Sudan University of Science And Technology

College of Engineering

School of Electrical and Nuclear Engineering

Study of Transformer's Protection In Bahri Thermal Station

دراسة حماية المحولات في محطة بحري الحرارية

A Project submitted in partial fulfillments of the requirements for the degree of B.Sc. (Honors) in Electrical Engineering

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بسم الله الرحمن الرحيم

قال تعالى :

[قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْحَكِيمُ الْعَلِيمُ]

البقرة [32]

صدق الله العظيم

الإهداء

- إلى محمد بن عبد الله..

الرسول الخاتم..

المبشر بالنهايات الكبرى..

والمخلص الأعظم :

حين انصرفت عنك قلوب الإنس صرف الله إليك قلوب الجن ، حتى

وددنا لو أن لنا قلب جني لنحظى بفرصة الإستماع إلى الحروف المبجلة يتلوها فوك المطهر..

-إلى كل من كان لهم الدعم السخي المتواصل خلال كل عقبات الحياة :

الأسر الصغيرة ، العوائل وكافة الأصدقاء

كل الود والإحترام وجزاكم الكريم بما هو أهل له.

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Abstract

The transformer is important equipment in electrical system so it's protection is so necessary, we studied the protection of it by using a type of relay called numerical relay, the operation of relay is to sense the fault by comparing the current value with the preset one and send a signal to circuit breaker to open the circuit.

It is worth that protecting electrical equipment means reducing damage more than preventing it.

مستخلص

المحول هو جهاز مهم في النظام الكهربائي لذلك حمايته ضرورية, لقد قمنا بدراسة حماية المحول بإستخدام نوع معين من المرحلات يدعي المرحل العددي ,طريقة عمل هذا المرحل هو استشعار الخطأ بالمقارنة بين القيم الحالية والمضبوطة مسبقا وإرسال إشارة لقاطع الدائرة لفتح الدائرة الكهربائية.

الجدير بالذكر أن اكثر ما لفت إنتباهنا أن حماية المعدات الكهربائية معني بتقليل الضرر أكثر من منع حدوثه !

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List of Abbreviations

CT	Current Transformer
VT	Voltage Transformer
IEEE	Institute of Electrical and Electronic Engineering
IEC	International Electro technical Commission
DFT	Discrete Fourier Transform
VLSI	Very Large Scale Integration
DSPs	Digital Signal Processors
A/D	Analogue to Digital Convertors
DAS	Data Acquisition System
DC	Direct Current
AC	Alternating Current
S/H	Sampling and Hold
RTOS	Real Time Operating System
ELCBs	Earth leakage Circuit Breakers
HRC	High Rupturing Capacity
CBF	Circuit Breaker Failure

CHAPTER ONE

INTRODUCTION

1.1Background:

The purpose of an electrical power system is to generate and supply electrical energy to consumers. The system should be designed and managed to deliver this energy to the utilization points with both reliability and economy. Many items of equipment are very expensive, and so the complete power system represents a very large capital investment. To ensure the maximum return on the large investment in the equipment, which goes to make up the power system and to keep the users satisfied with reliable service the whole system must be kept in operation continuously without major breakdowns and also to reduce the impact of fault on the other parts of the system.

1.2 Problem Statement:

Faults occur in transformer will eliminate the services from the units for this reason effective protection action is required to minimize damage and repair costs where it senses fault, Ensure safety of personnel.

1.3 Objective:

The main objectives of this research are to develop and investigate protection system used in high power transformer rating protection.

1.4 Methodology:

The first stage in this project; numeric relays from ABB techniques used to obtain protection transformer. This protection using ABB REF615 which protect over current, restricted earth fault and differential protection. On second stage selected setting of numerical According to IEEE Standers and ABB Technical guides.

1.5 Project layout:

The thesis is organized simply by putting chapter one to give brief introduction about background, chapter two gives introduction about transformer construction and type of it ,chapter three gives introduction about protection of power system and component of protection,chapter four is power transformer protection and setting calculations and chapter five conclusion and recommendations.

CHAPTER TWO
CONSTRUCTION AND TYPE OF TRANSFORMER

2.1 Introduction:

The construction of a simple two-winding transformer consists of each winding being wound on a separate limb or core of the soft iron form which provides the necessary magnetic circuit.

This magnetic circuit -known more commonly as the "transformer core"- is designed to provide a path for the magnetic field to flow around, which is necessary for induction of the voltage between the two windings.

However, this type of transformer construction were the two windings are wound on separate limbs is not very efficient since the primary and secondary windings are well separated from each other. This results in a low magnetic coupling between the two windings as well as large amounts of magnetic flux leakage from the transformer itself. But as well as this shapes construction, there are different types of transformer construction and designs available which are used to overcome these inefficiencies producing a smaller more compact transformer.

Increasing and concentrating the magnetic circuit around the coils may improve the magnetic coupling between the two windings, but it also has the effect of increasing the magnetic losses of the transformer core.

As well as providing a low reluctance path for the magnetic field, the core is designed to prevent circulating electric currents within the iron core itself.

In all types of transformer construction, the central iron core is constructed from a highly permeable material made of thin silicon steel laminations assembled together to provide the required magnetic path with the minimum of losses. The resistivity of the steel sheet itself is high reducing the eddy current losses by making the laminations very thin.

Transformer construction is divided into two part:

- Main.
- Auxiliary.
-

2.2 Types of transformer:-

There are different types of transformer hence some of them:

- Power transformers.
- Distribution Transformer.
- Phase shifting transformer.
- Regulating Transformer.

2.2.1 Power transformers:

A power transformer is a passive electromagnetic device that transfers energy from one circuit to another circuit by means of inductive coupling. Power transformers differ from other transformer types in that they are designed to comply with regulatory requirements for mains power interfacing, working at mains voltages and relatively high currents. The most important specification of a power transformer is its primary to secondary transformer galvanic isolation, which is usually specified in Kv. This is a fundamental safety aspect in protecting humans from potentially lethal earth fault conditions.

Power transformers typically have a single primary (mains side) winding and one or more secondary windings. The secondary winding may be tapped at different points to generate multiple voltage outputs.A power transformer operates according to Faradays Law of Induction. Transformers are extremely efficient when operating within their design specifications.

Core type is an important consideration. Typical power transformer supplies include laminated core. Laminations can be important as they help prevent eddy currents flowing in the core that cause loss of efficiency. The maximum output current is specified at the point where the core is saturated, or the windings current rating is exceeded. Power transformers are found in any application that requires mains power.

6

Power transformers play an important and significant role in the power system to connecting the subsystems and delivering the electricity to the consumers. They are one of the most expensive elements in the power system which is why focusing on their status of parameters is the primary task. This

Seminar paper will focus on highlighting certain important aspects of voltage selection and thermal aspects. Voltage selection goes for determining and calculating transformer voltage ratio, the specification of insulation levels, examples of voltage regulation, rating, tap ranges and impedance calculations.

Thermal aspects go for specification of temperature rise and ambient conditions. Also, constructional features of different types of a transformer in common use together with the purpose and selection of accessories.

Transformer equivalent circuit:-

Transformer equivalent circuit is the essential basis for different calculations including voltage drop or regulation under various load conditions. In Fig 2.6 the magnetizing circuit is taken as a shunt-connected impedance. The magnetizing current is rich in harmonics which must be kept in check. This is done by keeping the flux density within specified limits. When the transformer is being energized, the transient current inrush rich in second harmonic will result. A mentioned effect can be uncovered using transformer protection relays in a way that they control the existence of the second harmonic component, so that the anomalous tripping is avoided.

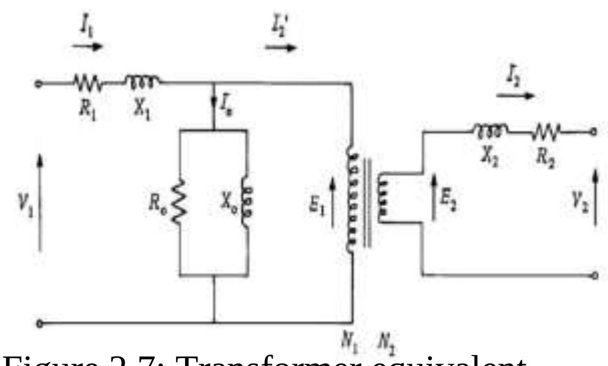

Figure 2.7: Transformer equivalent

circuitV1 (U1)– primary terminal voltage

e1 – primary induced emf (theoretical)

V2 (U2)– secondary terminal voltage

e2 – secondary induced emf (theoretical)

I0 no load current

I1 – primary current

I2 – secondary load current

I3 – load component of total primary current (reflected secondary current)

– magnetizing and core reactance and resistance

X1 &R1 – primary winding reactive leakage and coil resistance

X2 & R2 – secondary winding reactance and resistance

N1 – primary coil number of turns

N2 – secondary coil number of turns

2.2.2 Distribution Transformer

The step down transformer used for electric power distribution Purpose are referred as distribution transformer. There are several types of Transformer used in the distribution system. Such as single phase transformer, three phase transformer, pole mounted transformer, pad mounted transformer and underground transformer.

Distribution transformer are generally small in size and filled with insulating Oil. These transformer are available in the market in various sizes and efficiencies . selection of distribution transformer depends upon the purpose and budget of the end users.

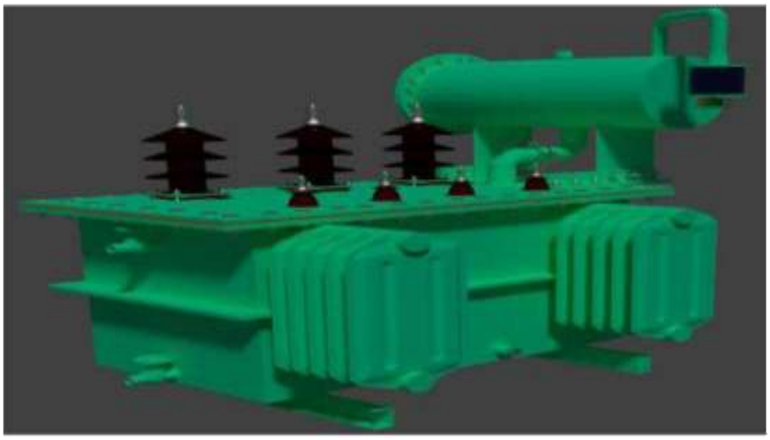

Figure 2.8 distribution transformer

Secondary Terminal of Distribution Transformer

Secondary terminal of distribution transformer deliver electrical power at utilization voltage level to the consumer and via energy metering system. In case of three phase distribution system three phase four wire secondary system are adopted. Here, three phases, which means red, yellow and blue phase conductor, come out from three low voltage bushing studs of the transformer. The neutral wire is connected to the fourth bushing which is also referred as a neutral bushing of the transformer. The neutral point of the distribution transformer is projected from the tie point of 3-phase winding inside the transformer. In case of Industrial heavy three phase load, four wire system is directly delivered to the consumer end, but in case of single phase light load, one phase and neutral connection of the three phase distribution transformer , are connected to the consumer's energy meter.

