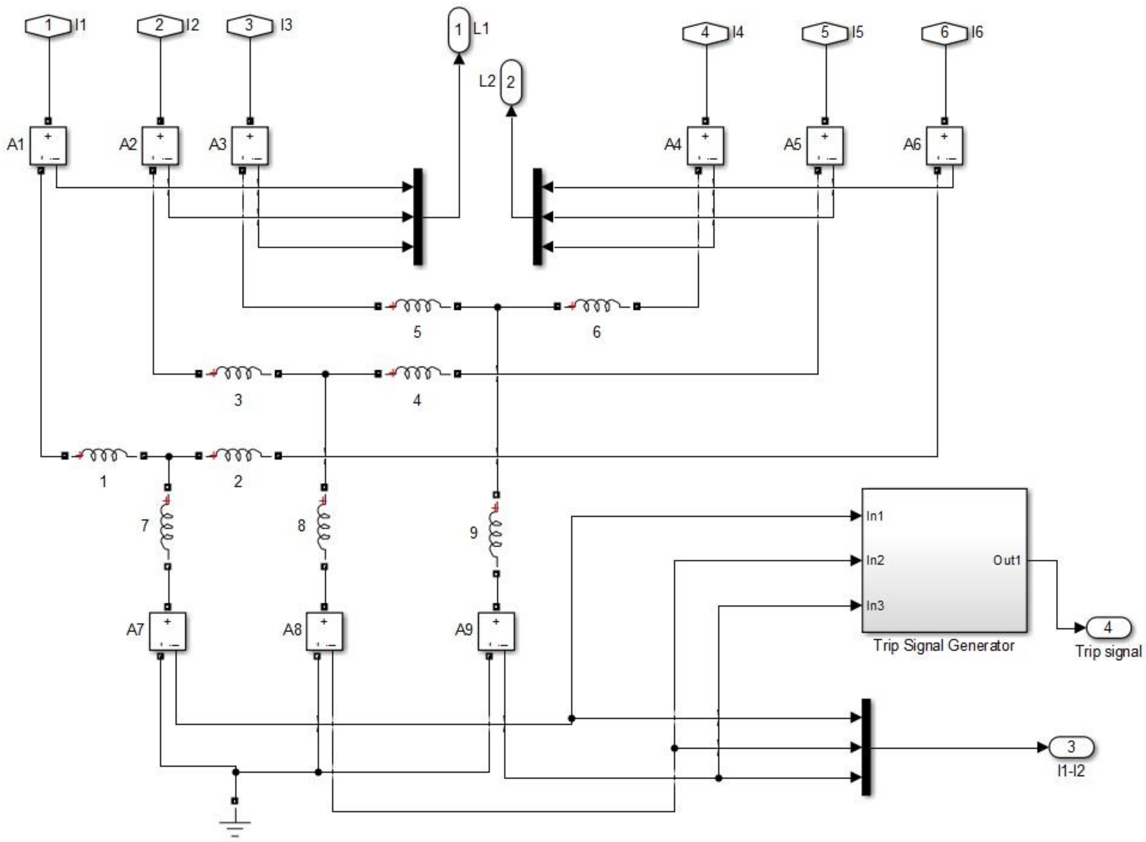


Fig 3.15: Percentage Differential Relay Block

When the current flow in operating coil above the limit then relay will be operated. In the normal conditions or no internal faults, the current though restraining coil are nearly equal and there is no current though operating coil. There phase is primary connected through CTs, we are comparing with secondary three phase is through CTs. In case external fault relay will not be operate. This differential relay gives the transformer protection only in internal fault or in protection zone which we are protecting. External fault means the faults which are occurring outside of protecting zone.

In figure 3.16 shows the faults generator, which is generating a fault signal when a fault occurs.

As shown in figure we are taking current from all three phase and then we compare with a certain value by relational operator. If current is above certain value, then relational operator will give 1(one) output. If current is less then certain value which is fixed, then it will give 0(zero).

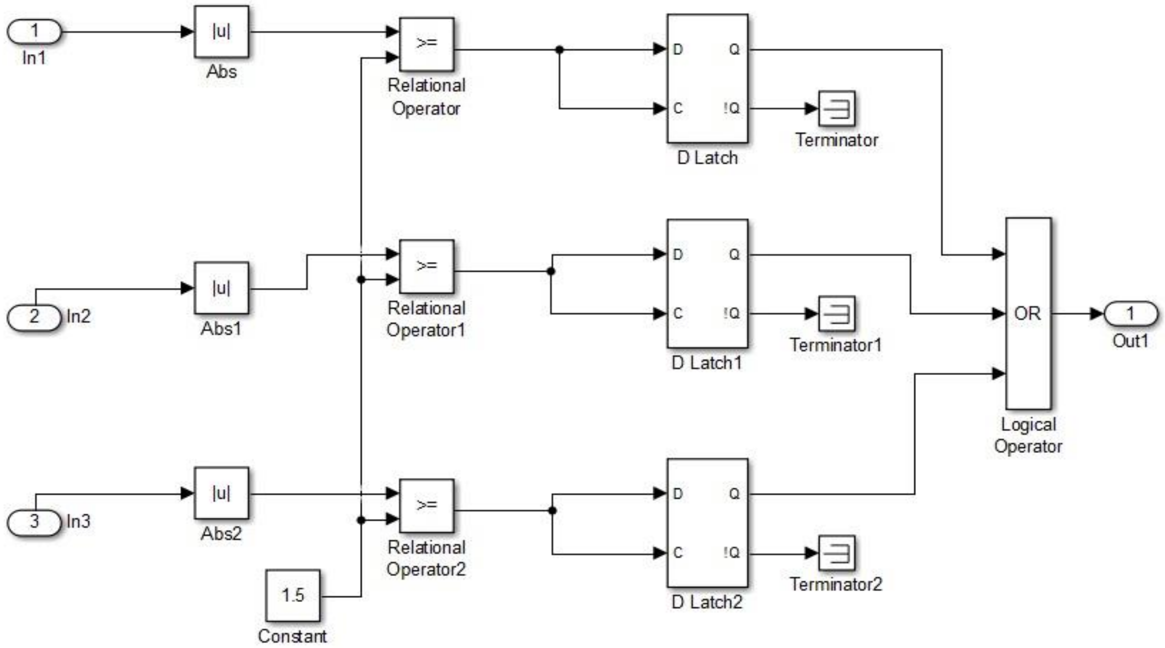


Fig 3.16: Trip Signal Generator Block

The output of relational operator goes to D-latch. This has two inputs terminal - one is D terminal and other is for clock pulse. In starting when there is no fault, relational operator gives zero and we give both D input terminal and clock pulse is zero. So output of D-latch is opposite of what we have given on the d- input terminal and that is one. But we are taking the compliment output of latch so it is zero, then signal given to the circuit breaker is zero its mean it will be close when there is no fault.

When there is internal fault then current will be greater than certain value and operational block gives the output 1(one). This goes to input of the d latch which has two input terminal one is D and other is clock pulse terminal. We will give same input on both input terminal of d-latch which give output zero. So we take compliment of this and gives to circuit breaker. When circuit breaker receives the signal 1(one), its starts open the contacts and separates the faulty part of the circuit from the healthy part.

3.3 Difficulties faced during this project: -

There were some difficulties faced due to lack of some toolbox in the sim-power –system. For example, in MATLAB simulation toolbox there is no current transformer. In this case, for solution of this problem, there were two choices, first one is that to use a single phase transformer and make some changes in its specification to fit the current transformer. And second choice is that to use a current measurement, but that will not solve our problems of the CT. The method used here is to use a single phase transformer and make it specific to our requirement of CT.

CHAPTER-4

RESULTS & CONCLUSIONS

4.1 INTRODUCTION

There are different types of faults in power system. I discuss here almost all faults. Firstly faults are two types: -

1.) External faults
2.) Internal faults

1. **External faults: -**
   Faults which occur outside of protecting zone is called external faults and relay protecting a certain zone will not be operate if there is faults. These external faults are also called through faults.
2. **Internal faults: -**
   Faults which occur inside the protecting zone is called internal faults. If we are protecting a certain zone then relay will be operated if there is fault inside the protecting zone. Ideally, a relay looking after the protection of a zone should operate only for internal fault.

