Modelling & Simulation of Differential Relay for Protection of Power Transformer

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IN

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SUBMITTED BY

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CERTIFICATE

This is to certify that the thesis entitled, " **Modelling & Simulation of Differential Relay for Protection of Power Transformer**" has been done in partial fulfillment of the requirements for award of the degree in M.Tech in Electrical Engineering (Power System) under my supervision by Sunit (2K13/PSY/20), at the Delhi Technological University.

This work has not been submitted earlier in any university or institute for the award of any degree to the best of our knowledge.

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ABSTRACTS

Internal fault is the main problem in today’s power system instruments. A differential relay is used for power transformer, bus-bars and generators etc. Although this relay is not use-full for external faults but is most important use-full during internal faults in an instruments. These configuration uses in three phase.

For current project, differential relay is designed for 250 MVA, 735/315KV power transformer. CTs are used on both side of transformer and on each phase on both sides. Although CTs are not available in simulation tool box, therefore a general single phase transformer with modifying its specifications according to current transformer is used. With help of CTs current on both side of transformer entering in relay is equal. In differential relay two types of coils is used one is operating coil and other are restraining coils. During no fault or external fault, current in operating coil is zero and during internal fault operating coils current above a certain limit so relay gives trip signal to circuit breaker. The simulation is carried out for various fault as L-G, LL-G, LLL-G. The circuit breaker separates faulty part of circuit from healthy circuit. This relay has developed in Matlab- Simulink environment.

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CHAPTER -1

INTRODUCTION

1.1 Background:

In this thesis work, a differential relay for protection of power transformer has been developed and operation of this relay under various faults is examined. Differential relay is used in case of internal fault only. A relay is a sensible element which practices the inputs from the system and issues a trip signal if a fault within the influence of relay is detected. The conceptual figure of a relay is shown in fig 1.1.

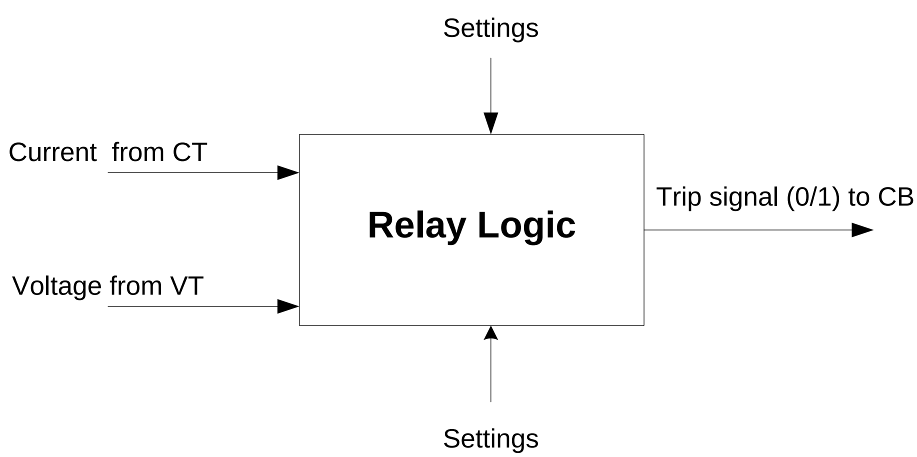

Fig 1.1 Conceptual diagram of relay

To examine the status of the instruments, relay senses current through the current transformers, voltage through the voltage transformers. 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:

- Electromechanical Relay
- Solid State Relay
- Numerical Relay

- **Electromechanical Relay:**

  When principle of the electromechanical energy conversion uses for decision making, relay is refers as an electromechanical relay. This relay is similar to the switch which is either open or closed. When switch is open no current is passes through relay, circuit is open and load is receiving no power. When circuit is closed current will pass through relay, circuit is closed and load is receiving the power. For open and close of the relay an electro-magnet is used and this will give trip signal when fault occurs to the circuit breaker. The electromechanical relay is used for separation of ac and dc circuits and interference between electronic control circuits and power circuits. The common applications are solenoid activation control and motor control any many automobile applications. There are some advantages like low initial costs, contacts can switch both ac and dc, high resistance to voltage transients.

- **Solid State Relays:** Theses relay has come after inventions of transistor, operation amplifier etc. Solid state relays are made up of many components like comparators etc. These relays are more flexible than electromechanical relay. The best advantage of these relay is that these have self-checking facility through which relay which care its health itself and if its components gets damaged then this relay will give alarm. There are some more advantage like low burden and reduced panel spacing. If there is more burden relay then amount of VA consumed by relay will increases and voltage sensor and current sensor consumes more current and voltage. If burden on CT/VT is increases then there will be problem of CT saturation and measurements will be inaccuracies. So that burden on CT should be low as possible.

- **Numerical Relays:** Also, a relay that communicate, can be made more adaptive by which it can adjust to changing device or the scheme conditions. Like as a differential protection relay can adjust to transformer tap change. For different loadings condition, the over current relay can acclimate. A numerical relay is both "the present and the future" schemes.

  The numerical relay block diagram is shown in fig 1.2. This contains analog to digital (A/D) conversion of analog voltages and currents achieved from secondary sides of voltage transformer and current transformer. Those voltage and current samples are given to the microprocessor or the digital signal processors where the protective part simulates voltage and current signals and decides there is fault or not. If a fault is found then a trip signal will be given to circuit breaker. In numerical relay, there is the most important flexibility in significant relaying logic. The difference between numerical relays and digital relays lies in what type of the microprocessor is used. Numerical relays contains digital signal processors (DSP) cards, which hold dedicated microprocessors specially designed for perform digital signal processing.

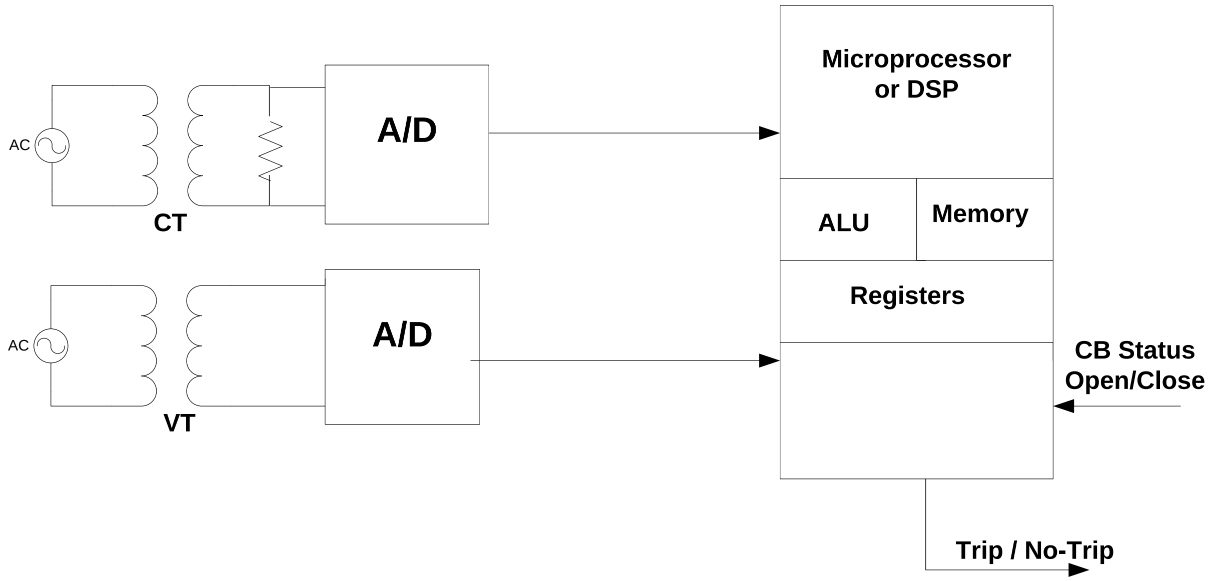

Fig 1.2 Numerical relay block diagram

1.3 Types of protective scheme:

Protection of instruments or a portion of a transmission line is done by using a protective schemes. In one protective scheme, one or more relays of same or different type can be used. The various protective schemes commonly used in protections are:

- Over current protection
- Distance protection
- Differential protection

- **Over current protection:** This scheme is based on the instinct that, faults typically short circuits, lead to the currents much above the load current. There are two setting inside this protection schemes time setting and plug setting. Time setting though which operating time of relay is decided and plug setting above which current above which relay operated is decided.

  Fig 1.3 shows a radial distribution system with a single source. The fault current is given from only one side of the feeder. From the system it can be observed that:

  - To relay R_1, both downstream faults F_1 and F_2 are observable so that IF_1 as well as IF_2 pass through current transformer of R1.
  - To relay R_2, fault F_1, an upstream fault is not seen, only F_2 is seen. This is because no components of IF_1 passes through current transformer of R_2. Thus, selectivity is achieved naturally. Relay decision is based only on the magnitude of fault current. This protection scheme is said to a non-directional relay.

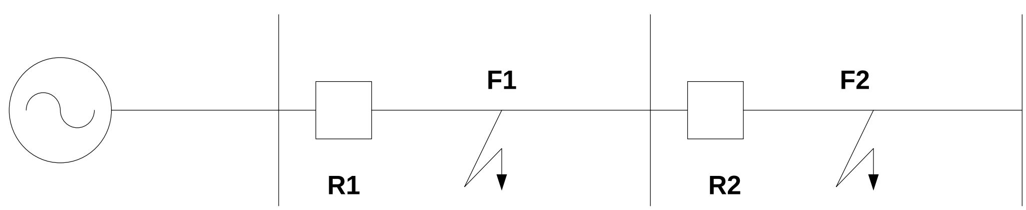

Fig 1.3 Radial distribution system

- **Distance Relay:** Consider a simple radial system, which is served from a single source. Let us measure the apparent impedance (V/I) at the sending end. For an unloaded system, I = 0, and the apparent impedance seen by relay is infinite. If system is loaded, the apparent impedances reduced to some finite values (Z_L+Z_{Line}) where Z_L is the load impedance and Z_{Line} is the line impedance. In presence of a fault at a per-unit distance ‘m', impedance can be seen by the relay drops to m*Z_{Line} as shown in fig 1.4.

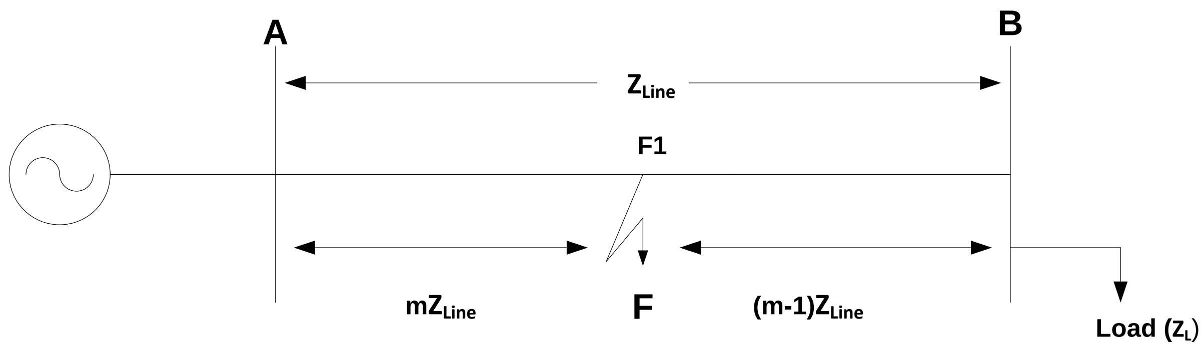

Fig 1.4 Fault in a transmission line

The basic principle of distance relay is that the actual impedance seen by the relay, which is defined as the ratio of phase voltages to the line currents of a transmission line (Z_{App}), reduces severely in the presence of a line fault. The distance relay compares this ratio with the positive sequence impedance (Z_1) of transmission line. If the fraction Z_{app}/Z_1 is less than unity, it shows a fault. This ratio also shows the distance of the fault occurred from the relay. Because, the impedance is a complex number, the distance protection is naturally directional. The first quadrant is the forward direction i.e. impedance of the transmission line to be protected lies in this quadrants. However, if only magnitude information is used, non-directional impedance relay results. Fig 1.5 and 1.6 shows a characteristic of an impedance relay and ‘mho relay'.