2.2.3 Phase shifting transformer

The necessity to control the power flow rose early in the history The development of electrical power system. When high-voltage grids were Were super imposed on local system, parallel-connected system or transmission line of different voltage level became stander . Nowadays large high- voltage power grids are connected to increase the reliability of the electrical power supply and to allow exchange of electrical power over large distances. Complications, attributed to several factors such as variation in power-generation output and/or power demand, can arise and have to be dealt with to avoid potentially catastrophic system disturbances. Additional Tools in the form of phase shifting transformer (PSTs) are available to control the power flow to stabilize the girds. These may be justified to maintain the required of electrical power supply. To transfer electrical power supply. To transfer electrical power between two points a system, a difference between source voltage (vs) and load voltage (VL) in quantity and/or in phase single angle is necessary.

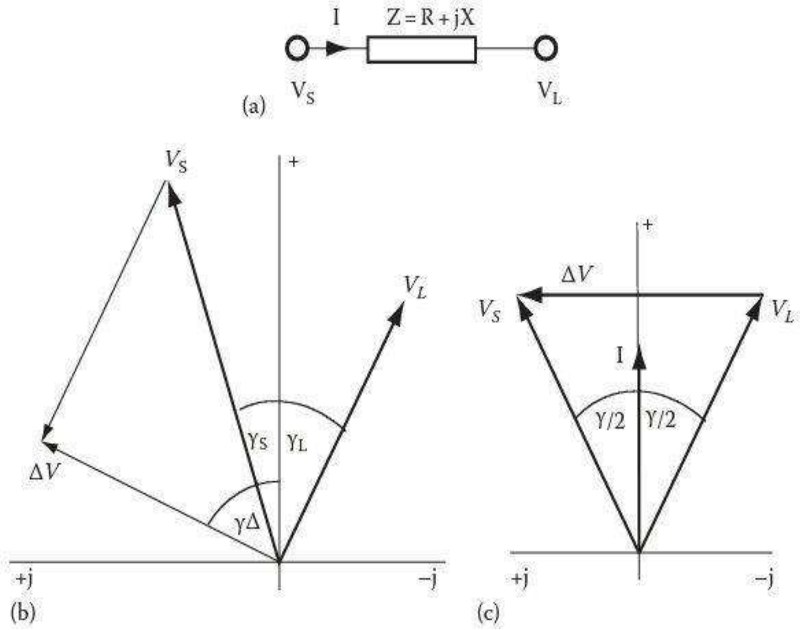

Figure 2.9: Power shifting transformer diagram

Transformer Tap Changer

A transformer tap is a connection point along a transformer winding that allows the number of turns to be selected. By this means, a transformer with a variable turns ratio is produced, enabling voltage regulation of the secondary side. Selection of the tap in use is made via a tap changer mechanism. Supply authorities are under obligation to their customers to maintain the supply voltage between certain limits. Tap changers offer variable control to keep the supply voltage within these limits.

2.2.4 Regulating Transformer

The transformer which changes the magnitude and phase angle at the certain point in the power system is known as the regulating transformer. It is mainly used for controlling the magnitude of bus voltage and for controlling the power flow, which is controlled by the phase angle of the transformer. They provide the small component of voltage between the line or phase voltage. The main function of the regulating transformer is to control the magnitude of voltage and power flow of the transmission line. The regulating transformer is of two types. One is used for changing the magnitude of voltage which is called online tap changing transformer and the other is called phase shifting transformer .The regulating transformer compensates the fluctuation of voltage and current. The arrangement of the regulating transformer is shown in the Fig (2.12).

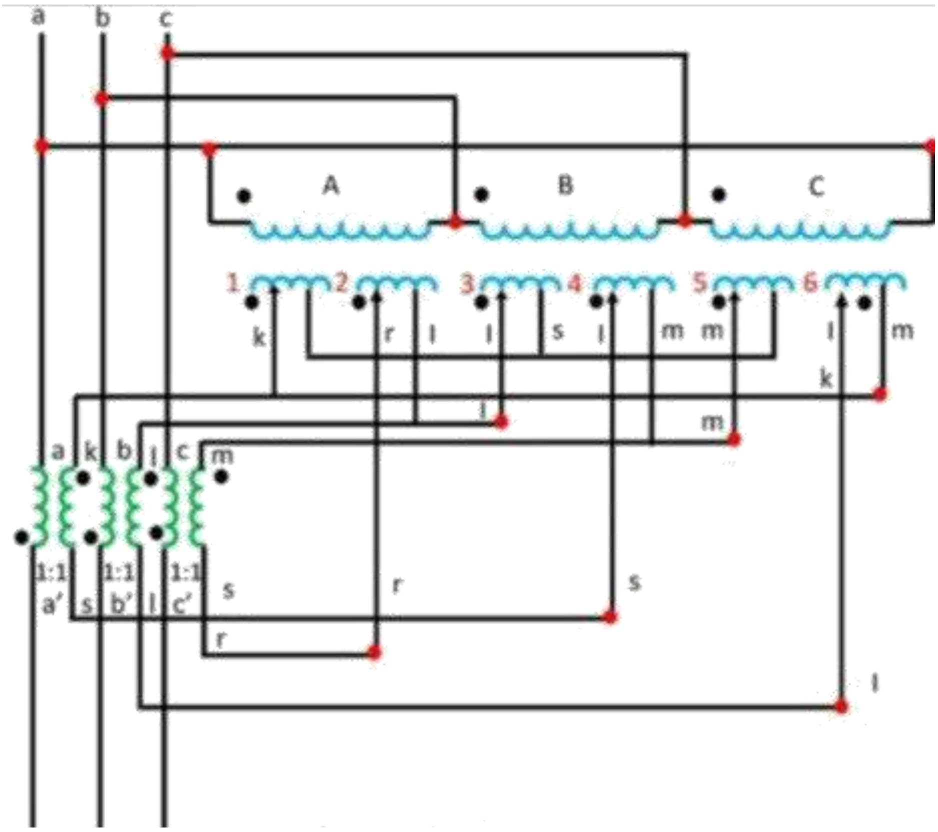

Figure 2.12: regulating transformer

The main application of power system is to reduce the circulating current and minimize the losses in the power system. The regulating transformer reduces the losses in the power system network, and it also controls the unwanted exchange of the reactive power in the system.

CHAPTRE THREE

PROTECTION

3.1 Introduction

It is not economically feasible to design and manufacture electrical equipment that will never fail in service. Equipment will and do fail, and the only way to limit further damage, and to restrict danger to human life, is to provide fast, reliable electrical protection. The protection of a power system detects abnormal conditions, localizes faults, and promptly removes the faulty equipment from service.Electrical protection is not an exact science, but is rather a philosophy based on a number of principles. There are countless unique circumstances where protection is needed, and the techniques that will be applied have to take the specific conditions into account. Economic principles, namely the cost of the equipment that is protected, the cost of the protection equipment itself, the secondary cost of an electrical fault (for example, lost revenue or production losses), as well as probability analyses, all play a role in determining the protection philosophy that will be followed.

3.2 Protection Importance

The importance of the protection lies in two basic points:

- Detect faults and identifies how serious they are and where are their places.

- Isolate the affected elements faults and opening the appropriate cutouts.

3.3 Protection System

A complete arrangement of protection equipment and other devices required to achieve a specified function based on a protection principal

3.4 Overview of electrical fault

Electrical faults usually occur due to breakdown of the insulating media between live conductors or between a live conductor and earth. This breakdown may be caused by any one or more of several factors, for example, mechanical damage, overheating, voltage surges (caused by lightning or switching), ingress of a conducting medium, ionization of air, and deterioration of the insulating media due to an unfriendly environment or old age, or misuse of equipment.

Fault currents release an enormous amount of thermal energy, and if not cleared quickly, may cause fire hazards, extensive damage to equipment and risk to human life. Faults are classified into two major groups: symmetrical and unbalanced (asymmetrical). Symmetrical faults involve all three phases and cause extremely severe fault currents and system disturbances. Unbalanced faults include phase-to-phase, phase-to-ground, and phase-to-phase-to-ground faults. They are not as severe as symmetrical faults because not all three phases are involved. The least severe fault condition is a single phase-to-ground fault with the transformer neutral earthed through a resistor or reactor. However, if not cleared quickly, unbalanced faults will usually develop into symmetrical faults.