4.2 RESULTS & DISCUSSION

4.2.1 Over current and Earth Fault Relay

Operation of O/C and E/F relay of power transformer is shown on each type of fault condition. The result is given in a tabular form. The figure 4.1 shows the fault current in the 3 phases for a LLL-G fault. The plug setting and TMS for Overcurrent relay is taken to be 1.2 and 0.35 and for Earth fault relay 0.4 and 0.35 respectively.

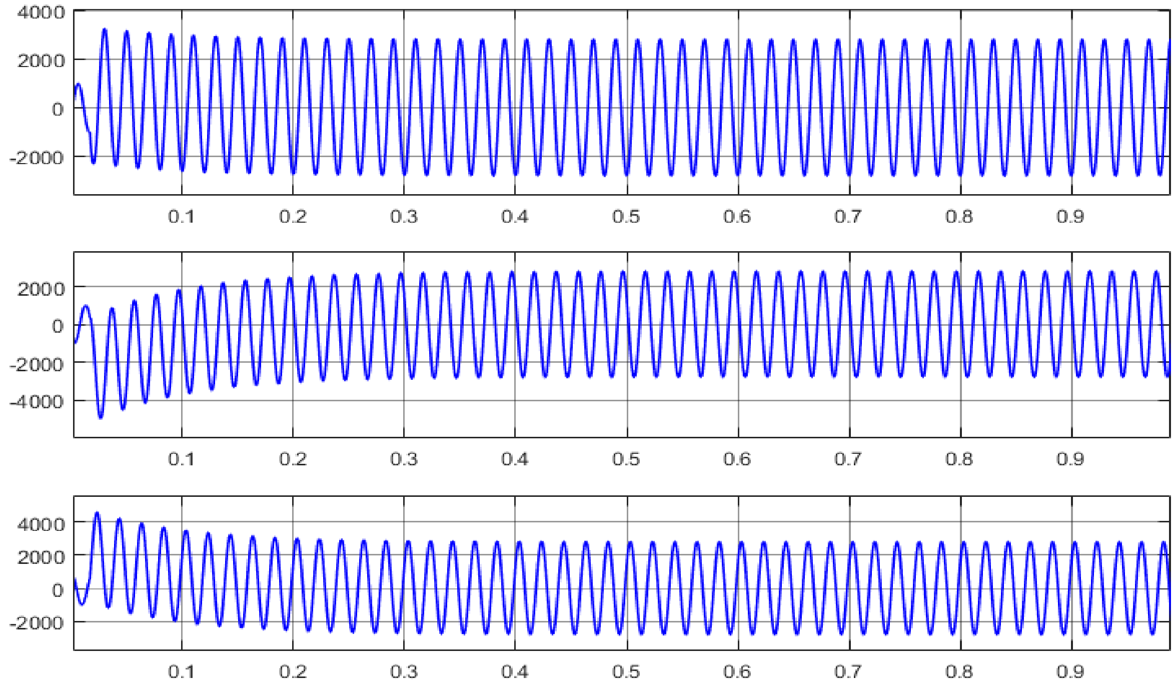


Fig: 4.1: Fault current vs time graph for all the 3 phases

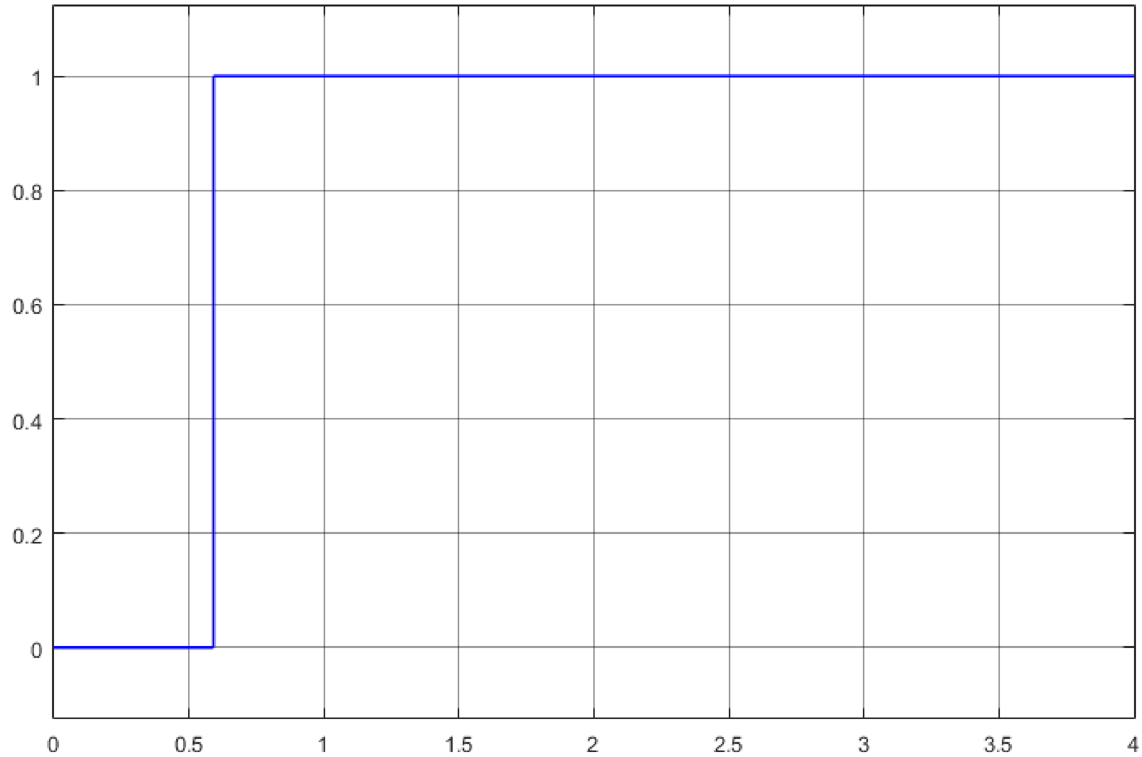


Fig: 4.2: Trip signal

Table 4.1: Fault current and operating time of O/C& E/F relay

Case no.	Fault type	Fault current (A)	Operating time for phase relay (s)	Operating time for earth fault relay (s)
1.	Three phase to ground fault	Ir = 2808	1.436	0.6819
		Iy = 2627	1.496	
		Ib = 2988	1.384	
2.	Line-gnd fault (B-G)	Ib = 2988	1.383	1.117
3.	Double line-gnd fault (YB-G)	Iy = 2627	1.496	0.8581
		Ib = 2988	1.384	

The table above shows the results for the operating time of the phase as well as the earth fault relay for different fault conditions i.e., L-G, LL-G and LLL-G faults. These results were verified in regard with simulation results [6].

4.2.2 Differential Protection Relay

Operation of differential relay protection of power transformer is shown on each type of faults. The system conditions are discussed below: -

