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College of Engineering

Electrical Engineering Department

Advanced Protections System of Substation using Numerical Relays

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

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الايـــــــــة

قَالَ تَعَالَىٰ:

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سورة الفاتحة

الإهداء

إلى قدوتي في حياتي

و من أتمنى مرافقته في الفردوس الأعلى

(محمد بن عبدالله صلى الله عليه و سلم**)**

إلى ... من علمانى بأن النشاط صفة الحياه

وأن الخمـــــــول صــــــــــــــفة الموت

إلى ... ذلك النهر الـــــــجارى المـــــــــتدفق

أملاً وتفـــــــــاؤلاً إلـــــــــــــيكما

أمى

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أبى

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إلى ... الشـــــــــــــــموع التى إحترقت لتـــــــــنير لى الدرب أساتذتي الأجلاء

إلــــــــى رفقاء درب المعرفة

زملائي

وإلـــــي كل باحث في درب العلم والمعرفة

نهدي هذا البحث المتواضع

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Abstract

The electrical power substations are important part of the electrical power system, if any fault occur in them it may lead to large damage of equipments and components of substation , also cut the supply of the consumers and perhaps lead to black out. For importance of substation and seriousness of the faults which occur in them, advanced protection systems are applied using numerical relays which have ability to deal with the different types of faults and isolate the faulted parts as fast as possible with high sensitivity in order to secure the continuity of supply and maintain the system stability.

In this project full protection is provided to transformer and bus-bar using advanced numerical relays from different types of faults which may occur on them.

المستخلص

المحطات التحويلية تمثل جزء مهم من اجزاء منظومة القوى الكهربائية , وفي حالة تعرضها لاي عطل قد يؤدي الي اتلاف معدات و مكونات المحطة و قطع الامداد لجزء كبير من المستهلكين و ربما يؤدي الاظلام التام.نسبة لاهمية المحطات التحويلية وخطورة الاعطال التي قد تحدث فيها تم استخدام انظمة حماية متطورة كمرحلات العددية والتي يمكنها التعامل مع مختلف انواع الاعطال الممكن وعزلها في اقل زمن ممكن وحساسية عالية . من اجل استمرار الامداد والمحافظة علي استقرارية المنظومة.

وفي هذا المشروع قد تم حماية المحولات و القضبان العمومية من كافة انواع الاعطال باستخدام احدث المرحلات العددية.

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List of Abbreviations

CT	Current Transformer
VT	Voltage Transformer
IEEE	Institute of Electrical and Electronic Engineering
IEC	International Electrotechnical 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

1.1 Background

The modern power systems which have grown both in size and complexity require fast accurate and reliable protective schemes to protect major equipment and to maintain the system stability [1].

Power system protection is a branch of electrical power engineering that deals with the protection of electrical power systems from faults through the isolation of faulted parts from the rest of the electrical network . The objective of a protection scheme is to keep the power system stable by isolating only the components that are under fault, whilst leaving as much of the network as possible still in operation [2]. Thus, protection schemes must apply with very pragmatic and pessimistic approach to clearing system faults. The devices that are used to protect the power systems from faults are called protection devices, The function of protective devices is not the preventive one its name would imply, in that it takes action only after a fault has occurred [3].

Protection schemes required for the protection of power system component against abnormal condition such as faults etc. Essentially consist of protective relaying and circuit breaker. protective relay functions as sensing device it senses the fault then determines it's location and finally, It send tripping command to the circuit breaker. The circuit breaker after getting the command from the protective relay, disconnects the faulted element [4] .

Optimization of the protection operation plays very high role to assure high reliability of electrical power system. The protection of substation is an important part of power system protection to continuity of supply and successful operation [5].

1.2 Problem Statement

The previous protective relays are electromechanical, static, and digital. They suffer from many drawbacks such as

i. The electromechanical relays need high burden of instrument transformers, high operating time, and contact problems.
ii. The static relays are inflexibility, inadaptability to changing the system conditions and complexity.
iii. The digital relays have not communication capability.

1.3 Objectives

i. Increase the sensitivity of protection system.
ii. Increase the speed and accuracy of protection system.
iii. Using advanced protection features in one box.
iv. Minimize the size of the protective relay.
v. Obtain full information about the faults.
vi. Reduce the burden of instruments transformers.

1.4 Methodology

Several stages were taken in order to ensure that the desired objectives of the project were achieved. The first stage of this project; necessary data of AL_mahdia substation was obtained. The second stage; CTs and VTs ratio were selected, and then the setting was calculated according to IEEE and IEC standards.

the third stage; numeric relays from Schneider which offers the last version of numerical relays in the field of protection were used in order to obtain full and advanced protection of the substation, the substation consist of transformers, bus bars, and switchgears.

1.5 Motivation

The protection of electrical grids is regarded the most interesting part of all power system studying, it is really the most important, comprehensiveness and impressiveness at the same time. The most important because if any fault in electrical power system did not detect as fast as possible, can lead to damage of a large parts of power system.

The most comprehensiveness because of any study of topics of power system protection needs to full knowledge about all others branches of electrical power system. The most impressiveness because of faults which occur in electrical power system are several, various, rescaled at the same time , and every fault has different situation.

1.6 Project Layout

This project consist of five chapters as follows: Chapter one is introduction including the background about electrical protection system, problem statement, objectives, methodology, motivation and project layout; while chapter two is literature review about relay technology improvement, protective device operation, protection of power transformer, protection of bus bar and switchgear protection; chapter three is power transformer protection and setting calculations. Chapter four is bus bar and switchgear protection and setting calculations. Chapter five is conclusion and recommendations .

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The protective relay is an electrical device designed to initiate isolation of a part of an electrical installation, or to operate an alarm signal, in the event of an abnormal condition or a fault. All the relays employed for protection against faults operate by virtue of the current and / or voltage by supplied to them by CTs or VTs. Failures in the system are indicated by the individual or relative changes in the currents or voltages supplied to the protective relaying equipment [4].

In the last thirty years enormous changes had been occurred in relay technology. The electromechanical relay in all of its different forms has been replaced successively by static, digital, and numerical relay, each hang brought with its reductions in size and improvements in functionality. At the same time, reliability levels had been maintained or even improved and availability significantly increased due to techniques not available with older relay types. This represents a tremendous achievement for all those involved in relay design and manufacture [6].

2.2 Electromechanical Relays

Those relays were the earliest forms of relay used for protection of electrical power systems, and their date back nearly 100 years [6]. In the most of electromechanical relays either electromagnetic attraction or electromagnetic induction principles are used for their operation [7]. 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 the 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 [6].

Electromechanical relays can be classified into several different types as follows :

i. Attracted armature type.
ii. Moving coil type.
iii. Induction type.
iv. Thermal type.
v. Motor operated type.
vi. Mechanical type.

2.3 Static Relays

Static relay (solid state relay) is an electrical device in which the response is developed by electronic, magnetic, optical or other components, without mechanical motion of component. Introduction of static relay 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 [4,6,8].

Early versions used discrete devices such as transistors and diodes in conjunction with resistors, capacitors, inductors, etc., they 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. A number of design problems had to be solved in static relays. In particular, the relays generally require a reliable source of D.C power and measures to prevent damage to vulnerable electric circuits had to be devised [6].

2.4 Digital Relays

Digital protection relays introduced a step change in technology. Microprocessor and microcontrollers replaced analogue circuits used in static relays to implement relay functions. Early examples began to be introduced in service around 1980, and, with improvement 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 introduced A/D conversion of all measured analogue quantities and use a microprocessor to implement the protection algorithm. The microprocessor may use some kind of counting technique, or use the discrete Fourier transform (DFT) to implement the algorithm. 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 communication link to a remote computer may also be provided.

The limited power of the microprocessor used in digital relays restricts the number of samples of the waveform that can be measured per cycle. Thus, in turn, limits the speed of operation of the relay in certain application. Therefore, a digital relay for a particular protection function may have a longer operation time than the static relay equivalent [6].

2.5 Numerical Relays

The numerical relay is the latest development in the area of power system protection and differs from conventional ones both in design and methods of operation. it has been developed because of tremendous advancement in VLSI and computer hardware technology. It was based on numerical devices e.g. microprocessors microcontroller digital signal processors(DSPs) this relay acquires sequential samples of the AC quantities in numeric data from through the data acquisition system (DAS). And processes the data numerically using a relaying algorithm to calculate the fault discriminates and make trip decisions [1].

In a numerical relay, the analog current and voltage signals monitored through primary transformer (CTs) and (VTs) are conditioned, sampled at specified instants of time and converted to digital from for numerical manipulation, analysis, display and recording. this process provides a flexible and very reliable relaying function, thereby enabling the same basic hardware unit to be used for almost any kind of relaying scheme. thus a numerical relay has an additional entity, the software, which runs in the background and makes the relay functional [1].

Hardware is more or less the same in almost all the numerical relays. the software used in a numerical relay depends upon the processor used and the type of the relay. hence, with the advent of the numerical relay, the emphasis has shifted from hardware to software. the evolution of the modern numerical relay has thus taken place from a torque balancing device to a programmable information processor[1].

The distinction between digital and numerical relay rests on points of fine technical detail, and is rarely found in areas other than protection. They can be viewed in 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 [6].

2.5.1 DSP Based Block Diagram of A numerical Relay

The levels of voltage and current signals of the power system are reduced by voltage and current transformers (VT and CT). The outputs of the CT and VT (transducers are applied to the signal conditioner which brings real-world signals into digitizer. The signal conditioner electrically isolates the relay from the power system, reduces the level of the input voltage, converts current to equivalent voltage and removes high frequency components from the signals using analog filters.

The output of the signal conditioner are applied to the analog interface, which includes sample and hold (S/H) circuits, analog multiplexer and analog-to-digital (A/D) converters. These components sample the reduced level signals and convert their analog levels to equivalent numbers that are stored in memory for processing. The signal conditioner and the analog interface (i.e., S/H CKt, analog multiplexer and A/D converter) constitute the data acquisition system (DAS).The acquired signals in the form of discrete numbers are processed by a numerical relaying algorithm to calculate the fault discriminates and make trip decisions. If there is a fault within the defined protective zone, a trip signal is issued to the circuit breaker [9].

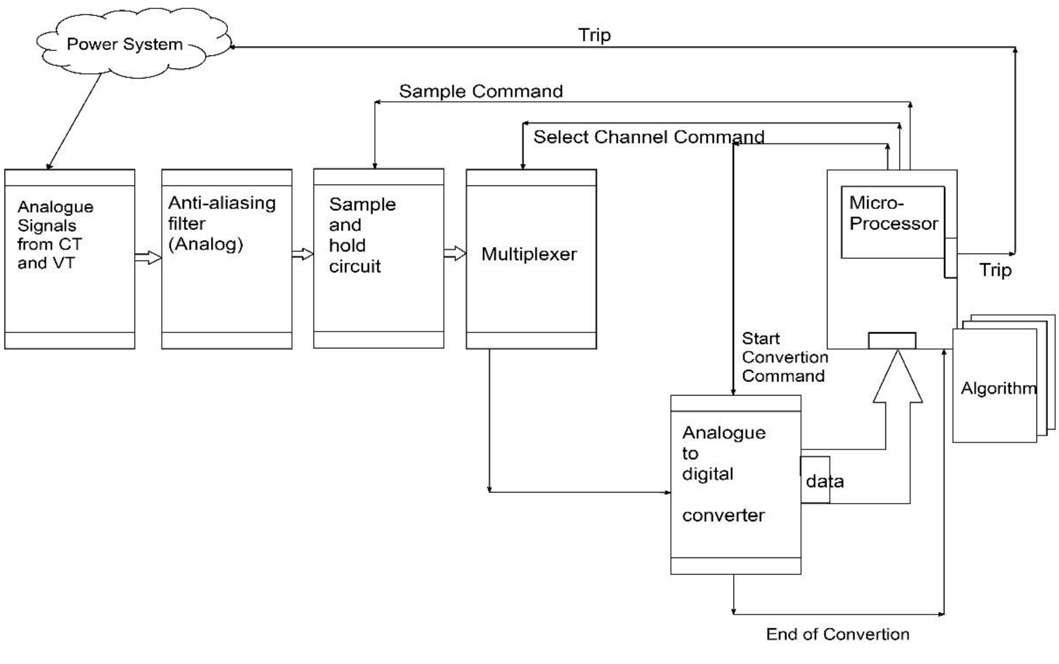

Fig. 2.1: DSP based block diagram of a numerical relay

i. Anti-aliasing Filter:

Input analogue signals contain not only fundamental and DC component, but also contain higher frequency and oscillatory unwanted components which affect the accuracy of microprocessor based on relay operation. By means of low-pass analogue filtering, unwanted oscillatory component can be omitted. This preferred done by analogue and not by digital filter the high frequency of the oscillatory components bring incorrect doing to the digital filtering.

ii. Input Analogue Signals Sampling:

The sampling and hold(S/H) devices are used to sample analogue input signals(i.e., currents or voltages). Each sample is measured by at instant defined by a clock. Number of samples per cycles determined by the sampling frequency.

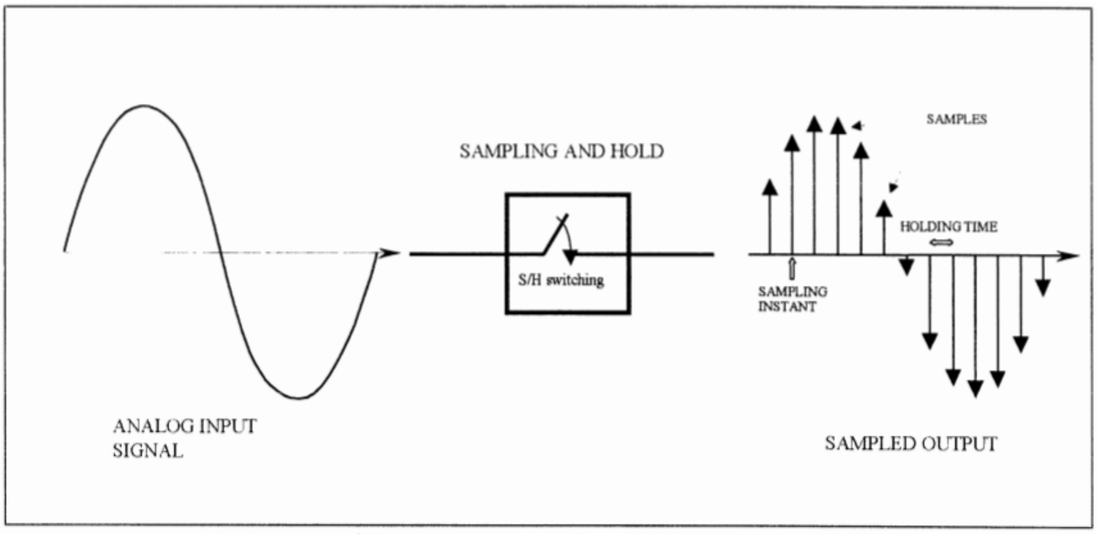

Fig. 2.2: Input analogue signals sampling

iii. Analogue to Digital Converter (A/D):

Analogue to digital converter (A/D) converts an analogue voltage and/or current level to its digital representation. And basically it converts an analogue signal to a binary number.

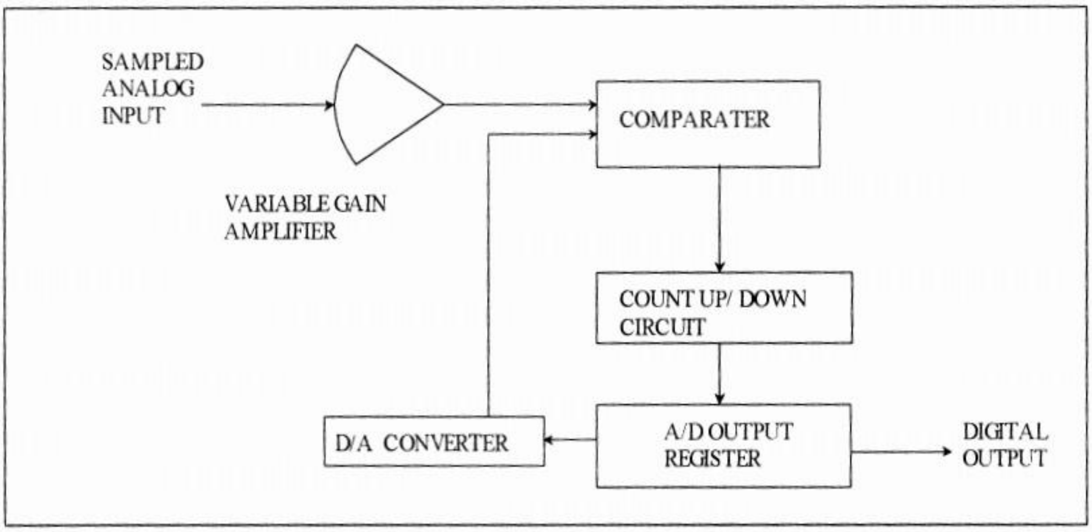

Fig. 2.3: Analogue to digital converter(A/D)

iv. Algorithm:

The term algorithm refers mainly to measuring. Digital algorithm can be extracted with aid of will known filtering techniques. Digital techniques requires a substantial processing power, since high resolution and time consuming operations are to be performed [10].