3.5 Electrical three phase System Fault Types:

- Single phase to ground fault
- Phase to Phase fault
- Double Phase to earth fault
- Three phase fault
- Three phase to ground fault

Figure (3.1) represent the types of electrical faults:

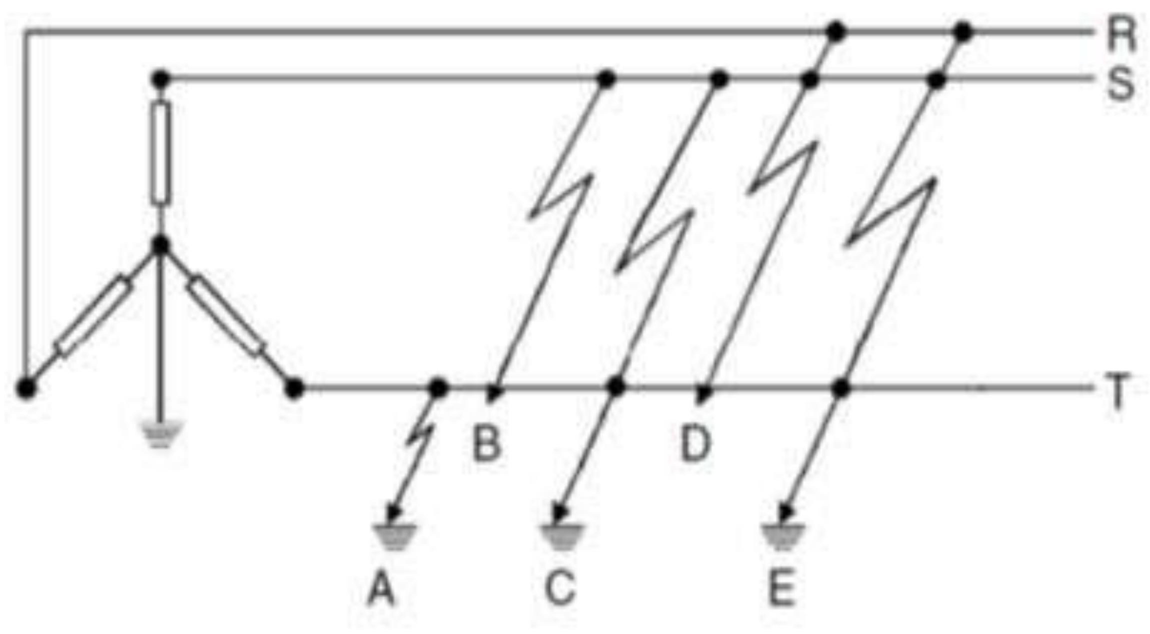

Figure 3.1: Type of faults on a three phase

3.6 Protection Scheme

A collection of protection equipment providing a defined function and including all equipment required to make the scheme work (i.e. relays, CT's, CB's, batteries, etc.).Relays are the devices, which monitor the conditions of a circuit and give instructions to open a circuit under unhealthy conditions .The basic parameters of the three-phase electrical system are voltage, current, frequency and power. All these have pre-determined values and/or sequence under healthy conditions. Any shift from this normal behavior could be the result of a fault condition either at the source end or at the load end .

Limiting the damage to a faulted transformer. Some protection functions, such as over excitation protection and temperature-based protection may aid this goal by identifying operating conditions that may cause transformer failure. The comprehensive transformer protection provided by multiple function protective relays is appropriate for critical transformers of all applications.

3.7 Protection component

A collection of protection devices (relays, fuses, etc.). Excluded are devices such as CT's, CB's, Contactors, etc**.**

3.7.1 Fuses

Probably the oldest, simplest, cheapest, and most-often used type of protection device is the fuse. The operation of a fuse is very straightforward. The thermal energy of the excessive current causes the fuse-element to melt and the current path is interrupted. Technological developments have made fuses more predictable, faster, and safer (not to explode) Fuses are very inexpensive and they can operate totally independently, that is, they do not need a relay with instrument transformers to tell them when to blow. This makes them especially suitable in applications like remote ring main units, et.

3.7.2 Relays

The most versatile and sophisticated type of protection available today, is undoubtedly the relay/circuit-breaker combination. The relay receives information regarding the network mainly from the instrument transformers (voltage and current transformers), detects an abnormal condition by comparing this information to pre-set values, and gives a tripping command to the circuit-breaker when such an abnormal condition has been detected. The relay may also be operated by an external tripping signal, either from other instruments, from a SCADA master, or by human intervention. Relays may be classified according to the technology used into:

3.7.2.1 Electromechanical Relays:

These relays were the earliest forms of relay used for the protection of power systems, and they date back nearly 100 years. They work on the principle of a mechanical force causing operation of a relay contact in response to a stimulus.

The mechanical force is generated through current flow in one or more windings on a magnetic core or cores, hence the term electromechanical relay.

The principle advantage of such relays is that they provide galvanic isolation between the inputs and outputs in a simple, cheap and reliable form therefore for simple on/off switching functions where the output contacts have to carry substantial currents, they are still used. Electromechanical relays can be classified into several different types as follows:

- Attracted armature
- Moving coil
- Induction
- Thermal
- Motor operated
- Mechanical

3.7.2.2 Static Relays

Introduction of static relays began in the early 1960's. Their design is based on the use of analogue electronic devices instead of coils and magnets to create the relay characteristic. Early versions used discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors, etc., but advances in electronics enabled the use of linear and digital integrated circuits in later versions for signal processing and implementation of logic functions. While basic circuits may be common to a number of relays, the packaging was still essentially restricted to a single protection function per case, while complex functions required several cases of hardware suitably interconnected. User programming was restricted to the basic functions of adjustment of relay characteristic curves. They therefore can be viewed in simple terms as an analogue electronic replacement for electromechanical relays, with some additional flexibility in settings and some saving in space requirements. In some cases, relay burden is reduced, making for reduced CT/VT output requirements.

3.7.2.3 Digital Relays:

Digital protection relays introduced a step change in technology. Microprocessors and microcontrollers replaced analogue circuits used in static relays to implement relay functions. Early examples began to be introduced into service around 1980, and, with improvements in processing capacity, can still be regarded as current technology for many relay applications.

However, such technology will be completely superseded within the next five years by numerical relays. Compared to static relays, digital relays introduce A/D conversion of all measured analogue quantities and use a microprocessor

The microprocessor may use some kind of counting technique, or use the Discrete Fourier Transform (DFT) to implement the algorithm. However, the typical microprocessors used have limited processing capacity and memory compared to that provided in numerical relays. The functionality tends therefore to be limited and restricted largely to the protection function itself. Additional functionality compared to that provided by an electromechanical or static relay is usually available, typically taking the form of a wider range of settings, and greater accuracy. A communications link to a remote computer may also be provided.

3.7.2.4 Numerical Relays

The distinction between digital and numerical relay rests on points of fie technical detail, and is rarely found in areas other than Protection. They can be viewed as natural developments of digital relays as a result of advances in technology. Typically, they use a specialized digital signal processor (DSP) as the computational hardware, together with the associated software tools. The input analogue signals are converted into a digital representation and processed according to the appropriate mathematical algorithm. Processing is carried out using a specialized microprocessor that is optimized for signal processing applications, known as a digital signal processor or DSP for short. Digital processing of signals in real time requires a very high power microprocessor. In addition, the continuing reduction in the cost of microprocessors and related digital devices (memory, I/O, etc.) naturally leads to an approach where a single item of hardware is used to provide a range of functions (one-box solution approach).By using multiple microprocessors to provide the necessary computational performance, a large number of functions previously implemented in separate items of hardware can now be included within a single item.

3.7.3 Instrument Tansformers (CT\VT)

Relays need information from the power network in order to detect an abnormal condition. This information is obtained via voltage and current transformers (collectively called instrument transformers), as the normal system voltages and currents are too high for the relays to handle directly, and the instrument transformers protect the relay from system (Spikes) to a certain extent.[2]

3.8 Zones of protection

To limit the extent of the power system that is disconnected when a fault occurs, protection is arranged in zones. The principle is shown in Figure (3.2).

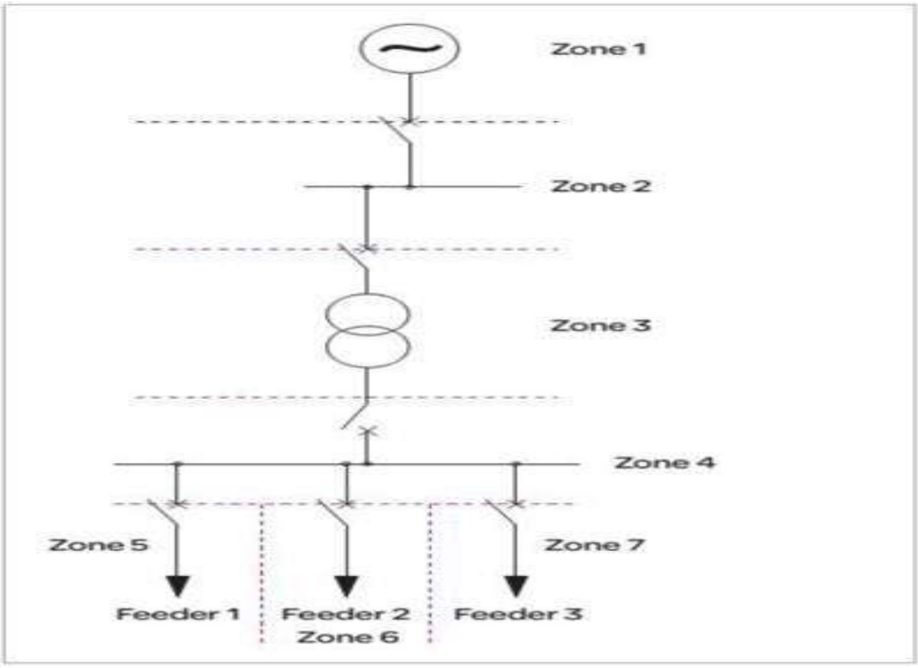

Figure 3.2: Division of Power System into Protection Zone

Ideally, the zones of protection should overlap, so that no part of the power system is left unprotected. The circuit breaker being included in both zones. For practical physical and economic reasons, this ideal is not always achieved, accommodation for current transformers being in some cases available only on one side of the circuit breakers. This leaves a section between the current transformers and the circuit breaker that is not completely protected against faults. In Figure 2.3 a fault at F would cause the bus bar protection to operate and open the circuit breaker but the fault may continue to be fed through the feeder. The feeder protection, if of the unit type, would not operate, since the fault is outside its zone. This problem is dealt with by inter-tripping or some form of zone extension, to ensure that the remote end of the feeder is tripped also.