4.2.2.1 Normal condition
4.2.2.2 L-G faults
4.2.2.3 LL-G faults
4.2.2.4 LLL-G faults
4.2.2.5 External faults

4.2.2.1 Normal condition- In this case we consider that there is no Fault.

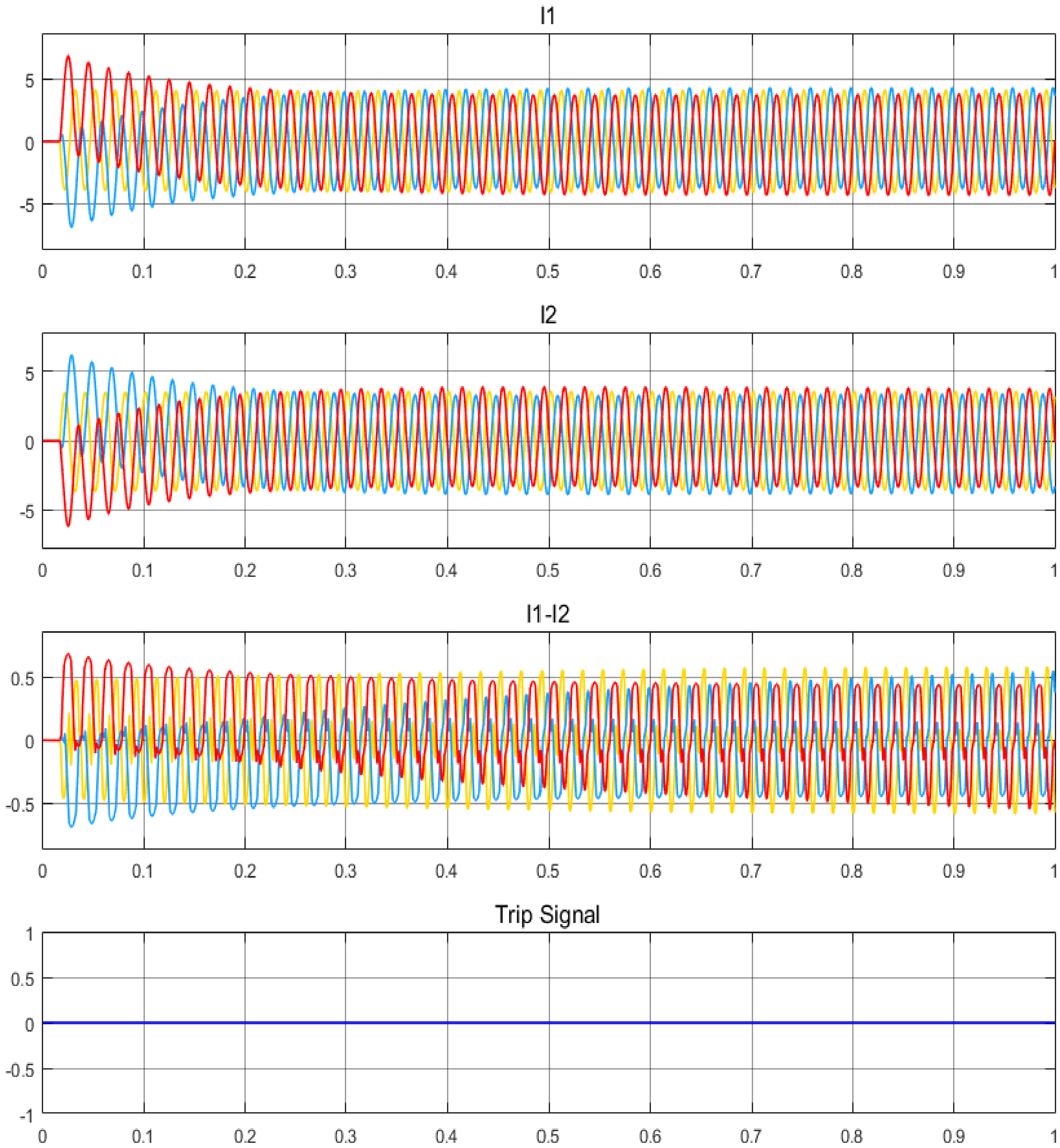


Fig: 4.3- In normal condition restraining coil currents(I_1 & I_2); operating coil current (I_1 - I_2); and the trip signal

As shown in the above figure 4.3, (I_1 & I_2) restraining coil current waveforms are shown. (I_1-I_2) operating coil current is zero, so the relay will not operate. The trip signal is zero which means the circuit breaker is closed.

Trip signal – 1 = Circuit Breaker open

Trip signal – 0 = Circuit Breaker closed

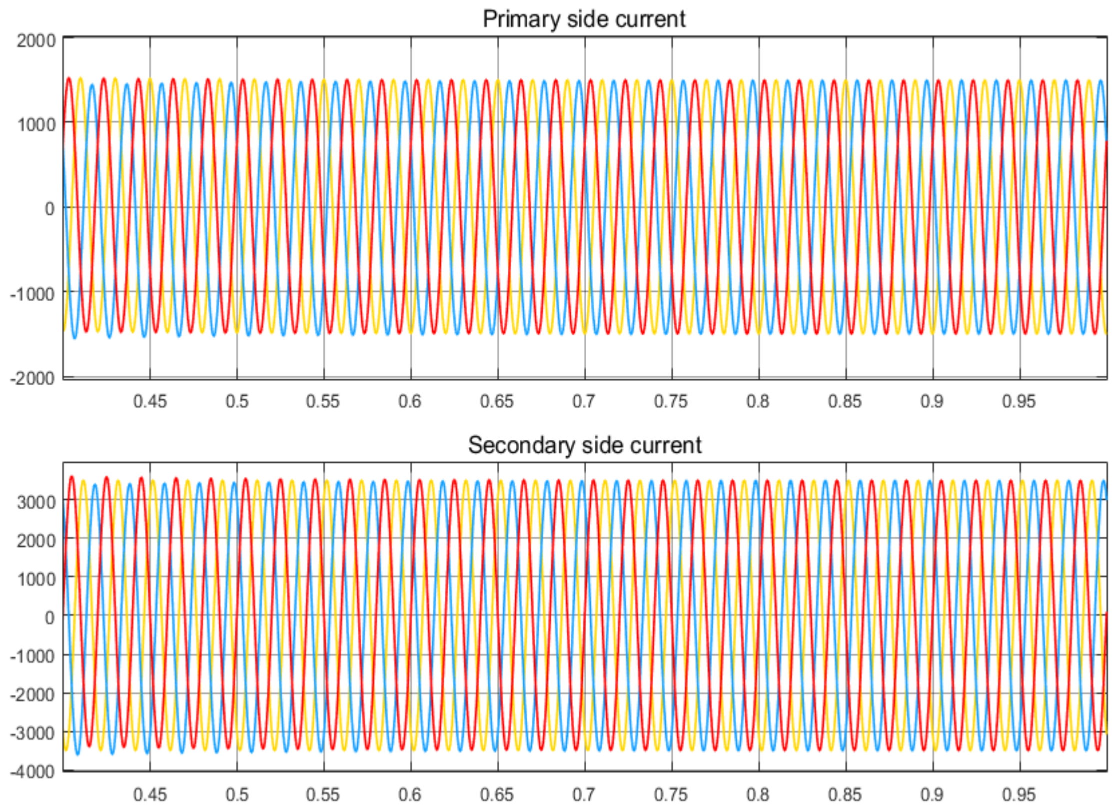


Fig 4.4 - Primary side current and Secondary side current of the power transformer in normal condition

In the table 4.2 explaining figure 4.3 and showing current of all three phases at different time. Each time I_1-I_2 is zero and less than $(I_1+I_2)/2$. So that each time relay status is no trip in normal condition. Table 4.3 explaining figure 4.4 shows power transformer secondary side current and primary side current, all three phase current is shown in the table at different time locations in normal condition. The minus sign in the table is showing that its value in opposite axis.

Table 4.2 (I_1, I_2, I_1- I_2) currents & relay status at different time for normal condition

S.No.	Time (sec)	I_1			I_2			I_1-I_2			Relay Status
		I_A	I_B	I_C	I_A	I_B	I_C	I_A	I_B	I_C	
1	0.1	-3.661	3.787	-0.1257	3.728	-3.694	-0.0333	0.0667	0.0923	-0.159	No Trip
2	0.21	4.289	-1.864	-2.426	-4.258	1.173	2.546	0.0309	-0.161	0.1201	No Trip
3	0.32	-3.279	-0.7707	4.05	3.162	0.9236	-4.086	-0.1174	0.1527	-0.0352	No Trip
4	0.43	1.017	3.1111	-4.128	-0.8584	-3.207	4.065	0.1584	-0.0954	-0.0629	No Trip
5	0.54	1.634	-4.263	2.629	-1.773	4.265	-2.2992	-0.1395	-0.0023	-0.1372	No Trip
6	0.65	-4.215	1.363	2.862	4.164	-1.206	-2.968	-0.0606	0.1516	-0.1054	No Trip
7	0.69	-2.272	4.272	-1.7	2.688	-4.234	1.546	0.1154	-0.0378	-0.1532	No Trip

Table 4.3 Primary side current and Secondary side current of the power transformer in normal condition

S.No.	Time(sec)	$I_{PRIMARY}$			$I_{SECONDARY}$		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.1	-1.507	717	788	-3.92	2997	95
2	0.21	1195	198	-1393	3486	-1343	2143
3	0.32	-426	-1039	1465	-2548	-823	3372
4	0.43	-504	1482	-977	637	-2676	-3314
5	0.54	1243	-1360	116	1517	-3506	1989
6	0.65	-1070	-383	1464	-3400	924	2475
7	0.69	-1416	1155	260	-2258	3463	-1205