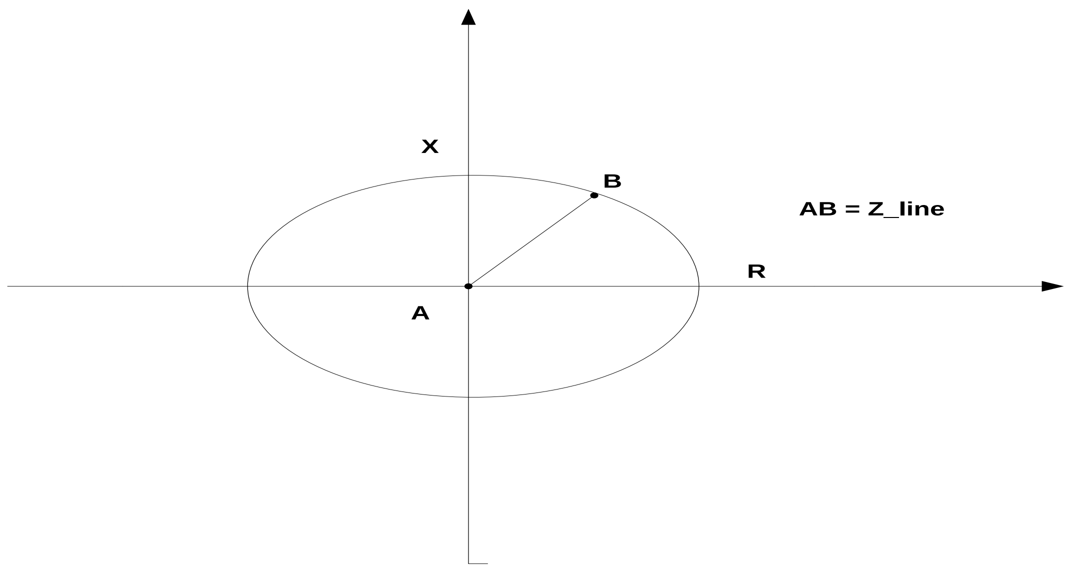

Fig. 1.5 Impedance relay characteristics on R-X diagram

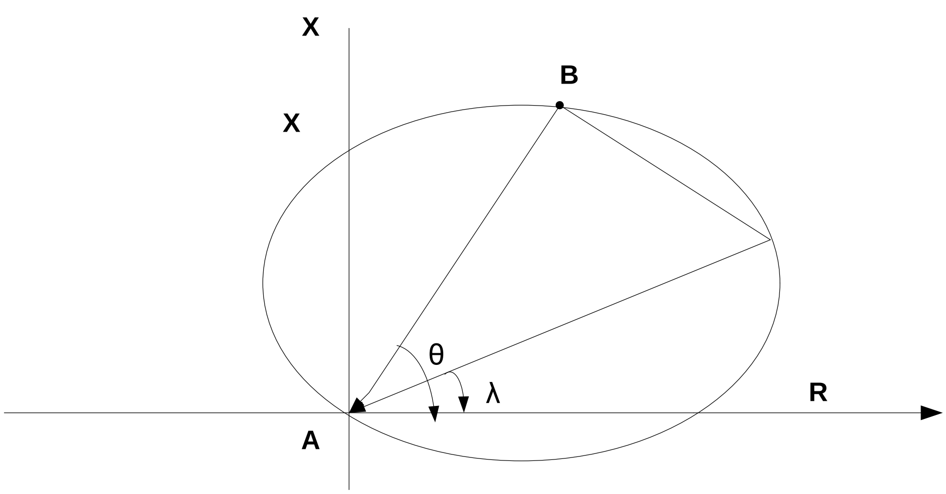

Fig 1.6 Mho relay characteristics on R-X diagram

- **Differential relay:** Take an example of ideal transformer with the CT connections, as shown in fig 1.7. To explain the principle let us consider that current ratings of primary winding is 100A and secondary winding is 1000A. Then if we use 100:5 and 1000:5 CT in the primary and secondary winding, then under normal (no fault) operating conditions the scaled CT currents will match in the magnitudes. By connections the primary and secondary CTs with due care to the dots (polarity markings).

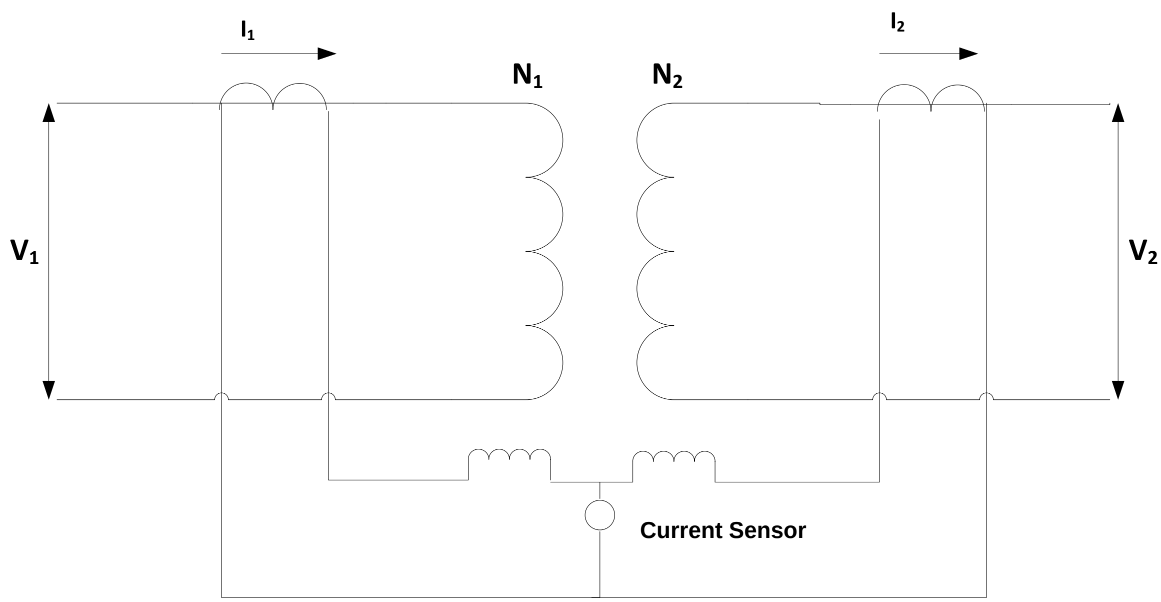

Fig 1.7 Differential protection scheme for transformer

In this figure, both secondary side and primary side of power transformer are connected with the current transformers. So current entering must be equal to current leaving. In this protection scheme if $I_1 - I_2$ should be zero. If difference is greater than certain limit then relay will give trip signal to circuit breaker and circuit breaker will remove the faulty part from healthy part of the circuit. This differential relay work for only internal faults not for external faults. In practice, the transformer is not ideal. Consequently, even if, it is the magnetization current or (no load) current. Thus, a differential current always flows through over-current relay.

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

- Necessities of speed in relaying
- Speed vs. accuracy conflict

- **Necessities of Speed in Relaying:** To maximize safety, and minimize equipment damage and system instability, a faulty part should be cleared as fast as possible. This means that relay should quickly reach at a decision and circuit breaker operation should be fast. Typically, a fast circuit breaker should operate in about two cycles. A reasonable time estimate for determining presence of fault is one cycle. This suggests approximately three cycles fault clearing time for primary protection. On the other hand, if five cycles circuit breaker is used, fault clearing time increased to six cycles. When there is a short circuit fault occurred in a transmission system, the electrical outputs of generator remain below the mechanical inputs.

- **Speed Vs. Accuracy Conflict:** Inside this tells about us that quickness is an offer to disaster. The possible concerns of quick tripping decisions are:
    - Nuisance Tripping
    - Tripping for faults outside the relay jurisdiction.

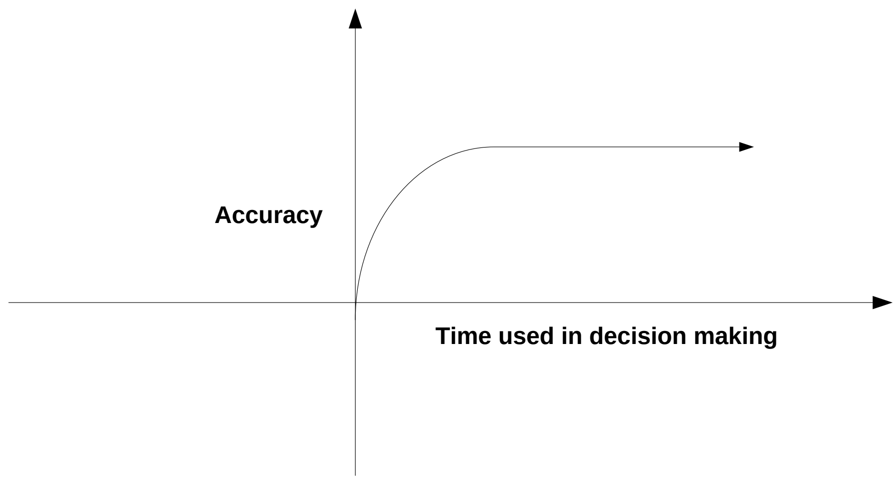

Fig 1.8 Conceptual illustration of Speed Vs Accuracy Conflict

Nuisance or bad tripping is the tripping when there is no fault, e.g. an overcurrent relay tripping on load. It concessions faith in the relaying system due to unnecessary loss of service. On the other hand, if tripping on faults that are outside the relay's dominion also cause an unwarranted loss of service in the healthy parts of the circuit. It has to be mentioned that speed and accuracy allow a reverse relationship. The high-speed systems tend to be less accurate for the simple reason that a high speed system has lesser amount of information available at it's disposal for making decision. Thus, the protection engineer should be strike a balance between these two unsuitable requirements.

CHAPTER-2

Literature Review

2.1 Introduction

There is a lot of evolution has been in the field of differential relay since it used in many applications. The applications in which it mainly used are protection of transformer, generator, bus-bar and so many. As demand of power is increasing and we have very complex power system in today's life. So that chances of fault also increases due to more complexity, so I tried to modify existing power system and doing for that I had designed more capacitive and more complex power system network. In my system a three phase power transformers with all possible faults is realized. For development of my project "modelling and simulation of differential relay for protection of power transformer I have used MATLAB SIMULINK software.

Adel Aktaibi [1], the modelling of differential protection for the power transformer is designed by using MATLAB-SIMULINK. This paper discuss that the simulation differential relay for protection the power transformer. This implementation is shown step to step. This simulation is verified for different cases and all cases gave acceptable results.

B. Vahidi [2], he had developed the simulation of digital differential relay for protection of power transformer by using MATLAB-SIMULINK. In this faults are sensed by outside and in currents. With fast tripping facility with complete selectivity, this is best suited for safety of all important parts of the plant. Inside this paper, a method is explained how to teach relay in laboratory by using MATLAB-SIMULINK. In this paper a MATLAB-SIMULINK based model given for simulate the relay and determining its performance during internal faults protection in transformer.

Nikhil Paliwal [3], the analysis of modern digital differential relay protection for the power transformer by using MATLAB-SIMULINK & Fuggy-Logic. The paper describes the analysis of digital differential protection relay for the power transformers. Full protection is required for efficient and nonviolent process of the electrical power system. Inside this protective relay, this blocks the tripping during external faults or magnetizing inrush and speedy operation the tripping during internal faults of power transformer. The most important object of this paper is to analysis digital differential relay during external and internal faults and to trigger the relay with proper fault judgment.

Adel Aktaibi [4], differential relay by a software design technique for protection for the power transformers is designed by using Fourier Transform. Inside paper, A software is designed of digital differential relay for simulate problem of internal faults in electrical power transformers. With this improves and boosts the understanding power of taking action of the digital differential relay which protects transformers by judicious between fault current and inrush current without blocking the relay during the power transformers eneriginization and avoid the tripping when tape changer process take place. This digital differential relay is designed using matlab-simulink environments.

Kadri Kadriu [5], he has developed the differential protection relay miss-operation during the dynamic processes of faults in the secondary protection circuit of relay by using MATLAB-SIMULINK. If the short circuit arises in secondary circuit side, then the differential current will be increased up to a significant value. Currents value depends on the fault locations and power of circuit loop and protection of relay. This differential current is not so sufficient for the relay to be operate, if in normal circumstances, there is no energetic processes in the power system. Therefore, this matter corresponds to the situations when a short circuit occurs in secondary circuits, where the neutral points of the power transformer is grounded. As a model, the numerical relay of the type “MICOM” (ALSTOM) is used inside this paper.

Ivi Hrrmanto [6], the stand alone digital protection relay of three phase power transformer is designed by using fourier algorithm analysis. This papers describes the detailed description of hardware and software model of the relay. The protection functions employed includes a differential protection relay with a second-harmonic limitation for magnetizing inrush and a fifth-harmonic limitation for over-excitations conditions, and to separate protection for high impedance primary and secondary ground faults. The relay hardware contains of a data acquisition board and a digital processing board which is based on the ThIS3’70El5 processor.

Hatem A. Darwish [7], dynamic performance of differential relay system is designed by using MATLAB-SIMULINK. The developed modelling facilitates testing the energetic behavior of the power differential relay during the fast system transients. For this different outputs have been recorded for various operating conditions to visualize the most critical simulation subjects such as load angle, active and reactive powers difference and power through.

Wenkui Zhang [9], he has designed the self-adaptive differential protection relay for power transformer. This is an attempt to make both the sensitivity and security of power transformer differential protection. A novel adaptive protection criterion is given in this paper through which we can self-regulates the parameters of relay characteristics (e.g. restraint current and restraint coefficient in the slope characteristic at the knee point) on the basis of working conditions of the transformers. This relay operates for internal faults as well as external faults.

Kuniaki Yabe [10], the power differential method for judgment between faults and magnetizing inrush currents in the transformers is designed. This paper describes a different method for categorize inrush currents from internal faults by flowing the active power flowing from every terminals sum into transformer. For the energizing, average power is just about zero, but an internal fault takes more power. For performance checking of this method, voltage waveform and actual inrush current of 500/154kV power transformer is correctly dignified by digital instruments.