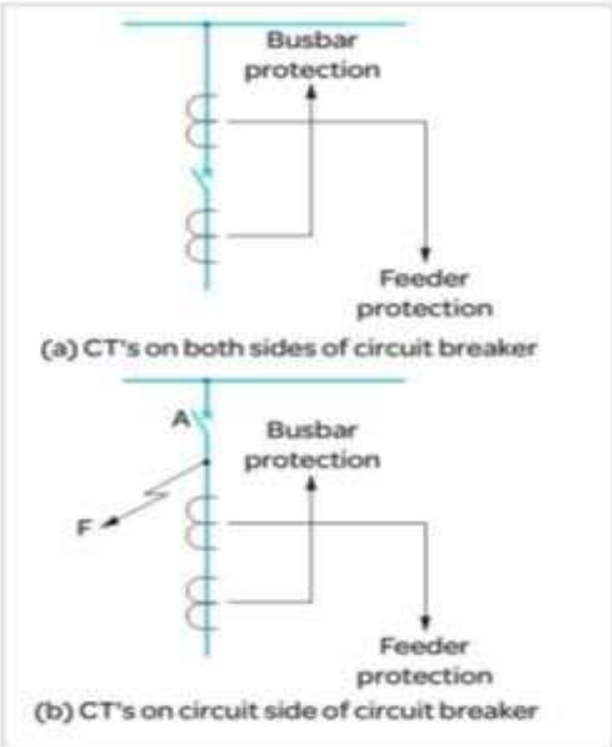

Figure 3.3: CT locations .

he point of connection of the protection with the power system usually defines the zone and corresponds to the location of the current transformers. Unit type protection will result in the boundary being a clearly defined closed loop. Figure (3.4) illustrates a typical arrangement of overlapping zones. [2]

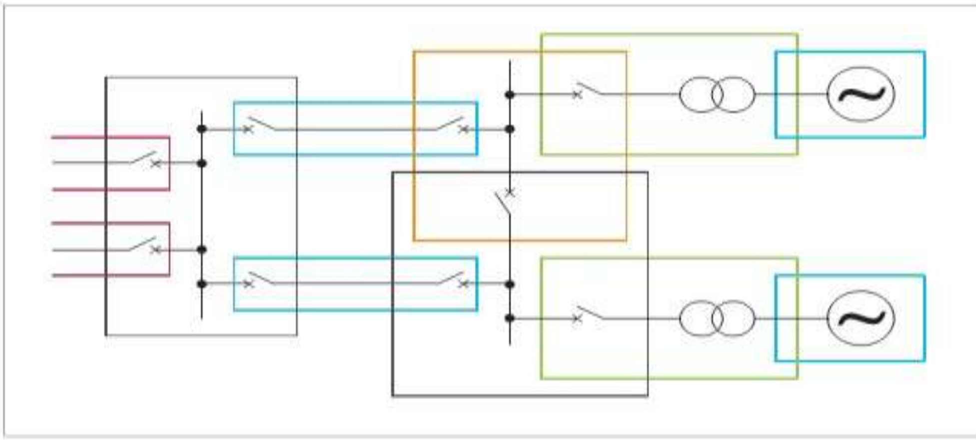

Figure 3.4: Overlapping Zones of Protection System3

3.9Protection quality

Protection quality represents: discrimination, stability, reliability, speed of operation and sensitivity.

3.10 Discrimination

Discrimination, or selectivity, is the ability of the protection to isolate only the faulted part of the system, minimizing the impact of the fault on the power network. Absolute discrimination is only obtained when the protection operates exclusively within a clearly defined zone.

This type of protection is know as 'unit protection', as only one unit is exclusively protected for example transformer, or specific feeder cable

• There has to be a means of communication between the devices at each end, in order to compare electrical conditions and detect a fault when present.

The main advantages of unit protection are:

- ❖ Only the faulted equipment or part of the network is disconnected, with minimum disruption to the power network.
- ❖ Unit protection operates very fast , limiting damages to equipment and danger to human life. Fast operation is possible because the presence or absence of a fault is a very clear-cut case.
- ❖ Unit protection is very stable.
- ❖ Unit protection is very sensitive
- ❖ Unit protection is very reliable.

The main advantages of unit protection are:

- ❖ Only the faulted equipment or part of the network is disconnected, with minimum disruption to the power network.

The major disadvantages of unit protection are the following:

- It is very expensive.
- It relies on communication between the relays installed at either end.

3.11Stability

Stability, also called security, is the ability of the protection to remain inoperative for normal load conditions (including normal transients like motor starting). Most stability problems arise from incorrect application of relays and lack of maintenance.

3.11Stability

Stability, also called security, is the ability of the protection to remain inoperative for normal load conditions (including normal transients like motor starting). Most stability problems arise from incorrect application of relays and lack of maintenance.

3.12 Reliability

Reliability, or dependability, is the ability of the protection to operate correctly in case of a fault . Reliability is probably the most important quality of a protection system .

3.13 Speed of operation

The longer the fault current is allowed to flow, the greater the damage to equipment and the higher the risk to personnel. Therefore, protection equipment has to operate as fast as possible, without compromising on stability. The best way to achieve this is by applying unit protection schemes. The phase shift between voltages at different bus bars on the system also increases, and therefore so does the probability that synchronism will be lost when the system is disturbed by a fault. The shorter the time a fault is allowed to remain in the system, the greater can be the loading of the system. Figure (3.5) shows typical relations between system loading and fault clearance times for various type of fault.

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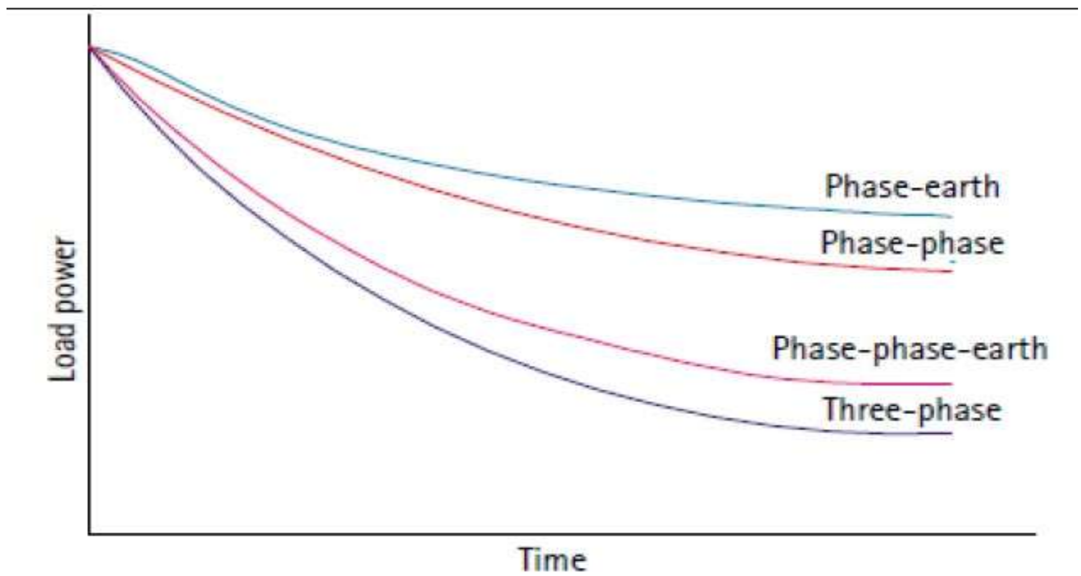

Figure 3.5: Typical Power / Time Relationship for Various Fault Types

3.14 Sensitivity

The term sensitivity refers to the magnitude of fault current at which protection operation occurs.

A protection relay is said to be sensitive when the primary operating current is very low. Therefore, the term sensitivity is normally used in the context of electrical protection for expensive electronic equipment, or sensitive earth leakage equipment [2].

3.15 Transformer protections Types:

- Over current protection
- Earth fault protection
- Differential protection

3.15.1 Over Current Protection

The term (overcurrent) refers to abnormal current flow higher than the normal value of current flow in an electrical circuit. Uncorrected (overcurrent) can cause serious safety hazards and costly damage to electrical equipment and property. The overcurrent relay typically displays the inverse definite minimum time (IDMT) characteristic as displayed in Figure (3.6) Traditionally, normally inverse (NI), very inverse (VI), and extremely inverse (EI) have been applied, with each type of curve characteristic to a specific type of relay. Multitudes of curves, up to 15 in one relay, user selectable, are available with modern relays.

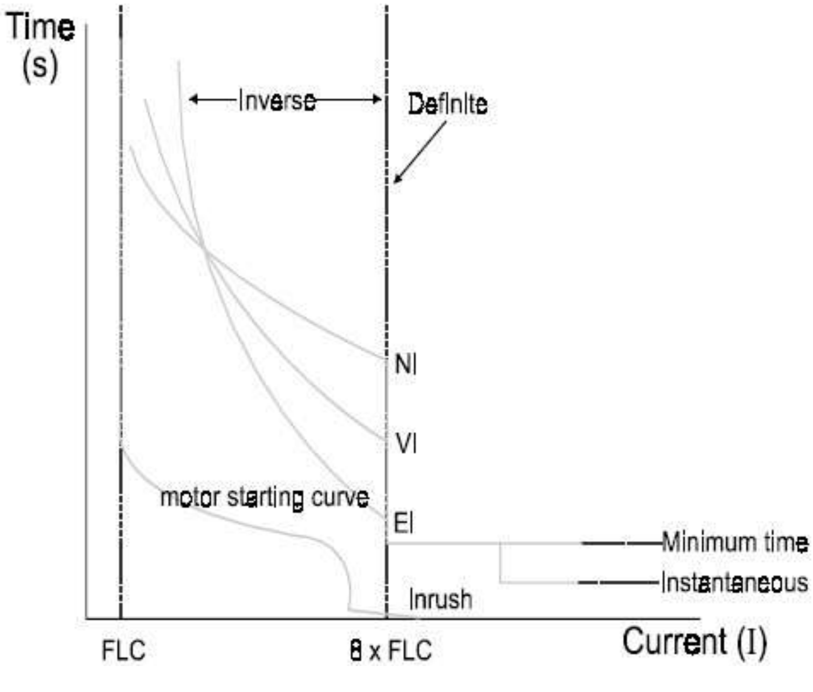

Figure 3.6: Traditional Over Current Curve .

3.15.2 Earth fault protection

Phase-to-earth faults are covered by earth fault relays. The most common form of earth Fault protection operates on the principle that the vector sum of currents flowing in a balanced three-phase system equals zero. A very effective combination of overcurrent and earth fault protection has developed in the era of electromechanical relays, and the same principle is still used today in most protection schemes. This is illustrated in Figure (3.7).