4.2.2.2 **L-G Fault** – In this case we consider that the internal fault on the transformer is L-G fault

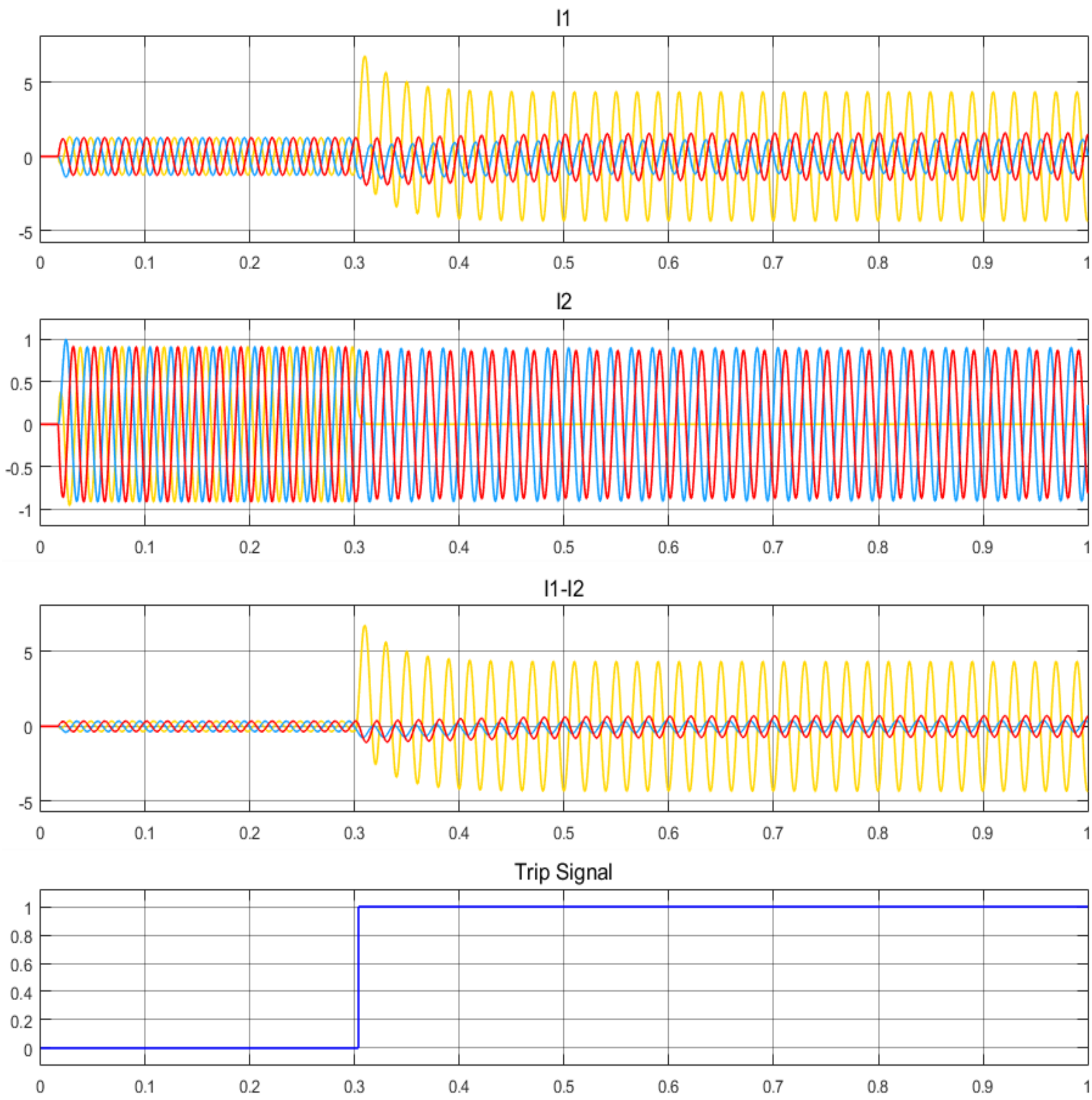


Fig: 4.5- In L-G fault restraining coil currents(I_1 & I_2); operating coil current (I_1 - I_2); and the trip signal

The figure 4.5 shows the results for a L-G fault as an internal fault which is initiated after 0.3 sec. As can be seen, before 0.3 seconds, the difference between (I_1 & I_2) remains 0 and thus trip signal is 0 thus the circuit breaker remains closed. When the fault is initiated, (I_1 - I_2)$\neq$ 0, and thus the trip signal becomes high i.e., 1 and the circuit breaker opens.

Table 4.4 (I_1, I_2, I_1- I_2) currents & relay status at different time for L-G Fault

S. No.	Time (sec)	I_1			I_2			I_1-I_2			Relay Status
		I_A	I_B	I_C	I_A	I_B	I_C	I_A	I_B	I_C	
1	0.3008	3.231	-3.953	0.722	-1.055	3.94	0.5	2.17	-0.013	0.221	Trip
2	0.3009	4.052	-3.132	-0.919	-1.547	3.042	1.101	2.505	-0.09	0.1813	Trip
3	0.3010	4.254	-2.547	-1.707	-1.714	2.422	1.858	2.539	-0.1251	0.1513	Trip
4	0.3012	4.304	-2.101	-2.203	-1.821	1.982	2.283	2.484	-0.119	0.6733	Trip
5	0.305	0	0	0	0	0	0	0	0	0	Relay Tripped, CB opened

For figure 4.5 the values of currents are shown in table 4.4 for different time intervals where (I_1-I_2) is greater than (I_1+I_2)/2 for phase A. thus, the relay gives trip signal. Figure 4.6 is showing the operating characteristics of the differential relay during single line to ground fault.

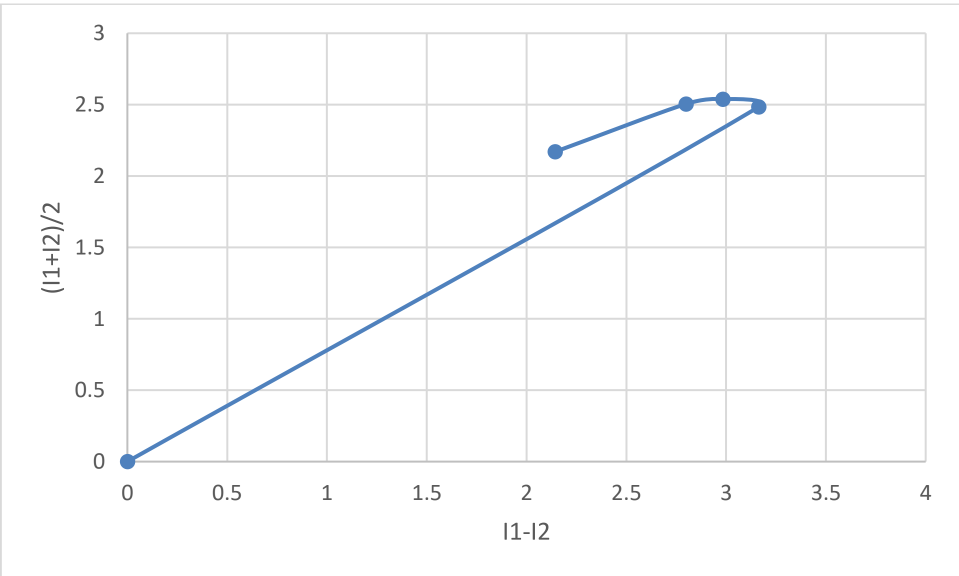


Fig 4.6: Operating characteristics of the relay for single line to ground fault

4.2.2.3 **LL-G Fault –** In this case we consider that the internal fault is LL-G.

