Design Of Protection Scheme For Three Phase Transformer

A Major Project Report

Submitted to the Rajasthan Technical University

in partial fulfillment of requirements for the award of degree

Bachelor of Technology

in

Electrical Engineering

by

Bhuveneshwari Dhamala

18ETCEE003

DEPARTMENT OF ELECTRICAL ENGINEERING

TECHNO INDIA NJR INSTITUTE OF TECHNOLOGY

UDAIPUR, RAJASTHAN

June 2022

DEPARTMENT OF ELECTRICAL ENGINEERING

TECHNO INDIA NJR INSTITUTE OF TECHNOLOGY UDAIPUR, RAJASTHAN

2021 - 22

CERTIFICATE

This is to certify that the report entitled **Design Of Protection Scheme For Three Phase Transformer** submitted by **Bhuveneshwari Dhamala** (18ETCEE003), to Department of Electrical Engineeringin partial fulfillment of the B.Tech. degree in **Electrical Engineering** is a bonafide record of the seminar work carried out by her under our guidance and supervision. This report in any form has not been submitted to any other University or Institute for any purpose.

Dr. Abrar Ahmed Chhipa
(Project Guide)
Assistant Professor
Dept.of EE
Techno India NJR Institute
of Technology
Udaipur, Rajasthan

Mr. Rajkumar Soni
(Project Coordinator)
Assistant Professor
Dept.of EE
Techno India NJR Institute
of Technology
Udaipur, Rajasthan

Dr. Prakash Bahrani
Professor and Head
Dept.of EE
Techno India NJR Institute of Technology
Udaipur, Rajasthan

DECLARATION

I Bhuveneshwari Dhamala hereby declare that the major project report **Design Of Protection Scheme For Three Phase Transformer**, submitted for partial fulfillment of the requirements for the award of degree of Bachelor of Technology of the Rajasthan Technical University, Kota, Rajasthan is a bonafide work done by me under supervision of Dr. Abrar Ahmed Chhipa

This submission represents my ideas in my own words and where ideas or words of others have been included, I have adequately and accurately cited and referenced the original sources.

I also declare that I have adhered to ethics of academic honesty and integrity and have not misrepresented or fabricated any data or idea or fact or source in my submission. I understand that any violation of the above will be a cause for disciplinary action by the institute and/or the University and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been obtained. This report has not been previously formed the basis for the award of any degree, diploma or similar title of any other University.

Bhuveneshwari

Bhuveneshwari Dhamala

Udaipur

13-06-2022

Acknowledgement

I take this opportunity to express my deepest sense of gratitude and sincere thanks to everyone who helped me to complete this work successfully. I express my sincere thanks to **Dr. Prakash Bahrani**, Head of Department, Electrical Engineering, Techno India NJR Institute of Technology Udaipur for providing me with all the necessary facilities and support.

I would like to express my sincere gratitude to **Mr. Rajkumar Soni**, department of Electrical Engineering, Techno India NJR Institute of Technology, Udaipur for their support and co-operation.

I would like to place on record my sincere gratitude to my project guide **Dr. Abrar Ahmed Chhipa**, Assistant Professor, Electrical Engineering, Techno India NJR Institute of Technology for the guidance and mentorship throughout the course.

Finally I thank my family, and friends who contributed to the succesful fulfilment of this project work.

Bhuveneshwari

Bhuveneshwari Dhamala

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Chapter 1

Introduction

The electrical power produced at generating stations needs to be transferred over high voltage transmission lines to the load center. The power transformer is one of the most important components in a power-system network. Because of its relatively simple construction, it is a highly reliable piece of equipment. Being a static device, totally enclosed and oil immersed, it rarely develops faults. The consequences of even a rare fault may be serious unless the transformer is quickly disconnected from the system.

1.1 Transformer

A transformer is a passive component that transfers electrical energy from one electrical circuit to another circuit, or multiple circuits. A varying current in any coil of the transformer produces a varying magnetic flux in the transformer's core, which induces a varying electromotive force across any other coils wound around the same core. Electrical energy can be transferred between separate coils without a metallic (conductive) connection between the two circuits. Faraday's law of induction, discovered in 1831, describes the induced voltage effect in any coil due to a changing magnetic flux encircled by the coil. Transformers are used to change AC voltage levels, such transformers being termed step up or step-down type to increase or decrease voltage level, respectively. Transformers can also be used to provide galvanic isolation between circuits as well as to couple stages of signal-processing circuits. Since the invention of the first constant-potential transformer in 1885, transformers have become essential for the transmission,distribution, and utilization of alternating current electric power.[2] A wide range of transformer designs is encountered in electronic and electric power applications. Transformers range in size from RF transformers less than a cubic centimeter in volume, to units weighing hundreds of tons used to interconnect the power grid.

1.2 Working Principle of a Transformer

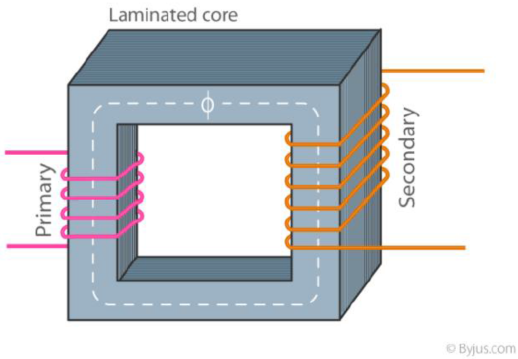


Fig. 1. 1 Transformer

Figure 1.1: Transformer

The transformer works on the principle of Faraday’s law of electromagnetic induction and mutual induction.

There are usually two coils, a primary coil and a secondary coil on the transformer core.The core laminations are joined in the form of strips. The two coils have high mutual inductance. When an alternating current passes through the primary coil it creates a varying magnetic flux. As per faraday’s law of electro magneticinduction, this change in magnetic flux induces an emf (electromotive force) in the secondary coil which is linked to the core having a primary coil. This is mutual induction.