CHAPTAR-3

Methodology & Modelling

3.1 Differential Relay– This relay based on the principle that output power of power transformer is equal to the input power. In the normal condition, no current flows in differential current coil. But when there is fault then there will be flow of current in the operating current coil. The relay gives trip signal to the circuit breaker. Then circuit breaker opens its contacts and remove the faulty part from the healthy part. So differential relay compares secondary current and primary side current of power transformer. By using the current transformers on both side of power transformer, we change the current on both side of power transformer equal for relay during no-fault. The polarity of CTs must be selected as there will no flow of current in primary relay in normal condition and external faults. The rating of CTs should be selected carefully so that this should match with power transformer then secondary side of CTs will be equal. But there is a lots of problem like that CTs ratios available in market is of standard rating only. Therefore, the turn ratio of the secondary side current transformer is $\frac{1}{N_2}$ is equal to the turn ratio of the primary 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: CT_1 secondary side current

N_1: Number of turns of CT_1 on secondary side

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

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

Where:

I_S: Power transformer secondary side current

I_2: CT_2 secondary side current

N_2: Number of turns of CT_2 on secondary side

Differential current flowing is $I_d = I_1 - I_2$

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

$$I_d = \frac{I_P}{N_1} - \frac{I_S}{N_2} \qquad 3.3$$

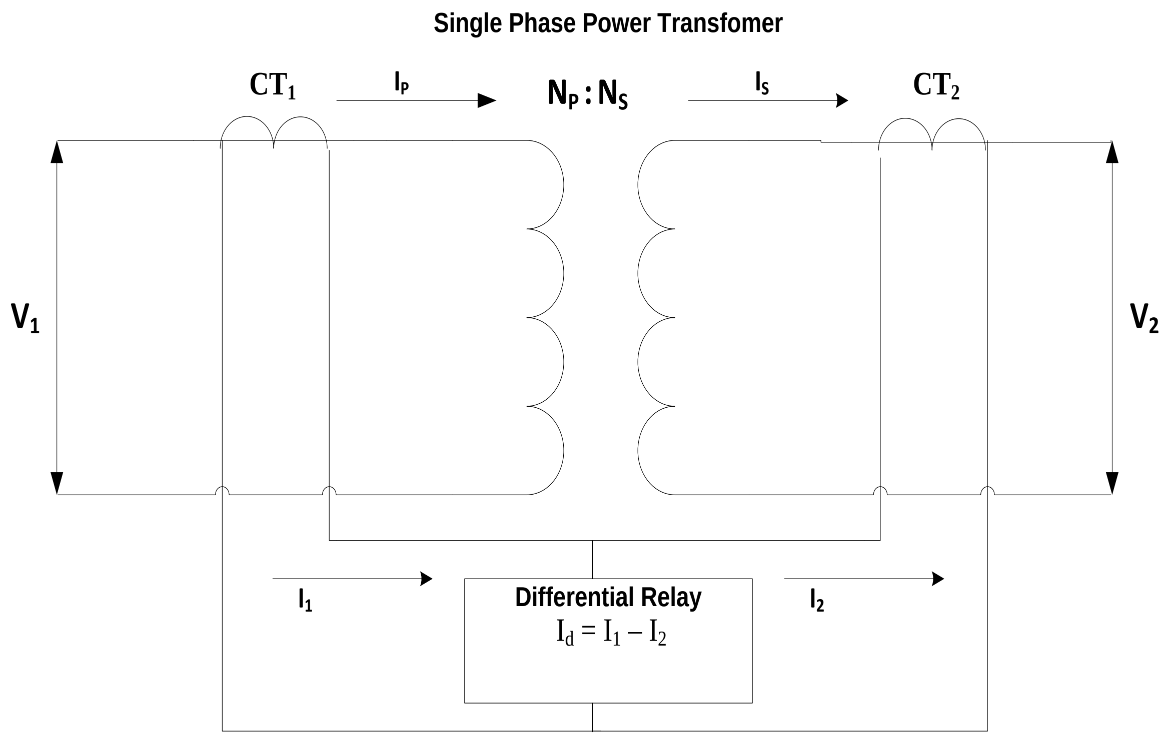

Figure 3.1 Differential protection of single phase transformer

If there is no internal fault then, I_1 and I_2 are supposed to be equal in magnitude but opposite in direction so that I_d will be zero as shown in the figure 3.2. The power transformer secondary side and primary side current are relate 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.

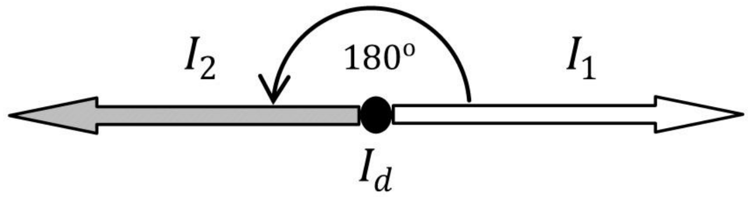

Figure 3.2 Secondary current of CTs are equal in magnitude and opposite in direction

Suppose, there is any internal fault in the protective zone, then I_1 and I_2 are not equal. So there will be current flow and I_d current has some value through which relay will be operate as shown in fig 3.3.

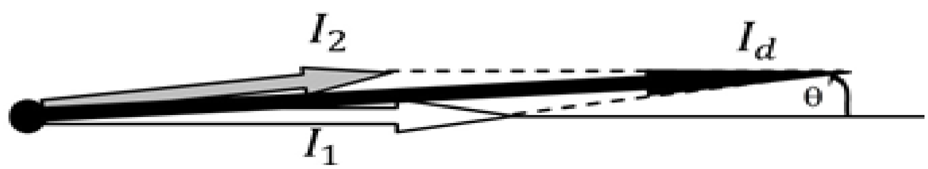

Figure 3.3 Secondary current of CTs are not equal

The $I_d = I_d < \theta$, 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

$$I_S = \frac{N_P}{N_S} * I_P \qquad 3.5$$

Using 3.3 and 3.5 equation,

$$I_d = \frac{I_P}{N_1} - \frac{I_P \times (\frac{N_P}{N_S})}{N_2}$$

$$I_d = \frac{I_P}{N_1}(1 - \frac{N_P/N_S}{N_2/N_1}) \qquad 3.6$$

$$\gamma = (1 - \frac{N_P/N_S}{N_2/N_1})$$

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

$$(1 - \frac{N_P/N_S}{N_2/N_1}) = 0$$

$$\frac{N_2}{N_1} = \frac{N_P}{N_S} \qquad 3.7$$

This equation 3.7 giving 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 turns ratio of the power transformer.

3.2 Current Transformer- Practically all electrical measurements and relaying decisions are taken from current and voltage signals. Since relaying hardware works with smaller range of current (in amperes and not kA) and voltage (volts and not kV), real life signals (feeder or transmission line currents) and bus voltages have to be scaled to lower levels and then fed to the relays. This job is done by current and voltage transformers (CTs and VTs). CTs and VTs also electrically isolate the relaying system from the actual power apparatus. The electrical isolation from the primary voltage also provides safety of both human personnel and the equipment. Thus,

CT and VTs are the sensors for the relay. CT and VT function like ‘ears' and the ‘eyes' of the protection system. They listen to and observe all happening in the external world. Relay itself is the brain which processes these signals and issues decision commands implemented by circuit breakers, alarms etc.

The equivalent circuit of a CT is not much different from that of a regular transformer (fig 3.4). However, a fundamental difference is that while regular power transformers are excited by a voltage source, a current transformer has current source excitation. Primary winding of the current transformer connected with the transmission line is in series. The load on the secondary side is the relaying burden and the lead wire resistance.

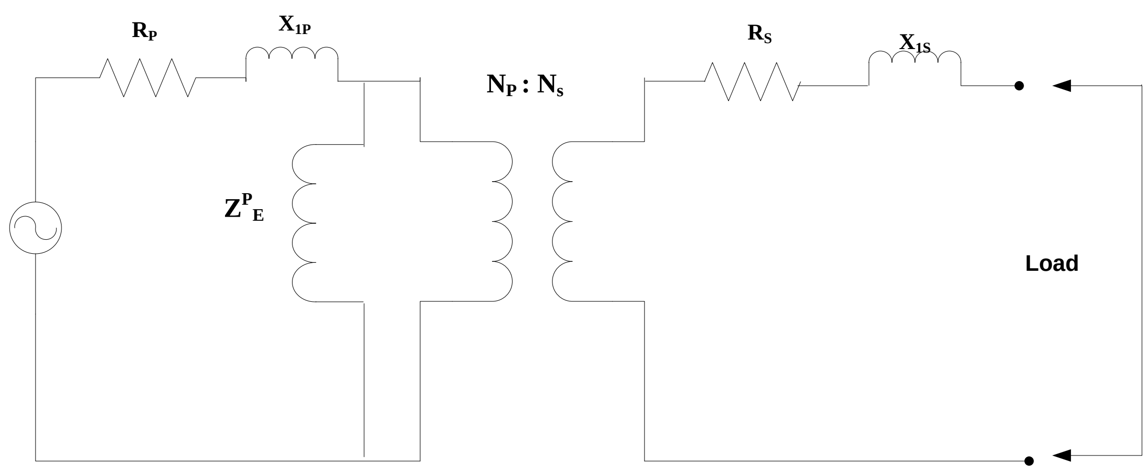

Figure 3.4 Equivalent circuit of Transformer

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 or the power apparatus at all. Hence from modeling perspectives 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 3.5. The remaining steps in modeling 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 modeling.

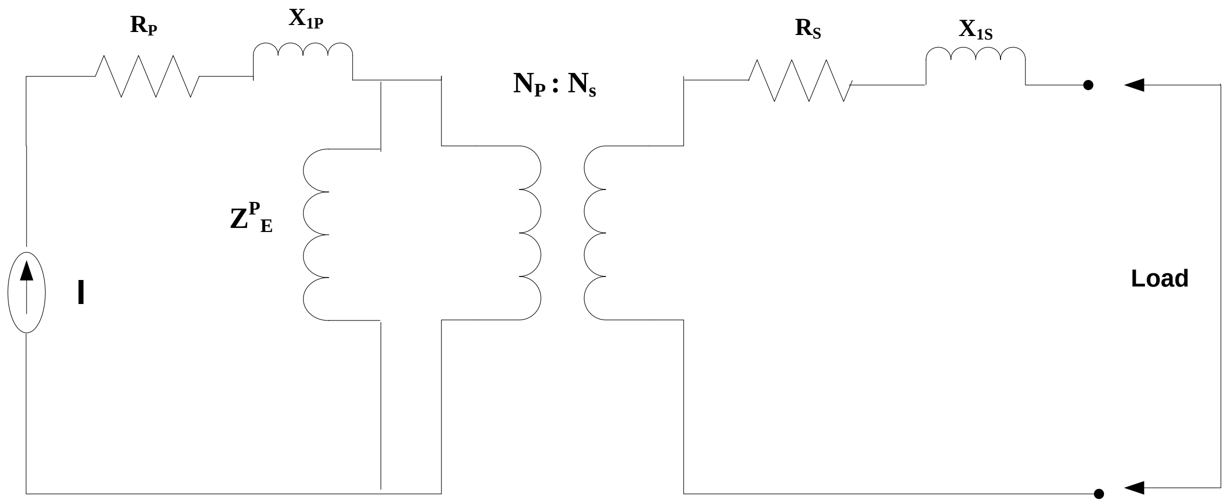

Figure 3.5 Modelling of Current Transformer

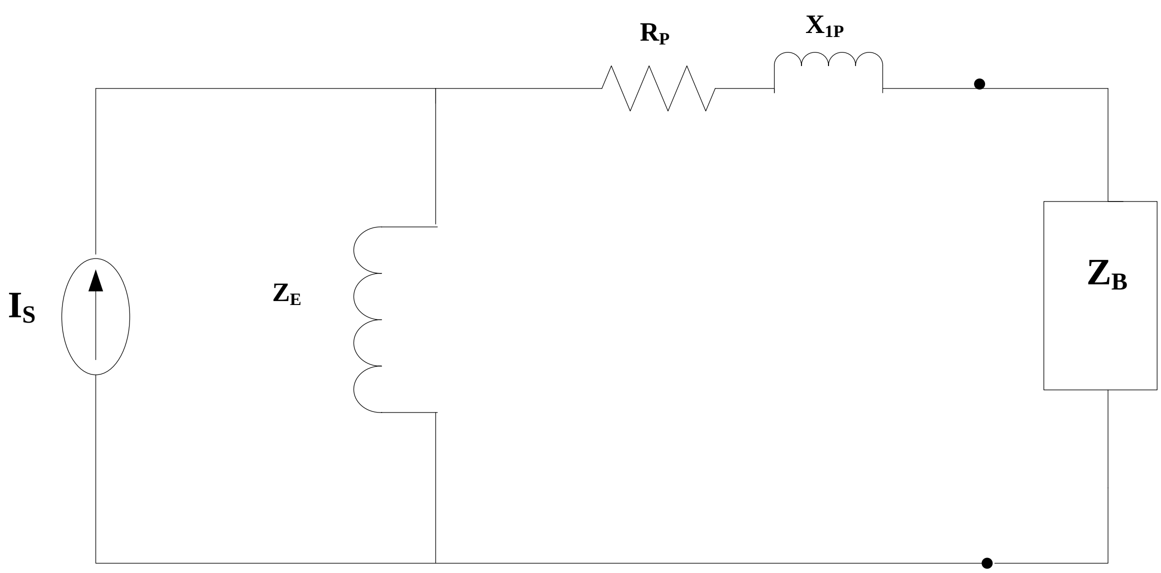

Figure 3.6 Final equivalent circuit of Current Transformer

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 3.6.

3.3 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 as follows:

Nominal Power (VA)	250
Frequency (Hz)	50
CT_1 Turns	5/3000

CT_2 Turns	5/4200

3). Differential Relay –

$I_1 - I_2 \geq K (I_1+I_2)/ 2$ 3.8

$K = N_r / N_O$ 3.9

N_o (Operating Coil) = 1 mH

N_r (Restraining Coil) = 0.5 mH

By putting in equation (2), we get

K=0.5

When there is no fault, maximum current flows in coils are $I_1 = 4.3A$, $I_2 = 4.28A$

By putting in equation (1), we get

$I_1 - I_2 \geq 2.15A$

So when $I_1 - I_2 \geq 2.15A$ then relay will be operate. Otherwise relay will not be operate.