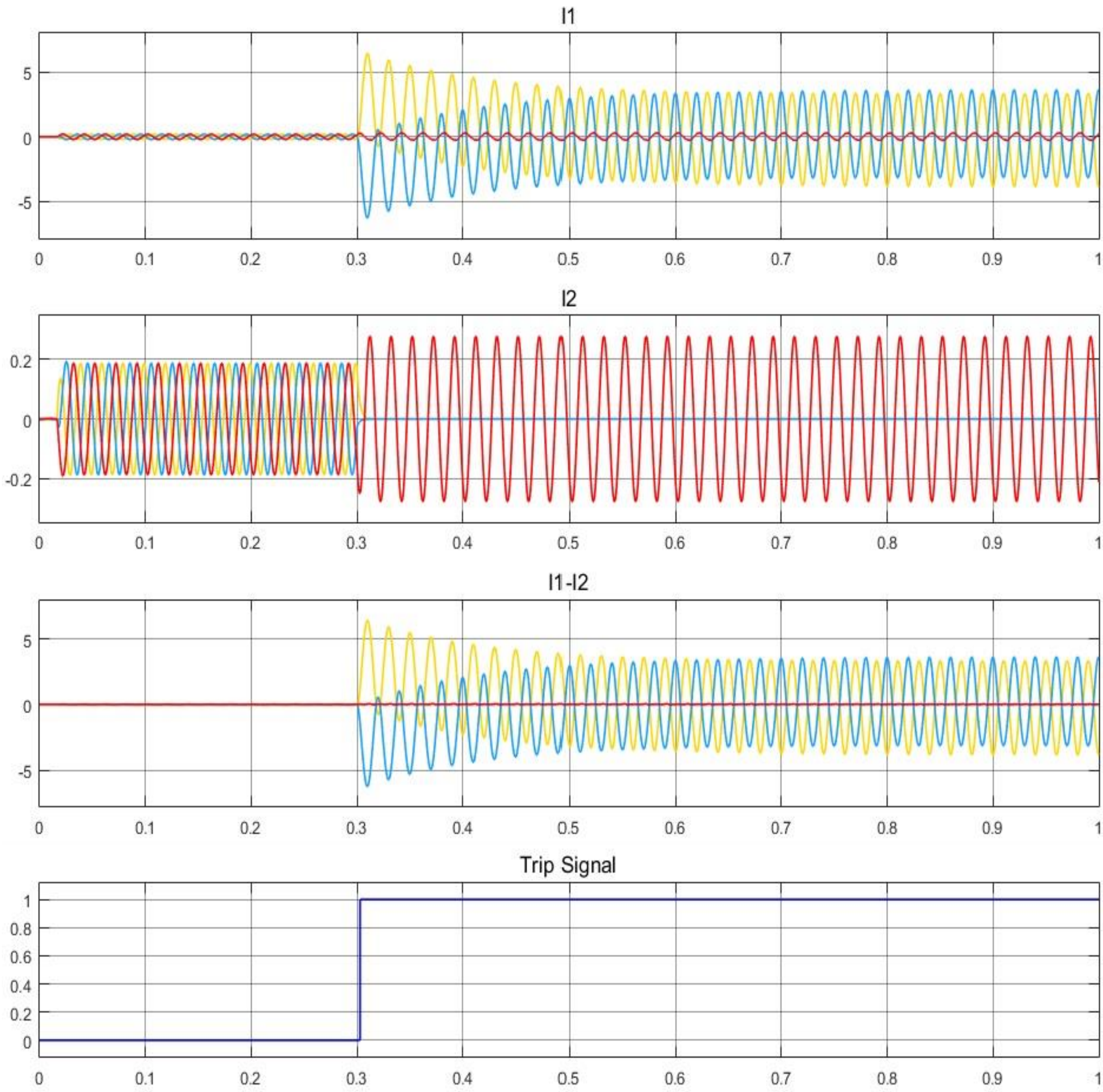


Fig: 4.7- In LL-G fault restraining coil currents(I_1 & I_2); operating coil current (I_1 - I_2); and the trip signal

The figure 4.7 shows the results for a LL-G fault as an internal fault which is initiated after 0.3 sec. As can be seen, before 0.3 seconds, the difference between (I_1 & I_2) remains 0 and thus trip signal is 0 thus the circuit breaker remains closed. When the fault is initiated, (I_1 - I_2)$\neq$ 0, and thus the trip signal becomes high i.e., 1 and the circuit breaker opens.

Table 4.5 (I_1, I_2, I_1- I_2) currents & relay status at different time for LL-G Fault

S.No	Time (sec)	I_1			I_2			I_1-I_2			Relay Status
		I_A	I_B	I_C	I_A	I_B	I_C	I_A	I_B	I_C	
1	0.308	3.236	-3.977	0.742	-0.424	1.315	-0.605	2.812	-2.663	0.237	Trip
2	0.309	4.11	-3.238	-0.877	-0.968	1.007	1.098	3.142	-2.231	0.226	Trip
3	0.309	4.336	-2.686	-1.647	-1.192	0.795	1.866	3.149	-1.894	0.208	Trip
4	0.31	4.371	-2.203	-2.168	-1.367	0.615	2.29	3.013	-1.689	0.122	Trip
5	0.32	0	0	0	0	0	0	0	0	0	Relay Tripped, CB opened

In the table 4.5 explaining figure 4.7 and showing current of all three phases at different time. When fault occurs, it gets detected by differential relay as each time (I_1-I_2) is greater than (I_1+I_2)/2. So, the relay gives trip signal to the CB very fast.

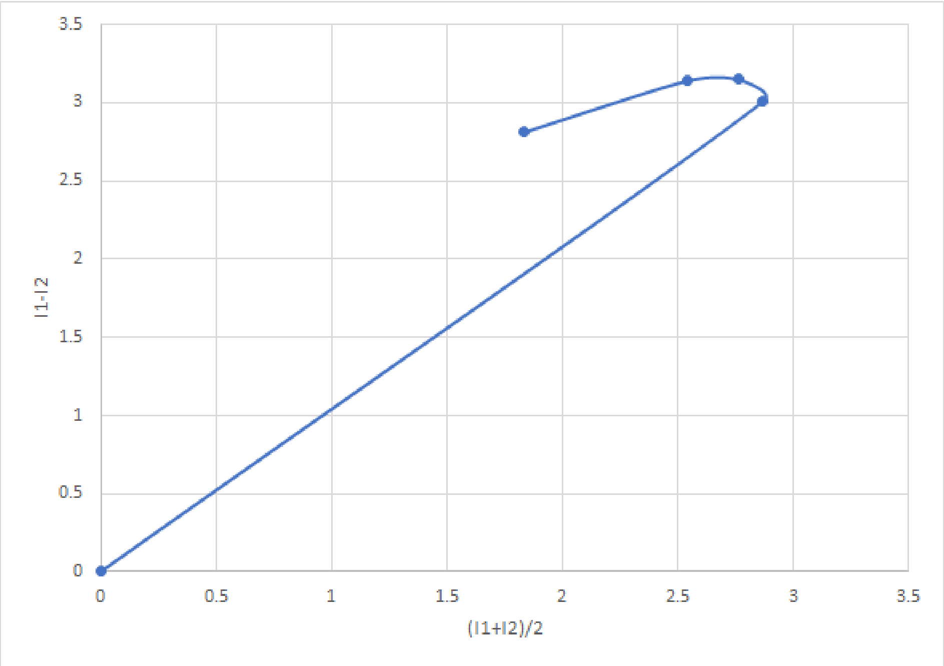


Fig 4.8: Operating characteristics of the relay for double line to ground fault

4.2.2.4 LLL-G Fault - In this case we consider that the internal fault is LLL-G.

The figure 4.9 shows the results for an LLL-G fault as an internal fault which is initiated after 0.3 secs. As can be seen, before 0.3 seconds, the difference between (I_1 & I_2) remains 0 and thus trip signal is 0. When the fault is initiated, (I_1 - I_2)≠ 0, and thus the trip signal becomes high i.e. 1.