2.5.2 Relay Software

The software provided is commonly organized into a series of tasks, operating in real time. An essential component is the Real Time Operating System (RTOS), whose function is to ensure that the other tasks are executed as and when required, on a priority basis [6,9].

2.6 Protective Device Operation

The protective device usually consist of elements that are arranged to test the system condition, make decisions regarding the normality of observed variables, and make action as required. The philosophy of operation protective device can be illustrated in figure below.

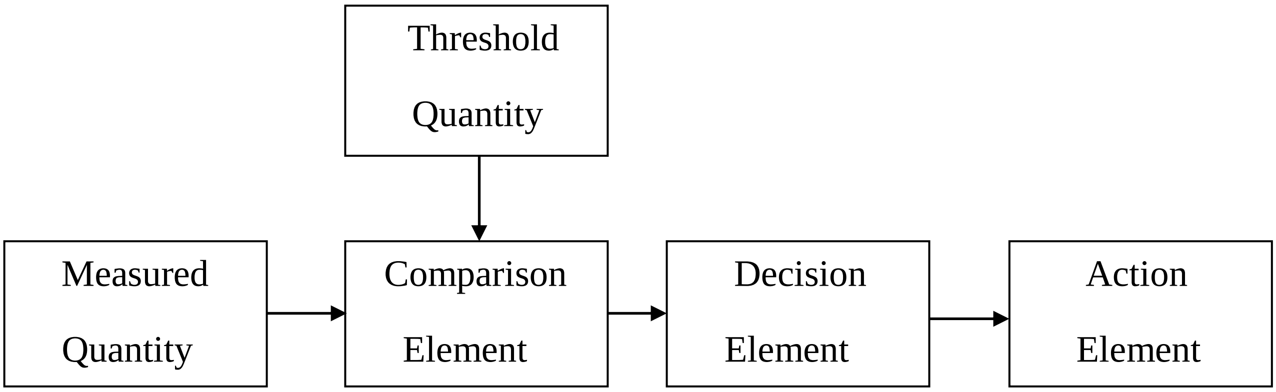

Fig. 2.4: Protective Device Operation

The protective system measures certain system quantities, such as voltages and currents, and compares the system quantities, or some combination of these quantities, against a threshold setting that is computed by the protection engineer and is set into the device. If this comparison indicate alert condition, a decision element is triggered. this may involve timing element, to determine the permanence of the condition, and may require other checks on the system at other points in the network. Finally, if all checks are satisfied, an action element is released to operate, which means that circuit breakers are instructed to open and isolate a section of network.

The time required to take any necessary corrective action is called the clearing time and is defined as follows:

$$\mathbf{T}\mathbf{c} = \mathbf{T}\mathrm{p} + \mathbf{T}\mathrm{d} + \mathbf{T}\mathrm{a} \qquad (2.1)$$

Where

Tc = clearing time

Tp = comparison time

Td = decision time

Ta = action time, including circuit breaker operating time.

The clearing time is very important since other protection system in the network may be time- coordinated with this protective device in order to ensure that only the necessary portions of the network are interrupted. The clearing time is also important because some disturbances such as short circuits, must be cleared promptly in order to preserve system stability [11].

2.7 Protection of Power Transformer

There are different kinds of transformers such as two winding or three winding electrical power transformers, auto transformer, regulating transformers, earthing transformers, rectifier transformers etc. Different transformers demand different schemes of transformer protection depending upon their importance, winding connections, earthing methods and mode of operation etc [12].

It is common practice to provide Buchholz relay protection to all 0.5 MVA and above transformers. While for all small size distribution transformers, only high voltage fuses are used as main protective device. For all larger rated and important distribution transformers, over current protection along with restricted earth fault protection is applied. Differential protection should be provided in the transformers rated above 5 MVA . Depending upon the normal service condition, nature of transformer faults, degree of sustained over load, scheme of tap changing, and many other factors, the suitable transformer protection schemes are chosen [12].

2.7.1 Transformer Magnetizing Characteristics

When a transformer is energized, it follows the classic magnetization curve For efficiency reasons transformers are generally operated near to the ‘knee-point’ of the magnetic characteristic. Any increase above the rated terminal voltage tends to cause core saturation and therefore demands an excessive increase in magnetization current [13].

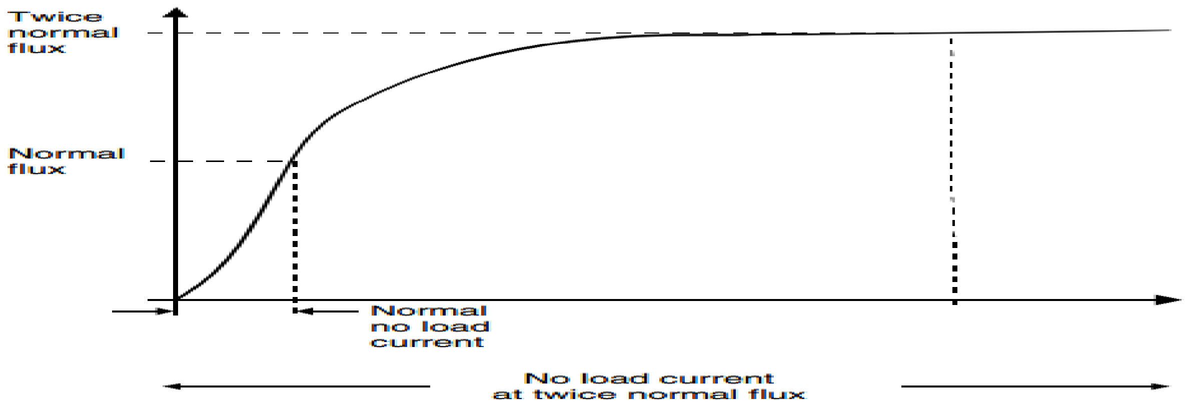

Fig. 2.5: Transformer magnetizing characteristics

2.7.1.1 Steady State Magnetizing Currents

The steady state magnetic flux in the core is proportional to the ratio of the voltage and frequency applied to the power transformer winding, as shown by the following equation [14].

$$\Phi = C.\ U/F \qquad (2.2)$$

where:

Φ - is the magnetic flux in the core;

C - is a constant dependent on the particular power transformer construction details;

U - is the voltage; and

F -is the frequency of the voltage signal.

2.7.1.2 Transient Magnetizing Currents

Transient magnetizing currents will appear every time the magnitude or phase angle of the voltage, applied to the power transformer, is suddenly changed. Transient magnetizing currents can have quite a big magnitude 300% and can cause unwanted operation of the protection relays [14]. This transient current is generally termed inrush current and is typically caused by:

i. Initial energization of the power transformer (initial inrush)
ii. Voltage recovery after the clearing of an external, heavy short Circuit in the surrounding power system (recovery inrush)

iii. Energization of another, parallel power transformer(sympathetic inrush)
iv. Out-of–phase synchronization of a generator-transformer block with the rest of the power system.

2.7.2 Inrush Current

Under normal steady-state conditions, the magnetizing current required to produce the necessary flux is relatively small, usually less than 1% of full load current

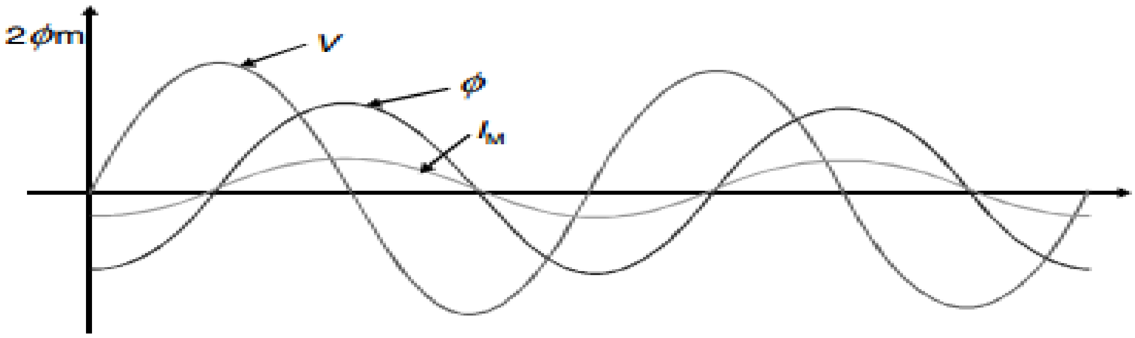

Fig. 2.6: Steady-state conditions

if the transformer is energized at a voltage zero then the flux demand during the first half voltage cycle can be as high as twice the normal maximum flux. This causes an excessive unidirectional current to flow, referred to as the magnetizing inrush current as shown.

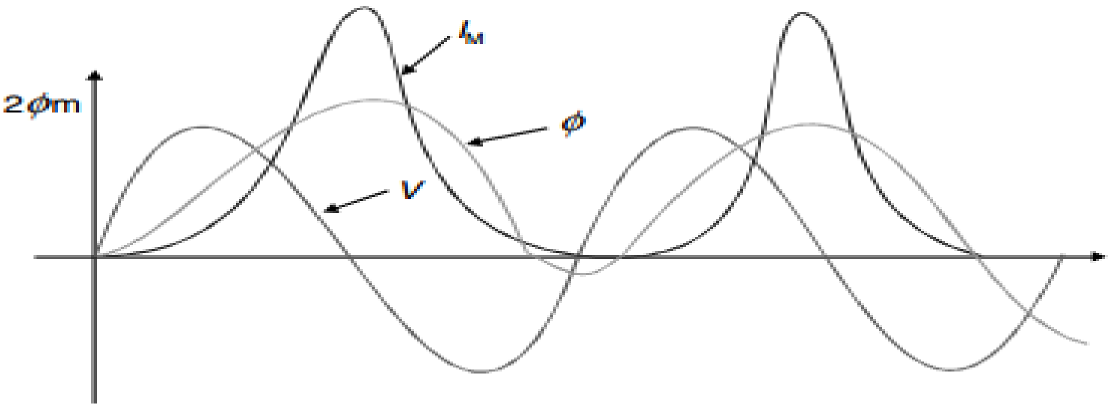

Fig. 2.7: Illustration of magnetizing in-rush current

An analysis of this waveform will show that it contains a high proportion of second harmonic and will last for several cycles. Residual flux can increase the current still further, the peak value attained being of the order of 2.8 times the normal value if there is 80% reminisce present at switch-on. As the magnetizing characteristic is non-linear, the envelope of this transient in-rush current is not strictly exponential. In some cases, it has been observed to be still changing up to 30 min after switching. It is therefore important to be aware of this transient phenomenon when considering differential protection of transformers [13].

2.7.2.1 Inrush Current Calculation

The simplified equation often used to calculate the peak value of the first cycle of the inrush current is given by:

$$I_{pk} = \frac{\sqrt{2} \times U}{\sqrt{(\omega \times L)^2 + R^2}} \times \left(\frac{2 \times B_N + B_R - B_S}{B_N} \right) \tag{2.3}$$

where,

Ipk - Peak inrush current in [Primary Amperes];

U - Applied voltage in [Volts];

L - Air core inductance of the energized winding in[Henry];

R - Total DC resistance of the transformer windings in [Ohms];

BR - permanent flux density of the transformer core in[Tesla];

BS - Saturation flux density of the core material in [Tesla]; and,

BN - Normal rated flux density of the transformer core in [Tesla]

2.7.3 Nature of Transformer Faults

Although an electrical power transformer is a static device, but internal stresses arising from abnormal system conditions, must be taken into consideration. A transformer generally suffers from following types of transformer faults [12].

2.7.3.1 The Internal Faults

Occur within the transformer protection zone such as incipient fault (overheating, over fluxing, overpressure) and active faults (turn-to-earth, turn-to-turn, tank fault, core fault).

i. Earth faults

The fault current in this case is controlled mainly by the leakage reactance, which varies in a complex manner depending on the position of the fault in the winding. The reactance decreases towards the neutral so that the current actually rises for faults towards the neutral end.

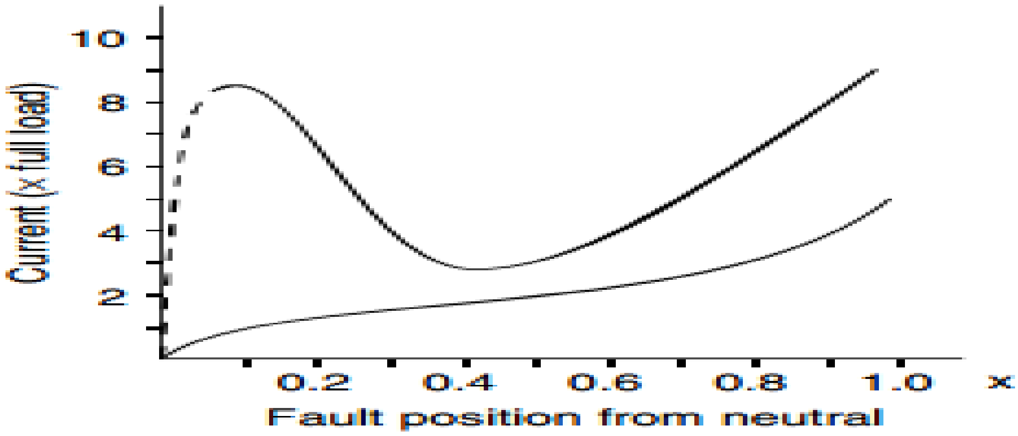

Fig. 2.8: Relationship of fault current to position from neutral (earthed)

ii. Resistance earthed neutral

For this application, the fault current varies linearly with the fault position, as the resistor is the dominant impedance, limiting the maximum fault current to approximately full load current

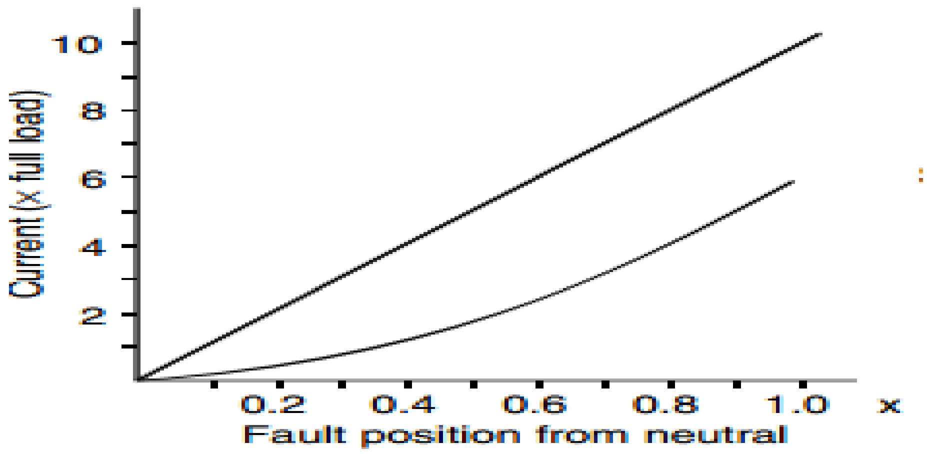

Fig.2.9 Relationship of fault current to positions from neutral (resistance earthed)

iii. Inter-turn faults

Insulation between turns can break down due to electromagnetic or electromechanical forces on the winding causing chafing or cracking. Ingress of moisture into the oil can also be a contributing factor. Also an HV power transformer connected to an overhead line transmission system will be subjected to lightning surges sometimes several times rated system voltage. These steep fronted surges will hit the end windings and may possibly puncture the insulation leading to a short-circuited turn. Very high currents flow in the shorted turn for a relatively small current flowing in the line.

iv. Core faults

Heavy fault currents can cause the core laminations to move, chafe and possibly bridge causing eddy currents to flow, which can then generate serious overheating. The additional core loss will not be able to produce any noticeable change in the line currents and thus cannot be detected by any electrical protection system.

Power frequency over voltage not only increases stress on the insulation but also gives an excessive increase in magnetization current. This flux is diverted from the highly saturated laminated cor into the core bolts, which normally carry very little flux. These bolts may be rapidly heated to a temperature, which destroys their own insulation, consequently shorting out core laminations. Fortunately, the intense localized heat, which will damage the winding insulation, will also cause the oil to break down into gas. This gas will rise to the conservator and detected by the Buchholz relay.

v. Tank faults

Loss of oil through a leak in the tank can cause a reduction of insulation and possibly over heating on normal load due to the loss of effective cooling. Oil sludge can also block cooling ducts and pipes, contributing to overheating, as can the loss of forced cooling pumps and fans generally fitted to the larger transformer [13].

2.7.3.2 External Faults

Are those faults that happen outside the transformer such as overloads, over voltage, under frequency, external system short circuits. There are two types of transformer protection as following:

i. Non electrical Protection:

The non electrical protection operates independently from current and voltage of the transformer. It operates based on the physical and the chemical condition of the transformer or insulation media of the transformer (oil).

Buchholz Relay:

This relay is actuated by gas and oil inside the transformer bank.

Temperature Relay:

Temperature relay works based on the temperature of the transformer. When the temperature is high, then this relay will give the alarm signal. If the temperature is extremely high, then this relay will send a trip command to the circuit breaker.