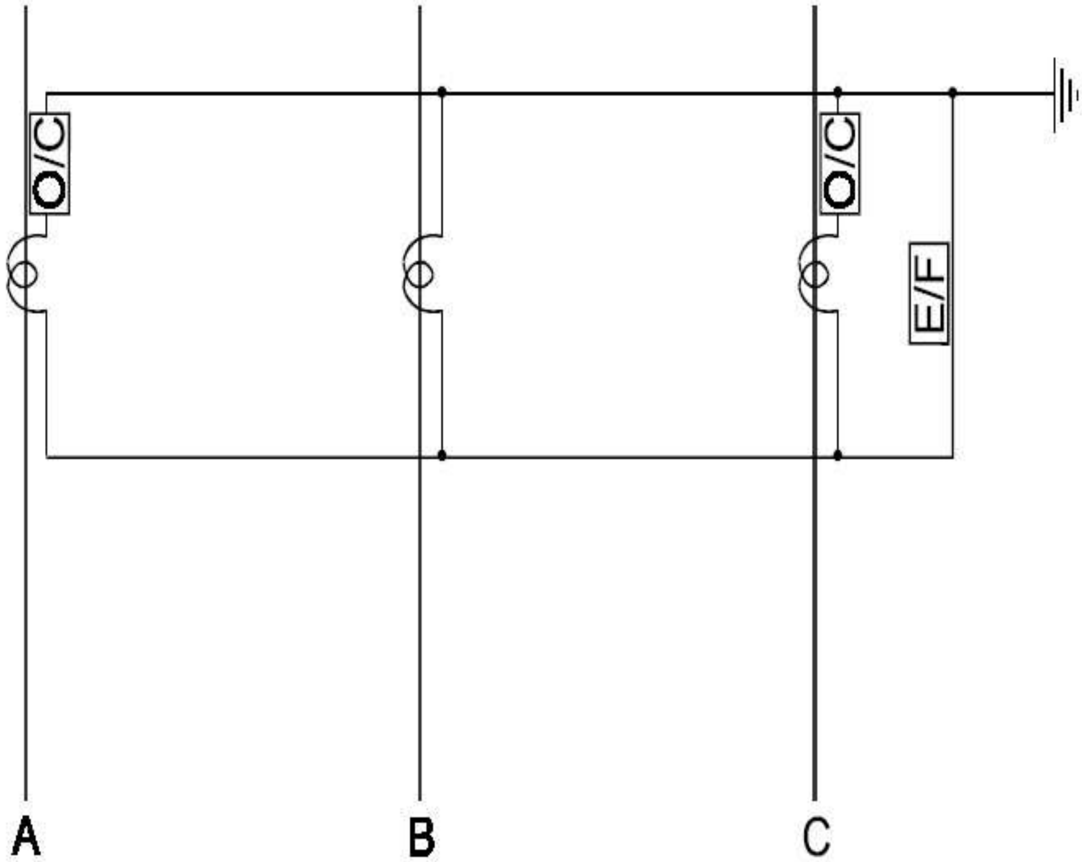

Figure 3.7: Economical CT Arrangement for O /C and E/ F

Only two phases need to be monitored by the overcurrent relay, the reason being that a fault on the third phase will be either to one of the other two phases, or to earth. A phase to-earth fault will cause an unbalance in the three phases, resulting in a current flowing in the earth fault element, tripping the earth fault relay. The same protection CTs are thus being used in this arrangement [3] .

3.15.3 Differential protection

Differential protection schemes vary according to the type of equipment to be protected, the most common being machine and feeder differential protection. The protection relays. Differ in their compensation methods for typical internal losses in the equipment to be protected, but operates on basically the same principle. The values of current going into and out of the equipment are measured and compared. The relay trips if the difference in Current exceeds a pre-set value, compensating for internal losses in the equipment and CT Inaccuracies. Figure (3.8) and figure (3.9) illustrate the use of a differential protection scheme.

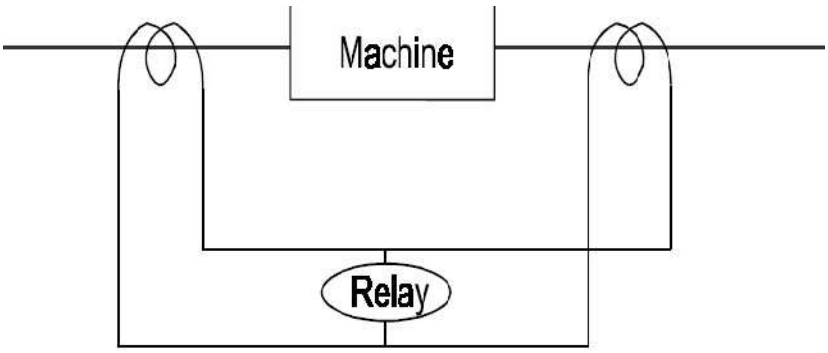

Figure 3.8: Machine Differential Protection

CHAPTER FOUR

TRANSFORMER PROTECTION

4.1 Introduction:

The transformer can be protected by many types of protection schemes, and the following table illustrates these types of protection schemes with their standard functions, abbreviation and AREVA relay used for them.

Table 4.1: Function conversion for transformer protection

Function NO. (ANSI)	Abbreviation	Description	AREVARelay type
87 T	TDP	Transformer Differential protection	MiCOM P633
87 NT	REFP	Restricted earth fault protection	MiCOM P122
50/51 TD	OCPP	Over current protection , phases	MiCOM P127
51/49	SEF	Standby earth fault	MiCOM P122
49	TOLP	Thermal over load protection	MiCOM P123
50 N/51 NS	EFOCP	Earth fault over current protection	MiCOM P127

4.2 Differential Protection (ANSI 87T):

Differential protection is used as main protection for power transformers, it is a fast, selective method of protection against short circuits in transformers.

Differential protection is a practical application of Kirchhoff's current law. The sum of the currents entering the transformer should equal the sum of the currents leaving the transformer.

Differential protection adds the measured currents entering and leaving the transformer to create a differential current [5], this can be illustrated in figure (4.1).

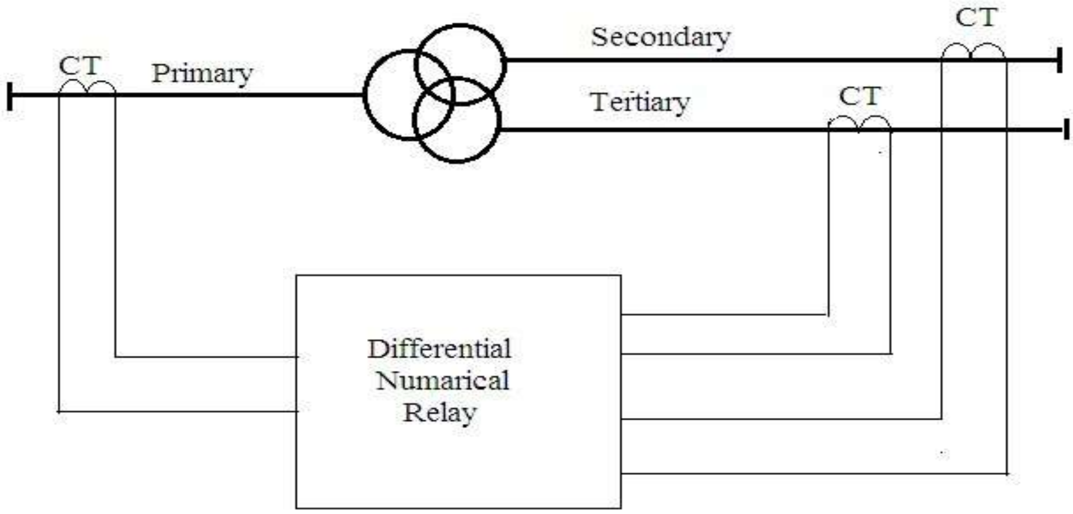

Fig.4.1: Differential protection scheme for three winding transformer

Differential protection provides protection against internal faults such as:

- Phase to phase faults.
- Earth faults.
- Inter turn faults.
- Open circuit fault (in one phase).
- Core fault.
- Tank fault

- **4.2.1 Data of Transformer:**

Table 4.2: Data of power transformer Tap changer range: 8*1.25

Winding	Rated (MVA)	Voltage (KV)	Connection
Primary	150	220	Star
Secondary	150	110	Star
Tertiary	50	33	Delta

4.2.2 Selection of Current Transformer (CTs) ratio

Full load currents in each side of power transformer:

$$I_{\text{full load}} = \frac{MVA \times 10^3}{\sqrt{3} \times KV} \qquad (4.1)$$

Primary current (I)$= \frac{MVA \times 10^3}{\sqrt{3} \times KV}$ =393.65 Amp

Secondary current (I)$= \frac{MVA \times 10^3}{\sqrt{3} \times KV} =$ 787.3 Amp

Tertiary current (I)$= \frac{MVA \times 10^3}{\sqrt{3} \times KV}$ =874.77 Amp

According to above values of currents the suitable CTs ratio are as shown in Table (4.3)

Table 4.3: Current transformer ratios

Transformer Side	Primary	Secondary	Tertiary
CTs Ratio	400/1	800/1	1000/1
Class	30VA,5P30	30VA, 5P30	30VA,5P30
Secondary current of CTs (Amp)	0.984	0.984	0.875

4.3 Over Current Protection (ANSI 50/51):

Over current protection is provided as back up protection for power transformer from faults such as phase faults, through faults and over loading.

4.3.1 Primary Side Directional over Current Protection:

CT and VT data:

Phase CT primary : 1000 Amp

Phase CT secondary: 1 Amp

Class: 30VA, 5P30

Main VT primary : 220kV

Main VT secondary: 110V

Setting Calculation:

i. Phase current setting (I >):

The low set threshold is set to protect the transformer against over loading is set 120% of the rated primary current.

Rated primary current: 393.7 Amp

Over load factor k = 1.2

Setting (I_{OP}) $\geq$ (k ×I I_{FL})/1000 (4.2)

$\geq$ 0.47 Amps

Selection of time characteristic: IEC S Inverse (IEC standard Inverse)

$$T_{op} = \frac{0.14 \times \text{T.M.S}}{\left(\frac{I}{I_S}\right)^{0.02} - 1} \quad (4.3)$$

I_s =1000× T_{op} (4.4)

The T.M.S is set to ensure a tripping time of 10 sec for 2 I_{FL} then :

I=2×I_{FL} (4.5)

=2×393.7=787.4 Amp

$$10 = \frac{0.14 \times T.M.S}{\left(\frac{787.4}{470}\right)^{0.02} - 1}$$

T.M.S= 0.73

ii. Phase current setting stage (I >>):

Selection of time characteristic DT (definite time).The high threshold is set to see the fault only on the primary side of transformer.

(I >>) = 2 Amp

(t >>) = 0.1 sec

iii. Selection of (I >) char angle:

Characteristic angle " I > char angle"

Select: I > char angle = + 45 (this is typical setting for transformer feeder).

4.3.2 Secondary Side Directional over Current Protection:

CT and VT data:

Phase CT primary : 1200 Amp

Phase CT secondary: 1 Amp

Class: 30VA, 5P30

Main VT primary : 110kV

Main VT secondary: 110V

Setting Calculation:

i. Phase current setting (I >):

The low set threshold is set to protect the transformer against over loading is set 120% of the rated secondary current.