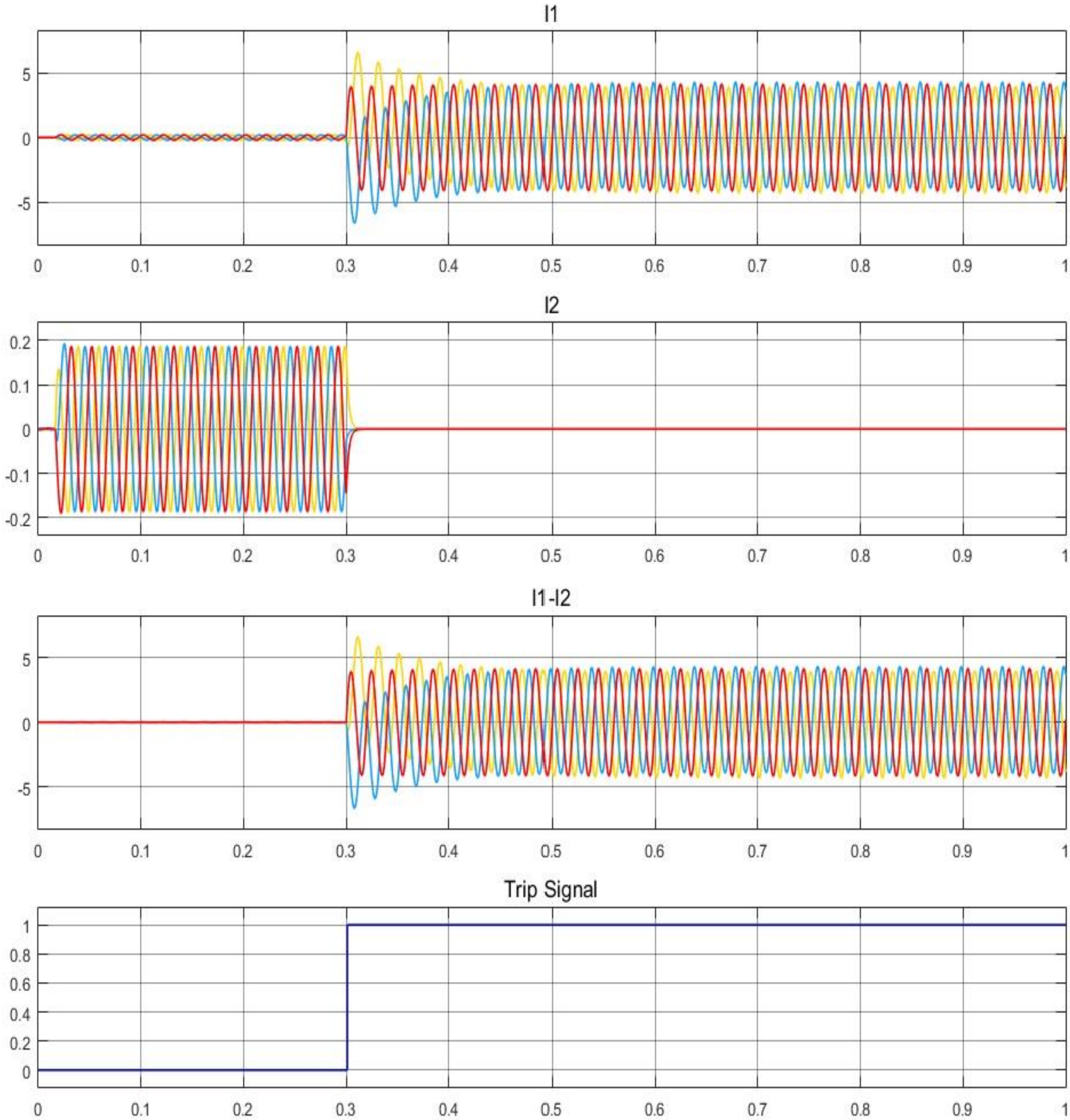


Fig 4.9- For internal fault LLL-G restraining coil currents(I_1 & I_2); operating coil current (I_1-I_2); and the trip signal

Table 4.6 (I_1, I_2, I_1- I_2) currents & relay status at different time for LLL-G Fault

S.No	Time (sec)	I_1			I_2			I_1-I_2			Relay Status
		I_A	I_B	I_C	I_A	I_B	I_C	I_A	I_B	I_C	
1	0.1	-3.661	3.787	-0.1257	3.728	-3.694	-0.0333	0.0667	0.0923	-0.159	No Trip
2	0.21	4.289	-1.864	-2.426	-4.258	1.713	2.546	0.0309	-0.161	0.1201	No Trip
3	0.305	-3.645	0.026	3.618	1.542	-0.6493	-0.8929	-2.103	-0.6225	2.726	Trip
4	0.304	-2.694	-1.509	4.202	1.146	-0.0512	-1.094	-1.548	-1.56	3.108	Trip
5	0.305	-1.841	-2.347	4.188	0.8576	0.3169	-1.174	-0.988	-2.03	3.014	Trip
6	0.306	-1.479	-2.476	3.955	0.7184	0.4426	-1.159	-0.7627	-2.033	2.796	Trip
7	0.32	0	0	0	0	0	0	0	0	0	Relay Tripped CB Opened

In the table 4.6 explaining figure 4.9 and showing current of all three phases at different point of time. When fault occurs, it gets detected by differential relay when (I_1-I_2) is greater than (I_1+I_2)/2. So, the relay acts very fast and immediately gives trip signal to the CB and it operates very fast.

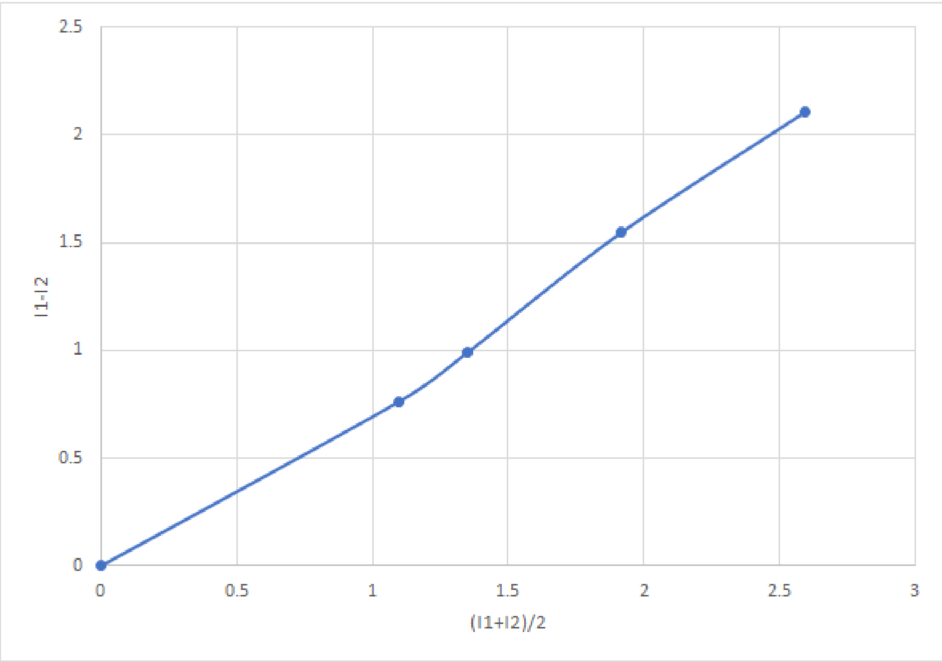


Fig 4.10: Operating Characteristics of the relay for three-phase to ground fault

4.2.2.5 External Fault- In this case we consider that the fault occurs outside the protection zone of the differential relay