Sudden Pressure Relay:

The sudden pressure relay operates based on the rate of rise of gas in the transformer. It can be applied to any transformer with the sealed air or gas chamber above the oil level. It will not operate on static pressure or pressure changes resulting from normal operation of the transformer.

ii. Electrical Protection:

There are many electrical protective relays that are installed to protect the transformer [15].

2.7.4 Differential Protection

Differential protection, as its name implies, compares currents entering and leaving the protected zone and operates when the differential current between these currents exceed a pre-determined level. The type of differential scheme normally applied to a transformer is called the current balance or circulating voltage is theoretically nil, therefore no current passes through the relay. The CTs are connected in series and the secondary current circulates between them. The relay is connected across the midpoint where the hence no operation for faults outside the protected zone.

Under internal fault conditions (i.e. faults between the CTs) the relay operates , since both the CT secondary currents add up and pass through the relay. This protection is also called unit protection, as it only operates for faults on the unit it is protecting, which is situated between the CTs. The relay therefore can be instantaneous in operation, as it does not have to coordinate with any other relay on the network[13].

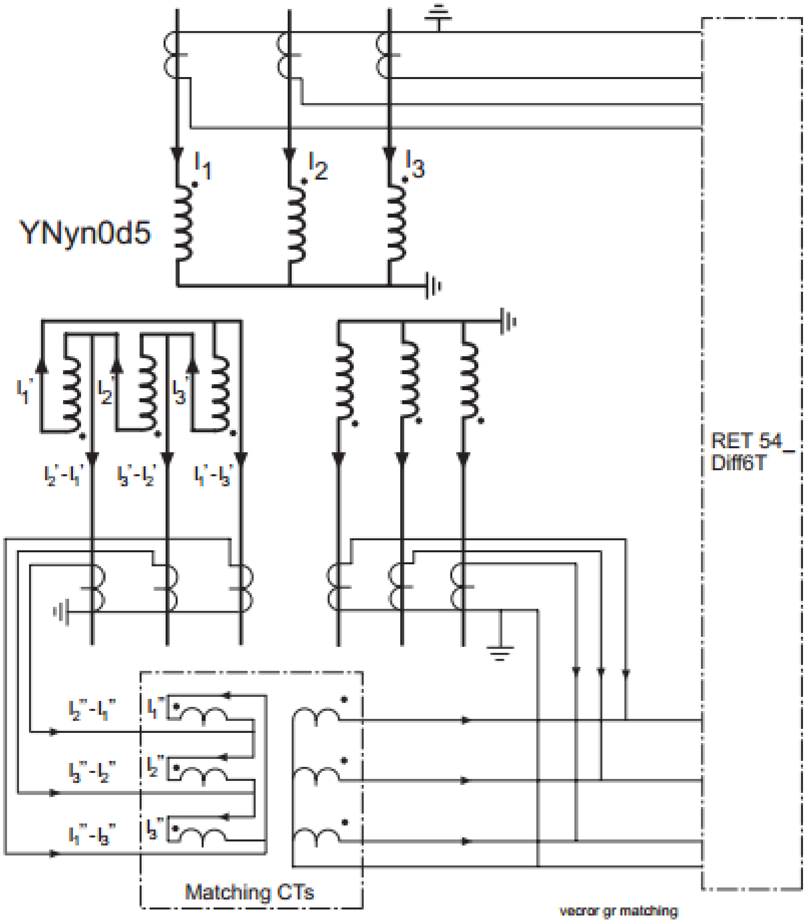

Fig. 2.10: Biased differential configurations(Vector group matching with interposing CTs)

Within the differential relay two quantities are derived:

i. The stabilizing current (often as well called bias or restraining Current) which flows through the restraining circuitry

ii. The differential current differential protection provides for fast tripping with absolute Selectivity for internal, high-level shunt faults when the relay operating point defined by the current pair [I bias, I diff] is above the tripping characteristic. Differential relays are often used as main protection for all important elements of the power system such as generators, transformers, buses, cables and short overhead lines.

The protected zone is clearly defined by the positioning of the main current Transformers to which the differential relay is connected. Transformer differential protection is as well quite specific because it has to cope with non-linearity of the power transformer. This is traditionally achieved by 2nd and 5th harmonic blocking/restraining features which are typically found in all power transformer differential relays [14].

2.7.4.1 Second Harmonic Blocking (Ratio I2f/I1f>)

Power transformers are ferromagnetic devices. At the moment of Energization, the power transformer draws a magnetizing inrush current, which is perceived by the differential protection relay solely as a differential current. Because the transformer magnetizing impedance is non-linear, the inrush current contains a lot of second order harmonics. A well-known principle is to detect an inrush situation from the content of the 2nd order harmonics and block the differential protection relay (low-set stage) for the time of the inrush.

The recommended setting for the second harmonic blocking is 15% in power transformer protection. It is also recommended to use the factory default for the Setting 2. Harm .block. The factory default setting is "With de block". This setting allows a special algorithm to inhibit the second harmonic blocking in case the algorithm detects a fault inside the protected area. The content of 2nd harmonics in the inrush current depends on transformer construction, material and remanence. Therefore, the setting for the 2nd harmonic blocking cannot be calculated in a straight forward way.

The disturbance recorder can be used for detecting the content of the 2nd harmonic in the search of the final setting for the second harmonic blocking. It should be noted that if the transformer has been out of use for some time (i.e. after storage) its remanence may be very small, causing the 2nd harmonic blocking not to operate at the first energizing attempt. Therefore, the setting could be lowered to 10% for the first energizing attempt [16].

2.7.4.2 Fifth Harmonic Blocking and de Blocking (Ratio I5f/I1f>,I5f/I1f>>)

The purpose of this function is to block the relay operation at a sudden voltage rise or frequency drop. The reason for blocking is the increasing magnetizing current flowing on the primary side which by the relay is perceived as an increase in the differential current. According to numerous studies made the fifth harmonic component of the magnetizing current has proved to be most suitable for monitoring over excitation of power transformers. There are two major reasons for that. Firstly, the proportional part of the fifth harmonic is clearly increasing when the transformer core is beginning to saturate. Secondly, other situations, for example, the saturation of current transformers do not produce so much fifth harmonics.

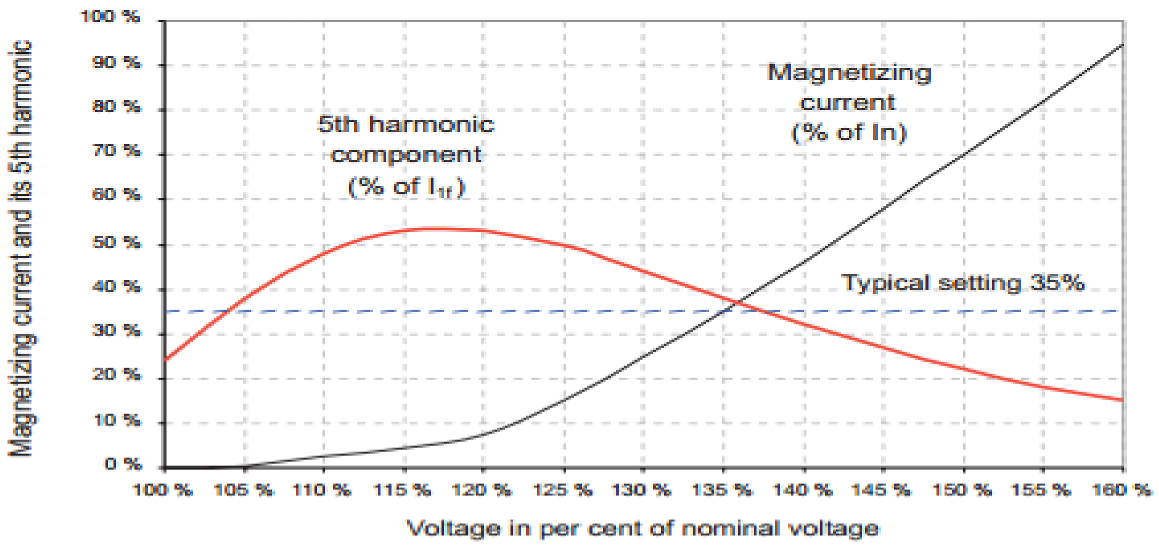

Fig. 2.11: Magnetizing current and its 5th harmonic component in the windings of an overexcited power transformer

A typical behavior of the proportion of the fifth harmonic to the fundamental component of the magnetizing current as a function of the overvoltage. Illustrates how the proportion of the fifth harmonic initially increases until it reaches its maximum, and if the voltage continues rising, the transformer will go into an even deeper saturation and part of the fifth harmonic starts to decline. The main problem when defining the setting values Is that the fifth harmonic curve as a function of overvoltage should be known for the transformer concerned.

The critical voltage values and the over capacity of the magnetic circuits depend on the construction of the transformer. The only one to know the influence of overvoltage or the **U/F** ratio on the content of the fifth harmonic is the manufacturer of the power transformer. A value often used for blocking is 35%, but its usefulness in each separate case is very difficult to know without access to the real curves, which should be made available by the transformer manufacturer[16].

2.7.5 Over Current Protection

Over current protection is classified as back up protection of the transformer because it is not sensitive enough to detect the internal fault. It is installed at the source side and also the load side of the transformer. It will work if the current is over the setting of the relay[17].

Over current relaying is used for fault protection of transformers having circuit breakers only when the cost of differential relaying cannot be justified. Over current relaying cannot begin to compare with differential relaying in sensitivity. Three CT's, one in each phase, and at least two over current phase relays and one over current ground relay should be provided on each side of the transformer bank that is connected through a circuit breaker to a source of short-circuit current.

The over current relays should have an inverse-time element whose pickup can be adjusted to somewhat above maximum rated load current, say about 150% of maximum, and with sufficient time delay so as to be selective with the relaying equipment of adjacent system elements during external faults. The relays should also have an instantaneous element whose pickup can be made slightly higher than either the maximum short-circuit current for an external fault or the magnetizing-current inrush.

When the transformer bank is connected to more than one source of short-circuit current, it may be necessary for at least some of the over current relays to be directional in order to obtain good protection as well as selectivity for external faults. The over current relays for short-circuit protection of transformers provide also the external-fault back-up protection [18].

2.7.6 Restricted Earth Fault Protection

Restricted earth fault (REF) protection scheme refers to the differential protection of transformers against ground (earth) fault. It is called restricted because its zone of protection is limited only to the windings of the transformer [19]. A simple over current and earth fault relay will not provide adequate protection for winding earth faults.

Even with a biased differential relay installed, the biasing desensitizes the relay such that it is not effective for certain earth faults within the winding. This is especially so if the transformer is resistance or impedance earthed, where the current available on an internal fault is disproportionately low. In these circumstances, it is often necessary to add some form of separate earth fault protection. The degree of earth fault protection is very much improved by the application of unit differential or restricted earth fault systems.

On the HV side, the residual current of the three line CTs is balanced against the output current of the CT in the neutral conductor, making it stable for all faults outside the zone. For the LV side, earth faults occurring on the delta winding may also result in a level of fault current of less than full load, especially for a mid winding fault which will only have half the line voltage applied. HV over current relays will therefore not provide adequate protection.

A relay connected to monitor residual current will inherently provide restricted earth fault protection since the delta winding cannot supply zero sequence current to the system. Both windings of a transformer can thus be protected separately with restricted earth fault, thereby providing high-speed protection against earth faults over virtually the whole of the transformer windings, with relatively simple equipment. The relay used is an instantaneous high-impedance type[13].

2.7.7 Standby Earth Fault Protection

The standby earth fault relay was originally used as protection for the neutral earthing resistor which was usually rated at full load current for 30s. It had a long time characteristics typically 30s at five times setting. the setting was usually 20% so that at full load current, the level to which the neutral earthing resistor reduced the current, it would operate in 30s. Nowadays the standby earth fault relay is regarded as the last line of defence [20].

2.7.8 Thermal Overload Protection

A transformer is normally rated to operate continuously at a maximum temperature based on an assumed ambient. No sustained overload is usually permissible for this condition. At lower ambient it is often possible to allow short periods of overload but no hard and fast rules apply, regarding the magnitude and duration of the overload. The only certain factor is that the winding must not overheat to the extent that the insulation is cooked, thereby accelerating ageing.

A winding temperature of 98 °C is considered to be the normal maximum working value, beyond which a further rise of 8–10 °C, if sustained, is considered to half the life of the transformer. Oil also deteriorates from the effect of heat. It is for these reasons that winding and oil temperature alarm and trip devices fitted to transformers are [13].

Traditional methods of protecting power transformers use functions based on measured current and voltage. These functions are useful in detecting short circuits and other transient electrical fault events in the transformer. However, for liquid-immersed power transformers, the temperature of the winding hot-spot is the important factor in the long-term life of the transformer.

The insulating oil temperature is dependent on the winding temperature, and is used to indicate the operating conditions of the transformer. Many numerical transformer protection relays available today include protection functions that operate on insulating oil temperatures, calculated loss-of-life due to high oil temperature, and predicted oil temperatures due to load. These types of functions are not routinely applied, often since protection engineers may lack an understanding of the operating principles of these functions, and transformer operating conditions, to properly determine a settings methodology.

A factor to consider when looking at these temperature-based functions is the risk of accelerated aging, and transformer failure, is increasing. Modern utility operating practices try to maximize the utilization of power transformers, which may increase the occurrence of over-temperature conditions, and transformer aging. Over-temperature conditions and accelerated aging are adverse system events that must be identified and protected against.

The most common function provided for thermal protection of power transformers is the thermal overload (ANSI 49) function. To properly set this function, the protection engineer must understand the basics of the thermal performance of power transformers, and the basic design of the specific implementation of the 49 function. Northeast Utilities has implemented thermal protection of substation power transformers. The temperature protection is combined with distribution automation to manage transformer load.

Thermal overload levels of the transformers force an automatic load transfer through feeder circuit re-configuration. Predictive overload alarms warn the Distribution System Operators of the pending automatic forced load transfer, to allow manual intervention. The settings criteria, control logic, and operations criteria for the thermal overload protection are discussed, as well as an overview of the operating experience [21].

2.7.9 Core Balance Leakage Protection

This system consists of three primary conductors surrounded by the magnetic circuit of a current transformer. This has a single secondary winding which is connected to the relay operating coil. Under normal condition(when there is no earth fault the instantaneous sum of the current in the three phases is always zero, and there is no resultant flux in the core of the CTs no matter how much the load is out of balance). thus no flows through the relay operating coil and trip circuit remains open. When an earth fault occurs, the sum of the three current is no longer zero and a current is induced in the secondary of the CTs causing the trip relay to operate and isolate the transformer from the bus-bar[4].

2.7.10 Self Balance Protection System

It necessarily consists of two cables connected to the two ends of each phase and the cables are passed through the circular aperture of the ring type CTs .The protective transformer (CTs) can be located in the oil of the transformer tank. this system is also effective for phase to phase faults and is very sensitive type of earth fault protection scheme. This system protection of power transformer is not much used because it cannot provide protection to transformer terminal and the connected cables up to switchgear[4].

2.7.11 Differential Magnetic Balance Protection System

This system is a necessarily of circulating current and self balance protection system. The main advantages of this protection system are increased stability and sensitivity and its application to power transformer provided with load tap changers[4].

2.7.12 Self Stabilizing Magnetic Balance Protection System

For the protection of power transformer having tapping's it is necessary that the protective CTs connected on high voltage side must also be capable of changing its current ratio whenever power transformer tapping's are changed. When the transformer is operating under normal operating condition and carrying full- load current, the flux developed by the two halves is equal and relay winding coil is un-energized. Now when the tapping's of the main transformer are changed, MMFs of the two halves are changed causing the flux developed by them to be different. So an EMF, proportional to difference of the two fluxes, will be induced in the relay coil[4].

2.8 Bus-bar Protection

The bus-bar play an important role in the supply system. The bus-bar faults are rare but if occurs there can be interruption of supply, considerable damage and loss. Hence bus-bar protection is must and it must be fault, stable and reliable. The bus-bar protection needs to protect not only the bus-bar but the apparatus, isolating switches, instrument transformer etc. The causes of bus-bar faults are [4,22].

i. Failure of support insulator, due to material deterioration resulting in earth fault.
ii. Flash-over across support insulator, caused by prolonged and excessive overvoltages.
iii. Faulty operations performed by the attending personnel.
iv. Heavily polluted insulator causing flash-over.

v. Foreign objects accidently falling across bus-bar.
vi. Failure of circuit breakers to interrupt fault current or failure to clear under through fault conditions.

2.8.1. Bus bar Protection Requirements

Basic protection of a bus-bar is not much different from other components, but the key role of a bus-bar makes two of the requirements the more important; Speed and Stability.

i. **Speed**

The primary objective of bus-bar protection is to limit the damage and also to remove bus-bar faults before back-up line protection, to maintain system stability. Formerly, a low impedance differential system was used which had a relatively long operation time, of up to 0.5 seconds.