Overall, a transformer carries out the operations below:

1. Transfer of electrical energy from circuit to another
2. Transfer of electrical power through electromagnetic induction
3. Electric power transfer without any change in frequency
4. Two circuits are linked with mutual induction sectionWorking Principle of a Transformer

The figure shows the formation of magnetic flux lines around a current-carrying wire. The normal of the plane containing the flux lines are parallel to normal of a cross-section of a wire.

The figure shows the formation of varying magnetic flux lines around a wire-

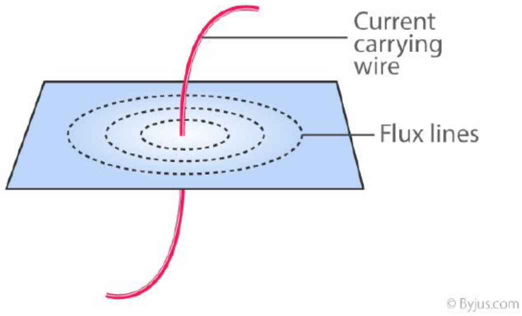


Figure 1.2: Formation of magnetic flux around a current carrying wire

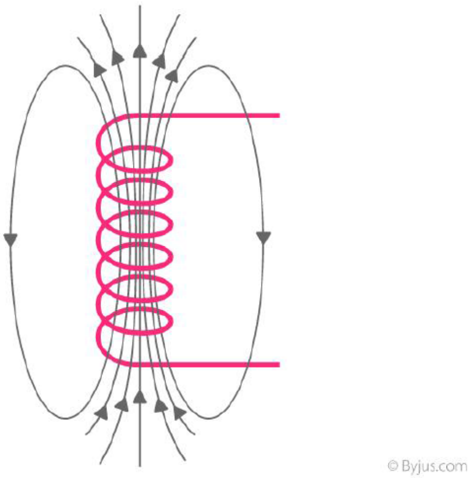


Figure 1.3: The formation of varying magnetic flux lines around a wire-wound

wound. The interesting part is that the reverse is also true, when a magnetic flux line fluctuates around a piece of wire, a current will be induced in it. This was what Michael Faraday found in 1831 which is the fundamental working principle of electric generators as well as transformers.

1.3 EMF Equation of Transformer

N1 – number of turns in primary.

N2 – number of turns in secondary.

m – maximum flux in weber (Wb).

T – time period. Time is taken for 1 cycle.

The flux formed is a sinusoidal wave. It rises to a maximum value m and decreases to negative maximum m. So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to T/4.

Average rate of change of flux = m/(T/4) = 4fm

Where f = frequency

T = 1/f

Induced emf per turn = rate of change of flux per turn

Form factor = rms value / average value

Rms value = 1.11 (4fm) = 4.44 fm [form factor of sine wave is 1.11]

RMS value of emf induced in winding = RMS value of emf per turn x no of turns

Primary Winding

Rms value of induced emf = E1 = 4.44 fm * N1

Secondary winding:

Rms value of induced emf = E2 = 4.44 fm * N2

This is the emf equation of the transformer.

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = k$$

For an ideal transformer at no load condition,

E1 = supply voltage on the primary winding.

E2 = terminal voltage (theoretical or calculated) on the secondary winding.

Voltage Transformation Ratio:

K is called the voltage transformation ratio, which is a constant.

Case1: if N2 ¿ N1, K¿1 it is called a step-up transformer.

Case 2: if N2¡ N1, K¡1 it is called a step-down transformer.

Transformer Efficiency:

Comparing system output with input will confirm transformer efficiency. The system is called better when its efficiency is high.

$$Efficiency\,(\eta) = \frac{Outputpower}{Inputpower} \times 100$$
$$Efficiency\,(\eta) = \frac{P_{out}}{P_{out}+P_{loses}} \times 100$$
$$Efficiency\,(\eta) = \frac{V_2 I_2 cos\theta}{V_2 I_2 cos\theta + P_c + P_{cm}} \times 100$$

Where $P_{cu} = P_{sc}$

$P_c = P_{oc}$

$$\eta(_{fullload}) = \frac{VAcos\theta}{VAcos\theta + P_c + P_{cm}} \times 100$$
$$\eta(_{loadn}) = \frac{nVAcos\theta}{nVAcos\theta + P_c + n^2 P_{cm}} \times 100$$

1.4 Transformer Types

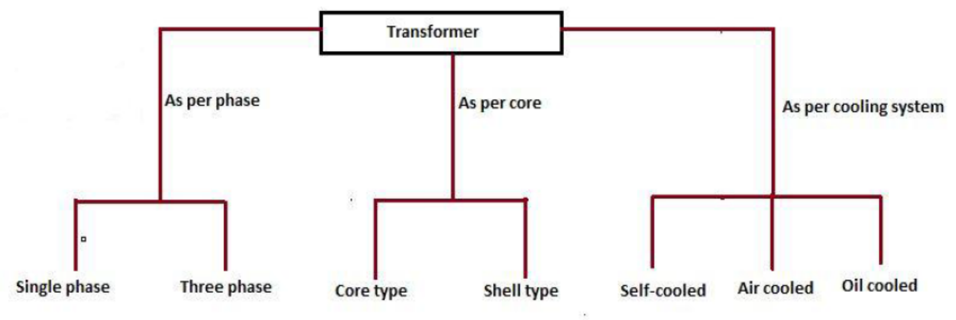
Transformers are used in various fields like power generation grid, distribution sector,transmission and electric energy consumption. There are various types of transformers which are classified based on the following factors;

• Working voltage range.

• The medium used in the core.

• Winding arrangement.

• Installation location.



Based on Voltage Levels:

Commonly used transformer type, depending upon voltage they are classified as:

• Step-up Transformer: They are used between the power generator and the power grid. The secondary output voltage is higher than the input voltage

• Step down Transformer: These transformers are used to convert high voltage primary supply to low voltage secondary output.

Based on the Medium of Core Used: In a transformer, we will find different types of cores that are used.

• Air core Transformer: The flux linkage between primary and secondary winding is through the air. The coil or windings wound on the non-magnetic strip.
• Iron core Transformer: Windings are wound on multiple iron plates stacked together, which provides a perfect linkage path to generate flux.