Rated secondary current: 787.3 Amp

Over load factor k = 1.2

Setting (I_{OP}) $\geq$ (k × I_{FL})/1200

$\geq$ 0.787 Amps

Selection of time characteristic: IEC S Inverse (IEC standard Inverse)

$$T_{op} = \frac{0.14 \times \mathrm{T.M.}S}{\left(\frac{\mathrm{I}}{\mathrm{I_s}}\right)^{0.02} - 1}$$

Is= 1200×Iop

The T.M.S is set to ensure a tripping time of 10 sec for 2 I_{FL} then :

I=2×I_{FL} =2×787.3=1574.6Amp

T.M.S = 0.734

ii. Selection of (I >) char angle:

Characteristic angle " I > char angle"

Select: I > char angle = +45 (this is typical setting for transformer feeder).

4.3.3 Tertiary side Directional over current protection:

CT and VT data:

Phase CT primary : 1600 Amp

Phase CT secondary: 1 Amp

Class: 30VA, 5P30

Main VT primary : 33kV

Main VT secondary: 110V

Setting Calculation:

Phase current setting (I >)

The low set threshold is set to protect the transformer against over loading is set 120% of the rated Tertiary current.

Rated primary current: 874.8 Amp

Over load factor k = 1.2

Setting (I_{OP}) ≥ (k × I_{FL})/1600

≥ 0.656 Amps

Selection of time characteristic: IEC S Inverse (IEC standard Inverse).

$$T_{op} = \frac{0.14 \times \mathrm{T.M.}S}{\left(\frac{\mathrm{I}}{\mathrm{I_s}}\right)^{0.02} - 1}$$

Where

Is = 1600×Iop

The T.M.S is set to ensure a tripping time of 10 sec for $2I_{FL}$ then :

$I = 2 \times I_{FL} = 2 \times 874.8 = 1749.6$Amp

$$10 = \frac{0.14 \times \mathrm{T.M.}S}{\left(\frac{1749.6}{1049.6}\right)^{0.02} - 1}$$

T.M.S=0.73

4.4 Restricted Earth Fault Protection (ANSI 87NT):

The degree of earth fault protection is very much improved by the application of unit differential or restricted earth fault systems. Restricted Earth Fault (REF) protection is basically a differential Protection. The only difference in between the differential Protection and REF Protection is that, latter protection is more sensitive as compared to the former protection scheme [21].

4.4.1 Primary Side Restricted Earth Fault Protection:

i. General Data

- Line CT parameters

  Ratio: 1000/1 Amp

Class: 30VA, 5P30

- NeutralCTparameters

  Ratio: 1000/1 Amp

Class: 20VA, 5P30

- Load length for the neutral CTs

  From neutral CT to relay panel = 180 m

Table 4.4: Lead resistance and CT resistance 0.4 sq mm cable max resistance /km = 4.4 ohm.

Length(m)	Resistance (Ω)	CT (Ω)	Parameters
180	0.79	-	D
-	-	5	N

ii. Relay Setting Calculations

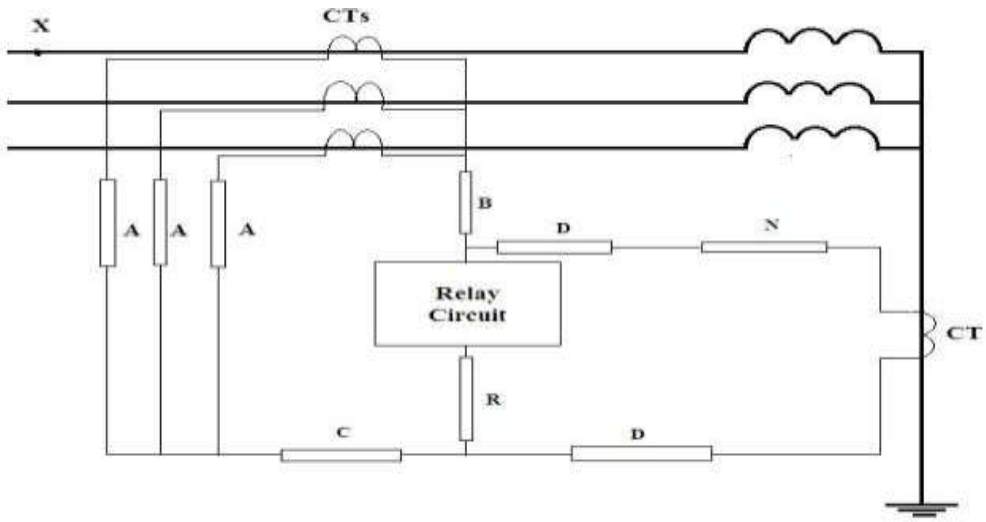

Fig. 4.2: Restricted Earth Fault Protection (High Impedance Principle) for primary side

Let:

T = turn ratio of line and neutral current transformer.

B, C, D = resistance of wiring.

A = resistance of wiring plus CT winding.

N = neutral CT resistance plus resistance of wiring.

V = relay circuit setting voltage.

I = relay circuit current at V volts.

I_f = fault current corresponding to rated stability limit.

$$I_F = I_f \times T \tag{4.6}$$

a. Rated Stability

Rated primary current $= \frac{150000}{\sqrt{3}\times 220}$ =393.7 Amp

For stability limit the maximum through fault current should be considered. An estimation of the maximum three phase fault current can be estimated by ignoring source impedance.

$$I_F = \frac{\text{primary full load currnet}}{\text{transformer \%impedance}} \tag{4.7}$$

$$= \frac{393.7}{0.133} = 2960 \text{ Amp}$$

Secondary fault current =2.96KA

b. Rated Stability Limit:

Consider a phase to earth short circuit at X point and assume complete saturation of the neutral CT, then shall be not less than :

I × (N+2D) volts. (4.8)

Where,

N = 5 Ω, D = 0.79 Ω

For phase to earth short circuit at X and assume neutral CT saturation using following, then V

V≥I × (N+2D) = 2.96× (5+2×0.79) = 19 volts

C. Current Setting and Fault Setting Resistor Calculation

- Relay Data

Recommended primary fault setting is between 10-60% of HV current. Let us consider 40% of HV current = 0.40×393.7 = 157.48 Amp

$$I_S = \frac{\text{primary fault setting}}{\text{CT ratio}} \quad (4.9)$$

= 157.48/1000 = 0.158

∴ Is = 0.16 Amp

- Establishing the Value of Setting Resistance

Resistor value R is given by:-

$R_S = V_S/I_S$ (4.10)

= 19/.158 = 119 Ω

Let us consider Rs = 120 Ω

iii. Setting

Restricted earth fault setting HV, = 0.16 Amp

Stabilizing resistance value = 120 Ω

4.4.2 Secondary Side Restricted Earth Fault Protection:

i. General Data

- Line CT parameters

Ratio: 1000/1 Amp

Class: 30VA, 5P30

- Neutral CT parameters

Ratio: 1000/1 Amp

Class: 20VA, 5P30

- Load length for the neutral CTs
- From neutral CT to relay panel = 180 m By using data from table 4.

ii. Relay Setting Calculations:

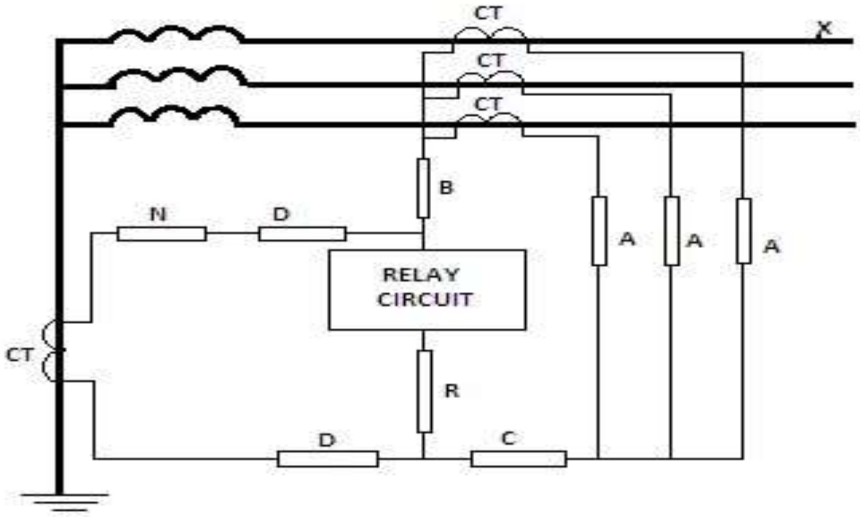

Fig.4.3: Restricted Earth Fault Protection (High Impedance Principle) for secondary side

Let:

T = turn ratio of line and neutral current transformer.

B, C, D = resistance of wiring.

A = resistance of wiring plus CT winding.

N = neutral CT resistance plus resistance of wiring.

V = relay circuit setting voltage.

I = relay circuit current at volts.

I = fault current corresponding to rated stability limit.

$I_F = I_f \times T$

a. Rated Stability:

Rated primary current $= \frac{150000}{\sqrt{3}\times 110} =$787.3 Amp

We assume maximum through fault current is 10000 Amp

Secondary full load current = 787.3/1000 = 0.7873

I_F =0.7873/0.133 = 5.92 Amp.

b. Rated Stability Limit:

Consider a phase to earth short circuit at X point and assume complete saturation of the neutral CT, then shall be not less than If× (N+2D) volts.

Where,

N = 5 Ω, D = 0.79 Ω

For phase to earth short circuit at X and assume neutral CT saturation using following, then Vs

$V_s \geq I \times (N+2D) = 10\times(5+2\times0.79) = 65.5$ volts

c. Current Setting and Fault Setting Resistor Calculation:

- Relay Data:

Recommended secondary fault setting is between 10-6 0% of MV current. Let us consider 40% of HV current=0.40 × 787.3 = 314.9 Amp

Is =314.9/1000 = 0.315

∴ Is = 0.32 Amp

- Establishing the value of setting Resistor value R is given by:

Resistor value R is given by:-

$R_S = V_S/I_S$

$= 65.5/0.315 = 208\ \Omega$

Let us consider R = 200 Ω

iii. Setting:

Restricted earth fault setting MV, >= 0.32 Amp

Stabilizing resistance value = 200 Ω

4.5 Earth Fault Protection:

Earth fault protection setting as below:

i. Selection of current threshold "I >”:

The low set (I_N >) threshold is used as back up of the restricted earth fault (REF) protection.