However, most modern protection schemes are a differential system capable of operating in a time of the order of one cycle. Of course, the operating time of the tripping relays should be added to this, but an overall tripping time of less than two cycles is achievable. Nowadays, with the introduction of high speed circuit breakers, complete fault clearance may be obtained in approximately 0.1 seconds[17].

ii. **Stability**

The stability of bus-bar protection is very important. It should be noted that rate of fault in bus-bar are quite low (about one fault per bus-bar in twenty years). Therefore, a weakness in the stability of a protection system may have detrimental effects on the stability of the protection system. Formerly, this has led to some uncertainty in placing protection systems in bus-bars, or placing very sophisticated protection mechanisms. With better analysis of the system, these systems can be applied with correct settings. To achieve a higher stability index, most of the time two independent measurements are required for tripping command[17].

2.8.2 Methods of Bus-bar Protection:

There are many protection schemes are used to protect bus-bar from different types of faults such as following:

2.8.2.1 Over Current Relays of Connected Circuits.

This type of protection is slow and evolves complicated control system to discriminate faults within the zone. Also, the zone of the bus-bar is not clearly identified. Used in distribution system (6-33kv) with transformer feeder supply to bus-bar. Time of the order to (100-400ms) [13].

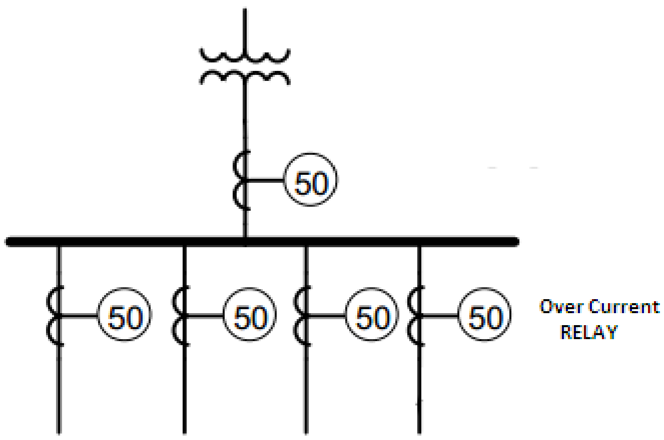

Fig. 2.12: Over current relays of connected circuits

2.8.2.2 Directional Interlock.

It uses directional relays in source circuits and over current relays in load circuits. It makes the discrimination between internal and external faults possible. The contacts of the relays are interlocked in such a way that if power flows the bus-bar is sufficiently low, all the circuit breakers on the source side and the load side are tripped[13].

2.8.2.3 Differential Protection.

The differential protection comes directly from Kirchhoff's current law. All of the currents are added together and the relay is only activated on cither sum of the currents is not zero, i.e. a fault is occurred on the bus-bar. The different in currents represents the fault current. One way to implement this arrangement is to use one relay and put all CTs in parallel This also gives earth fault protection which was thought to be sufficient. Moreover, if the CTs are connected as a group for each group of three phases, it is also possible to add phase fault protection to the system[17].

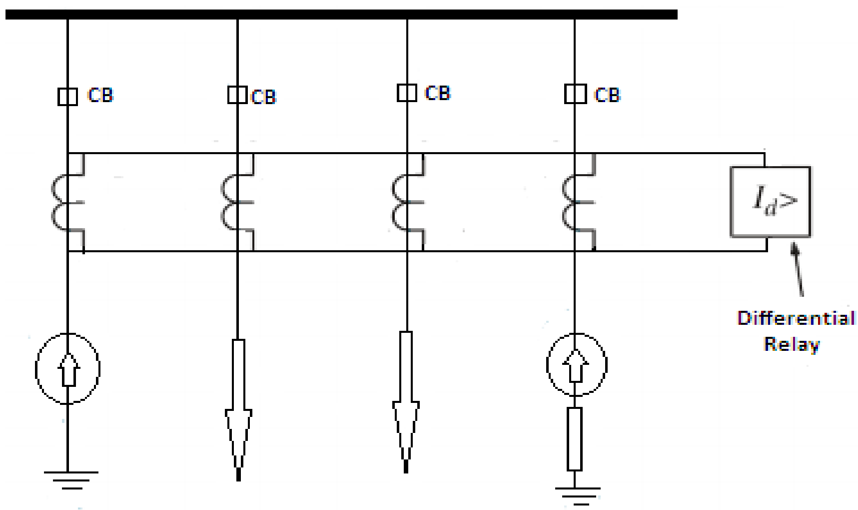

Fig. 2.13: Differential bus-bar protection

2.8.2.4 Digital Bus-bar Protection:

Digital relay application has lagged behind that of other protection functions. Usually static technology is still employed in these schemes, but now digital technology has become mature enough to be considered. Multiple communications paths have provided relays with links to various units[17].

2.8.2.5 Frame Leakage Earth Fault:

This method protection of bus-bar has been extensively used in the past. This involves measurement of fault current from switchgear frame to the earth. It consists of a current transformer connected between frames to earth points and energizes an instantaneous ground fault relay to trip the switchgear. It generally trips all the breakers connected to the bus-bars. Care must be taken to insulate all the metal parts of the switchgear from the earth to avoid spurious currents being circulated. A nominal insulation of 10 Ω to earth shall be sufficient. The recommended minimum setting for this protection is about 30% of the Minimum earth fault current of the system[11,18].

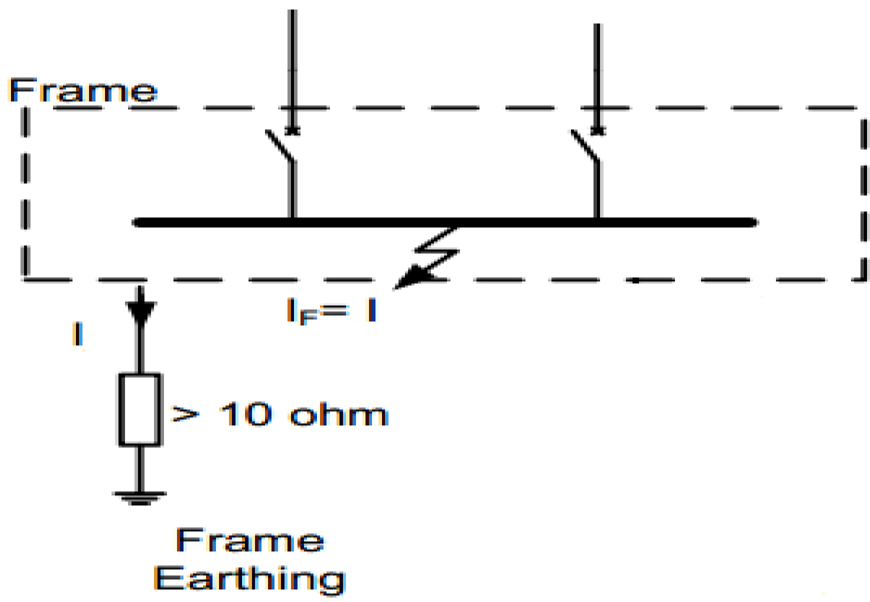

Fig. 2.14: Frame leakage earth fault

2.8.2.6 Discriminating Zone and Check Zone Protection

i. discriminating zone protection

The discriminating zone protection inputs currents and disconnector position signals from feeders, transformers banks, bus section and bus couplers which are connected to the protected zone and output trip signals to all the circuit breakers of the zone.

ii. Check zone protection

The check zone protection input current from all feeder bays and transformer bays performs the overall differential protection for the entire bus-bar system and outputs trip signals to all the circuit breaker of the feeders and transformer. As the protection does not use the disconnector position signals the check zone protection is very secure against such false operation in the no fault and through fault condition[23].

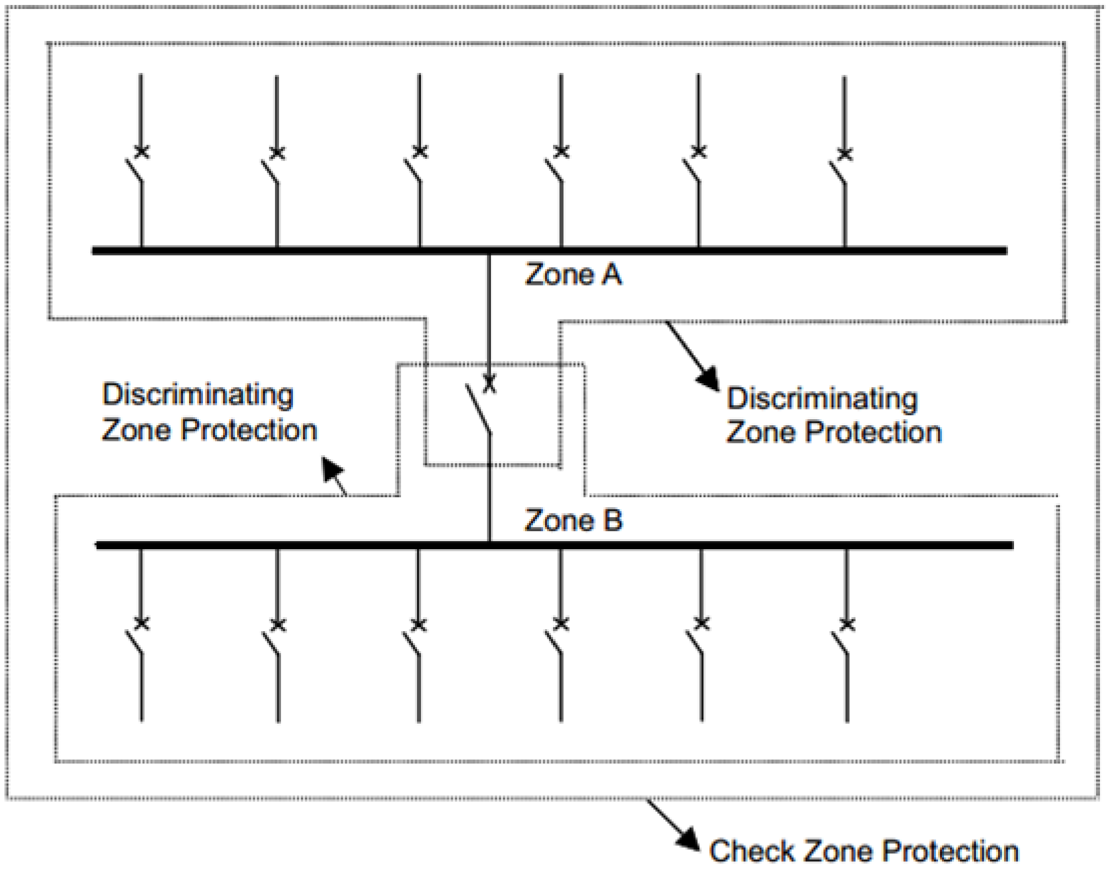

Fig. 2.15: Check zone and discriminating zone protection

2.9 Switchgear Protection

The apparatus used for switching, controlling and protecting the electrical circuits and equipment is known as switchgear. The term 'switchgear' is a generic term encompassing a wide range of devices like circuit breakers, switches, switch fuse units, off-load isolators, HRC fuses, contactors, earth leakage circuit breakers (ELCBs), etc.

A switchgear essentially consists of switching and protecting devices such as switches, fuses, isolators, circuit breakers, relays, control panels, lightning arrestors, current transformers, potential transformers, and various associated equipments. Some equipments are designed to operate under both normal and abnormal conditions. Some equipments are meant for switching and not sensing the fault.

During normal operation, switchgear permits to switch on or off generators, transmission lines, distributors and other electrical equipment. On the other hand, when a failure (e.g. short circuit) occurs on any part of power system, a heavy current flows through the equipment, threatening damage to the equipment and interruption of service to the customers. However, the switchgear detects the fault and disconnects the unhealthy section from the system.

2.9.1 Evolution of Switchgear

The switchgear equipment is essentially concerned with switching and interrupting currents either under normal or abnormal operating conditions.

- The tumbler switch with ordinary fuse is the simplest form of switchgear and is used to control and protect lights and other equipment in homes, offices etc.
- For circuits of higher rating, a high-rupturing capacity (H.R.C.) fuse in conjunction with a switch may serve the purpose of controlling and protecting the circuit. However, such a switchgear cannot be used profitably on high voltage system (33 kV) for two reasons.

i. Firstly, when a fuse blows, it takes sometime to replace it and consequently there is interruption of service to the customers.

ii. Secondly, the fuse cannot successfully interrupt large fault currents that result from the faults on high voltage system.

With the advancement of power system, lines and other equipments operate at high voltages and carry large currents. When a short circuit occurs on the system, heavy current flowing through the equipment may cause considerable damage. In order to interrupt such heavy fault currents, automatic circuit breakers (or simply circuit breakers) are used.

- A circuit breaker is a switchgear which can open or close an electrical circuit under both normal and abnormal conditions. Even in instances where a fuse is adequate, as regards to breaking capacity, a circuit breaker may be preferable.
- It is because a circuit breaker can close circuits, as well as break them without replacement and thus has wider range of use altogether than a fuse [17].

2.9.2 Essential Features of Switchgear

The essential features of switchgear are :

i. Complete reliability: With the continued trend of interconnection and the increasing capacity of generating stations, the need for a reliable switchgear has become of paramount importance. This is not surprising because switchgear is added to the power system to improve the reliability. When fault occurs on any part of the power system, the switchgear must operate to isolate the faulty section from the remainder circuit.

ii. Absolutely certain discrimination: When fault occurs on any section of the power system, the switchgear must be able to discriminate between the faulty section and the healthy section. It should isolate the faulty section from the system without affecting the healthy section. This will ensure continuity of supply.

iii. Quick operation: When fault occurs on any part of the power system, the switchgear must operate quickly so that no damage is done to generators, transformers and other equipment by the short-circuit currents. If fault is not cleared by switchgear quickly, it is likely to spread into healthy parts, thus endangering complete shut down of the system.

iv. Provision for manual control: A switchgear must have provision for manual control. In case the electrical (or electronics) control fails, the necessary operation can be carried out through manual control [24].

2.9.3 Protection of Switchgear

Although switchgears are protective devices, they need protection against some faults such as earth fault and frame leakage faults, and frame leakage protection is used to protect them against the previous type of faults.

2.9.4 Surge Arresters

The main task of an arrester is to protect equipment from the effects of overvoltages. During normal operation, an arrester should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage. Nonlinear resistors fulfill these requirements thanks to the following properties:

i. Low resistance during surges, so that over voltages are limited
ii. High resistance during normal operation to avoid negative effects on the power system
iii. Sufficient energy absorption capability, for stable operation With this kind of nonlinear resistor, there is only a small flow of current when continuous operating voltage is being applied. When there are surges, however, excess energy can quickly be removed from the power system by a high discharge current[25].

2.10 Breaker Failure Protection

When a fault remains un-cleared due to breaker failure the breaker failure protection clears the fault by tripping the local adjacent breaker or a breaker at a remote line end. If the current continues to flow following the output of a trip command the CBF judges it as a breaker failure, the existence of the current is detected by an over current element OCBF provided for each phase and each primary circuit. For high speed operation of the CBF a high speed reset over current element is used [23].

2.11 Summary

Protective relays are broadly classified into the following four categories depending on the technologies they use for their construction and operation, such relays are electromechanical, static, digital and numerical relays. The main components of substation (Transformers and Bus_bars) were protected by using several types of protection, which protect them from all types of faults which may occur in substation. Also secondary equipments(switchgears) were protected by using of frame leakage protection and surge arresters.

CHAPTER THREE

TRANSFORMER PROTECTION

3.1 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 3.1: Function conversion for transformer protection

Function NO. (ANSI)	Abbreviation	Description	AREVA Relay type
87 T	TDP	Transformer Differential protection	MiCOM P633
87 NT	REFP	Restricted earth fault	MiCOM P122

		protection	
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

3.2 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[20]. this can be illustrated in figure bellow

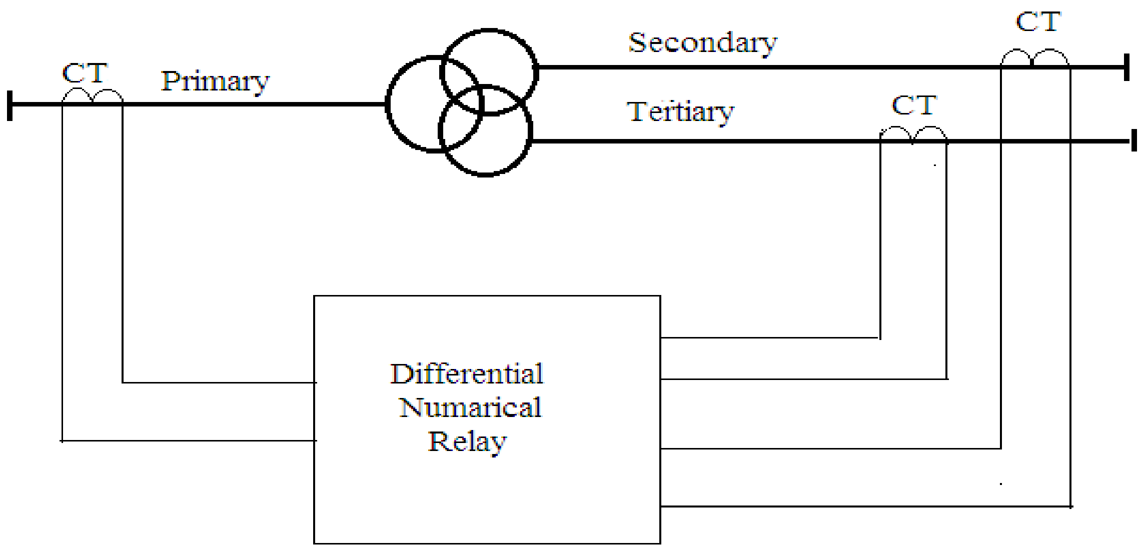

Fig. 3.1: Differential protection scheme for three winding transformer

Differential protection provides protection against internal faults such as :

i. Phase to phase faults
ii. Earth faults .
iii. Inter turn faults.
iv. Open circuit fault (in one phase).
v. Core fault.
vi. Tank fault.