Based on the Winding Arrangement:
• Autotransformer: It will have only one winding wound over a laminated core. The primary and secondary share the same coil. Auto also means "self" in language Greek.
Based on Install Location:
• Power Transformer: It is used at power generation stations as they are suitable for high voltage applications.
• Distribution Transformer: Mostly used at distribution lanes for domestic purposes. They are designed for carrying low voltages. It is very easy to install and characterized by low magnetic losses.
• Measurement Transformers: These are further classified. They are mainly used for measuring voltage, current, and power.
• Protection Transformers: They are used for component protection purposes. In circuits, some components must be protected from voltage fluctuation etc.Protection transformers ensure component protection.

1.5 Three-Phase Transformer

Three-phase transformers are used in three-phase circuits to step up and step down the voltage according to the needs in a power system. The transformers are designed to operate on three phase supply and are known as three phase transformers. Transformation of three phase alternating current from one volt age to another can be carried out either by using a single unit of three phase transformer or a bank of suitably connected three separate single-phase transformers. In practice, for three phase circuits,use of a three-phase transformer is generally preferred over a bank of three single phase transformers. The pictorial view of three phase transformer shown in Figure 1.4.

Figure 1.4: Three Phase Transformer pictorial view

1.6 Working Principle of Three Phase Transformer

To understand the operation of a three-phase transformer, consider three single phase transformers (secondaries eliminated for clarity) arranged as illustrated in Fig. 2. with their cores at 120° and touching each other. The primaries of these transformers are connected to a three-phase ac supply. As a result, the cores are magnetized and the center leg formed by the three cores carries the sum of the three fluxes P1, P2, and 3 produced by the three phase currents 11, 12, and 13 respectively

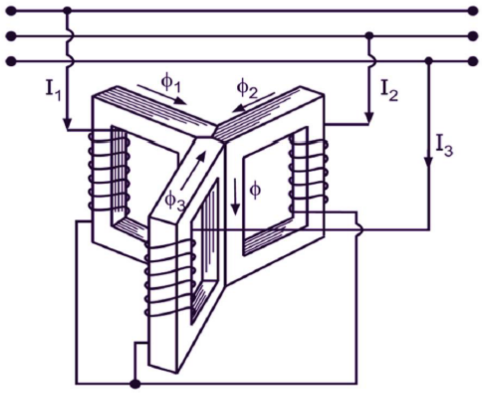


Figure 1.5: Principal of a Three phase transformer

As the sum of these three currents (differing in phase by 120°) at any instant is zero, the sum of the three fluxes meeting in the common leg must also be zero.

Hence, the common leg which carries no appreciable flux can be safely eliminated without disturbing the other conditions. This is because under such a condi tion, any two legs can provide the return path for the flux in the third leg. From the point of view of core construction, this is the principle adopted in the case of a three phase transformer. It considerably reduces the size and weight of a three phase trans former. The actual shape of the core used depends on the type of the transformer. The three phase transformer is constructed in two ways.

1. Three separate single phase transformers are suitably connected for three phase operation.

2. A single three-phase transformer in which the cores and windings for all three phases are merged into a single structure. The three single-phase transformers can be used as a three-phase transformer when their primary and secondary winding are connected to each other. The three-phase transformer supply has many advantages as compared to three single phase units like it requires very less space and also very lighter smaller and cheaper in size. The three phase transformer is mainly classified into two types, i.e., the core type transformer and the shell type transformer.

1.6.1 Core Type Three Phase Transformer

Consider a three single phase core type transformer positioned at 120° to each other as shown in the figure below. If the balanced three-phase sinusoidal voltages are applied to the windings, the fluxes a, b and c will also be sinusoidal and balanced. If the three legs carrying these fluxes are combined, the total flux in the merged leg becomes zero.This leg can, therefore, be removed because it carries the no flux. This structure is not convenient for the core.

The core of the three phase transformer is usually made up of three limbs in the same plane. This can be built using stack lamination. The each leg of this core carries the low voltage and high voltage winding. The low voltage windings are insulated from the core than the high voltage windings.

The low windings are placed next to the core with suitable insulation between the core and the low voltage windings. The high voltage windings are placed over the low

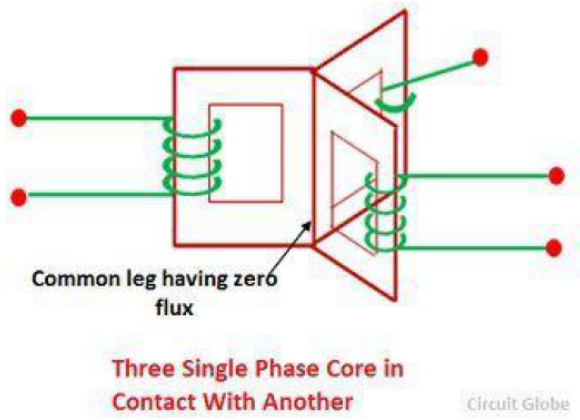


Figure 1.6: Core type three phase transformer

voltage windings with suitable insulation between them. The magnetic paths of leg a and c are greater than those of leg b, the construction is not symmetrical, and there is a resultant imbalance in the magnetizing current.

1.6.2 Shell type Three Phase Transformer

The shell type 3-phase transformer can be constructed by stacking three single phase shell transformers as shown in the figure below.The winding direction of the central unit b is made opposite to that of units a and c. If the system is balanced with phase sequence a-b-c, the flux will also be balanced

The magnitude of this combined flux is equal to the magnitude of each of its components.The cross-section area of the combined yoke is same as that of the outer leg and top and bottom section of the yoke. The imbalance in the magnetic path has very little effect on the performance of the three shell-type transformers. The windings of the shell type three phase transformer are either connected in delta or star as desired.