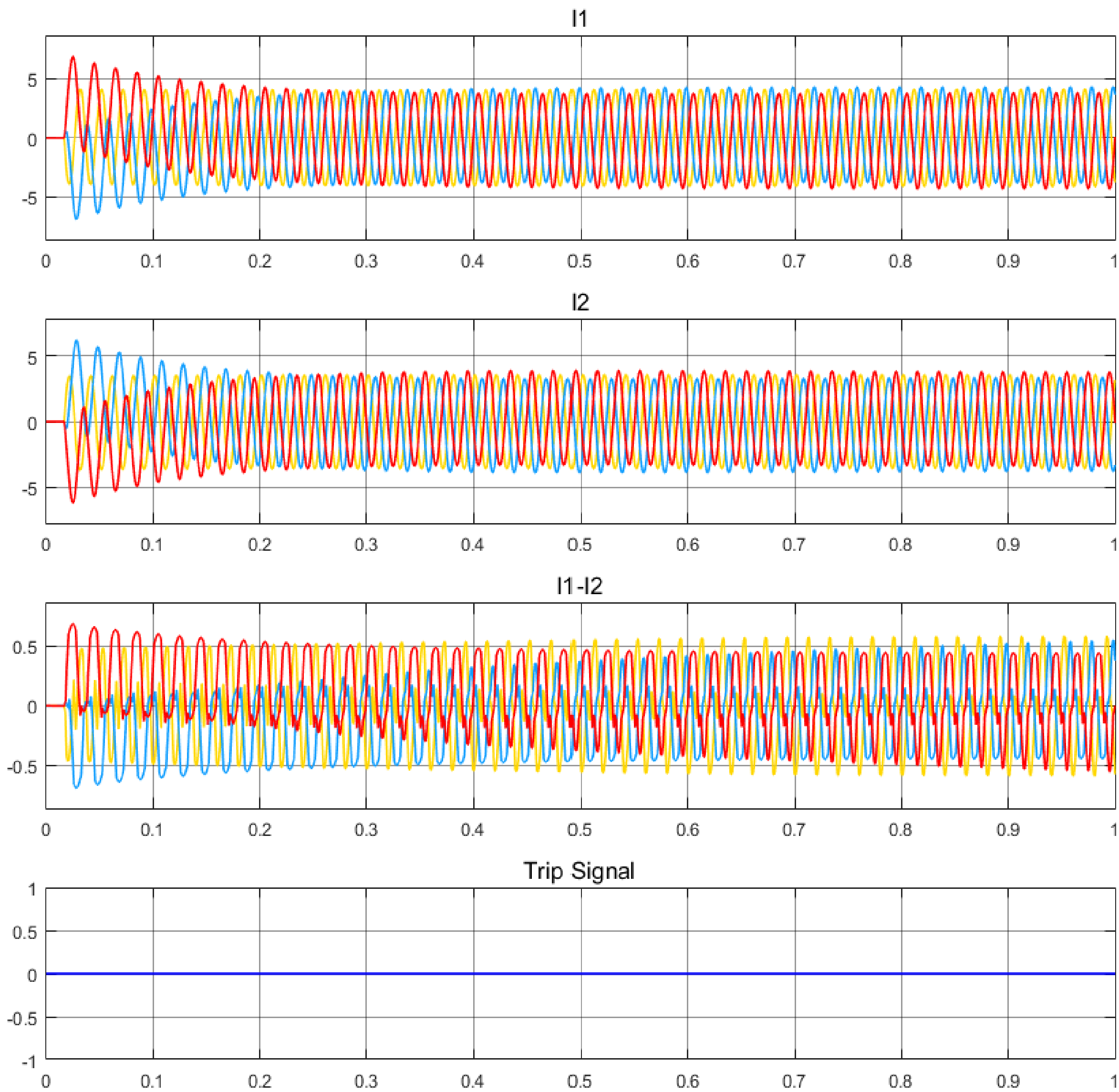


Fig: 4.11- In External fault condition restraining coil currents(I_1 & I_2); operating coil current (I_1 - I_2); and the trip signal

The figure 4.11 shows the results for Differential relay operation during an external fault. External fault are those which occur outside the protection zone of the relay. Differential relay will not operate for such faults as the difference between (I_1 & I_2) remains nearly 0 and thus trip signal is 0.

Table 4.7 (I_1, I_2, I_1- I_2) currents & relay status at different time for External Fault

S.No.	Time (sec)	I_1			I_2			I_1-I_2			Relay Status
		I_A	I_B	I_C	I_A	I_B	I_C	I_A	I_B	I_C	
1	0.1	-3.661	3.787	-0.1257	3.728	-3.694	-0.0333	0.0667	0.0923	-0.159	No Trip
2	0.21	4.289	-1.864	-2.426	-4.258	1.713	2.546	0.0309	-0.161	0.1201	No Trip
3	0.32	-3.201	3.003	0.1987	3.164	-2.968	0.1964	-0.0372	0.034	0.002	No Trip
4	0.43	-1.132	1.062	0.069	1.118	-1.049	-0.06914	-0.0139	0.0128	0.0008	No Trip
5	0.54	-0.4018	0.3784	0.0254	0.3965	-0.3713	-0.02519	-0.005	0.005	0.0002	No Trip
6	0.65	-0.1419	0.1338	0.0081	0.1396	-0.1316	-0.00801	-0.002	0.002	0.0001	No Trip
7	0.7	-0.0882	0.0837	0.0048	0.0867	-0.0821	-0.004734	0.0017	0.0016	0.00007	No Trip

In the table 4.7 explaining figure 4.11 and showing current of all three phases at different time. Each time I_1-I_2 is zero and less than $(I_1+I_2)/2$. So that each time relay status is no trip in external fault condition as it was for no fault or normal condition.

CONCLUSIONS

Electrical power systems are among the most sophisticated and significant systems that human society has ever created. The importance of electrical power systems in the development and expansion of modern civilizations' economic activity is unquestionable. Humans have become so reliant on energy that even a little outage grinds the entire country to a halt. As a result, when power system failures occur, power system protection becomes critical in order to reduce damages and maintain the system's safe and continuous operation. Based upon the above results following conclusions are made-

1. This thesis work involved the design and modelling of overcurrent and differential relays, as well as the development of a manual prototype using the MATLAB-SIMULINK software package.
2. The overcurrent and earth fault relays produce adequate results for the characteristics used, such as the standard inverse curve, and can be expanded to other curve characteristics as well. However, because MATLAB is an equation solver, the simulation duration is determined by the model's complexity. The simulation will take longer to complete if the model is more complex.

3. The differential relay performed effectively under various system operating situations, and this model can be further expanded for other transformer ratings.

a) When there is no fault in the transformer, fault current flows through the differential relay's operational coil.

b) When (I1-I2) is greater than (I1+I2)/2, the relay operates in faults such as single line to ground, double line to ground and three phase to ground faults.

c) Due to the fact that external faults occur outside of the protective zone, the differential relay is not activated.

d) For L-G, LL-G and LLL-G faults, the graph is shown between (I1-I2) and (I1+I2)/2. The graph depicts the differential relay's operational characteristics during a fault.

FUTURE SCOPE OF WORK

The most simple and versatile relay utilised in power system protection is the overcurrent relay. It can serve as both the primary and backup protection relay for an equipment. Other sorts of curves, such as extremely inverse, very inverse, and long-time inverse, can simply be added to the model constructed in this study. In addition, when the fault current is too high, a definite time feature can be included to account for saturated current transformers.

The differential relay in this model is designed to work when there is an internal fault, but it will not operate if there is an external fault. There is a new adaptive protection that allows the parameters of differential relay characteristics to self-regulate (e.g. restrain current and restrain coefficient at knee point of slope, pick up current). The “self-adaptive differential relay” is a differential relay that operates for both internal and external faults. This results in a high level of operating sensitivity during internal failures and significantly increased security during external faults. This is better suited to situations when the only requirement is to provide the relay's lower and upper limits rather than specific values.

The modelling of relays done in this research shows that MATLAB/SIMULINK for modelling of any kind of relay. Thus, configuring the operation of the relay according to different network parameter is made possible, which makes the study even simpler.