3.2.1 Data of Transformer

Table 3.2: Data of power transformer

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

- Tap changer range: 8*1.25%

3.2.2 Selection of Current Transformer (CTs) ratio

Full load currents in each side of power transformer

$$I_{FL} = \frac{MVA*10^3}{\sqrt{3}*KV} \quad (3.1)$$

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

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

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

According to above values of currents the suitable CTs ratio are as shown in Table 3.3.

Table 3.3: 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

3.2.3 Setting Calculations:

i. The differential starting threshold ($I_{Diff} >$)

The differential starting threshold ($I_{Diff} >$) is set between $0.1\times I_{ref}$ and $0.4\times I_{ref}$ to take in account the CT accuracy. At this transformer, we select following:

$$(I_{Diff} >) = 0.2 \times I_{ref}. \quad (3.2)$$

% error = 10%(CT) + 5%(Relay) + 3%(TR excitation current) +5%(Margin)

ii. The differential threshold ($I_{r.m2}$)

Thus the threshold ($I_{r.m2}$) is used to disable the possible MAX load current .The differential threshold ($I_{r.m2}$) is set between $1.5\times I_{ref}$ and $5\times I_{ref}$ to take into account the CT accuracy.

$$(I_{r.m2}) = 4 \times I_{ref}. \quad (3.3)$$

iii. The differential threshold ($I_{Diff} \gg$)

The differential threshold ($I_{Diff} \gg$) is used to disable the inrush and overflux restraint functions.

It must be set above the magnetizing inrush current of the power transformer.

$$(I_{Diff} \gg) = K_q \times I_{ref} \quad (3.4)$$

Where

I_{ref} = rated current.

K_q = factor, the value can be confirmed according to rated power of the transformer size (S_N).

K_q =7~12, when $S_N \leq$ 3600KVA;

K_q =4.5~7, when 3600KVA $\leq S_N \leq 31500KVA$;

K_q =3~6, when 4000KVA $\leq S_N \leq$ 120000KVA;

K_q =2~5, when 120000KVA $\leq S_N$;

In this transformer we take, $K_q = 5$;

$\therefore (I_{Diff} \gg) = K_q \times I_{ref} = 5 \times I_{ref}$.

iv. First slope

Standard the value is set

M1=0.3

v. Second slope

Standard the value is set

M2=0.7

vi. Second harmonic restraint

This function is used to avoid the tripping of the protection (mal-operation) in case of differential current due to inrush current. The threshold of the 2^{nd} harmonics limitation is set 15% .

$$\frac{I_{(2f_0)}}{I_{(f_0)}} = 15\% \qquad (3.5)$$

vii. 5^{th} harmonics restraint

The function is used to avoid the mal-operation of the protection due to the over fluxing. When a load is suddenly disconnected, it will allow temporary overvoltage, that would increase the flux and cause saturation. The threshold of the 5^{th} harmonics limitation is set to 25%.

$$\frac{I_{(5f_0)}}{I_{(f_0)}} = 25\% \qquad (3.6)$$

viii. Zero sequence filtering

To avoid the tripping from the differential protection in case of external phase-to-earth fault the zero sequence filtering must be enabled for any star connected winding (220KV side and 110KV side).

setting:

Zero sequence filtering; Yes .

3.2.4 Setting

- The differential starting threshold ($I_{Diff} >$) ,

  ($I_{Diff} >$) $= 0.2 \times I_{ref}$;
- The differential threshold ($I_{r.m2}$**)** ,

  ($I_{r.m2}$**)** $= 4 \times I_{ref}$;
- The differential threshold **(**$I_{Diff} \gg$) ,

  ($I_{Diff} \gg$) $= 5 \times I_{ref}$;
- Slope of the first paragraph slash, M1= 0.3;
- Slope of the second paragraph slash, M2= 0.7;

  Second harmonics restraint, $\frac{I_{(2f_0)}}{I_{(f_0)}} = 0.15$;
- 5^{th} harmonics restraint,

  $\frac{I_{(5f_0)}}{I_{(f_0)}} = 0.25$;
- Zero sequence filtering, Yes .

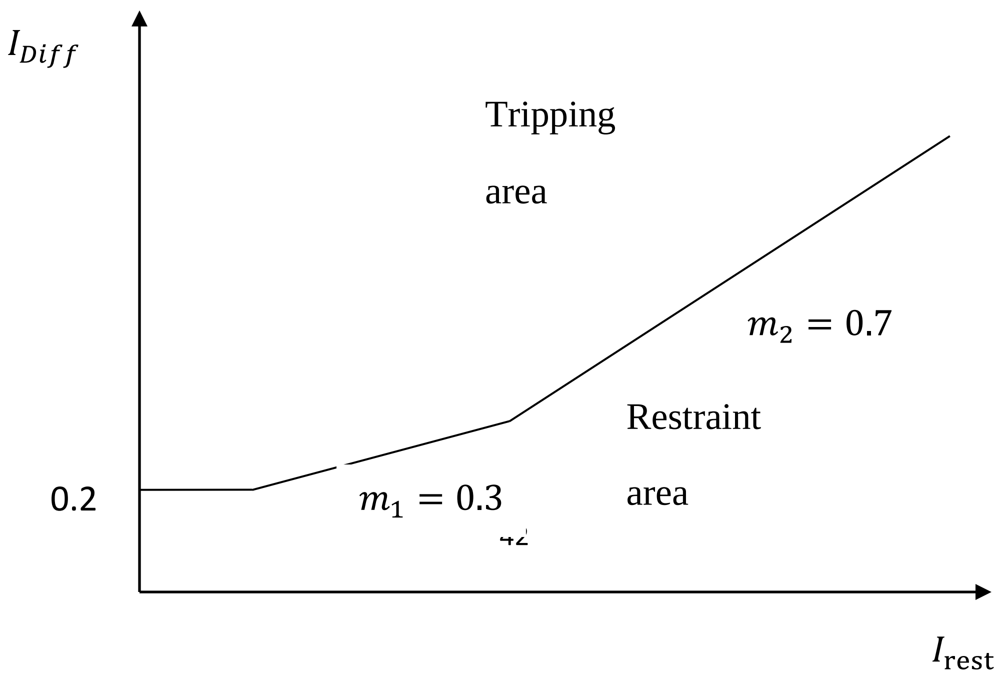

Fig. 3.2: Differential protection operating characteristic

3.3 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.

3.3.1 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}) $\geq (k \times I_{FL})/1000$ (3.7)

≥ 0.47 Amps

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

$$T_{op} = \frac{0.14 \times T.M.S}{\left(\frac{I}{I_S}\right)^{0.02} - 1} \qquad (3.8)$$

where,

$$I_s = 1000 \times I_{op} \qquad (3.9)$$

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

$$I = 2 \times I_{FL} \qquad (3.10)$$

$= 2 \times 393.7 = 787.4$ Amp

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

T.M.S = 0.74

ii. Phase current setting 2^{nd} 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 = + 45^0(this is typical setting for transformer feeder).

3.3.2 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}) ≥ (k × I_{FL})/1200

≥ 0.787 Amps

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

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

where

$I_s = 1200 \times I_{op}$

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

$$I = 2 \times I_{FL} = 2 \times 787.3 = 1574.6 \text{ Amp}$$

$$10 = \frac{0.14 \times T.M.S}{\left(\frac{1574.6}{944.4}\right)^{0.02} - 1}$$

T.M.S = 0.734

ii. Selection of (I>) char angle

Characteristic angle " I> char angle"

Select: I> char angle = $+45^{0}$(this is typical setting for transformer feeder).

3.3.3 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:

i. **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}) $\geq$ (k $\times$ I_{FL})/1600

$\geq$ 0.656 Amps

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

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

where

$I_s = 1600 \times I_{op}$

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

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

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

T.M.S = 0.734

3.4 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].

3.4.1 Primary Side Restricted Earth Fault Protection

i. General Data

a. Line CT parameters

   Ratio : 1000/1 Amp

   Class : 30VA, 5P30

b. Neutral CT parameters

   Ratio: 1000/1 Amp

   Class : 20VA, 5P30

c. Load length for the neutral CTs

   From neutral CT to relay panel = 180 m

Table 3.4: 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

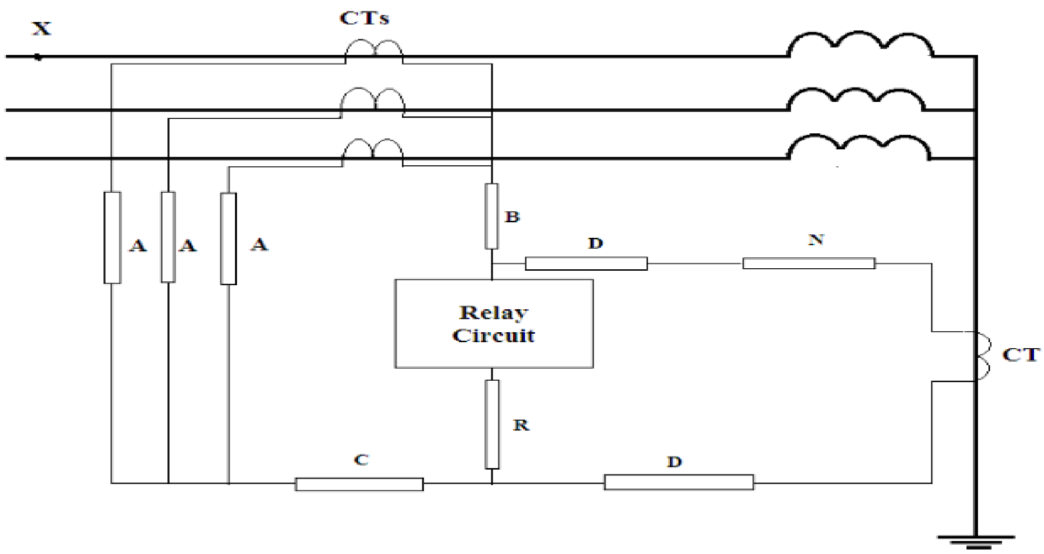

Fig. 3.3: Restricted Earth Fault Protection (High Impedance Principle)

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_s = relay circuit setting voltage.

I_s = relay circuit current at V_s volts.

I_F = fault current corresponding to rated stability limit.

$I_F = I_f \times T$ (3.11)

a. Rated Stability

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

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

$$I_F = \frac{\text{primary full load current}}{\text{transformer \%impedance}} \quad (3.12)$$

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

$\text{secondary fault current} = 2.96 \text{ Amp}$

b. Rated Stability Limit

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

$I_f \times (N+2D)$ volts. (3.13)

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_s

$V_s \geq \frac{2960}{1000}(N+2D) = 2.96\times(5+2\times0.79) = 19$ volts

d. 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

  $I_s = \frac{\text{primary fault setting}}{\text{CT ration}}$ (3.14)

  $= \frac{157.48}{1000} = 0.158$

  $\therefore\ I_s = 0.16$ Amp

- **Establishing the Value of Setting Resistance**

  Resistor value R is given by:-

  $R_s = \frac{V_s}{I_s}$ (3.14)

  $= \frac{19}{0.158} = 119\ \Omega$

  Let us consider $R_s = 120\ \Omega$

iii. Setting

a. Restricted earth fault setting HV , I_s = 0.16 Amp

b. Stabilizing resistance value = 120 Ω

3.4.2 Secondary Side Restricted Earth Fault Protection

i. General Data

a. Line CT parameters

Ratio :1000/1 Amp

Class : 30VA, 5P30

b. Neutral CT parameters

Ratio: 1000/1 Amp

Class : 20VA, 5P30

c. Load length for the neutral CTs

From neutral CT to relay panel = 180 m

By using data from table 3.4

ii. Relay Setting Calculations

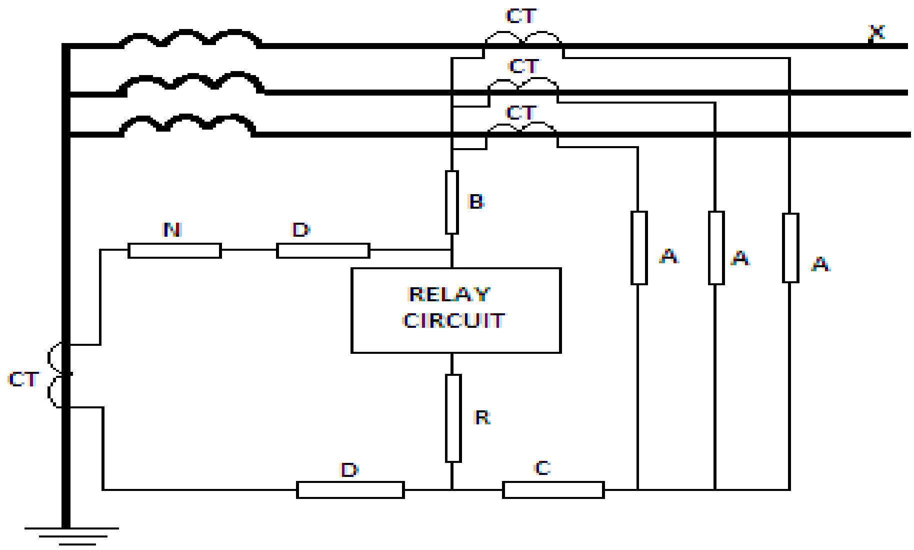

Fig.3.4. Restricted Earth Fault Protection (High Impedance Principle)

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_s = relay circuit setting voltage

I_s = relay circuit current at V_s volts

I_F = 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 = $\frac{787.3}{1000}$ = 0.7873

$I_F = \frac{0.7873}{0.133}$ = 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 V_s shall be not less than :- $I_f \times$ (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 V_s

$V_s \geq \frac{10000}{1000}$ (N+2D) = 10× (5+2×0.79) = 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

  $I_s = \frac{314.9}{1000} = 0.315$

  ∴ I_s = 0.32 Amp

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

  Resistor value R is given by:-

  $R_s = \frac{V_s}{I_s} = \frac{65.5}{0.315} = 208\ \Omega$

  Let us consider R_s = 200 Ω

iii. setting

a. Restricted earth fault setting MV , I_s >= 0.32 Amp

b. Stabilizing resistance value = 200 Ω

3.5 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 $I_{op} \geq 0.1 I_N$ (3.15)

ii. **selection of the time characteristic "$I_{op} > 1$ *function*"**

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

Selection of direction: Direction forward.

$$T_{op} = TMS \times \frac{K}{\left(\frac{I}{n \times I_{op}}\right)^{\alpha} - 1} \quad (3.16)$$

TMS=0.71

iii. **Phase current setting 2^{nd} 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 .