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

R= 1850 ohm L = 3.68 H

After converting these value to active and reactive power

P + j*Q = 50 + j * 37.5

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

3.4 Implementation of differential protection by using Simulink –

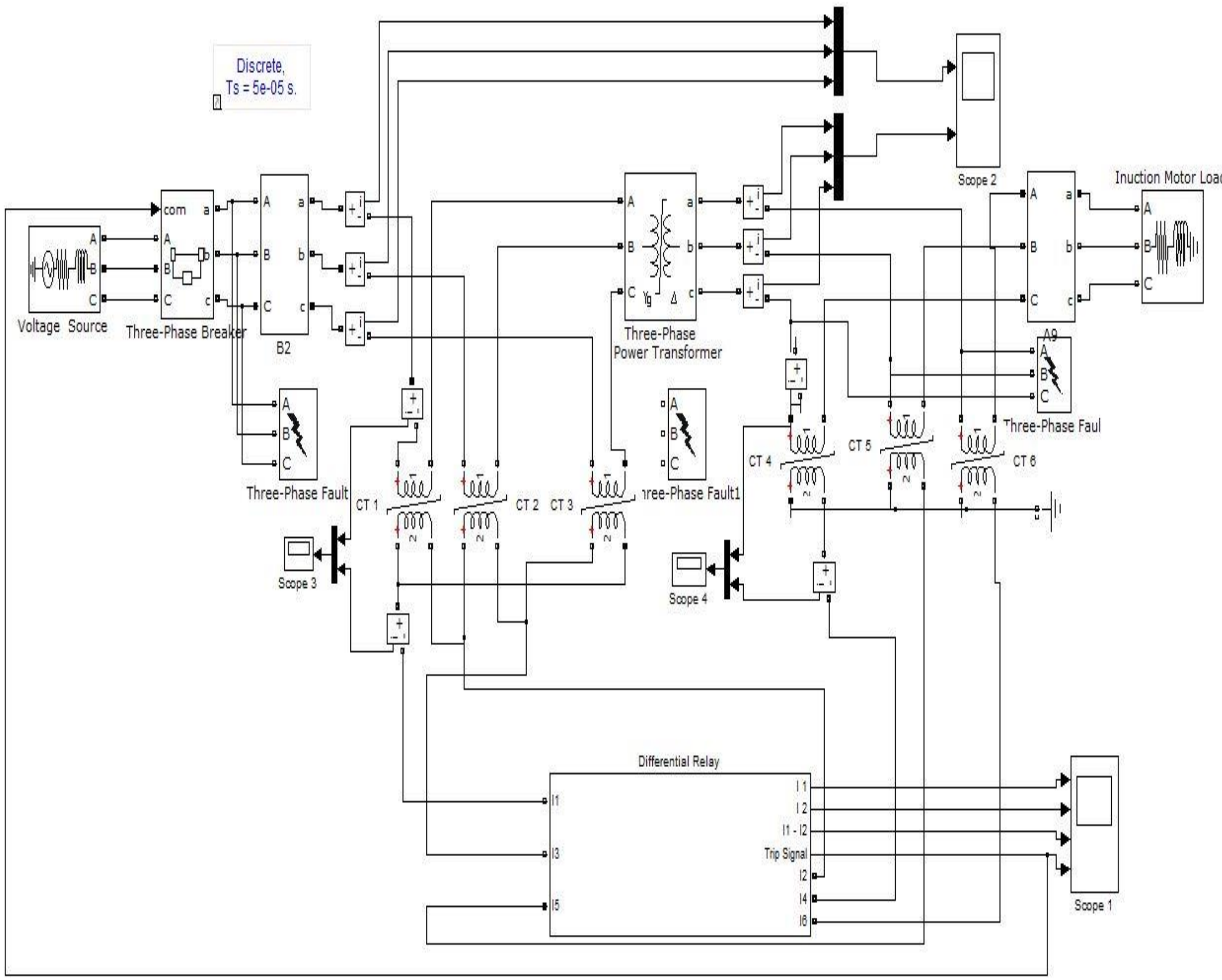

Figure 3.7 Percentage differential protection of power transformer

In the figure 3.7 shows, the problem in which 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 both side is star, then the current would not match up & I_d or spill current would result when there is no internal fault. We observe, that if the secondary winding of CTs on the star side are connecting in delta, then the line currents would exactly match with the secondary currents of CTs on the delta side, provided that these are connecting in star. So operating coil current will be zero then there exists no fault.

This relay will not be operate when there is 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. 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 obsoletely work.

In the figure 3.8 shows differential relay, in which we uses inductor for restraining and operating coil.

$$I_1 - I_2 \geq K (I_1+I_2)/ 2 \qquad 3.10$$

$$K = N_r / N_0$$

N_r = Restraining Coil

No = Operating coil

When the current flow in operating coil above the limit then relay will be operate. In the normal conditions or no internal faults, the current through restraining coils are nearly equal and there is no current through operating coil. Three phase of primary connected through CTs, we are comparing with secondary three phase as through CTs. In case of 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 fault which are occurring outside of protecting zone.

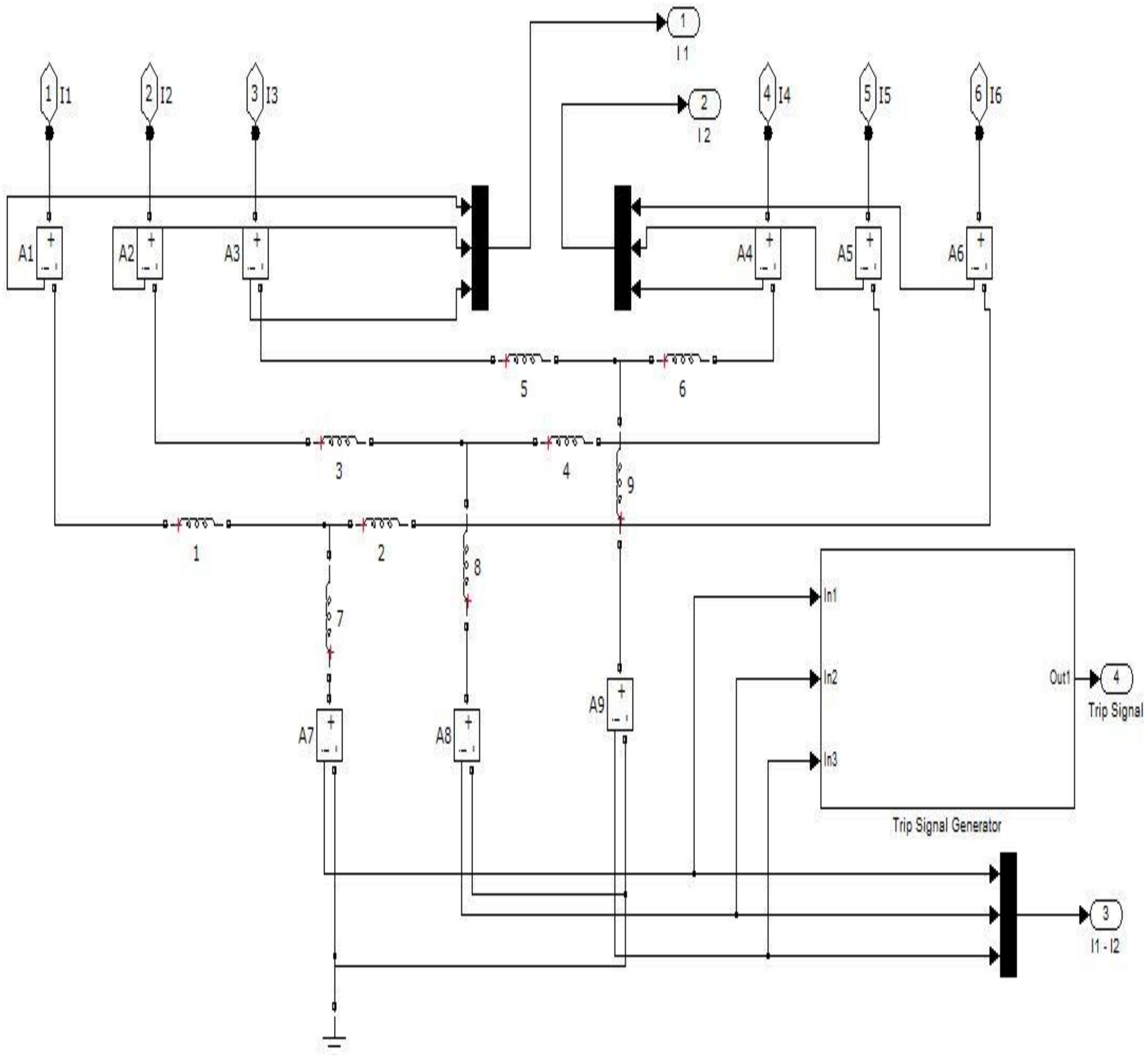

Figure 3.8 Percentage Differential Relay

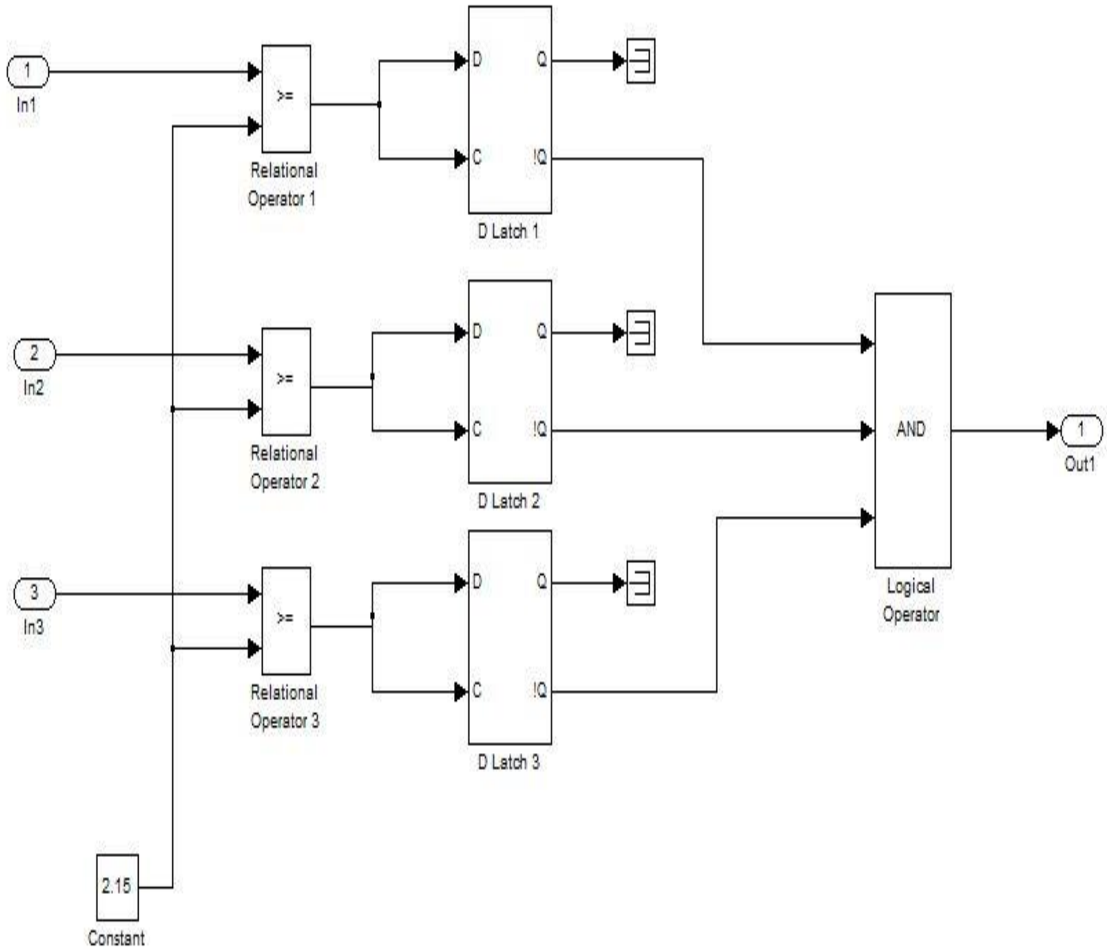

Figure 3.9 Fault Signal Generator

In figure 3.9 shows the fault generator, which is generating a fault signal when there occurs fault. 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 than certain value which is fixed, then it will give 0 (zero). Then 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 gives 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's come 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 one. This goes to input of the d latch which has two input terminals one is D and other is clock pulse terminal. We will give same inputs on both input terminals 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.

We are using three phase vi measurement blocks after the source for measuring the voltage values on primary side of power transformers. Single phase voltage measurement and current measurement blocks are also used as shown in the figures. Three phase circuit breaker we are using is automatic and automatically operates when there relay gives trip signal to it. We are using two scopes in this circuit one is for power transformer primary and secondary voltage. Other is for measuring operating coil current, restraining coils current and trip signal or status of the circuit breaker. The load we are using is induction motor load.

3.5 Difficulties faced during this project – There are some difficulties faced because 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 and make some changes in its specification to fit the current transformer. And second one choice is that to use a current measurement, but that will not solve our problems of the CT.

CHAPTER-4

Results & Discussions

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. Suppose we are protecting a certain zone and then fault occur outside of that zone is external faults and relay protecting a certain zone will not be operate for that fault. 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 operate if there is fault inside the protecting zone. Ideally, a relay looking after the protection of a zone should operate only for internal faults.

4.2 Results & Discussions - In this thesis, operation of differential relay protection of power transformer is shown on each type of faults. The system condition are discussed below-

4.2.1. Normal Condition

4.2.2 L-G Fault

4.2.3 LL-G Fault

4.2.4 LLL-G Fault

4.2.5 External Fault

4.2.1. Normal Condition - In this case we are considers, there is no fault occurs.

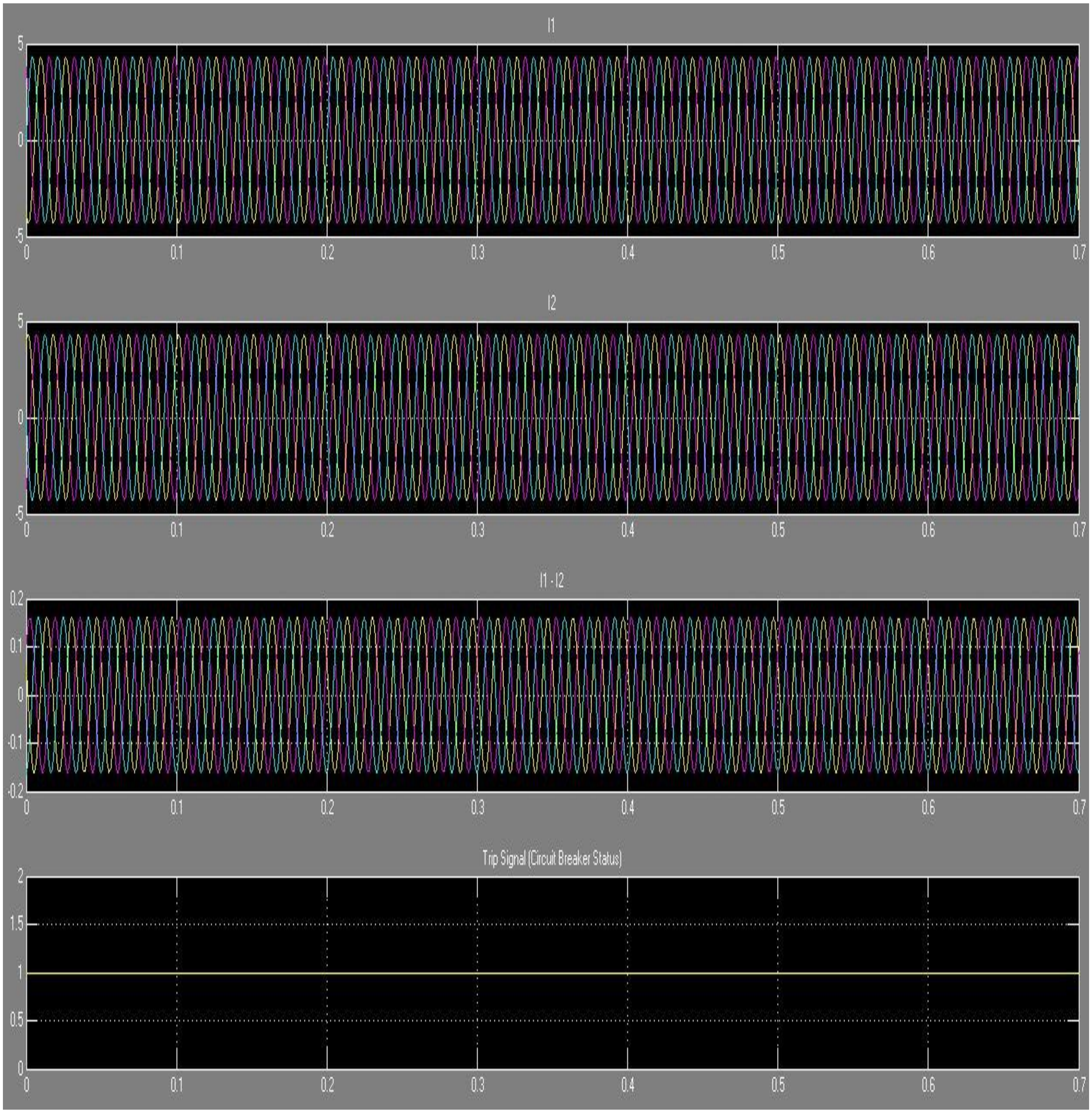

Figure 4.1 In normal condition restraining coil current (I_1 & I_2), operating coil ($I_1 - I_2$) and trip signal