1.7 FAULTS IN TRANSFORMERS

Faults can be divided into three main classes

(a) Faults in the auxiliary equipment of the transformer

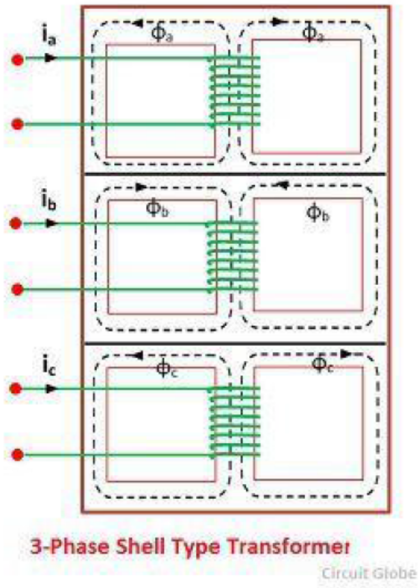


Figure 1.7: Shell type three phase transformer

(b) Internal faults in the transformer windings

(c) External faults

a.) Faults in the Auxiliary Equipment

These faults are usually minor faults. They do not affect the transformer immediately but, if allowed to persist, these may develop into faults within the transformer Therefore,such faults must be detected. The various faults in auxiliary equipment are as follows

(1)Oil Leakage in the Transformer Tank

(i) Deterioration of Dielectric Strength of Oil

(ii) Failure of Ventilation System

(iv) Inter-turn Faults

b.) Internal Faults

When the insulation between windings and between the winding and the core fails, it is termed an electrical fault. There can be phase-to-phase faults, phase-to-ground faults, faults between hv. and Iv. windings or inter-turn faults. The faults occurring in oil can be sensed by gas actuated relays but the faults outside the oil have to be taken care of by electrical relays only. As such, for the heavy electrical faults inside the oil, gas actuated relays are not entirely relied upon as we shall see later Such faults can develop because of overload loose connections or over voltage's due to lightning or switching surges and also as a consequence of minor faults. These electrical faults have to be cleared up by the transformer-protection scheme using different types of relays to be discussed in succeeding sections.

c.) External Faults

The through faults can occur due to overloads or external short-circuits. When such faults occur, the transformer must be disconnected only after allowing a predetermined time during which other protective gear should be operated. A sustained overload condition can be detected by thermal relays which give an alarm so that the situation can be attended to or the supply disconnected, if necessary For the external short-circuit condition, time-graded over current relays are usually employed. Proper coordination of this back-up transformer protection should be made with the primary protection of the associated power supply network. The reliability of a power transformer depends upon adequate design, care in erection, proper maintenance and the provision of certain protective equipment

Chapter 2

Literature Review

2.0.1 Transformer Protection and Transformer Protection Circuits

Transformers are one of the most critical and expensive components of any distribution system. It is an enclosed static device usually drenched in oil, and hence faults occurring to it are limited. But the effect of a rare fault can be very dangerous for the transformer, and the long lead time for repair and replacement of transformers makes things even worse. Hence power transformers protection becomes very crucial. Faults occurring on a transformer are mainly divided into two types, which are, external faults and internal faults, to avoid any danger to the transformer, an external fault is cleared by a complex relay system within the shortest possible time. The internal faults are mainly based on sensors and measurement systems. We will talk about those processes further in the article. Before we get there, it is important to understand that there are many types of transformers and in this article, we will discuss mainly power transformers that are used in distribution systems.

Basic protection features like over excitation protection and temperature-based protection can recognize conditions that eventually lead to a failure condition, but complete transformer protection provided by relays and current transformers are appropriate for transformers in critical applications.So, in this article, we will talk about the most common principles used to protect transformers from catastrophic failures.

2.0.2 Transformer Protection for Different Types of Transformers

The protection system used for a power transformer depends on the transformer's categories. The table below shows that,

Category	Transformer Rating - KVA	
	1 Phase	3 Phase
I	5 - 500	15 - 500
II	501 - 1667	501 - 5000
III	1668 - 10,000	5001 - 30,000
IV	> 10,000	>30,000

• Transformers within the range of 500 KVA fall under (Category I II), so those are protected using fuses, but to protect transformers up to 1000 kVA (distribution transformers for 11kV and 33kV) Medium Voltage circuit breakers are usually used.
• For transformers 10 MVA and above, which fall under (Category III IV), differential relays had to be used to protect them.Additionally, mechanical relays such as Buchholtz relays, and sudden pressure relays are widely applied for transformer protection. In addition to these relays, thermal overload protection is often implemented to extend a transformer's lifetime rather than for detecting faults.

2.0.3 Common Types of Transformer Protection

i.) Overheating protection
ii.) Overcurrent protection
iii.) Differential Protection of Transformer
iv.) Earth Fault Protection (Restricted)
v.) Buchholz (Gas Detection) Relay
vi.) Over-fluxing protection
i.) Overheating protection in Transformers
Transformers overheat due to the overloads and short circuit conditions. The allowable overload and the corresponding duration are dependent on the type of transformer and class of insulation used for the transformer. Higher loads can be maintained for a very short amount of time. If it is for a very long time, it can damage the insulation due to temperature rising above an assumed maximum temperature. The temperature

in the oil-cooled transformer is considered maximum when it's 95*C, beyond which the life expectancy of the transformer decreases and it has detrimental effects in the insulation of the wire. That is why overheating protection becomes essential. Large transformers have oil or winding temperature detection devices, which measure oil or winding temperature, typically there are two ways of measurement, one is referred to hot-spot measurement and second is referred to as top-oil measurement, the below image shows a typical thermometer with a temperature control box from reinhausen used to measure the temperature of a liquid insulated conservative type of transformer.