Refer to the existing TR1and TR2 setting:

I>> = 2 Amp

t>> = 0.1 sec

iv. **Selection of (I>) char angle**

Characteristic angle "I_N> char angle"

Select: I> char angle = - 45^0(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 φ= + 45^0

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 φ= - 45^0

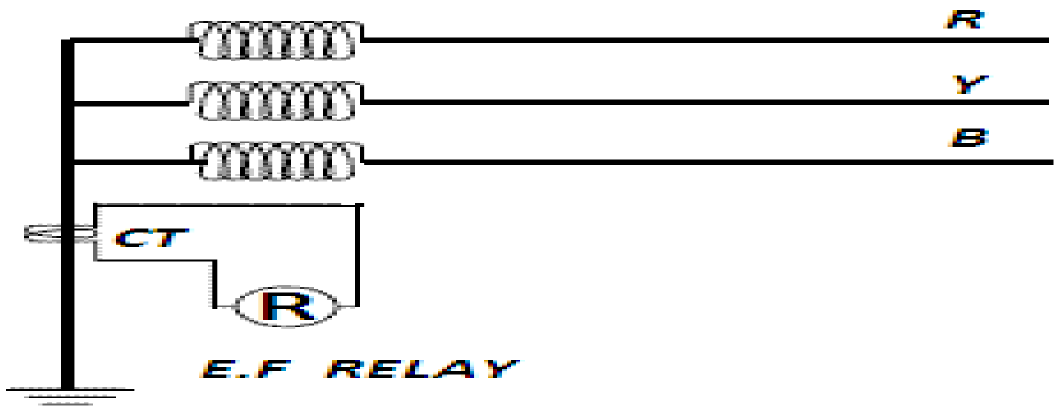

Fig. 3.5: Earth fault relay connection

3.6 Standby Earth Fault Protection (ANSI 51/49)

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

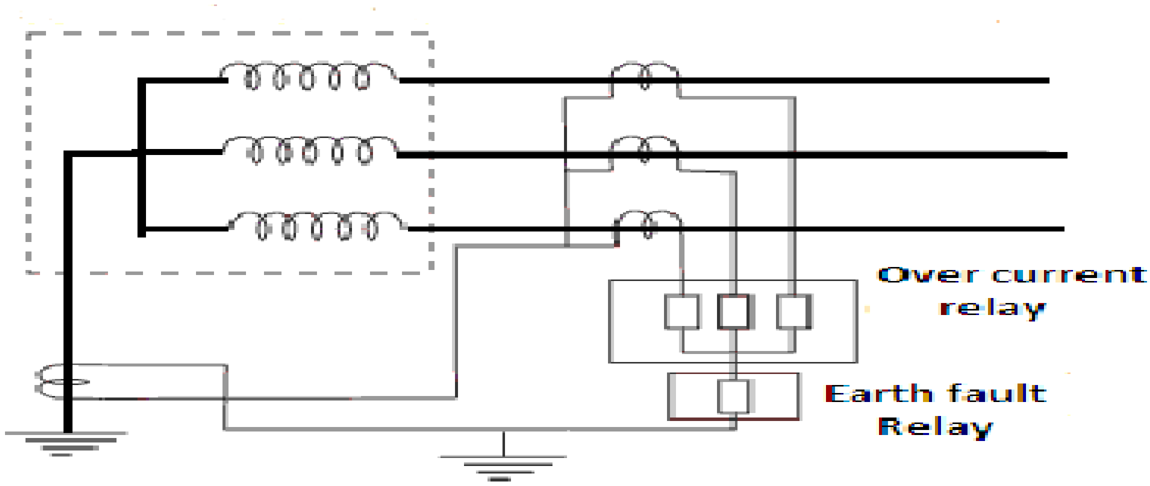

Fig. 3.6: Standby Earth Fault Protection connection

3.6.1 Standby Earth Fault Protection for Primary Side

i. **CT data**

Ratio: 400/1 Amp

Class: 20VA, 5P20.

ii. **setting calculation**

a. 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 = $\frac{78.74}{400}$ = 0.2 Amp

b. Selection of time characteristic

Definite time (DT)

Time delay = 10 sec

iii. Setting

a. standby earth fault setting HV side $I_{op} \geq 0.2$ Amp

b. Time delay = 10 se

3.6.2 Standby earth fault protection for Secondary side

i. CT data

Ratio: 600/1 Amp

Class: 20VA, 5P20

ii. setting calculation

a. 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 = $\frac{157.46}{600}$ = 0.26 Amp

b. Selection of time characteristic

Definite time (DT)

Time delay = 10 sec

iii. setting

a. standby earth fault setting HV side $I_{op} \geq 0.26$ Amp

b. Time delay = 10 sec

3.6.3 Standby Earth Fault Protection for Tertiary Side

i. CT data

Ratio: 300/1 Amp

Class: 20VA, 5P20

ii. setting calculation

a. 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 874.77 Amp

= 0.2 ×874.77=174.95 Amp

Current setting = $\frac{174.95}{300}$ = 0.58 Amp

b. Selection of time characteristic

Definite time (DT)

Time delay = 10 sec

iii. setting

a. standby earth fault setting HV side $I_{op} \geq 0.58$ Amp

b. Time delay = 10 se

3.7 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[11].

Setting Calculations:

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

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

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

Alarm stage = 80%

Trip stage = 100% maximum overload value

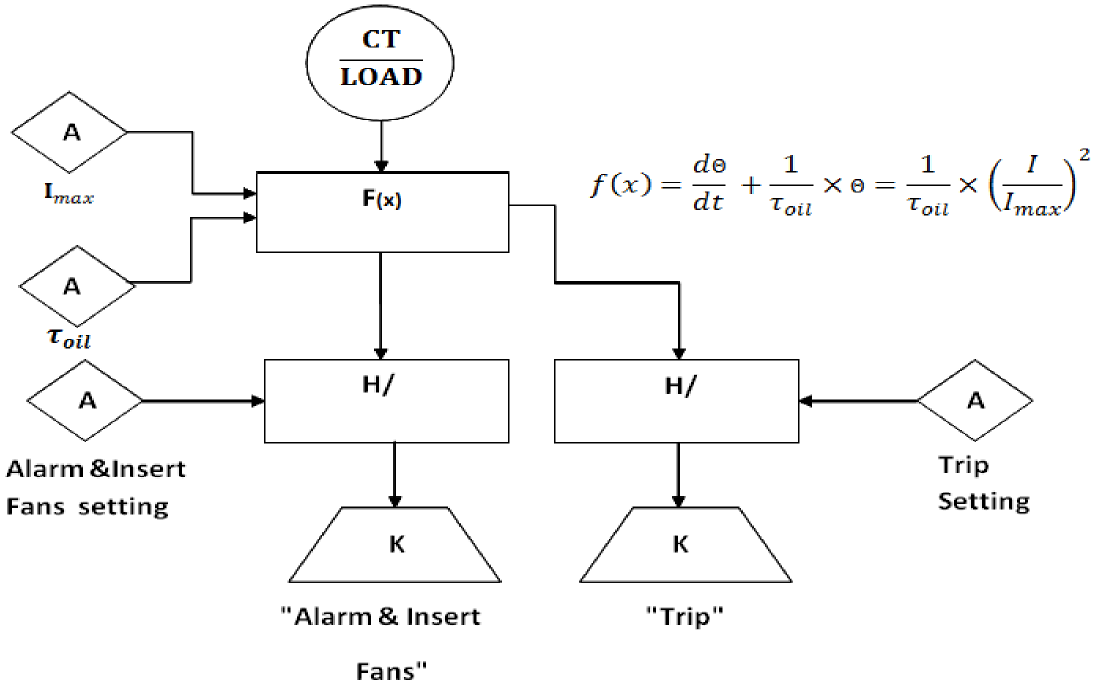

Fig. 3.7: Flowchart of thermal overload protection operation

CHAPTER FOUR

BUSBAR AND SWITCHGEAR PROTECTION

4.1 Protection of Bus bar

Bus-bar is the most important component in a power systems network, here the bus-bar is protected using two methods of protection as following.

4.1.1 Biased current differential protection

The basic operating principle of the differential protection is based on the application of Kirchhoff's law. This compares the amount of current entering and leaving the protected zone and the check zone.

Under normal operation, the amount of current flowing into the area and the check zone concerned is equal in to the amount of the current flowing out of the area. Therefore the currents cancel out. In contrast, when a fault occurs the differential current that arises is equal to the derived fault current. Several methods of summation can be used for a differential protection scheme:

i. Vector sum
ii. Instantaneous sum

The instantaneous sum method has the advantage of cancelling the harmonic and DC components of external origin in the calculation and in particular under transformer inrush conditions. The other advantage of using an instantaneous sum lies in the speed of decision, which in turn is dictated by the sampling. frequency Differential currents may also be generated under external fault conditions due to CTs error.

To provide stability for through fault conditions the relay adopts a biasing technique, which effectively raises the setting of the relay in proportion to the through fault current thereby preventing relay mal-operation. The bias current is the scalar sum of the currents in the protected zone and for the check zone. Each of these calculations is done on a per phase basis for each node and then summated.

4.1.1.1 Bias characteristic and Differential current

The operation of the bus bar differential protection is based on the application of an algorithm having a biased characteristic, (Figure below) in which a comparison is made between the differential current and a bias or restraining current. A trip is only permitted if this differential current exceeds the set slope of the bias characteristic. This characteristic is intended to guarantee the stability of protection during external faults where the scheme has current transformers with differing characteristics, likely to provide differing performance.

The algorithm operands are as follows:

– Differential Current

$$I_{diff}(t) = |\Sigma I| \quad (4.1)$$

– Bias or Restraining current

$$I_{bias}(t) = \Sigma |I| \quad (4.2)$$

– Slope of the bias characteristic

kx

– Tripping permitted by bias element for:

$$I_{diff}x(t) > kx \times I_{bias}(t) \quad (4.3)$$

The main differential current element of the busbar protection will only be able to operate if the differential current reaches a threshold IDx>2. In general, this setting will be adjusted above the normal full load current.

4.1.1.2 Scheme supervision by "check zone" element

The use of a "check zone" element is based on the principle that in the event of a fault on one of the substation bus bars, the differential current measured in the faulty zone will be equal to that measured in the entire scheme. One of the most frequent causes of maloperation of differential bus bar protection schemes is an error in the actual position of an isolator or CB in the substation to that replicated in the scheme (auxiliary contacts discrepancy). This would produce a differential current in one or more current nodes. However, if an element monitors only the currents "entering" and "leaving" the substation, the resultant will remain negligible in the absence of a fault, and the error will lie with the zone's assumption of the plant position at this particular point in time.

4.1.2.1 Bias Characteristic and Differential Current Setting

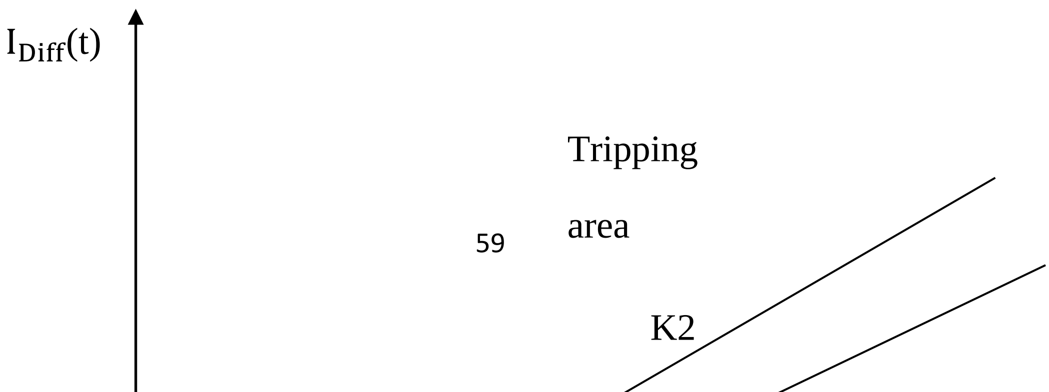

Fig. 4.1: Bias characteristic and differential current.

a) The Phase characteristic is determined from the following protection settings:

• Area above the ID>2 High-set zone differential current threshold setting and the set slope of the bias characteristic is

$k2 \times I_{bias}$

Where,

k2 = the percentage bias setting (“slope”)for the zone.

Note: The origin of the bias characteristic slope is 0.

When an external fault condition causes CT saturation, a differential current is apparent and is equal to the current of the saturated CT. The measured differential current may be determined as an internal fault and initiate an unwanted trip of the bus bar. In order to avoid a risk of tripping under these circumstances, most of the busbar protection use an ultra fast CT saturation detection algorithms.

- Area above the IDCZ>2 High-set check zone differential current threshold setting and the set slope of the bias characteristic is

  $(kCZ \times I_{bias})$

  Where

kCZ = the percentage bias setting ("slope") for the Check Zone
Note: The origin of the bias characteristic slope is 0.

- The check zone is the sum of all the current nodes entering and leaving the substation (feeders).

  Scheme differential current = sum of all differential current feeder nodes:

  $I_{diff}(t)$ CZ = $|\Sigma I_{diff}|$ (4.4)

  The Check Zone will operate as the Zone element.

b) Tripping setting

1. ID>1 as high as possible with a minimum of 2% of the biggest CT primary winding and less than 80% of the minimum load
2. Slope k1 (ID>1) usual recommendation is 10%
3. ID>2 as low as possible, whilst ensuring the single CT failure will not cause tripping under maximum load conditions
4. Slope k2 (ID>2) usual recommendation is generally 65%

   Therefore,

   $I_{Diff}x(t) > 0.65 I_{Bias}z(t)$ (4.5)
5. IDCZ>2 as low as possible
6. Slope kCZ (IDCZ>2) usual recommendation is generally 30%

   Therefore,

   $I_{Diff}x(t) > 0.3 I_{Bias}cz(t)$ (4.6)
7. The differential protection will operate only when

   $I_{Diff}x(t) > 0.65 I_{Bias}z(t)$ **AND** $I_{Diff}x(t) > 0.3 I_{Bias}cz(t)$
8. ID>1 Alarm Timer (from 0 to 100 s) shall be greater than the longest protection time (such as line, over current, etc…)

4.1.2 Over Current Protection

Over current protection is used as backup protection of bus bar.

Setting calculations:

- **Outgoing feeders**

  Since three phase fault current on 110kV bus bar is 9.3kA

Relay type: MiCOM P127

CT data:

Ratio: 1600/1

Class: 30VA, 5P30.

T.M.S= 0.65

$I_{FL} = 787.3A$

$I_s = 800A$

Time of operation is

$$T_{op} = \frac{0.14 \times T.M.S}{(\frac{I_F}{I_s})^{0.02} - 1} \quad (4.7)$$

$= 1.8$ sec

- **110kV bus bar**

Relay type: MiCOM P127

CT data:

Ratio: 1200/1

Class: 30VA, 5P30

$T_{op} = T_{op}$ of OGF +Discrimination time (4.8)

$= 1.8 + 0.3 = 2.1$ sec

Note

(Discrimination time used for relay setting calculation is 0.3 second).

$I_s = 1.2 \times I_{FL}$ (4.9)

$= 944.76$ A

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

T.M.S $= 0.7019$

set T.M.S $= 0.7$

Note

(The current setting is equal to 120% of the full load current of the power transformer).

4.2 Protection of Switchgear

Switchgear is a general term covering all equipment for switching, protection, control and isolation used in a power system Switchgears are necessary at every switching point in the power system because there are several voltage levels and fault levels which has to be controlled and protected by accessible switching devices and for isolation, if the need arises.

4.2.1 Frame leakage protection

This is purely an earth fault system, and in principle involves simply measuring the fault current flowing from the switchgear frame to earth. To this end a current transformer is mounted on the earthing conductor and is used to energize a simple instantaneous relay. This protection can be provided to the metal clad switchgear. The arrangement is shown in the figure below.

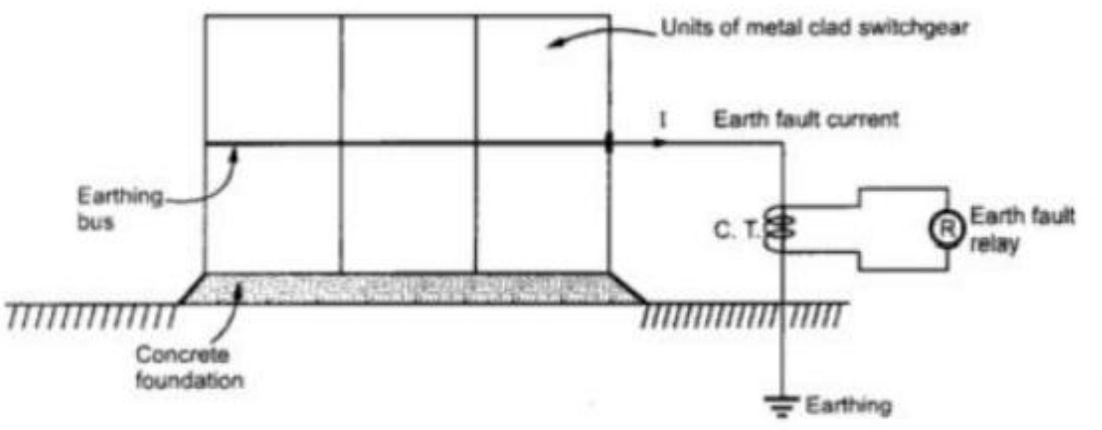

Fig .4.2: Frame leakage protection of switchgear

The metal clad switchgear is lightly insulated from the earth. The enclosure of the frame housing different switchgears is grounded through a primary of current transformer in between. The concrete foundation of switchgear and the other equipments are lightly insulated from the ground. The resistance of these equipments with earth is about 12 ohms. When there is an earth fault, then fault current leaks from the frame and passes through the earth connection provided. Thus the primary of C.T. senses the current due to which current passes through the sensitive earth fault relay, thereby operating the relay.

4.2.2Protection Against Overvoltage Due to Lightning

Surge arresters are used to protect high-voltage equipments in substation, such as transformers circuit breakers and bushings, against the effects of overvoltage's caused by incoming surges. such overvoltage's can be caused by a direct or nearby lightning strike, an electromagnetic pulse, electrostatic discharge, or switching operation in the power supply system as well as in device. some overvoltages are very high in energy. the current from the surge is diverted through the arrester in most causes to earth.

Calculations to choose of the surge arrester can be obtain in five steps as following :

Step 1: Calculation of rated voltage of surge arresters U_r

The rated voltage U_r of surge arrester shall be decided according to the following formula:

$U_r \geq kU_t$

where,

U_r _ the rated voltage of surge arrester;

k _ the factor relevant to the time of breaking short circuit fault,

if the fault was broken within 10s, k=1.0; and if the fault was was broken more than 10s, k = 1.3;

in this substation, the fault shall be broken within 10s, so k=1.0;

U_t_ transient overvoltage.