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APPENDIX

TEST REPORT FOR 500MVA AUTO TRANSFORMER

EQUIPMENT INFORMATION

SUBTATION NAME	400/200/132/33KV GIS PROJECT AT SECTOR 148, NOIDA, UPPTCL		
Serial Number	14071-001	**Year of Mfg**	2016

RATING	500 MVA 400 / 220 / 33 KV ABB Make		**HV Current** : 433.01/577.35/721.69 **IV Current** : 787.32/1049.76/1312.20 **LV Current :** 87.47(ACTIVE)
Vector Group	YNa0d11	**Type of Cooling**	ONAN/ONAF/ODAF

Tap Changer	On Load / Off Load		
Range of Taps	1	9B	17
% IMPEDANCE HV-IV 500MVA BASE	9.71	11.80	15.51

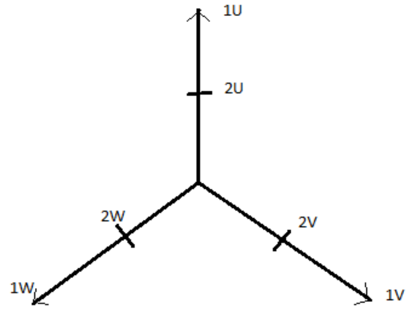
1. MAGNETIZING CURRENT TEST:

TAP POSITION	APPLIED VOLTAGE(V)			MEASURED CURRENT(mA)		
	1U-1V	1V-1W	1W-1U	1U	1V	1W
1	419	418	418	1.5	0.9	1,9
2	419	418	418	1.8	0.9	2.1
3	419	418	418	1.8	0.9	2.1
4	419	418	418	1.9	0.9	2.2
5	419	418	418	1.9	1.0	2.2
6	419	418	418	1.9	1.0	2.2
7	419	418	418	2.0	1.1	2.3
8	419	418	418	2.0	1.1	2.3
9b	419	418	418	2.1	1.1	2.4
10	419	418	418	2.1	1.1	2.4
11	419	418	418	2.1	1.1	2.4
12	419	418	418	2.2	1.1	2.5
13	419	418	418	2.2	1.2	2.6
14	419	418	418	2.3	1.2	2.6
15	419	418	418	2.3	1.3	2.7
16	419	418	418	2.4	1.3	2.8
17	419	418	418	2.5	1.3	2.8

1. **VECTOR GROUP CONFIRMATION**

A. VECTOR GROUP YNa0

Connect Neutral Point with earth.



VOLTAGE APPLIED TO TERMINALS

1u-1v = 418

1v-1w = 418

1w-1u = 419

APPLIED TERMINALS	MEASURED VOLTAGE
1U-2U	108.0
1V-2V	108.0
1W-2W	108.0
2U-1N	132.0
2V-1N	132.0
2W-1N	132.0
1U-1N	241.0
1V-1N	241.0
1W-1N	241.0

CONDITIONS:

1. (1U-2U) + (2U-1N) ≈ (1U-1N).
   (108.0) + (132.0) ≈ (241.0).

2. (1V-2V) + (2V-1N) ≈ (1V-N)
   (108.0) + (132.0) ≈ (241.0)

3. (1W-2W)+(2W-1N) ≈ (1W-1N)
   (108.0) + (132.0) ≈ (241.0)

THE VECTOR GROUP IS YNa0

B. VECTOR GROUP YNd11

Connect Neutral Point with earth. Short 1W & 3W Terminals

VOLTAGE APPLIED TO TERMINALS

1u-1v = 418

1v-1w = 418

1w-1u = 418

APPLIED TERMINALS	MEASURED VOLTAGE
1U-3U	389.0
1U-3V	389.0
1V-3V	388.0
1V-3U	420.0
1W-3V	34.0
3V-1N	207.0
1W-1N	241.0

CONDITIONS:

1. (1W-3V) + (3V-1N) ≈ (1W-1N)
   (34.0) + (207.0) ≈ (241.0)

2. (1V-3V) ‹ (1V-3U)
   (388.0) ‹ (420.0)

3. (1U-3U) ≈ (1U-3V)
   (389.0) ≈ (389.0)

THE VECTOR GROUP IS YNd11.

Vector group Ynaod11 is confirmed and polarity verified

3. SHORT CIRCUIT TEST

SHORT CIRCUIT TEST BETWEEN HV – IV (short IV)

TAP NO	APPLIED VOLTAGE (V)			MEASURED IV CURRENT (A)		
	1U-1V	1V-1W	1W-1U	2U	2V	2W
1	415	415	415	13.1	13.2	13.2
9B	415	415	415	12.8	12.9	12.7
17	415	415	415	12.2	12.2	12.3

SHORT CIRCUIT TEST BETWEEN HV – LV (short LV)

TAP NO	APPLIED VOLTAGE (V)			MEASURED IV CURRENT (A)		
	1U-1V	1V-1W	1W-1U	3U	3V	3W
1	415	415	415	12.6	12.6	12.6
9B	415	415	415	11.5	11.4	11.4
17	415	415	415	9.6	9.6	9.6

4. MEASUREMENT OF WINDING RESISTANCE:

HV-IV WINDING

APPLIED CURRENT : 10A. WINDING TEMP:30°C

TAP	TERMINAL 1U-2U in mΩ	TERMINAL 1V-2V in mΩ	TERMINAL 1W-2W in mΩ
	At 30 °C	At 30 °C	At 30 °C
1	269.61	269.1	269.6
2	265.2	264.5	265.3
3	260.6	260.0	260.6
4	256.2	255.6	256.1
5	251.4	250.9	251.7
6	246.9	246.5	247.2
7	242.2	242.0	242.3
8	237.7	237.2	237.8
9B	232.9	232.5	233.1
10	237.4	237.1	237.5
11	241.9	241.7	242.3
12	246.5	246.3	246.8
13	251.0	250.8	251.3
14	255.7	255.4	255.9
15	260.5	260.4	260.8
16	265.1	264.9	265.3
17	269.9	270.1	270.3

IV Winding: Applied current : 10A. TEMP: 30°C

TAP	TERMINAL 2U-N mΩ	TERMINAL 2V-N mΩ	TERMINAL 2W-N mΩ
9B	250.3	250.0	250.7

LV Winding: Applied current : 1A. TEMP: 30°C

TAP	TERMINAL 3U-3V mΩ	TERMINAL 3V-3W mΩ	TERMINAL 3W-3U mΩ
9B	13.83	14.12	14.43

TURNS RATIO TEST:

HV-IV

TAP POSITION	1U-N/2U-N		1V-N/2V-N		1W-N/2W-N	
	RATIO	%DEVIATION	RATIO	%DEVIATION	RATIO	%DEVIATION
1	2.0010	0.05	2.0030	0.15	2.0040	0.2
2	1.9833	0.30	1.9851	0.39	1.9840	0.33
3	1.9581	0.18	1.9572	0.13	1.9575	0.15
4	1.9370	0.26	1.9371	0.27	1.9401	0.42
5	1.9141	0.26	1.9130	0.20	1.9145	0.28
6	1.8940	0.40	1.8941	0.40	1.8950	0.45
7	1.8691	0.29	1.8699	0.33	1.8686	0.26
8	1.8441	0.17	1.8458	0.26	1.8446	0.20
9b	1.8237	0.30	1.8257	0.41	1.8235	0.29
10	1.7942	-0.07	1.7974	0.10	1.7989	0.18
11	1.7742	0.08	1.7727	0	1.7732	0.02
12	1.7487	-0.07	1.7495	-0.02	1.7518	0.10
13	1.7325	0.30	1.7331	0.33	1.7334	0.35
14	1.7098	0.31	1.7080	0.20	1.7087	0.24
15	1.6848	0.17	1.6833	0.08	1.6835	0.10
16	1.6773	1.09	1.6762	1.03	1.6751	0.96
17	1.6303	-0.37	1.6343	-0.12	1.6320	-0.26

HV-LV

TAP POSITION	1U-N/3U-3W		1V-N/3U-3V		1W-N/3V-3W	
	RATIO	%DEVIATION	RATIO	%DEVIATION	RATIO	%DEVIATION
1	7.723	0.32	7.748	0.64	7.733	0.45
2	7.687	0.99	7.687	0.99	7.697	1.11
3	7.614	1.20	7.610	1.15	7.617	1.18
4	7.538	1.37	7.539	1.38	7.529	1.25
5	7.452	1.41	7.445	1.31	7.446	1.33
6	7.357	1.32	7.359	1.35	7.360	1.36
7	7.268	1.32	7.263	1.25	7.275	1.42
8	7.176	1.27	7.180	1.32	7.177	1.28
9b	7.079	1.15	7.087	1.26	7.084	1.22
10	6.997	1.24	6.993	1.21	6.993	1.21
11	6.911	1.28	6.902	1.15	6.913	1.29
12	6.815	1.17	6.819	1.23	6.813	1.20
13	6.732	1.25	6.720	1.07	6.721	1.09
14	6.642	1.23	6.633	1.10	6.641	1.21
15	6.557	1.29	6.532	0.90	6.553	1.23
16	6.455	1.08	6.456	1.09	6.469	1.30
17	6.375	1.22	6.356	0.91	6.375	1.22

The measured values confirms to the values in the factory acceptance report of this Transformer.