Figure 2.1: Overheating protection in Transformers

The box has a dial gauge which indicates the temperature of the transformer (which is the black needle) and the red needle indicates the alarm set point. If the black needle surpasses the red needle, the device will activate an alarm. If we look down, we can see four arrows through which we can configure the device to act as an alarm or trip or they can be used to start or stop pumps or cooling fans. As you can see in the picture, the thermometer is mounted on the top of the transformer tank above the core and the winding, it's so done because the highest temperature is going to be at the center of the tank because of the core and the windings. This temperature is known as the top oil temperature. This temperature gives us an estimate of the Hot-spot Temperature of the transformer core. Present-day fiber optic cables are used within the low voltage winding to accurately measure the temperature of the transformer.That

Figure 2.2: Transformer with Overheating protection attached

is how overheating protection is implemented.

ii.) Over current Protection in Transformer

The over current protection system is one of the earliest developed protection systems out there, the graded over current system was developed to guard against over current conditions. power distributors utilize this method to detect faults with the help of the IDMT relays. that is, the relays having:

1. Inverse characteristic, and
2. Minimum time of operation.

The capabilities of the IDMT relay are restricted. These sorts of relays have to be set 150to 200 percent of the max rated current, otherwise, the relays will operate for emergency overload conditions. Therefore, these relays provide minor protection for faults inside the transformer tank.

iii.) Differential Protection of Transformer

The Percentage Biased Current Differential Protection is used to protect power transformers and it is one of the most common transformer protection schemes that provide the best overall protection. These types of protection are used for transformers of ratings exceeding 2 MVA. The transformer is a star connected on one side and delta connected to the other side. The CTs on the star side are delta-connected and those on the delta-connected side are starconnected.The neutral of both the transformers are grounded.The transformer has two coils, one is the operating coil and the other is the restraining coil. As the name implies, the restraining-coil is used to produce the restraining force,and the operating-coil is used to produce the operating force. The restraining-coil is connected with the secondary winding of the current transformers, and the operating coil is connected in between the equipotential point of the CT.

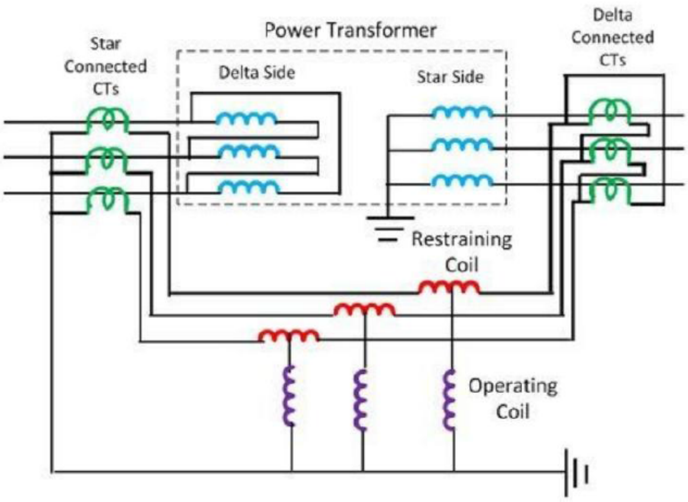


Figure 2.3: Differential Protection in Transformers

Transformer Differential Protection Working:
Normally, the operating coil carries no current as the current is matched on both sides of the power transformers, when an internal fault occurs in the windings, the balance is altered and the operating coils of the differential relay start producing differential current among the two sides of the transformer. Thus, the relay trips the circuit breakers and protects the main transformer.
iv.) Restricted Earth Fault Protection

A very high fault current can flow when a fault occurs at the transformer bushing. In that case, the fault needs to be cleared as soon as possible. The reach of a particular protection device should be only limited to the zone of the transformer, which means if any ground fault occurs in a different location, the relay allocated for that zone should get triggered, and other relays should stay the same. So, that is why the relay is named

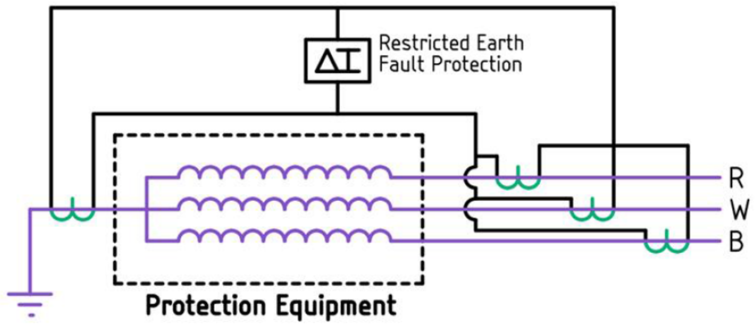


Figure 2.4: Restriced Earthed Fault protection in Transformers

Restricted earth fault protection relay.

In the above picture, the Protection Equipment is on the protected side of the transformer. Let's assume this is the primary side, and let's also assume there is a ground fault on the secondary side of the transformer. Now, if there is a fault on the ground side, because of the ground fault, a Zero Sequence Component will be there, and that will circulate only on the secondary side. And it will not be reflected in the primary side of the transformer This relay has three phases, if a fault occurs, they will have three components, the positive sequence components, the negative sequence components, and the zero sequence components. Because the positive sequins components are displaced by 120*, so at any instant, the sum of all the currents will flow through the protection relay. So, the sum of their currents will be equal to zero, as they are displaced by 120*. Similar is the case for the negative sequence components. Now let us assume a fault condition occurs. That fault will be detected by the CTs as it has a zero-sequence component and the current starts flowing through the protection relay. When that happens, the relay will trip and protect the transformer.

v.) Buchholz (Gas Detection) Relay

The above picture shows a Buchholz relay. The Buchholtz relay is fitted in between the main transformer unit and the conservator tank when a fault occurs within the transformer, it detects the resolved gas with the help of a float switch. If you look closely, you can see an arrow, gas flows out from the main tank to the conservator tank, normally there should not be any gas in the transformer itself. Most of the

Figure 2.5: Buchholtz Relay

gas is referred to as dissolved gas and nine different types of gases can be produced depending on the fault condition. There are two valves at the top of this relay, these valves are used to reduce the gas build-up, and it's also used to take out a gas sample. When a fault occurs, we have sparks between the windings, or in between the windings and the core. These small electrical discharges in the windings will heat the insulating oil, and the oil will break down, thus it produces gases, the severity of the breakdown, detects which glasses are created.
A large energy discharge will have the production of acetylene, and as you may know, acetylene takes a lot of energy to be produced. And you should always remember that any type of fault will produce gases, by analyzing the amount of gas, we can find the severity of the fault.

vi.) Over-fluxing Protection

A transformer is designed to operate at a fixed flux level exceed that flux level and the core gets saturated, the saturation of the core causes heating in the core that quickly follows through the other parts of the transformer that leads to overheating of components, thus over flux protection becomes necessary, as it protects the transformer core. Over-flux situations can occur because of overvoltage or a reduction in system frequency.To protect the transformer from over-fluxing, an over-fluxing relay is used.