Setting $I_{OP} \geq 0.1 I_N$ (4.11)

ii. Selection of the time characteristic (>1) :

Selection of time characteristic: IEC S Inverse (IEC standard inverse)

Selection of direction: Direction forward.

$$T_{op} = TMS \times \frac{K}{(\frac{I}{n \times I_{op}})^{\alpha} - 1} \quad (4.12)$$

TMS=0.7

iii. Phase current setting stage (I >>):

Selection of time characteristic DT (definite time)

Selection of direction: Direction forward.

The high threshold is set to see the fault only on the primary side of transformer.

I>> = 2 Amp

t>> = 0.1 sec

iv. Selection of (I>) char angle:

Characteristic angle "IN> char angle"

Select: I> char angle = -45(this is typical setting for solidly earthed distribution system)

V. setting:

Phase over current (I>), (I>) =0.9 Amp

T.M.S = 0.71 characteristic angle = + 45

E/F (I>), (I>) =0.25 Amp T.M.S = 0.71

E/F (I>>), (I>>) =2 Amp

Time delay, (I>>) = 0.1 sec

Characteristic angle = -45

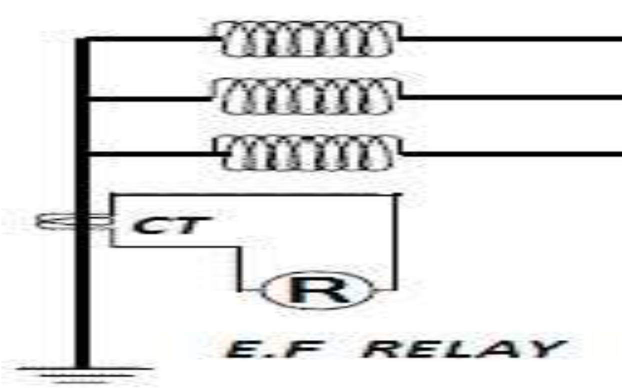

Fig. 4.4: Earth fault relay connection

4.6 Standby Earth Fault Protection (ANSI 51/49)

Standby earth fault protection operates after all the other earth fault protection schemes fail to operate.

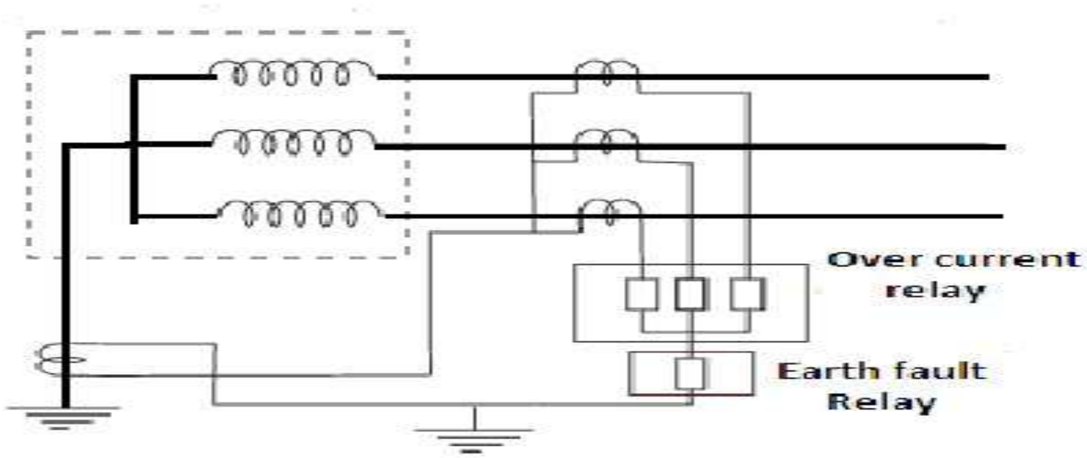

Fig. 4.5: Standby Earth Fault Protection connection

4.6.1 Standby Earth Fault Protection for Primary Side:

i. CT data

Ratio: 400/1 Amp

Class: 20VA, 5P20.

ii. Setting calculation

- standby earth fault

The standby earth fault shall be set in order to detect the lowest current available. The fault current could nominally be set to 10-30% of relay setting.

The current to be protected = 20% of 393.7 Amp = 0.2 ×393.7=78.74 Amp

Current setting = 78.74/400 = 0.2 Amp

- Selection of time characteristic

Definite time (DT), Time delay = 10 sec

iii. Setting

- standby earth fault setting HV side   I ≥ 0.2 Amp
- Time delay = 10 sec

4.6.2 Standby earth fault protection for Secondary side:

i. CT data

Ratio: 600/1 Amp

Class: 20VA, 5P20

ii. Setting calculation

- standby earth fault

The standby earth fault shall be set in order to detect the lowest current available. The fault current could nominally be set to 10-30% of relay setting.

The current to be protected = 20% of 787.3 Amp = 0.2 ×787.3=157.46 Amp

Current setting = 157.46/600 = 0.26 Amp

- Selection of time characteristic

Definite time (DT) Time delay = 10 sec

iii. Setting

- standby earth fault setting HV side $I_{op} \geq 0.26$ Amp
- Time delay = 10 sec

4.6.3 Standby Earth Fault Protection for Tertiary Side:

i. CT data

Ratio: 300/1 Amp

Class: 20VA, 5P20

ii. Setting calculation

- standby earth fault

The standby earth fault shall be set in order to detect the lowest current available. The fault current could nominally be set to 1030% of relay setting.

The current to be protected = 20% of 874.77 Amp

= 0.2 ×874.77=174.95 Amp

Current setting = 174.95/300= 0.58 Amp

- Selection of time characteristic

Definite time (DT), Time delay = 10 sec

iii. Setting

- standby earth fault setting HV side $I_{OP} \geq 0.58$ Amp
- Time delay = 10 sec

4.7 Thermal Overload Protection (ANSI 49):

Thermal overload protection operate in principle of thermal replica method. Only have two operating stages. This method has two operating stags, one stage is typically used for alarming, set at the temperature level equating to 80% to 90% of the maximum current load. The other stage is a final trip stage, set at the maximum allowable operating temperature as shown in flowchart in fig 4.6 [6].

Setting Calculations:

$I_{full\ load}$ = 393.65 Amp at 220KV

I_{MAX} = 512 Amp 130% of full load current

T_{Oil} = 5 minutes a typical value for hot-spot based on size/cooling

Alarm stage = 80%

Trip stage = 100% maximum overload value

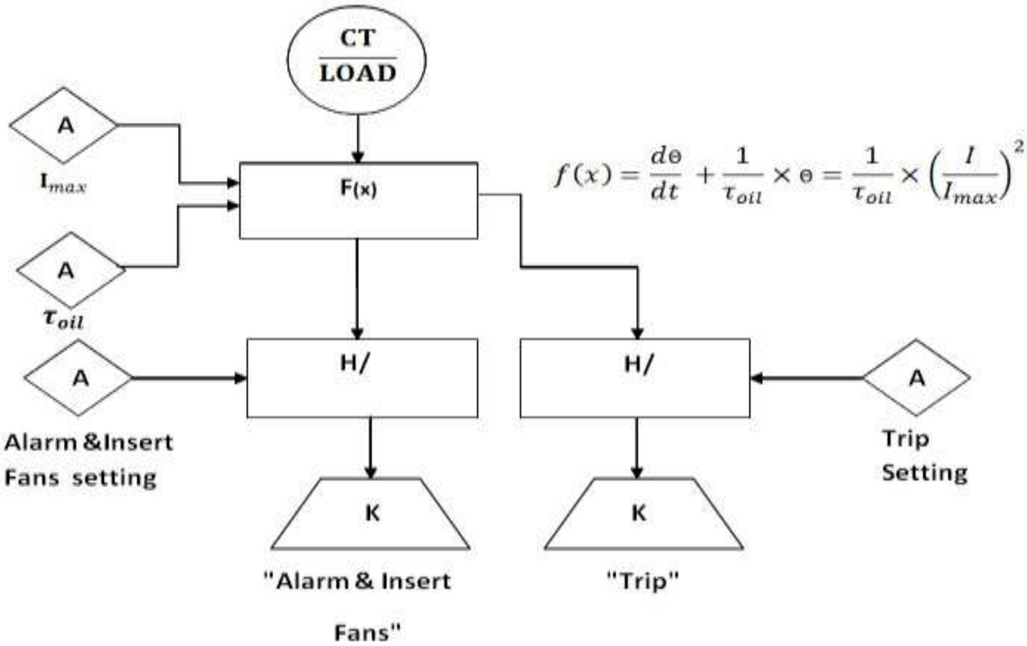

Fig. 4.6: Flow chart of thermal overload protection operation

4.8 Buchholoz Protection

On the occurrence of internal fault in oil immersed power transformer Gas is usually generated slowly for an incipient fault and violently for heavy faults. Most short circuit caused either by impulse breakdown be tween adjacent turns at the end turn of the winding or as a poor initial point contact which will immediately heat to arcing temperature . Buchloz protection employing buchloz relay is the simplest form of Protection and is most commonly used on all oil immersed transformer.

4.9 Over flux protection

Transformer overflux protection is provided to protect the transformer core from overfluxing. A Transformer is designed to operate at a particular flux level. In case the flux the core of transformer exceeds a certain level th core Increases which may lead to overheating of components which in turn may Result into internal fault.

4.10 Breather unit

Silca gel crystal has tremendous capacity of absorbing moisture .when air passes through these crystal in the breather the moisture of the air is absorbed by them. Therefore, the air reaches to conservator is quite dry the dust particles in the air get trapped by the oil in the oil seal cup.

4.11Simulink for phase two protection

Figure bellow shows a screenshot had been taken from the Simulink of

Bahri Station phase two protection system by using E-Tap application.