For the neutral point directly grounded power system, the U_t shall be equal to $1.4\frac{U_m}{\sqrt{3}}$, the U_m is the rated voltage of the power system, Therefore,

i. For 220KV system,

$$U_r \geq kU_t = k\times(1.4\times\frac{U_m}{\sqrt{3}}) \quad (4.10)$$

$$U_r \geq kU_t = k\times(1.4\times\frac{U_m}{\sqrt{3}}) = 1\times(1.4\times\frac{245}{\sqrt{3}}) = 198.03KV$$

ii. For 110KV system,

$$U_r \geq kU_t = k\times(1.4\times\frac{U_m}{\sqrt{3}}) = 1\times(1.4\times\frac{123}{\sqrt{3}}) = 99.42KV$$

iii. For 33KV system,

iv. $U_r \geq kU_t = k\times(1.4\times\frac{U_m}{\sqrt{3}}) = 1\times(1.4\times\frac{36}{\sqrt{3}}) = 29.1KV$

According to the calculation result, the rated voltage of the chosen surge arresters in table 1 can meet the requirement.

Step 2: Maximum continuous operating voltage U_c

The maximum continuous operating voltage U_c shall be decided according to the following formula:

$$U_c \geq 0.8U_r \quad (4.11)$$

and

$$U_c \geq U_t/\sqrt{3} \quad (4.12)$$

Where,

U_r = the rated voltage of the surge arrester;

U_m = the rated voltage of power system.

Therefore,

i. For 220KV system,

$U_c \geq 0.8U_r$, as in the table 1, $U_r = 204kV$,

$U_c \geq 0.8U_r = 0.8\times204 = 163.2$ kV

and $U_c \geq U_m/\sqrt{3} = \frac{245}{\sqrt{3}} = 141.45$ kV so, $U_c \geq 163.2$ kV

ii. For 110kV system,

$U_c \geq 0.8U_r$, as in the table, $U_r = 102$kV,

$U_c \geq 0.8U_r = 0.8\times102 = 81.6$ kV

and $U_c \geq U_m/\sqrt{3} = \frac{123}{\sqrt{3}} = 71.01$ kV

so, $U_c \geq 81.6$ kV

iii. For 33kV system,

$U_c \geq 0.8U_r$, as in the table, $U_r = 45$kV,

$U_c \geq 0.8U_r = 0.8\times45 = 36$ kV

and $U_c \geq U_m/\sqrt{3} = \frac{36}{\sqrt{3}} = 20.78$ kV

so, $U_c \geq 36$ kV

According to the calculation result, the maximum continuous operating voltage of the chosen surge arresters shown in table 1 can meet the requirement.

Step 3: Standard nominal discharge current

According to the 4.2 of IEC 60099-4.2004, for surge arresters $3 \leq U_r \leq 360$kV, the standard nominal discharge current shall be 10kA.

Step 4: Choice of residual voltage for lightning impulse U_{rvl}

According to insulation co-ordination, the residual voltage for lightning impulse U_{rvl} shall be

$$U_{rvl} \leq \frac{U_{pl}}{K_c} \quad (4.13)$$

Where,

U_{pl} = Lightning impulse withstand voltage of electrical equipment;

K_c = Lightning impulse co-ordination factor, normally K_c should be greater than 1.4, that means when surge arrester act because of lightning wave, the residual voltage effecting on the protected electrical equipment shall be 40% under the lightning impulse withstand voltage of the equipment to keep the safe margin.

According to the relevant parameters the tables, the actual K_c of chosen surge arresters are:

1) For 220kV system,

$$K_c = \frac{U_{pl}}{U_{rvl}} \tag{4.14}$$

$$K_c = \frac{U_{pl}}{U_{rvl}} = \frac{1050}{506} = 2.075$$

2) For 110kV system,

$$K_c = \frac{U_{pl}}{U_{rvl}} = \frac{550}{253} = 2.17$$

3) For 33kV system,

$$K_c = \frac{U_{pl}}{U_{rvl}} = \frac{185}{115} = 1.61$$

All are greater than 1.4.

Step 5: Choice of residual voltage for chopped impulse U_{rvs}

According to insulation co-ordination, the residual voltage for steep impulse U_{rvs} shall be

$$U_{rvs} \leq \frac{1.15U_{pl}}{K_s}$$

Where,

U_{pl} = Lightning impulse withstand voltage of electrical equipment;

K_s = steep impulse co-ordination factor.

1. For 220kV system,

$$K_s = \frac{U_{pl}}{U_{rvs}} = \frac{1.15 \times 1050}{557} = 2.17$$

2. For 110kV system,

$$K_s = \frac{U_{pl}}{U_{rvs}} = \frac{1.15 \times 550}{279} = 2.27$$

3. For 33 kV system,

$$K_s = \frac{U_{pl}}{U_{rvs}} = \frac{1.15 \times 185}{132} = 1.61$$

All are greater than 1.4.

Table 4.1: Choice of residual voltage for chopped impulse

Nominal Voltage of system U_n (kV)	Rated Voltage of system U_m (kV)	Main parameters of surge arrester chosen by design			
		Rated voltage U_r (kV)	Maximum continuous operating voltage (kV)	Standard nominal discharge current (kA)	Residual Voltage for lightning Impulse (kV)
220	245	204	163.2	10	506
110	123	102	81.6	10	253
33	36	45	36	10	115

Table 4.2: Residual voltage and Lightning impulse withstand voltage

Nominal voltage of system U_n(kV)	Main parameters of surge arrester chosen by design	
	Residual voltage for chopped impulse (kV)	Lightning impulse withstand voltage (kV)
220	557	1050
110	279	550
33	132	185

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The project objectives have been achieved where the 220kV/110kV substation 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.

Bus bars are one of the most critical components where all the power system equipments are connected, needs an important attention from protection and from reliability point of view. The following schemes i.e., differential protection, over current protection were used to protect bus bars. and also secondary equipment (switchgear) are protected using frame leakage protection and surge arrester.

5.2 Recommendations

According to this project and the facts that we had known during the operation in project, we recommend the following points:

- Numerical relays must be brought in the protection laboratory in the university instead of or with the electromechanical relays, and then the students will understand and have full information about the last technique in protection field.
- As the ETAP program become very important program in electrical engineering field, it must be learned in the university , and then the students will not find any difficulties to deal with it during they do their projects.

- As Al_mahdia substation one of the biggest transformation substations in the national grid, the reliability must be utilized to it, and the future studies must execute the following recommendations to utilize that:
    i. The distribution substation which feeds the local area must be protection by using last versions of numerical relays.
    ii. The transmission lines which feed Khartoum North via Al_mahdia- Ezergap transmission line and feed Omdurman an Khartoum via Al_mahdia-Omdurman-Banat- Al_mugran transmission line must be protected also and then full protection of substation is achieved.

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Appendices

Appendix A

Introduction

ETAP 12.6 is considered as one of the important programs used for studying and analyzing the transient and dynamic performances for electrical power systems under different operation conditions in Microsoft windows operation system. It used to obtain high level performance for big grids which require intensive calculations and online monitoring for control applications of those grids.

ETAP 12.6 depends on the work regulation by considering each file as independent project containing electrical power system include a group of connected electrical elements to analyze this system in addition to a group of control elements are provided to user. With the ETAP power station program can build one-line diagram, underground raceway system,

load flow, motor starting and transit stability and other studies of power systems with both simple and composite structure.

The Main Interface of Program

Fig.1.1: Bar Tests Study Status

This mode provides a variety of tasks and studies such as following:

1. Edit
2. Load Flow Analysis
3. Short Circuit Analysis

4. Motor Acceleration Analysis
5. Harmonic Analysis
6. Transient Stability Analysis
7. Star-protective Device Coordination
8. DC Load Flow Analysis
9. DC Short Circuit Analysis
10. Battery Discharge Sizing
11. Unbalanced Load Flow Analysis
12. Optimal Power Flow Analysis
13. Reliability Assessment
14. Optimal Capacitor Placement
15. Switching Sequence Management

Toolbar and Components

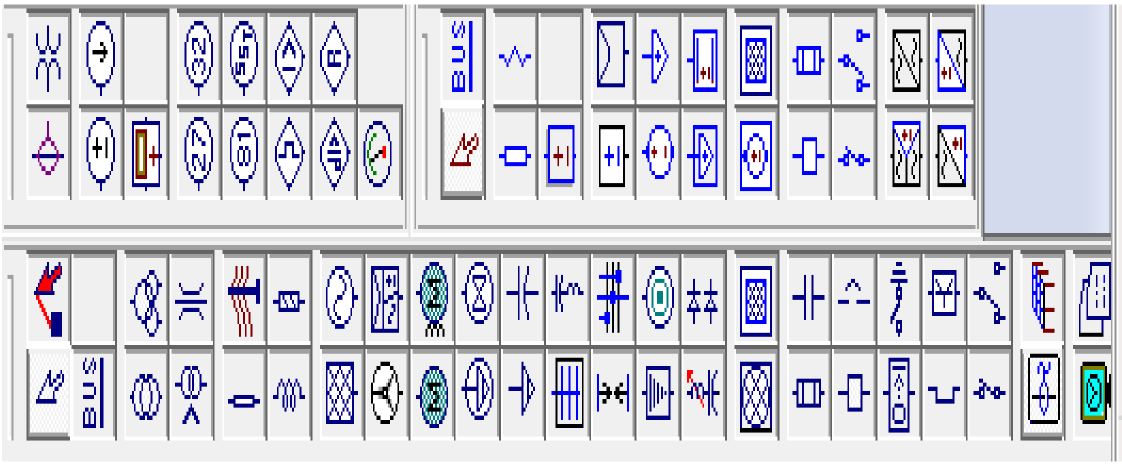


Fig.1.2: Toolbar and Components

Appendix B

The Basic Components of the Process Circuit:

1- Power grid
2- Bus-bar
3- Power transformer three winding
4- Static load
5- Circuit breaker
6- Current and voltage transformer
7- Relays

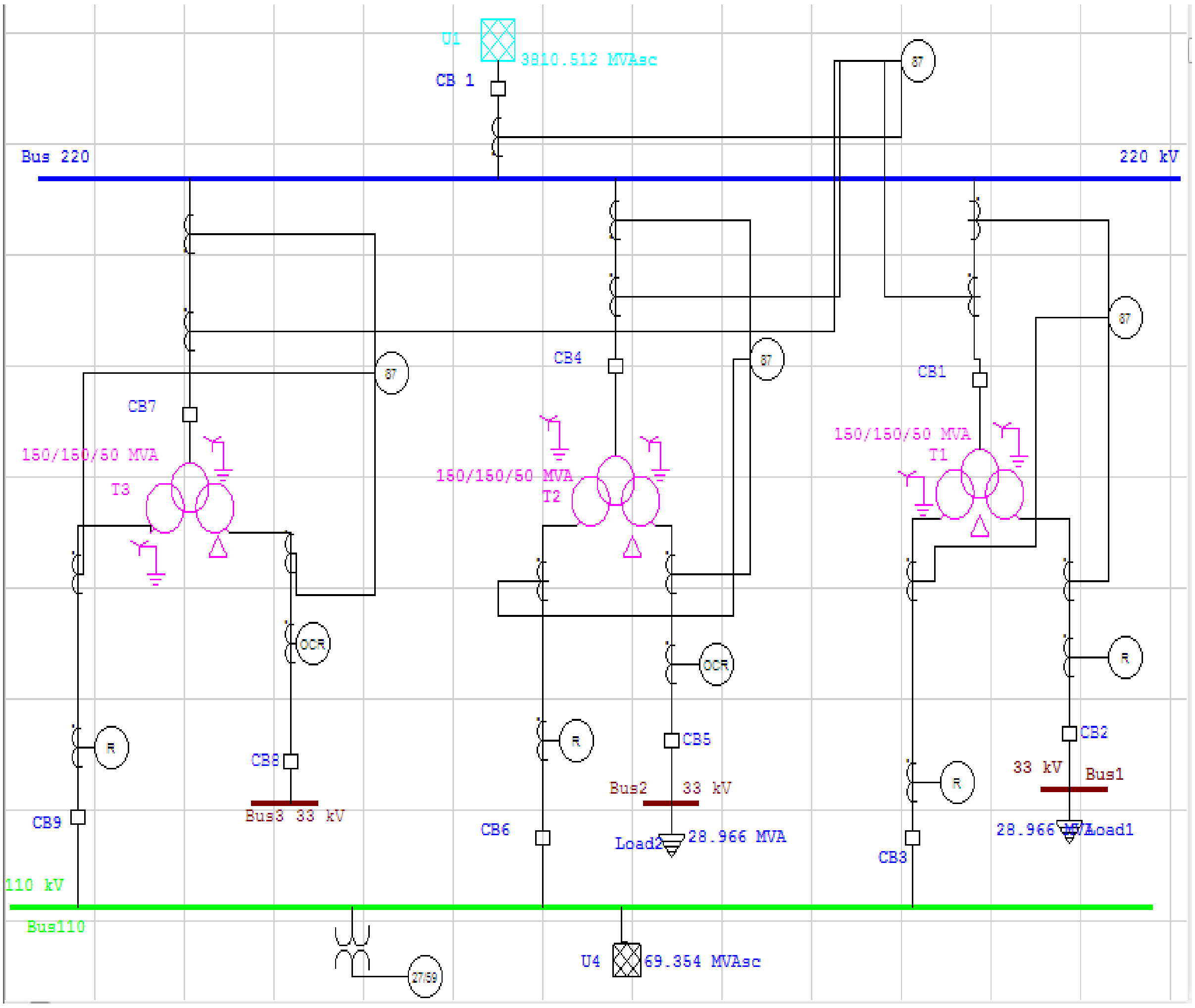


Fig 2.1: The Basic Compponents of the Process Circuit

Data Entry:

The input of the circuit data is done by entering the data of each individual unit according to the requirements.

Power Grid data:

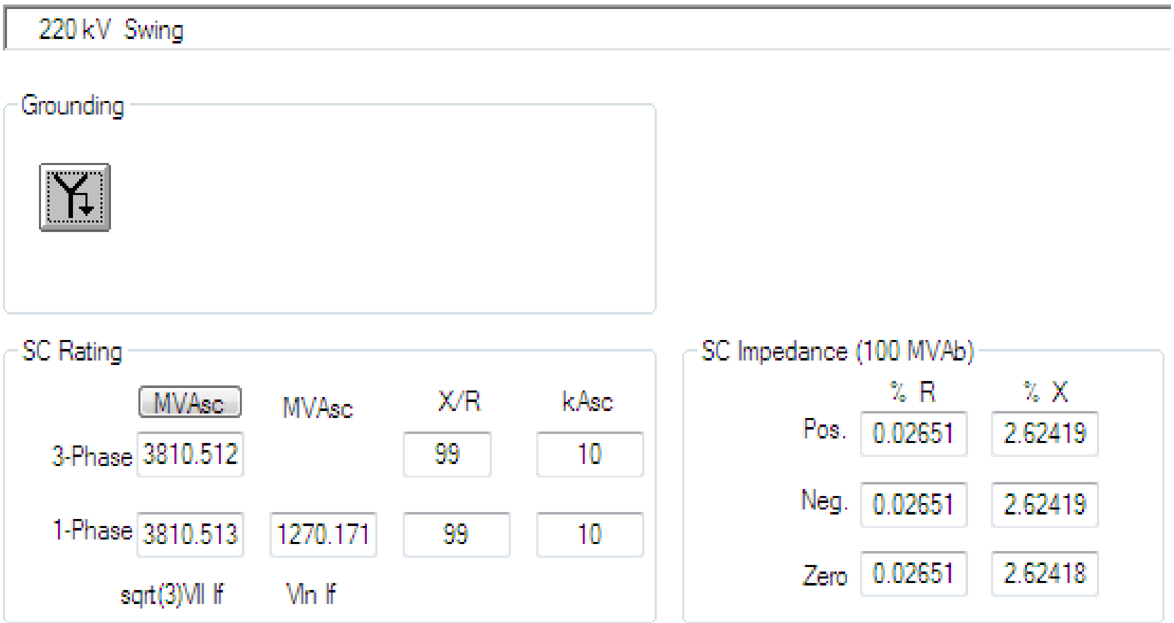


Fig 2.2 Power Grid Data Entering

Power Transformer Data:

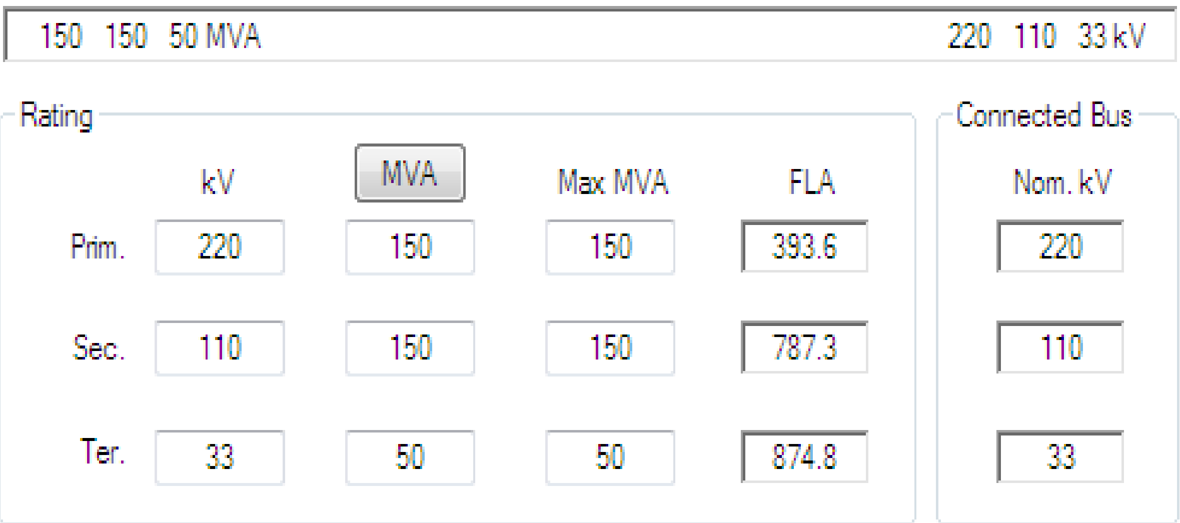


Fig.2.3 rated voltage and power

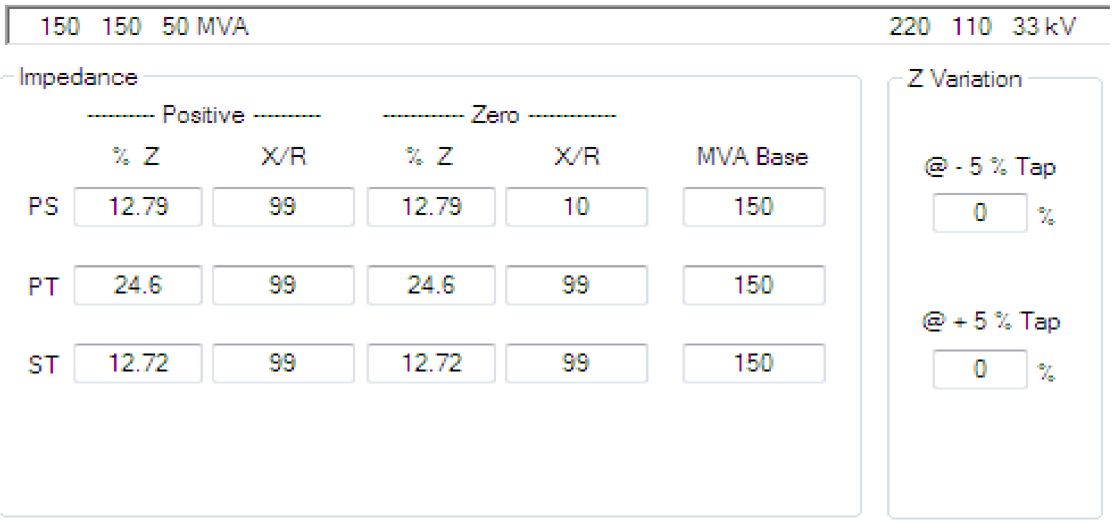
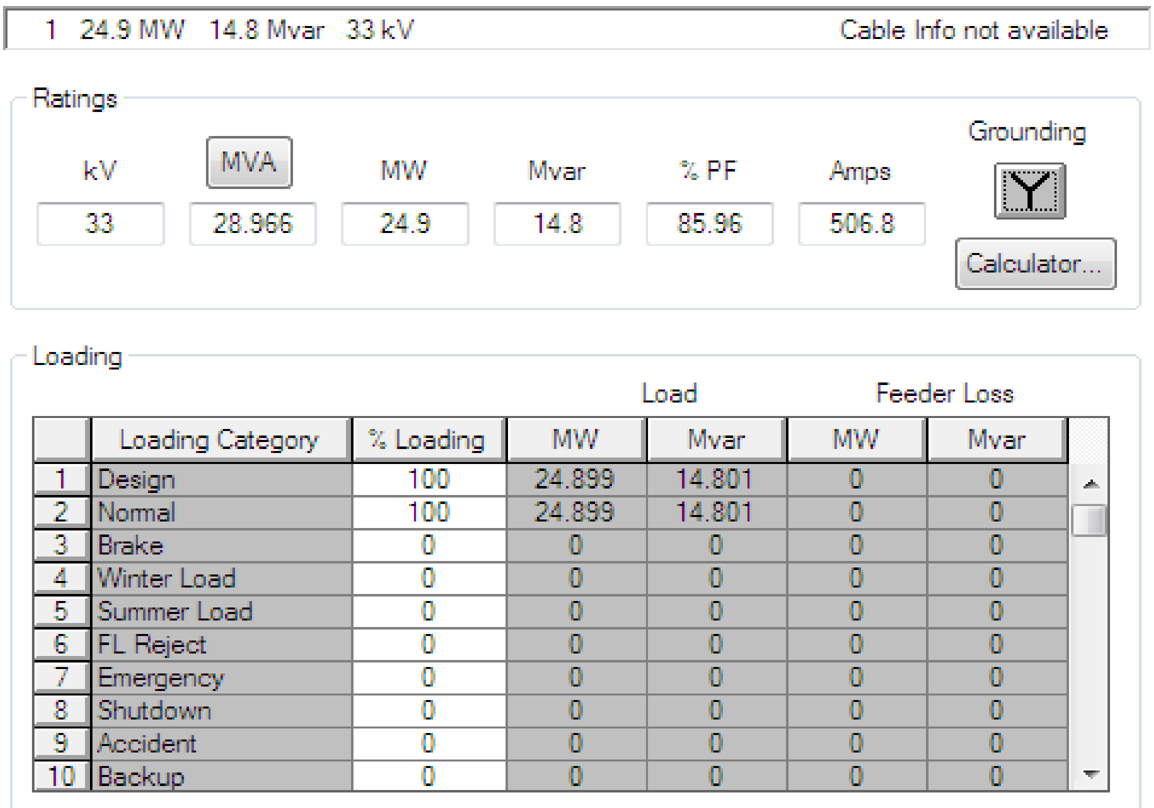


Fig 2.4 Impedance data

Static load Data:



	Loading Category	% Loading	Load MW	Load Mvar	Feeder Loss MW	Feeder Loss Mvar
1	Design	100	24.899	14.801	0	0
2	Normal	100	24.899	14.801	0	0
3	Brake	0	0	0	0	0
4	Winter Load	0	0	0	0	0
5	Summer Load	0	0	0	0	0
6	FL Reject	0	0	0	0	0
7	Emergency	0	0	0	0	0
8	Shutdown	0	0	0	0	0
9	Accident	0	0	0	0	0
10	Backup	0	0	0	0	0

Fig 2.5 Static Load Data

Current and voltage transformer Data:

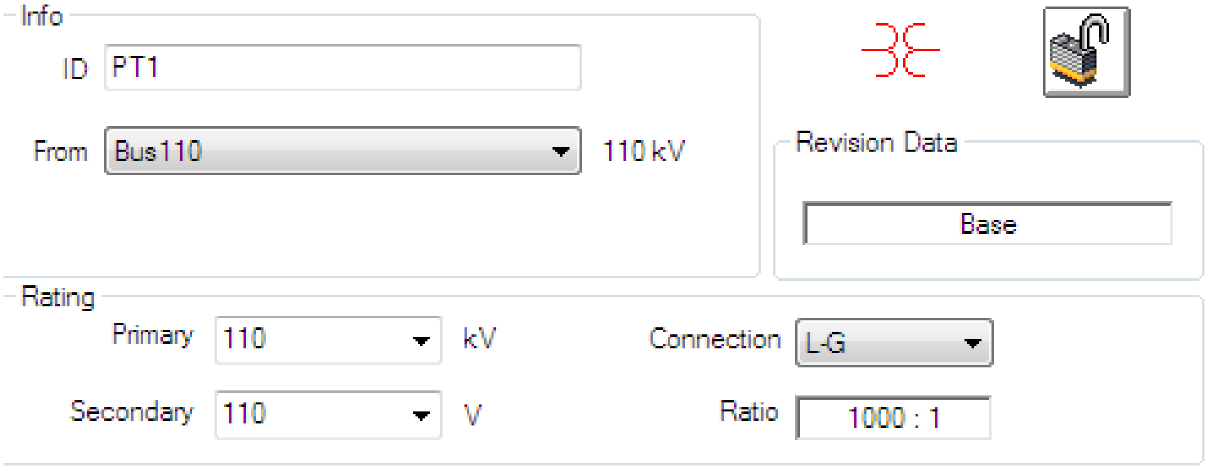


Fig 2.6 Voltage Transformer Data

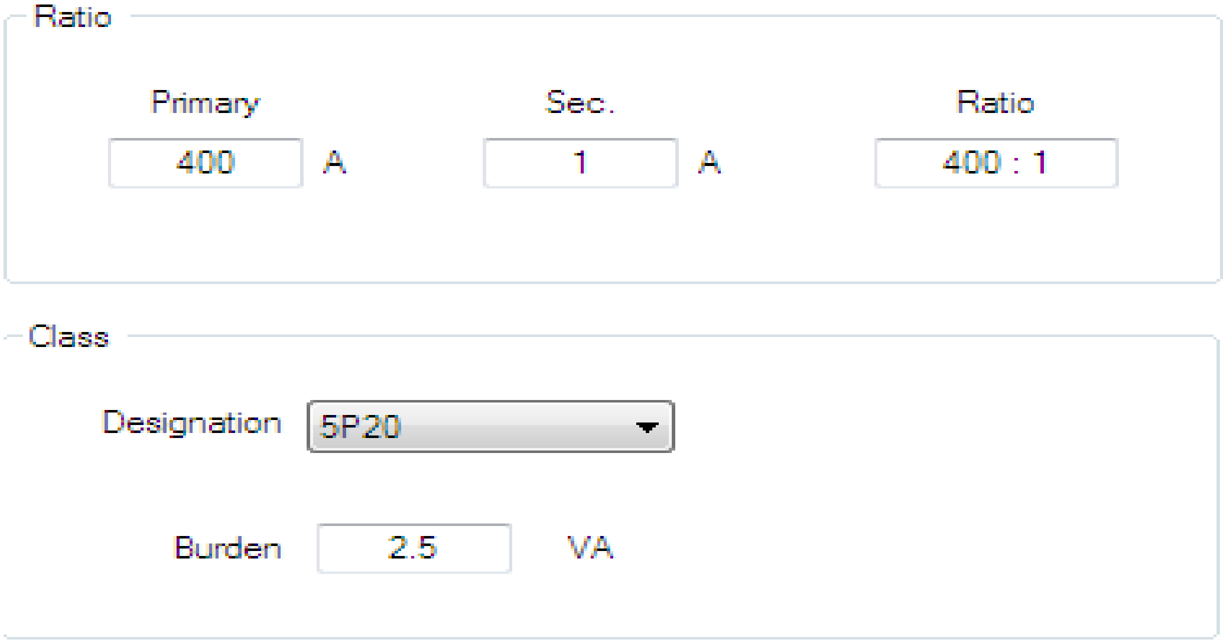


Fig.2.7 Current Transformer Data

Circuit Breaker Data

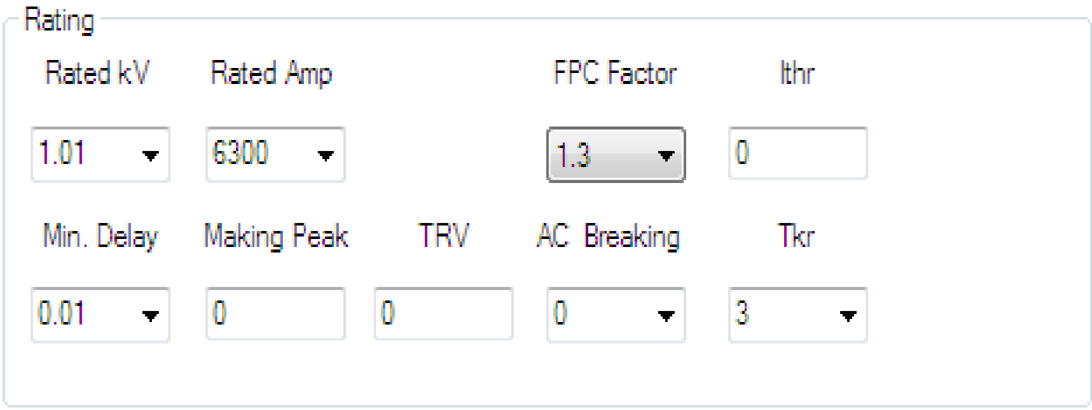


Fig.2.8 Circuit Breaker Data

Bus-bar Data

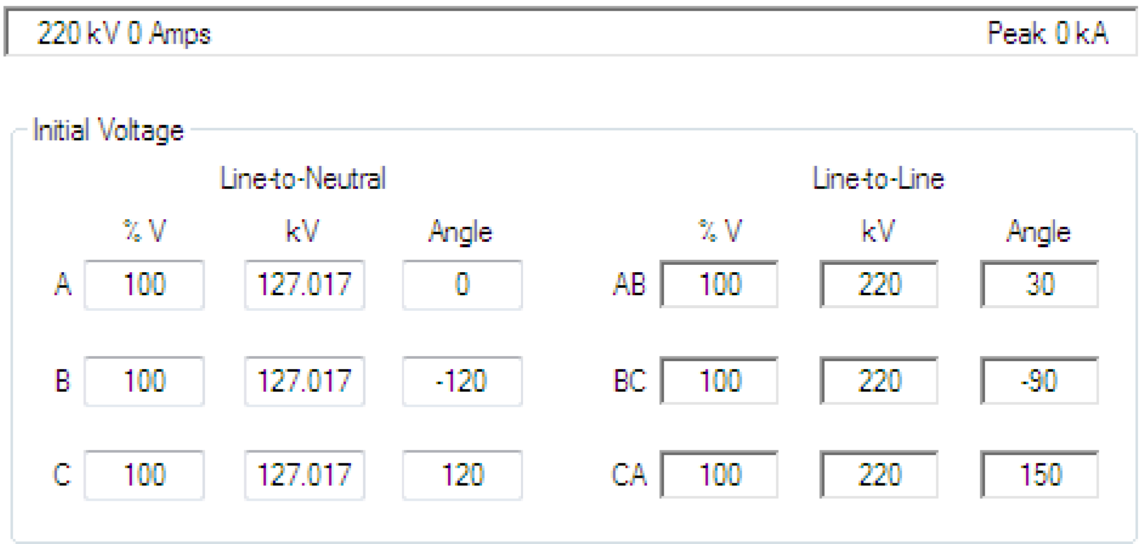


Fig .2.9 Bus-bar Data

Appendix C

Comparison of Protection Relay Types:

Characteristic	Electromechanical Relay	Static Relay	Digital Relay	Numerical Relay
Technology Standard	1st generation relays.	2nd generation relays.	Present generation relays.	Present generation relays.
Operating Principle	They use principle of electromagnetic principle.	In this relays transistors and IC's been used	They use microprocessor. Within built software with predefined values	They use microprocessor. Within built software with predefined values
Measuring elements/ Hardware	Induction disc, electromagnets, induction cup, balance beam	R, L, C, transistors, analogue ICs comparators	Microprocessors, digital ICs, digital signal processors	Microprocessors, digital ICs, digital signal processors
Measuring method	Electrical force converted into mechanical force, torque	Level detects, comparison with reference value in analogue comparator	A/D conversion, numerical algorithm techniques	A/D conversion, numerical algorithm techniques
Relay Size	Bulky	Small	Small	Compact
Speed of Response	Slow	Fast	Fast	Very fast
Timing function	Mechanical clock works, dashpot	Static timers	Counter	Counter
Time of Accuracy	Temp. dependant	Temp. dependant	Stable	Stable
Reliability	High	Low	High	High
Vibration Proof	No	Yes	Yes	Yes
Characteristi	Limited	Wide	Wide	Wide

cs				
Requirement of Draw Out	Required	Required	Not required	Not required
CT Burden	High	Low	Low	Low
CT Burden	8 to 10 VA	1 VA	< 0.5 VA	< 0.5 VA
Reset Time	Very High	Less	Less	Less
Auxiliary supply	Required	Required	Required	Required
Range of settings	Limited	Wide	Wide	Wide
Isolation Voltage	Low	High	High	High
Function	Single function	Single function	Multi function	Single function
Maintenance	Frequent	Frequent	Low	Very Low
Resistance	100 mille ohms	10 Ohms	10 Ohms	10 Ohms
Output Capacitance	< 1 Pico Farad	> 20 Pico Farads	> 20 Pico Farads	> 20 Pico Farads
Deterioration due to Operation	Yes	No	No	No
Relay Programmin g	No	Partially	Programmabl e	Programmable
SCADA Compatibilit y	No	No	Possible	Yes
Operational value indication	Not Possible	Possible	Possible	Possible
Visual indication	Flags, targets	LEDs	LEDs, LCD	LEDs, LCD

Self monitoring	No	Yes	Yes	Yes
Parameter setting	Plug setting, dial setting	Thumb wheel, dual in line switches	Keypad for numeric values, through computer	Keypad for numeric values, through computer
Fault Disturbance Recording	Not possible	Not possible	Possible	Possible