As shown in above figure 4.1 (I_1 & I_2) restraining coils current waveforms are shown. (I_1 - I_2) operating current coil is zero so relay will not be operated because (I_1 - I_2) value is less than k*(I_1 + I_2)/2. Trip signal is 1 (one) which mean circuit breaker is closed.

Trip Signal 1 = Circuit Breaker Closed

Trip Signal 0 = Circuit Breaker Open

Figure 4.2 shows primary and secondary side current of power transformer.

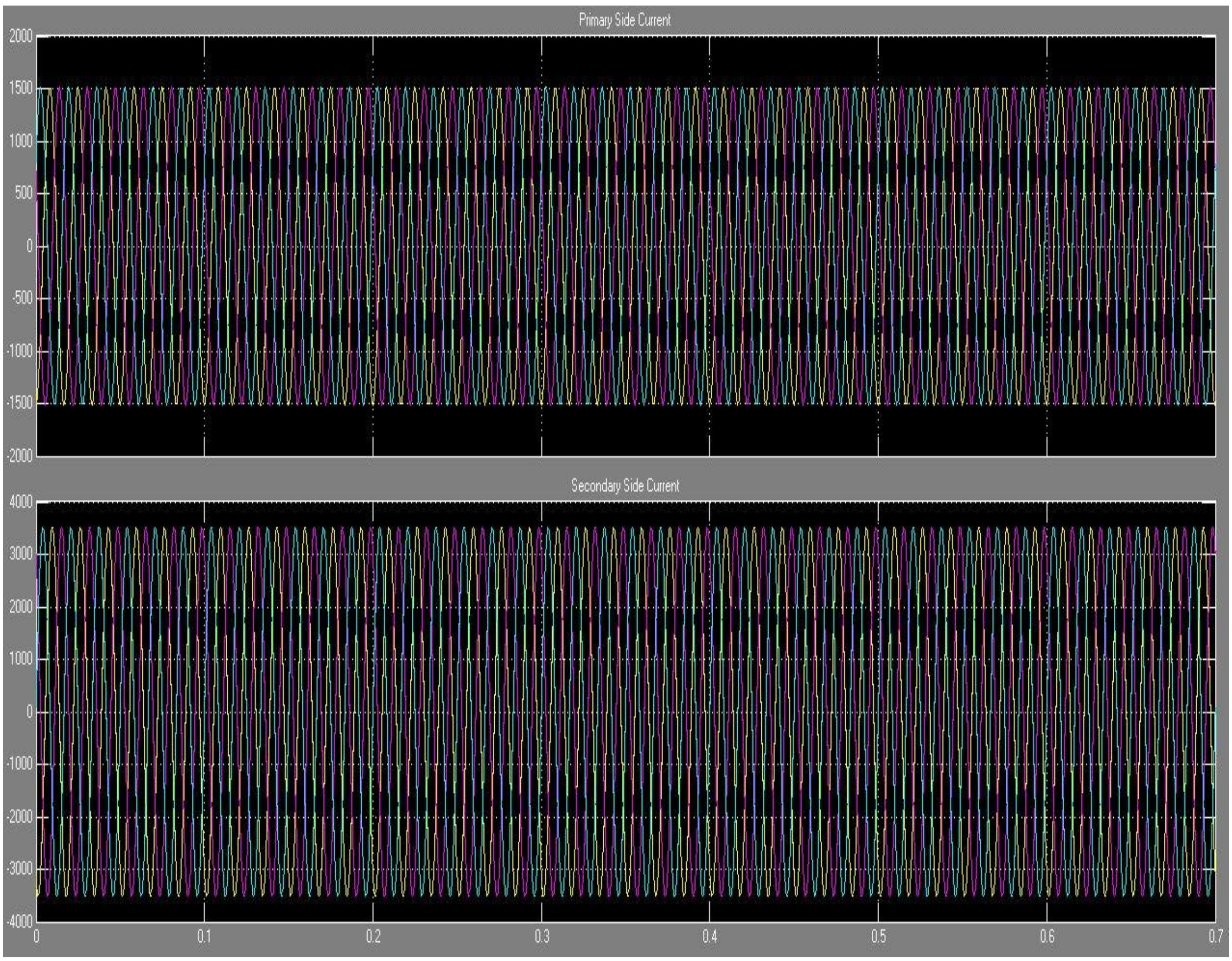

Figure 4.2 Power Transformer primary side current & secondary side current in normal condition

Table 4.1 (I_1, I_2, $I_1 - I_2$) currents & relay status at different time for normal condition

Sr.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	-3.279	-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	-2.992	-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	-2.572	4.272	-1.7	2.688	-4.234	1.546	0.1154	-0.0378	-0.1532	No Trip

In the table 4.1 explaining figure 4.1 and showing current of all three phases at different time. Each time $I_1 - I_2$ is zero and less than $(I_1 + I_2)/2 = 2.15A$. So that each time relay status is no trip in normal condition. Table 4.2 explaining figure 4.2 shows power transformer secondary side current and primary side current, all three phase current is shown in table at different time locations in normal condition. The minus sign in the tables is showing that its value in opposite axis.

Table 4.2 Primary Side Current and Secondary Side Current of power transformer in normal condition

Sr. No.	Time (sec)	$I_{PRIMARY}$			$I_{SECONDARY}$		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.1	-1507	717	788	-3092	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. L-G Fault – In this case we considers internal fault which is line to ground fault.

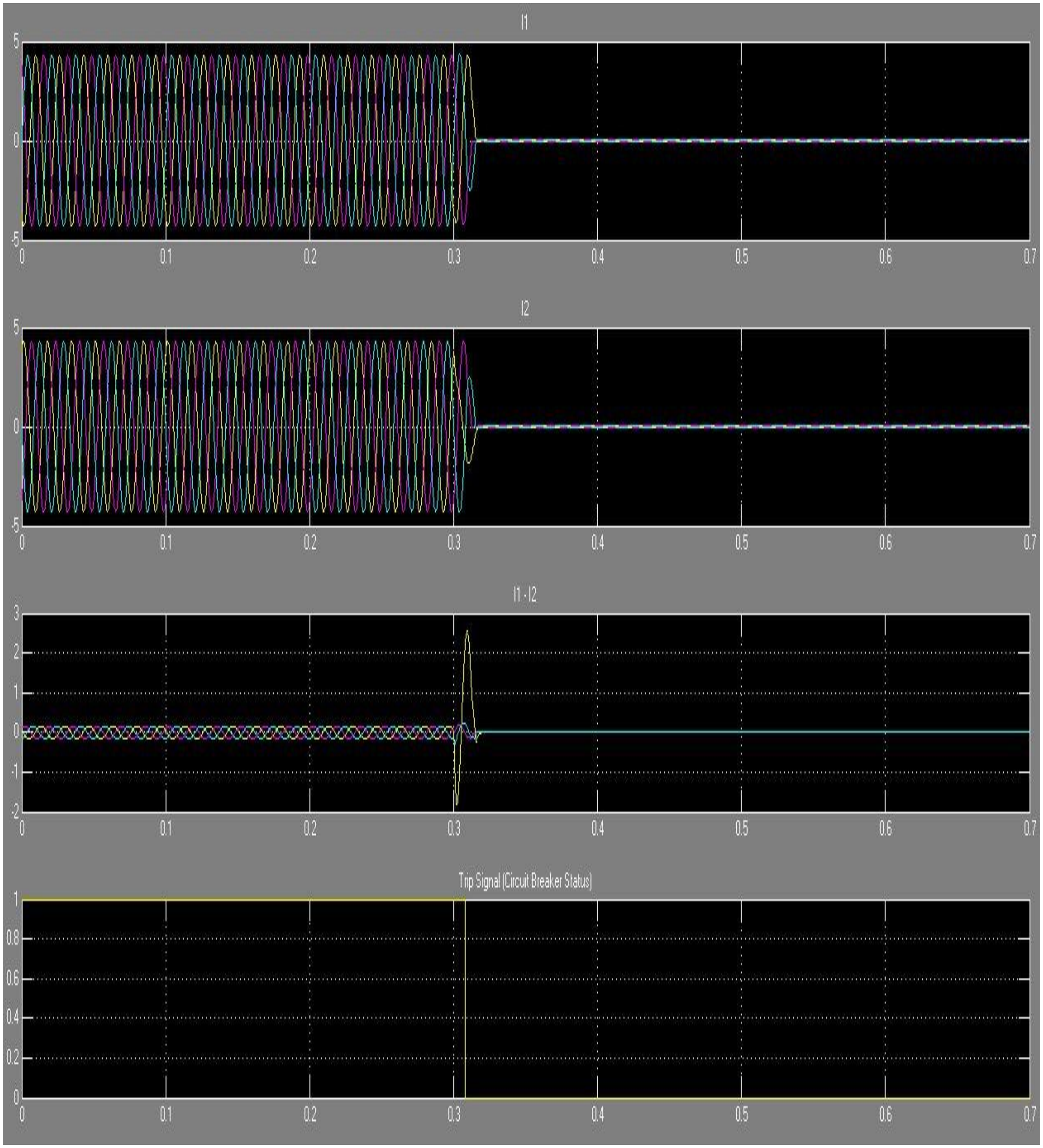

Figure 4.3 In line to ground fault restraining coil current (I_1 & I_2), operating coil (I_1 - I_2) and trip signal

As shown in above figure 4.3, relay operates is operating normally after 0.3 sec when there is no fault. But when there is fault operating coil current starts increasing cross the limit 2.15A. So relay will be operate fast and give the trip signal to circuit breaker. So circuit breaker removes the faulty part of circuit from healthy circuit.

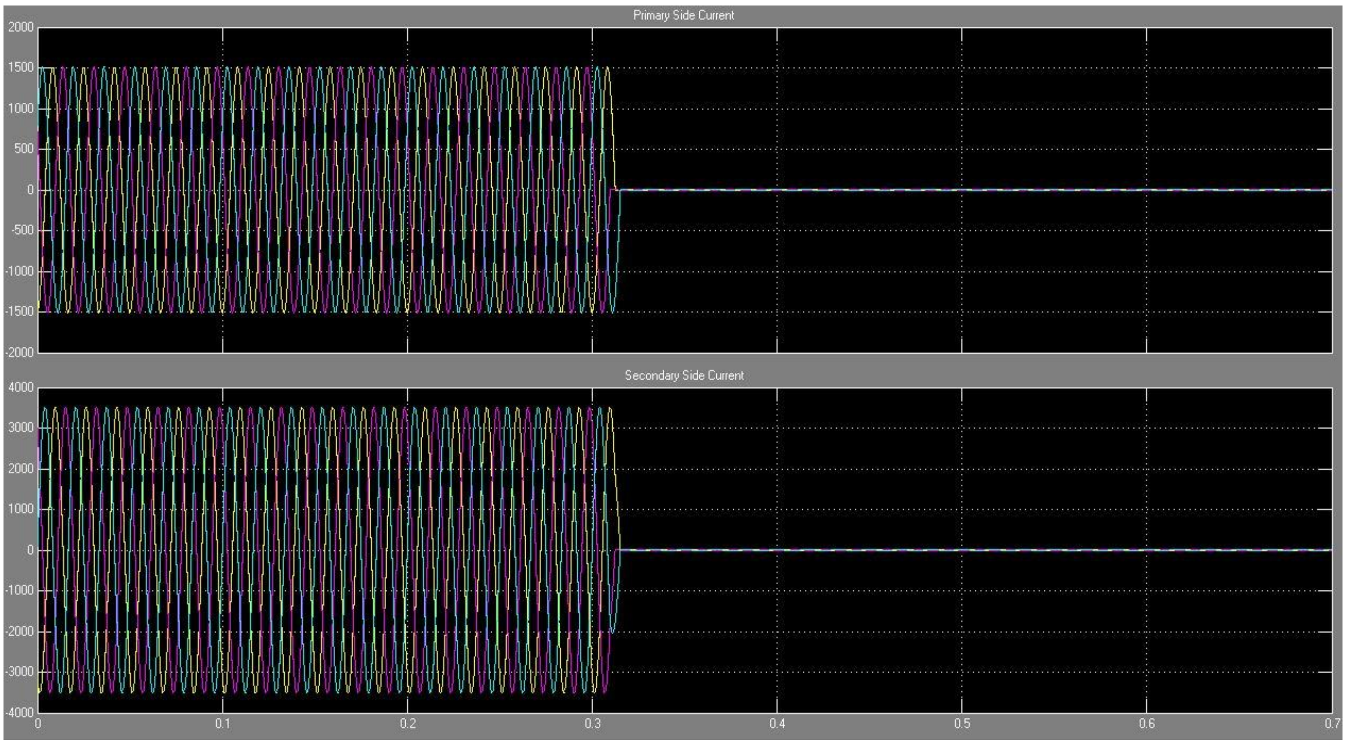

Figure 4.4 Primary Side Current & Secondary Side Current in line to ground fault

In figure 4.4, current in power transformer on primary side and secondary side is shown. As fault occurs in circuit relay operates and give signal to circuit breaker. Circuit breaker removes that instrument from circuit and currents become zero inside it. As shown in figure 4.4 relay operates with in a mille-second disconnect power transformer.