The overfluxing relay measures the ratio of Voltage / Frequency to calculate the flux density in the core. A rapid increase in the voltage due to transients in the power system can cause over fluxing but transients die down fast, therefore, the instantaneous tripping of the transformer is undesirable. The flux density is directly proportional to the ratio of voltage to frequency(V/f) and the instrument should detect the ration if the value of this ratio becomes greater than unity, this is done by a microcontroller-based relay which measures the voltage and the frequency in real-time, then it calculates the rate and compares it with the pre-calculated values. The relay is programmed for an inverse definite minimum time (IDMT characteristics). But the setting can be done manually if that is a requirement. In this way, the purpose will be served without compromising the over-flux protections. Now, we see how important it is to prevent the tripping of the transformer from over-fluxing. Hope you enjoyed the article and learned something useful. If you have any questions, leave them in the comment section or use us forums or other technical queries.

2.1 MODERN SOLUTIONS FOR PROTECTING THE POWER SYSTEM TRANSFORMERS OF THE TRANSMISSION NETWORKS

For several decades, the power system protection relay has experienced many important changes, from purely electro mechanical type to the mixture of electronic and electro mechanical type, then to fully static and now fully numerical relays based on microprocessors. In the transformer protection area, similar changes can be seen. This new numerical technology had been developed so much that now the protection systems integrate in the same device, besides the protection function also the control functions, this kind of systems also being called as multi functional protection system (MPS). The paper relieves the main features of the newly developed transformer protection and control systems, the positive impact on the faults clearance times and also the development trends in this domain.

2.1.1 Introduction

A modern transformer protection and control system has many functions reflecting the technical trends of function integration, such as transformer differential protection,restricted earth fault protection, thermal overload protection, overexcitation protection, earth fault protection, directional or nondirectional overcurrent protection, overvoltage and undervoltage protection, voltage control function for single transformer and parallel transformers as well as frequency measurement function. The integrated transformer protection and control system also includes adaptive functions such as the adaptive measurement with analogue inputs during the frequency change in power systems, and on load tap changer position compensation for increased sensitivity of the differential protection. The modern transformer differential protection demonstrates more adaptive features that give the possibility to combine high stability for inrush and external faults with a high sensitivity for internal faults. In addition to the features described above, the new system can be configured and set in a flexible way for different types of applications with an advanced configuration tool [1], [2]. The paper will present the main features of a multi functional protection system in general and the typical protection and control functions implemented in such a device in particular alongside communication aspects. For a better highlight of all this it is also present a fault clearance of this kind of protection system for an auto transformer which is functioning in a transmission network.

2.1.2 The main features of a multi functional protection system

Fig.1 shows the block diagram of a typical multi-function protection system. The system has analog inputs (currents, voltages, temperature etc.), binary inputs, contact inputs for switch status use in the control circuits, and contact outputs for sending trip and alarm signals. An MPS may also have bi-directional communication ports which may use electrical or optical interfaces and protocols, on copper wires, on fiber optic cables or on some other hardware interface for communicating with other devices in the substation and outside the substation. Internal hardware consists of an analog data acquisition system which includes signal scaling, isolating, filtering (anti-aliasing) analog multiplexing, and analog to-digital converting. The digital subsystem consists of a microprocessor, flash memory for program storage, random-access memory

(RAM) for temporary storage of information, and electrically erasable programmable memory (EEPROM) for storage of set points. The operation and performance of these systems are determined by the hardware of the system and the software programs used to perform the protection functions. Digital signal-processing algorithms are used to filter the voltage and current inputs and calculate the parameters required for the relaying functions. The relay logic program compares the set points to the calculated parameters and implements the required time delay characteristics. The software program also implements other features such as communication, oscillography, event recording, and local interface with the user. The drawback is the need for more skilled protection engineers, more settings to be calculated and transferred to the relay, more detailed system analysis and intensive tests of the relay. Even the large amount of technical documentation to be studied and applied represents more than is usually needed for classical relays. The need for numerical relay configuration is perhaps the most difficult task for a protection engineer when dealing with numerical relays. Although this feature gives large possibilities to fit numerical relays to any kind of application, configuration takes a lot of time to be implemented and to be carefully tested.