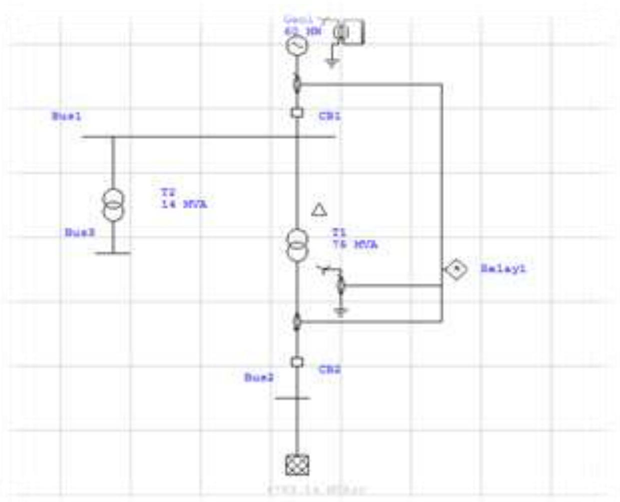

Figure 5.3: Phase two protection system simulink

T1: Main transformer

T2: Auxiliary Transformer

CB1: Circuit Braker number 1

CB2: Circuit Braker number 2

GEN1: Main Generator

U2: Transmition line network

R: Numerical Relay

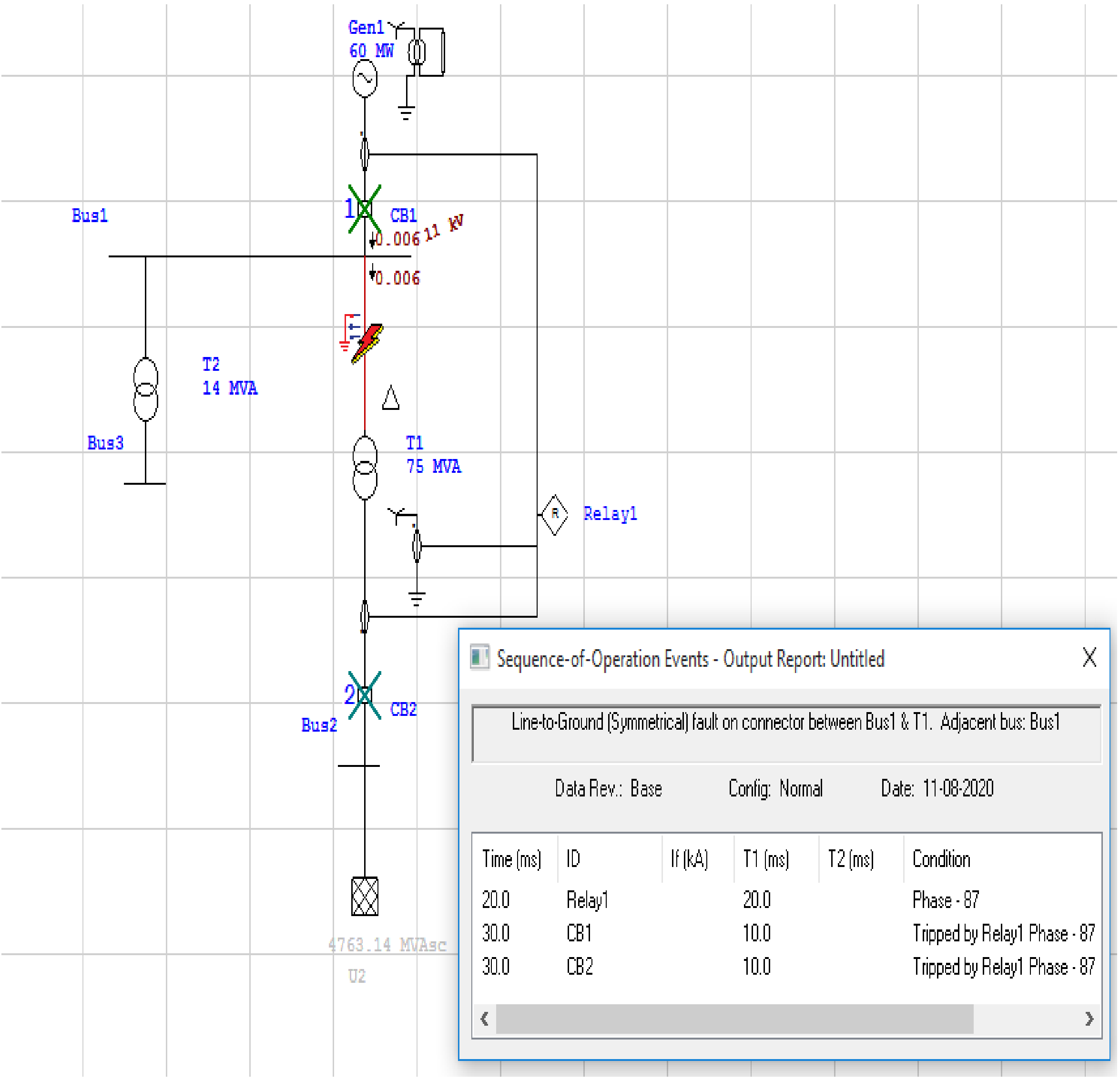

Figure.5.4: Fault 1 at differential zone

87: Differential protection tripped

When fault happens at deferential protection zone (inside transformer) the numerical relay sends a signal to the two circuit breakers to open the circuit at each side of generator and transmission line network sections.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The project objectives have been achieved where the 220kV/110kV transformer has been protected by using numerical relays. They are the latest development in the area of protection, which are based on microprocessors. The multi-function numerical relays provide better protection, high reliability, troubleshooting and recording the fault information.

Depending on the types of the transformers, windings connections, earthing methods, and other factors, the following schemes i.e., differential protection, over current protection, earth fault protection, restricted earth fault protection, standby earth fault protection and thermal overload protection were used to provide full protection of the transformers.

5.2 Recommendations

- Python programming method represents a good tool for developing and improving power transformer protection.
- There are many types of faults which must be aware of it when design a new power transformer protection scheme

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APPENDIX

Appendix A

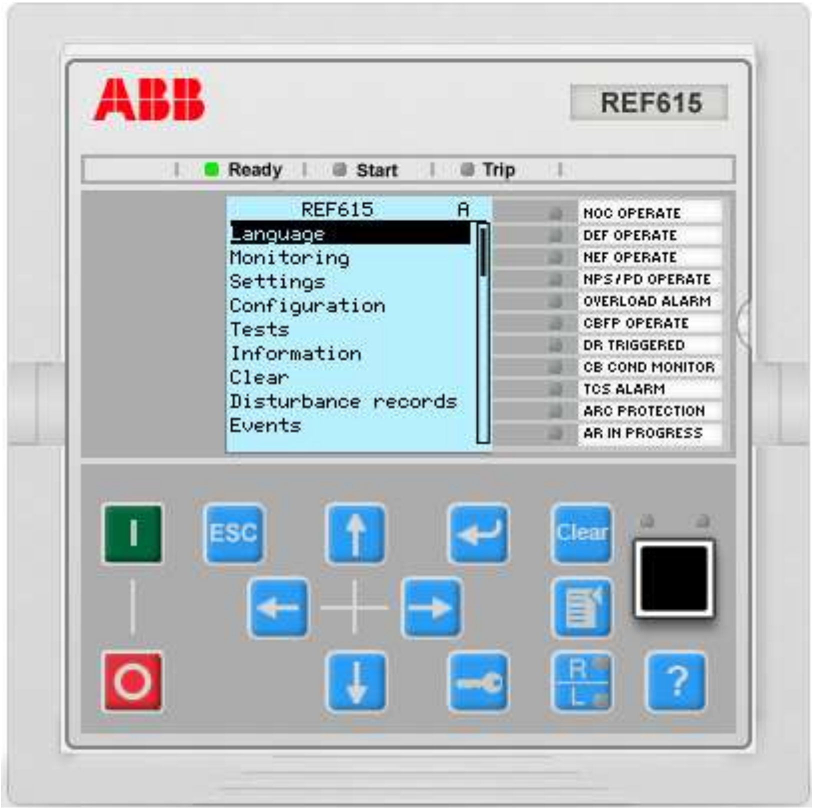

Figure 5.1 Main menu of relay

The figure 5.1 shows the main menu of relay which include:

1. Language of system.
2. Monitoring.
3. Settings.
4. Configuration.
5. Tests.
6. Information.
7. Clear.
8. Disturbance recorder.
9. Events.
10. Measurement.

And figure bellow shows 615 series panel HMI.

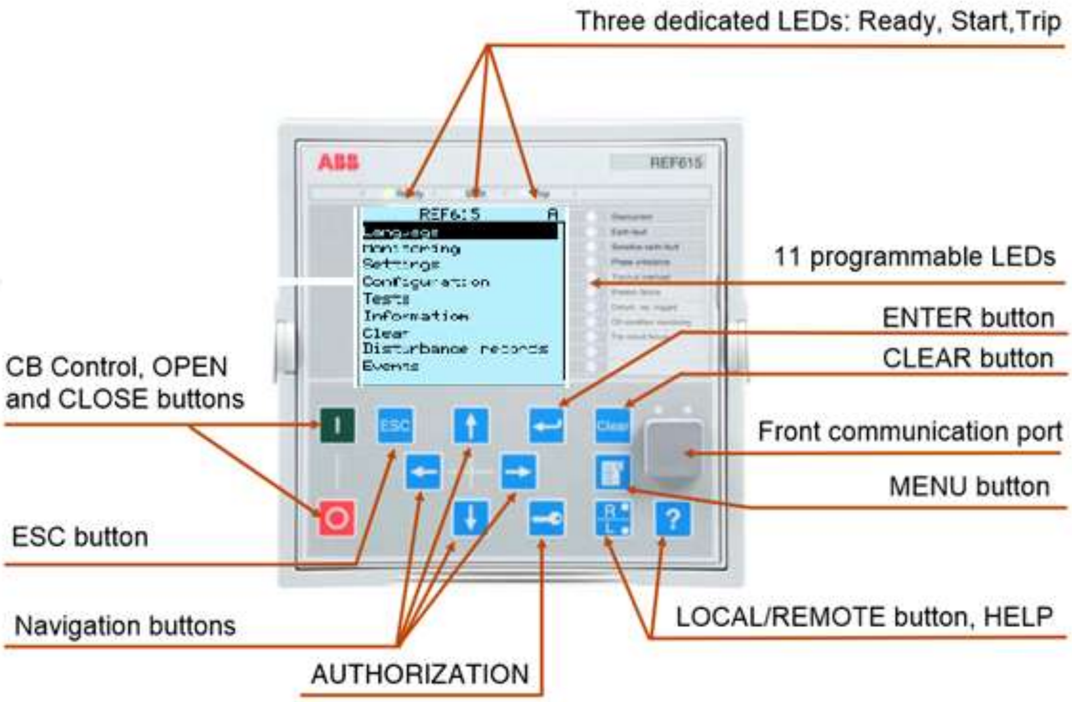

Figure 5.2- 615 series panel HMI.