Table 4.3 (I_1, I_2, $I_1 - I_2$) currents & relay status at different time for L-G fault

Sr. 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	3.231	-3.953	0.722	-1.055	3.94	0.5	2.17	-0.013	0.221	Trip
2	0.309	4.052	-3.132	-0.919	-1.547	3.042	1.101	2.505	-0.09	0.1813	Trip
3	0.3095	4.254	-2.547	-1.707	-1.714	2.422	1.858	2.539	-0.1251	0.1513	Trip
4	0.31	4.304	-2.101	-2.203	-1.821	1.982	2.283	2.484	-0.119	0.6799	Trip
5	0.35	0	0	0	0	0	0	0	0	0	Relay Tripped, CB opened

The figure 4.3 values is shown In table 4.3 currents at different time interval, as when I_1- I_2 is greater than $(I_1 + I_2)/2$ then relay is operated. All the value of current (I_1- I_2) in phase A is greater than 2.15A. So relay gives the trip signal to the circuit breaker and circuit breaker opens its contacts in 0.02 second. The figure 4.4 is explained in table 4.4 shows secondary and primary side current of power transformer is shown. When circuit breaker open its contact both side currents of power transformer starts decreasing to zero. The figure 4.5 is showing operating characteristics of relay during line to ground fault. If there is fault relay will operate when I_1- I_2 (operating coil current) exceed than 2.16 A and greater than $(I_1 + I_2)/2$.

Table 4.4 Primary Side Current and Secondary Side Current of power transformer in line to ground fault

Sr. No.	Time (sec)	$I_{PRIMARY}$			$I_{SECONDARY}$		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.308	1500	-878	-621	2857	-3204	346
2	0.309	1449	-365	-1083	3411	-2445	-966
3	0.3095	1346	-85	-1261	3511	-1928	-1583
4	0.31	1195	0.72	-1393	3486	-1609	-18.77
5	0.32	0	0	0	0	0	0

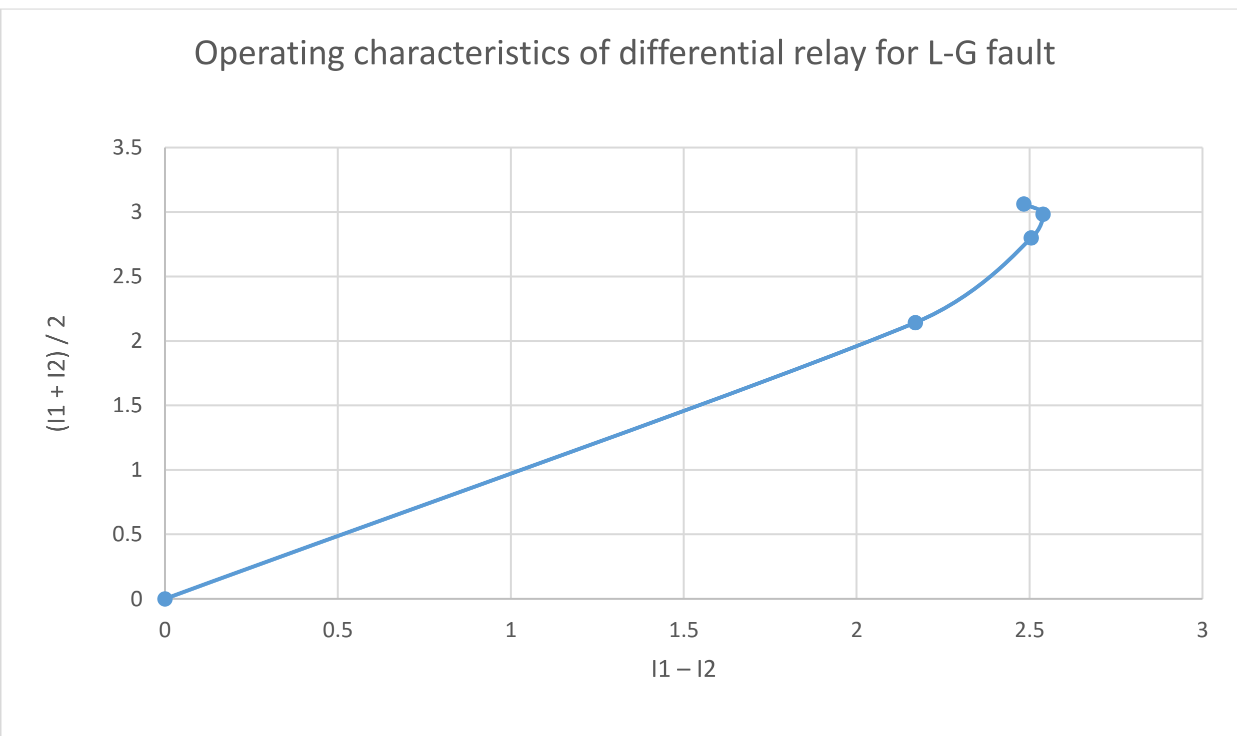

Figure 4.5 Operating Characteristics of relay during line to ground fault

4.2.3. LL–G Fault - In this case we considers internal fault is double line to ground fault.

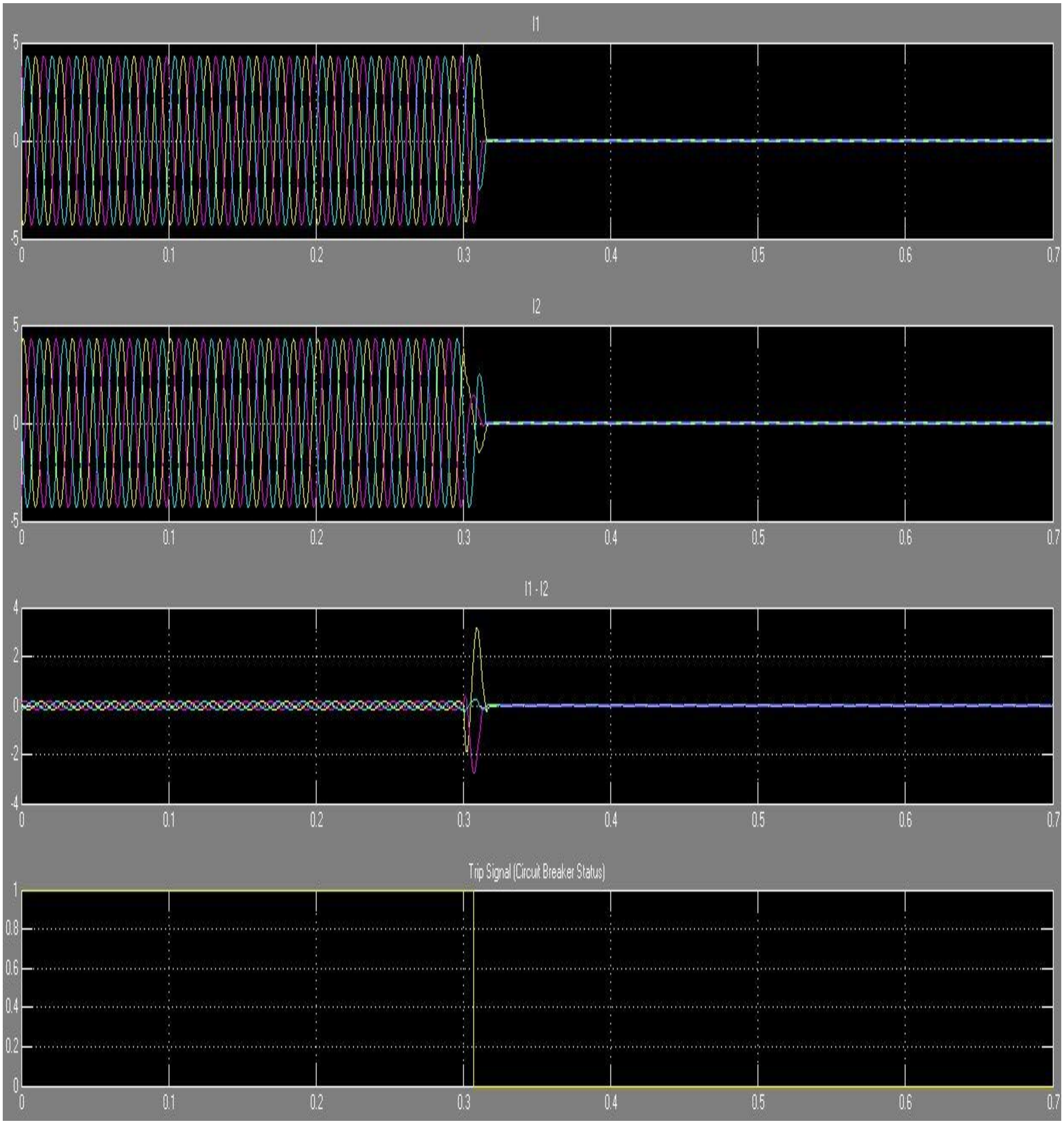

Figure 4.6 In LL-G fault condition restraining coil current (I_1 & I_2), operating coil (I_1 - I_2) and trip signal

In figure 4.6, the double line to ground fault occurs at time 0.3 sec. At this time value of $I_1 - I_2$ starts increasing and becomes greater than $k*(I_1 + I_2)/2$.When it becomes greater than that value it gives trip signal to circuit breaker. After the fault detection, relay gives 0 (zero) signal to the circuit breaker which means open the circuit breaker.

In figure 4.7 shows primary side current and secondary side current of power transformer, which put apart by circuit breaker when fault detected by differential relay.

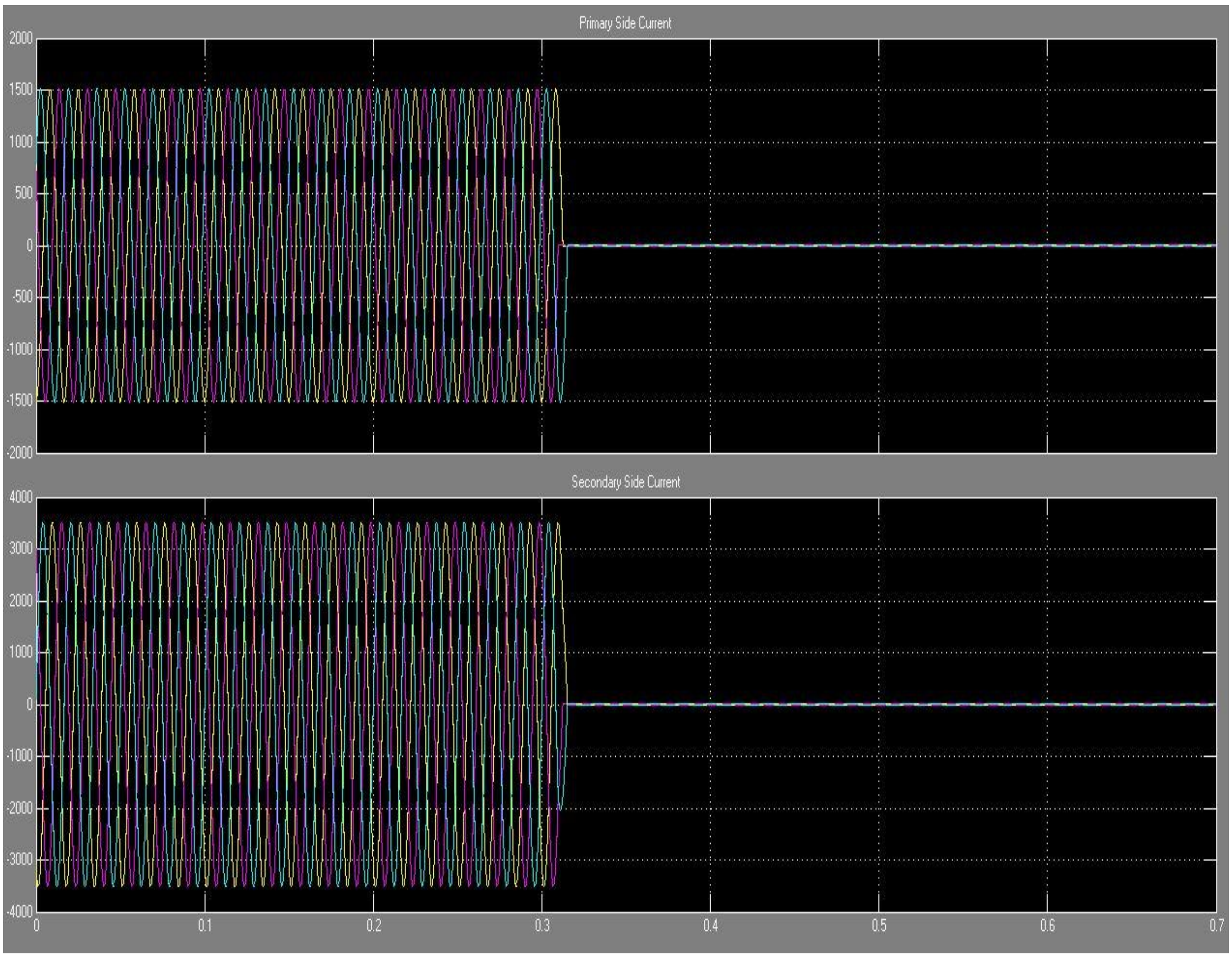

Figure 4.7 Primary Side Current & Secondary Side Current in double line to ground fault

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

Sr. 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	-0.6047	2.812	-2.663	0.237	Trip
2	0.309	4.11	-3.238	-0.8722	-0.9681	1.007	1.098	3.142	-2.231	0.226	Trip
3	0.3095	4.336	-2.686	-1.647	-1.192	0.7946	1.866	3.149	-1.894	0.208	Trip
4	0.31	4.371	-2.203	-2.168	-1.367	0.6146	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

The figure 4.6 values are shown in table 4.5, so when fault occurs detected by differential relay as value of ($I_1 – I_2$) is greater than ($I_1 + I_2$) / 2 and 2.15A. In phase A & B, values of ($I_1 – I_2$) is more so fault detected by relay and relay will give trip signal to the circuit breaker. As shown in table, relay give trip signal to the circuit breaker very fast and cutoff faulty part immediately. The figure 4.7 values are shown in table 4.6 shows primary and secondary side current of power transformer is shown. When circuit breaker open its contact both and apart the transformer from circuit.. Figure 4.8 show operating characteristics of relay during double LL-G fault.