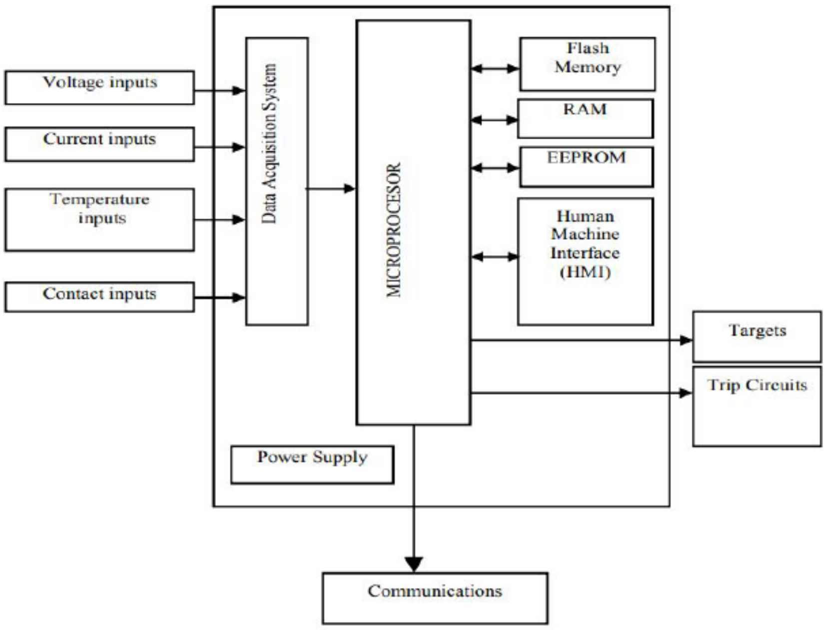


Figure 2.6: Block Diagram of a typical MPS

2.1.3 Typical protection and control functions of the transformers MPS'S

Protective functions integrated into MPS packages include two or more of the following: - Transformer Differential (87T) - Restricted earth fault or ground differential protection (87GN) - Instantaneous and inverse time Over current (50/51) - Ground instantaneous and inverse time Over current (50G/51G) - Current Unbalance/Negative Sequence (46) - Over-excitation (24) - Under-voltage (27) - Over-voltage (59) - Under-frequency (81U) - Thermal Protection (49) - Breaker failure (50BF) The numbers in the parenthesis in the list represent ANSI (American National Standards Institute) device function numbers. Function numbers 27 (Under-voltage) and 81U (Under-frequency) are used for load shedding on distribution transformer applications. Function 46 (Current Unbalance/Negative Sequence) is used to provide sensitive backup for phase-to-phase faults on a distribution feeder. A one-line diagram showing typical protection functions included in a multi function transformer protection system is shown in Fig. 2.7.

Beside this protection functions a MPS contain also control functions as: - Voltage control for Power Transformers - Synchro-check, energizing check and synchronizing - Apparatus control function - Event Function - Disturbance Report - Remote communication etc. Among protection functions not frequently used we point out the following: - Over-excitation protection function. The function is based on the Volt/Hertz criterion and usually covers generation transformer protection.
Residual high resistance differential protection function. The protection is specialized to protect for winding faults to ground in application where CT saturation could affect normal Differential Protection Function. - Miscellaneous over current protection functions, negative sequence over current protection functions, under voltage protection functions, etc. [3]. An example of oscillography registered at a fault inside an auto transformer of 200 MVA 220/110 kV, equipped with a numerical protection system,a SIEMENS technology, 7UT*** type can be seen in fig. 3. From this oscillography could be observed the fast reaction of the protection system and the functions which picked up, tripped, the moments of this reacts and other useful information in understanding the incident.

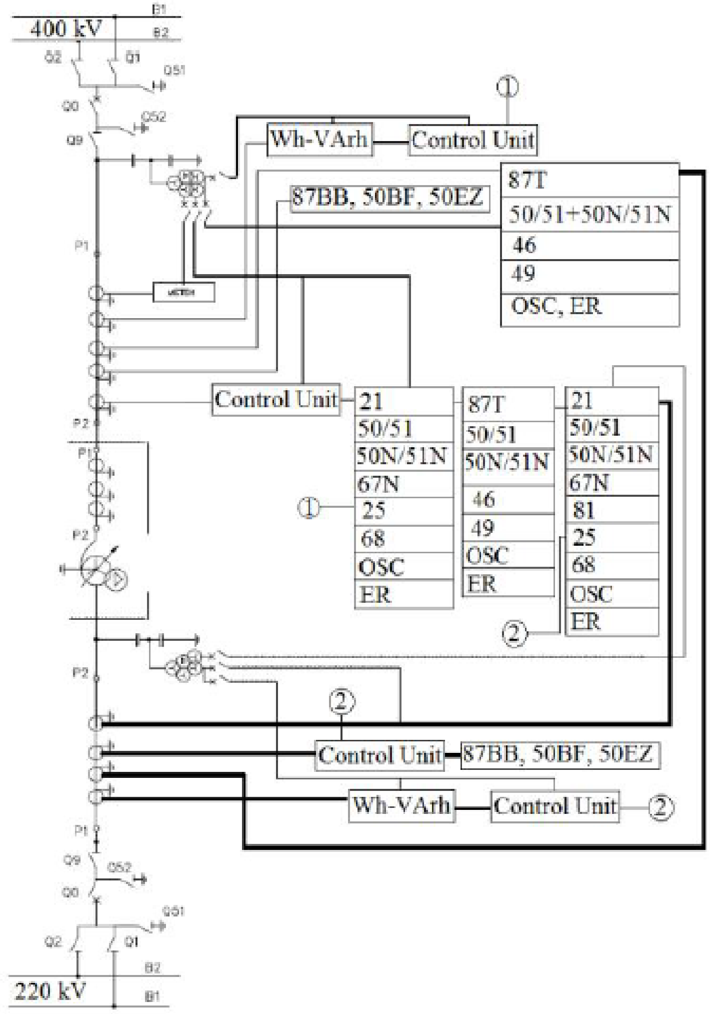


Figure 2.7: One-line diagram Block of a typical MPS

2.1.4 Communication

The digital electronics technology is naturally suited for use in numerical relays for communicating with other relays and with substation and central control computers. The additional cost is marginal and the benefits of the additional capabilities far exceed the cost. Most numerical relays now include facilities that allow them to exchange information with other relays, measuring instruments and substation and central control computers. One of the problems with the communication facilities is that different protocols were used previously in different parts of the world. The Utility Communication Architecture (UCA) Group started, in mid 1990s, to work on developing a North American communication standard for use in protection, automation and control applications. IEEE later joined the activity and provided sponsorship. At about the same time, IEC started working on developing

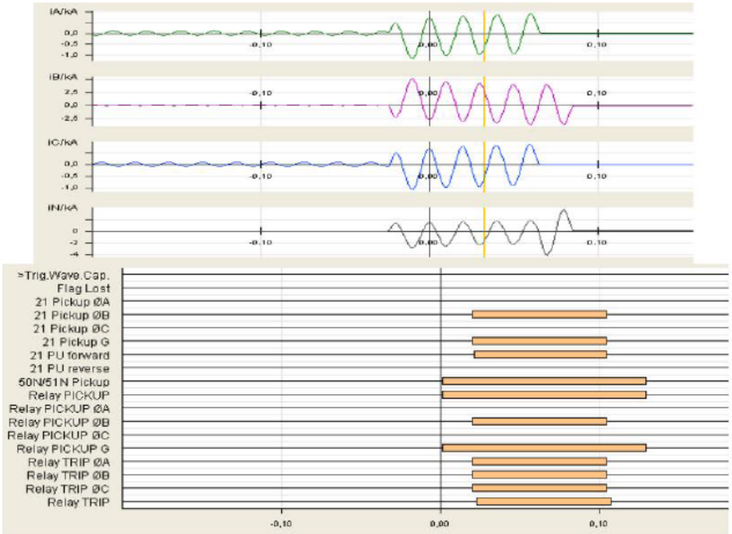


Figure 2.8: Oscillography from a 7UT*** numerical protection system

a communication standard for use in protection and automation . The two activities were consolidated in 1998 and it was agreed that the standard be developed as an IEC document. This activity finally resulted in the publication of the IEC 61850 Standard that is now being used by relay and IED manufacturers all over the world. The use of this standard has made it possible for devices installed in a substation, but provided by different manufacturers, to communicate with each other without the use of special purpose software for facilitating communications between devices designed by different manufacturers. This is a great feature for facilitating substation automation and control.