Table 4.6 Primary Side Current and Secondary Side Current of power transformer in double line to ground fault

Sr. No.	Time (sec)	IPRIMARY			ISECONDARY		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.308	1500	-878	-621	2857	-3204	346
2	0.309	1499	-366	-1083	3411	-2446	-566
3	0.3095	1346	-85	-1261	3511	-1928	-1583
4	0.31	1195	0.7	-1393	3486	-1609	-1877
5	0.32	0	0	0	0	0	0

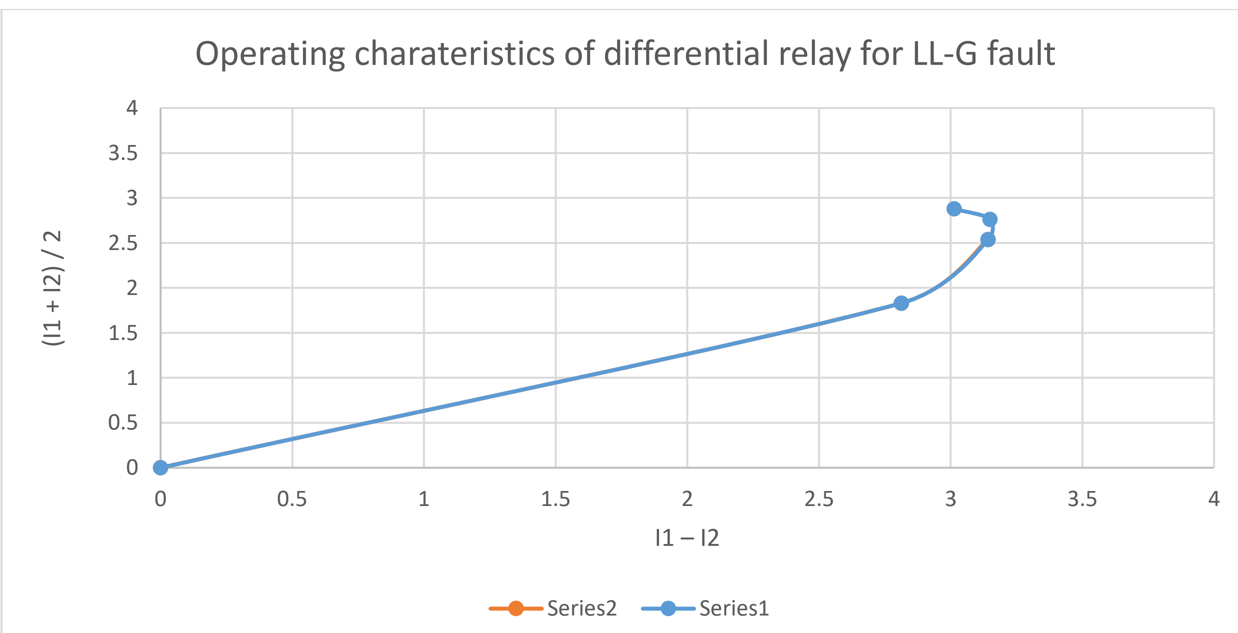

Figure 4.8 Operating characteristic of relay during double line to ground

4.2.4. LLL–G Fault - In this case we considers internal fault is triple line to ground fault.

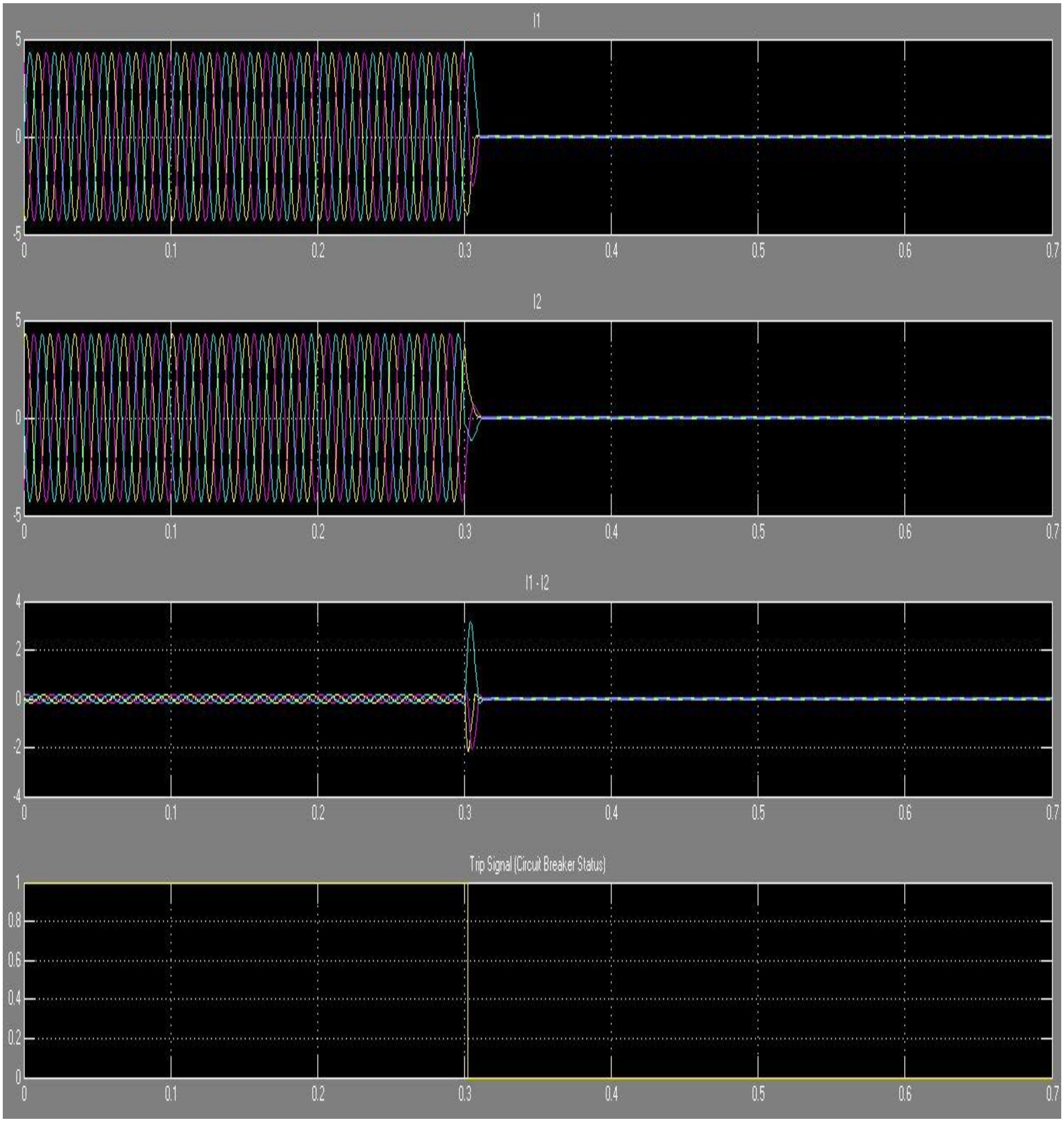

Figure 4.9 In LLL-G fault condition restraining coil current (I_1 & I_2), operating coil (I_1 - I_2) & trip signal

Figure 4.9 shows behavior of differential relay during three phase to ground. Current (I_1 - I_2) becomes greater than certain value in all three phases. Then differential relay give trip signal to circuit breaker and circuit breaker removes faulty part from healthy part of the circuit.

Figure 4.10 shows primary side current and secondary side current of power transformer, when fault occurs and detected by relay give trip signal to the circuit breaker.

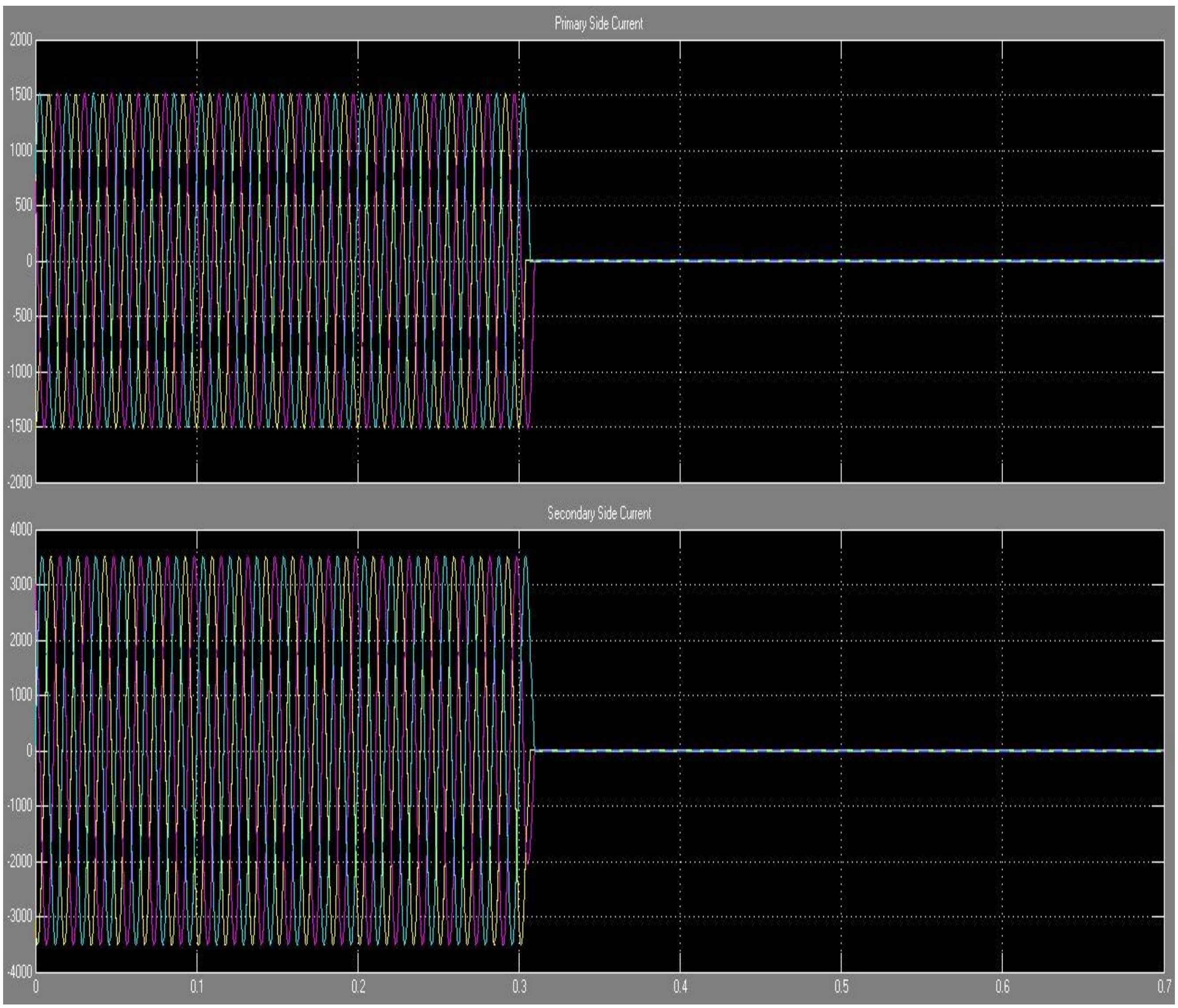

Figure 4.10 Primary Side Current & Secondary Side Current in three phase to ground fault

Table 4.7 (I_1, I_2, $I_1 - I_2$) currents & relay status at different time for LLL-G fault

Sr. 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

Table 4.7 explain about the figure 4.9. Inside this ($I_1 - I_2$) is greater than 2.15A in all three phases. So this signal received by relay and perform fast give the trip signal to circuit breaker. As shown in above table relay give immediately trip signal fault to the circuit breaker and circuit breaker cutoff that faulty part in just 0.02 sec. Table 4.8 explains the figure 4.10, as it shows primary and secondary side current at different time.

Table 4.8 Primary Side Current and Secondary Side Current of power transformer in triple line to ground fault

Sr. No.	Time (sec)	$I_{PRIMARY}$			$I_{SECONDARY}$		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.1	-1507	717	788	-3092	2997	95
2	0.21	1195	198	-1393	3486	-1343	2143
3	0.305	-604	-893	1498	-2835	-389	3221
4	0.304	-53	-1278	1331	-1866	-1648	3514
5	0.305	0.32	1482	977	-1317	-1997	3314
6	0.306	0.33	-1507	745	-1004	-2031	3035
7	0.32	0	0	0	0	0	0

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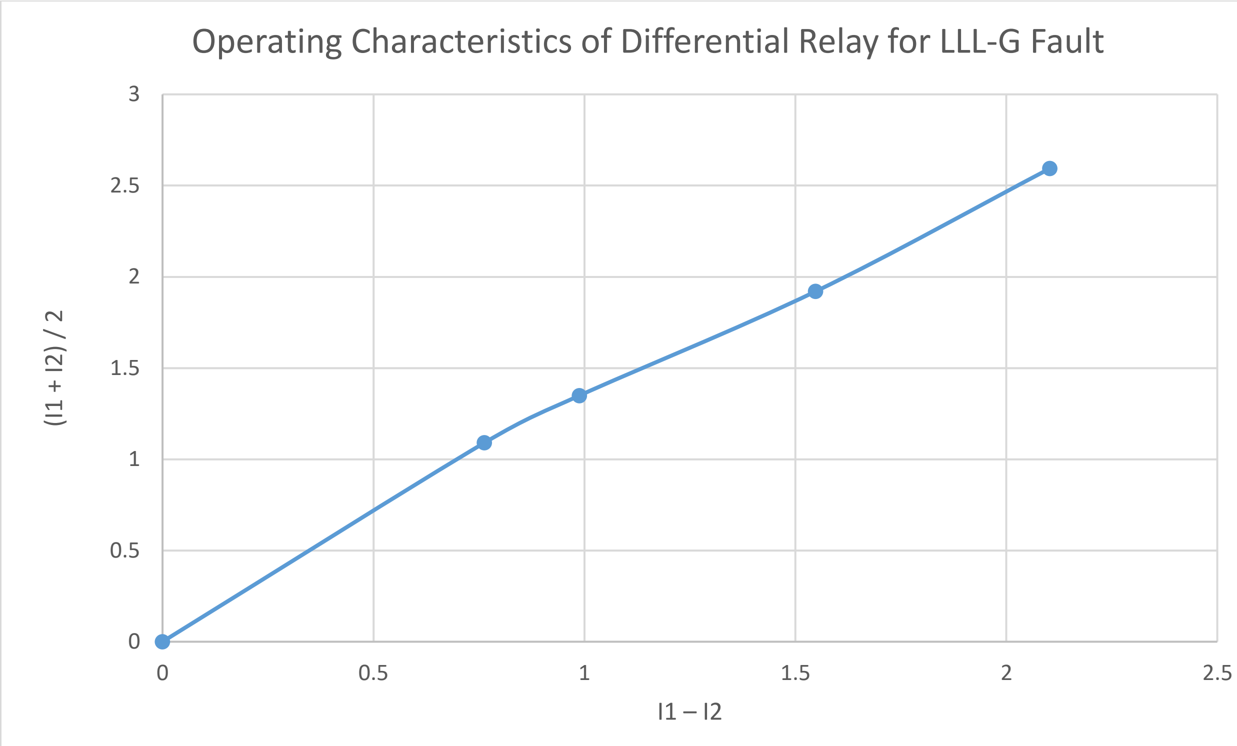

Figure 4.11 Operating characteristics of percentage differential relay

In figure 4.11 shows the characteristics of percentage differential relay during three phase fault, on x-axis shows $(I_1+I_2)/2$ value versus y-axis shows I_1-I_2 values. Inside this graph value of k is taken as 1. Relay operates when $I_1 – I_2$ greater than $(I_1+I_2)/2$ and exceeds than 2.15A.

$$I_1 – I_2 \geq K (I_1+I_2)/ 2$$

$$K = N_r / N_0$$

N_r = Restraining Coil

No = Operating coil

4.2.5. External Fault -

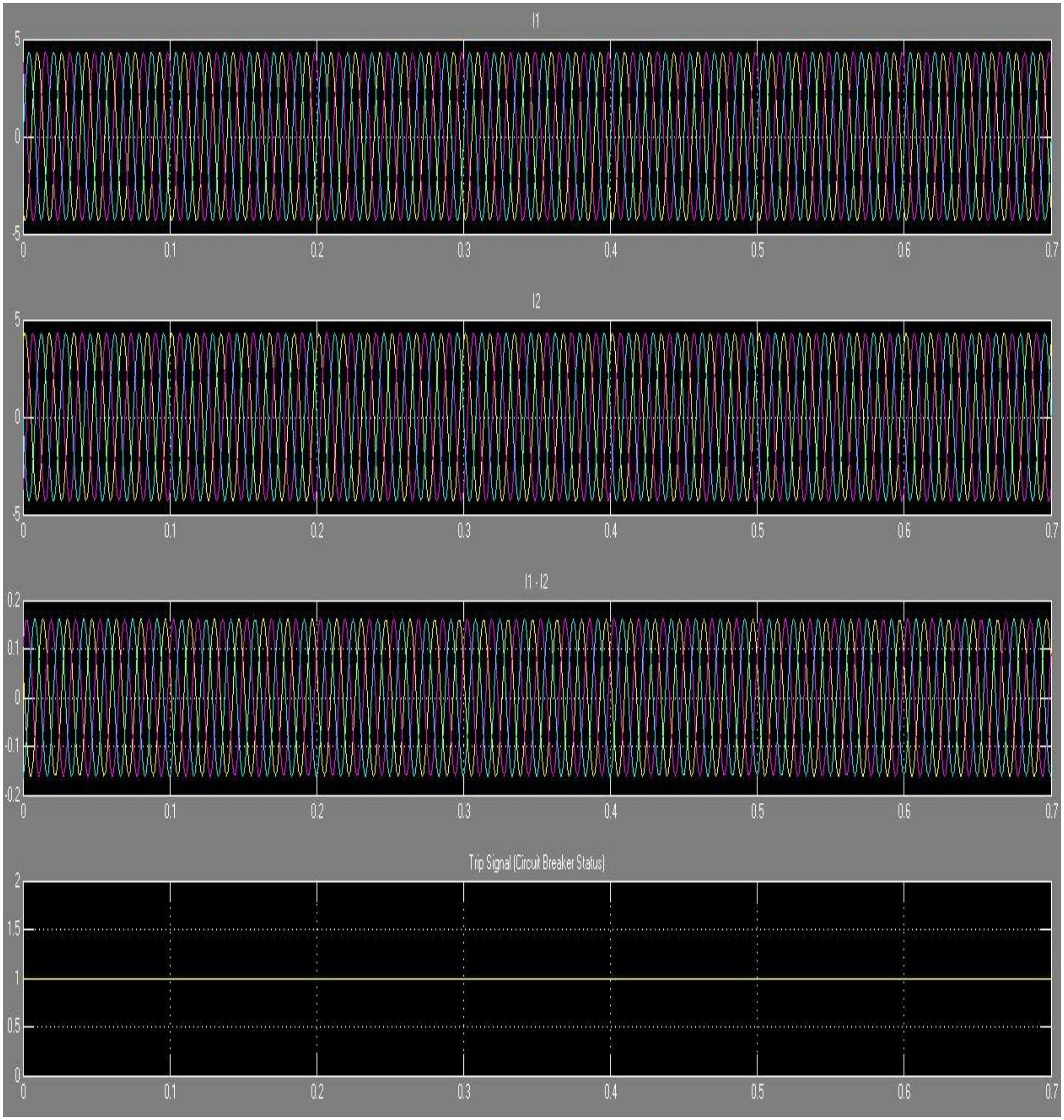

Figure 4.12 In external fault condition restraining coil current (I_1 & I_2), operating coil (I_1 - I_2) & trip signal

In figure 4.12 shows behavior of differential relay during external fault. External fault is which occurs outside of protecting zone. Suppose we are protecting power transformer, then fault occurs outside of this is external fault. Differential relay will not be operated for external faults because operating coil current is nearly zero.

In figure 4.13 shows primary and secondary side current during external fault

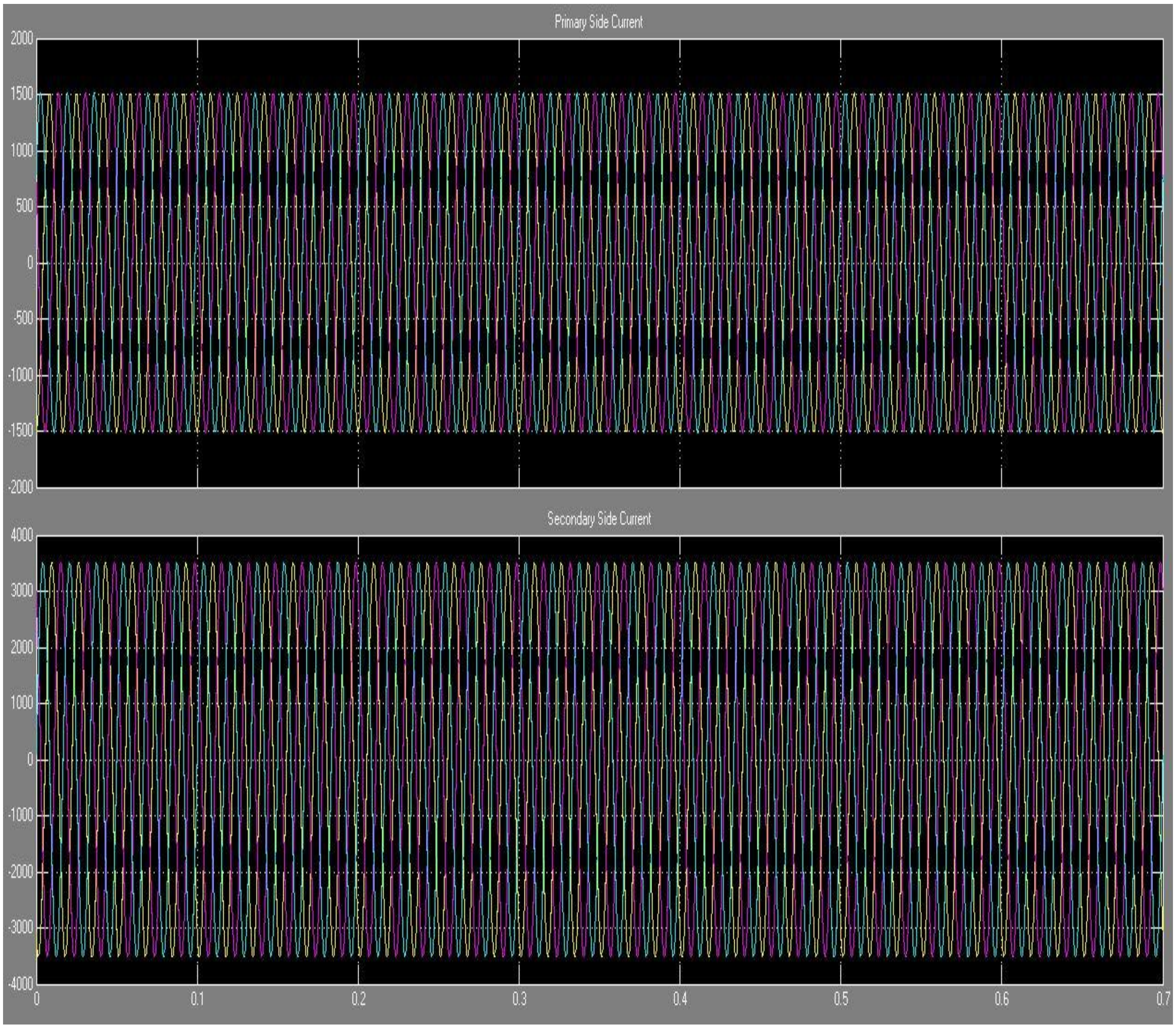

Figure 4.13 Primary Side Current & Secondary Side Current in external fault

Table 4.9 (I_1, I_2, $I_1 - I_2$) currents & relay status at different time for external fault

Sr.No.	Time	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	-0.03717	0.034	0.002	No Trip
4	0.43	-1.132	1.062	0.069	1.118	-1.049	-0.06914	-0.01388	0.01281	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

Table 4.9 explains about the figure 4.9, as results are like as no fault or normal condition. Operating coil current ($I_1 - I_2$) is zero in all three phases as shown in table 4.9. So differential relay will not be operated during external fault. That's why relay status in all the table is "No Trip". Table 4.10 shows primary and secondary side current of power transformer during external fault.

Table 4.10 Primary Side Current and Secondary Side Current of power transformer in external fault

Sr. No.	Time	$I_{PRIMARY}$			$I_{SECONDARY}$		
		I_A	I_B	I_C	I_A	I_B	I_C
1	0.1	-1507	717	788	-3092	2997	95
2	0.21	1195	198	-1393	3486	-1343	2143
3	0.32	-1246	563	583	-2598	2437	161
4	0.43	-440	199	241	-918	861	56
5	0.54	-156	170	85	-325	305	20
6	0.65	-55	25	30	-114	108	6
7	0.7	-34	18	18	-71	87	4

4.3 Conclusion- Electrical power systems are one of the more complex and important systems ever built by human civilization. The role of electrical power systems in the development and expansion of the economic activity of modern societies is of the first order of importance. However, power systems sometimes fail due to adverse environment and aging of equipment.

When the failures happen, protection of power systems acquires a main importance to minimize the damages and to keep the operation of the systems safe. Based upon above results following conclusions are made -

1. In this thesis work the design and modeling of differential relay has been done, and a manual prototype has been developed using MATLAB-SIMULINK software package.
2. In normal condition, when there is no fault in transformer, there is no current flow in operating coil of differential relay.
3. In faults like line to ground, double line to ground, three phase to ground fault the relay is operating when $(I_1 – I_2)$ greater than $(I_1 + I_2)/2$.
4. In external faults, fault occurs outside of protecting zone so differential relay is not operated.
5. In all cases, relay shows satisfactory results and in external fault relay is not operating.
6. The graph is plotted between $(I_1 – I_2)$ and $(I_1 + I_2)/2$ for L-G, LL-G and LLL-G faults. The graphs show operating characteristics of differential relay during faults.

4.4 Future scope of work- The model designed here is intended for relay operation during internal fault but when there is external fault the differential relay will not be operate. There is a novel adaptive protection that self-regulate the parameters of differential relay characteristics (e.g. restrain current and restrain coefficient at knee point of slope, pick up current,). The differential relay in which relay operates for internal faults as well as external faults is called "Self Adaptive Differential Relay". This gives a high operating sensitivity during internal faults and with much higher security during external faults. This is more suitable in that case where only need is to give the lower and upper limits but not exacts values of the settings of a relay.

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