2.1.5 Conclusions

The massive introduction in electric power substations of the modern equipment, especially digital control and protection systems and digital transmission systems had a positive impact synthesized in:

• Increasing safety operation of power systems with fast and safe removal fault and / or avoiding dangerous operating states

• Remote Management of the protection systems

• The software configuration and parameterization;

• Low and easy maintenance because of the real time functions of ”self-test” and ”self monitoring”

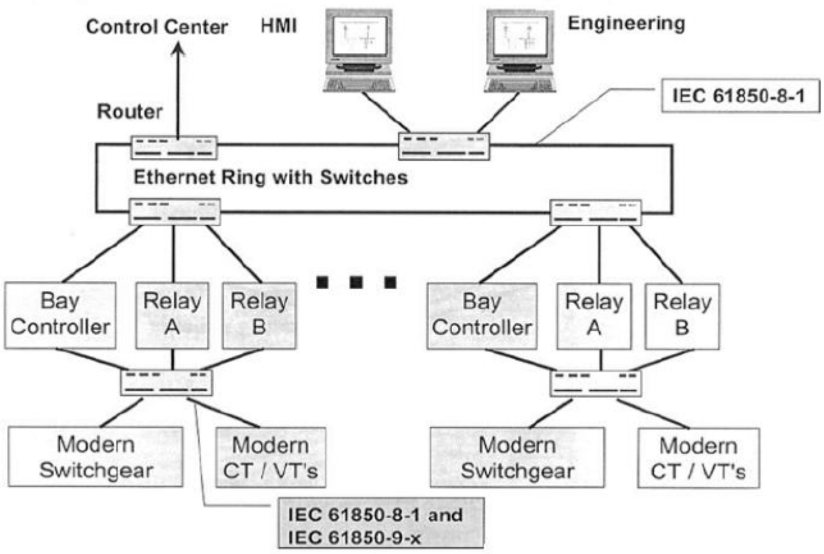


Figure 2.9: Example of the communication system architecture of a substation after the IEC61850 standard

• Short times of search and clearance fault • Accessible prices at present because of mass production Difficulties related to the use of numerical protection systems: control and transmission systems (not related to their operation itself):

• The staff used has to be highly skilled, multi-disciplinary trained, experienced;

• Inspections and tests (FAT, SAT, Commissioning) are very complex and must take place after appropriate procedures;

The paper aimed to underline the advantages of using a modern numerical protection and control system to protect a power system transformer and also expose the opportunity of implementing the adaptive concept, which represent the future of the numerical protection technology.

Chapter 3

MATHEMATICAL MODELLING

3.1 Over current Protection

o Transformers are provided with overcurrent protection against faults when the cost of differential relays cannot be justified. However, overcurrent relays are provided in addition to differential relays to take care of through faults and as aback-up to differential protection.

o The protection scheme using overcurrent relays is as shown.

While selecting the overcurrent protection of transformers, the following aspects need

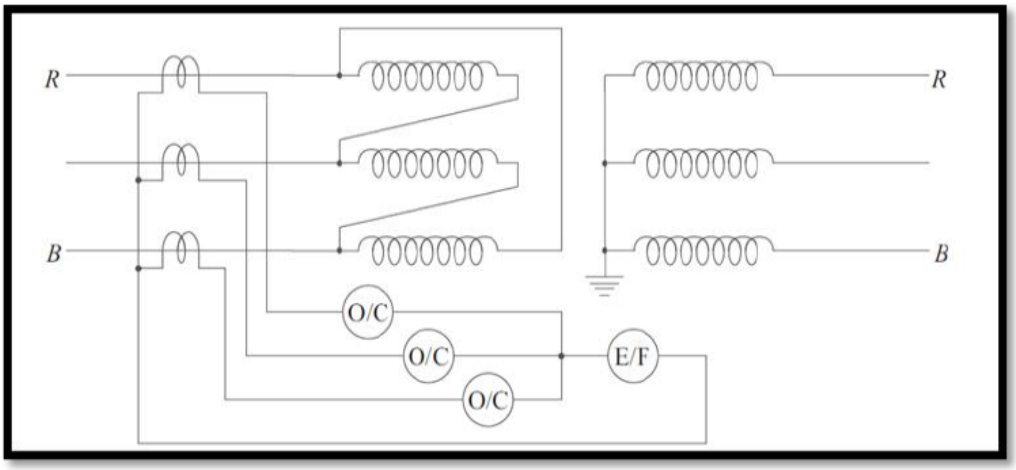


Figure 3.1: Overcurrent protection in transformer

consideration:

o Magnetising Inrush current - IDMT relays are not affected by the current inrush as they have enough time lag. Instantaneous overcurrent units should be set higher to avoid mal-operation. The setting of an instantaneous overcurrent relay on the primary side of the transformer should be a little above the asymmetrical value of the fault current for a three-phase fault on the secondary of the transformer. This setting is usually high enough to override magnetising inrush current.

o Primary full-load current should be considered while setting the overcurrent relay. The plug-setting of the IDMT overcurrent relay is generally selected as 125percent of the transformer rating to take care of normal overloads.

o The same set of current transformers cannot be used for both differential protection and overcurrent protection, as the CT requirements for these protection schemes are different.

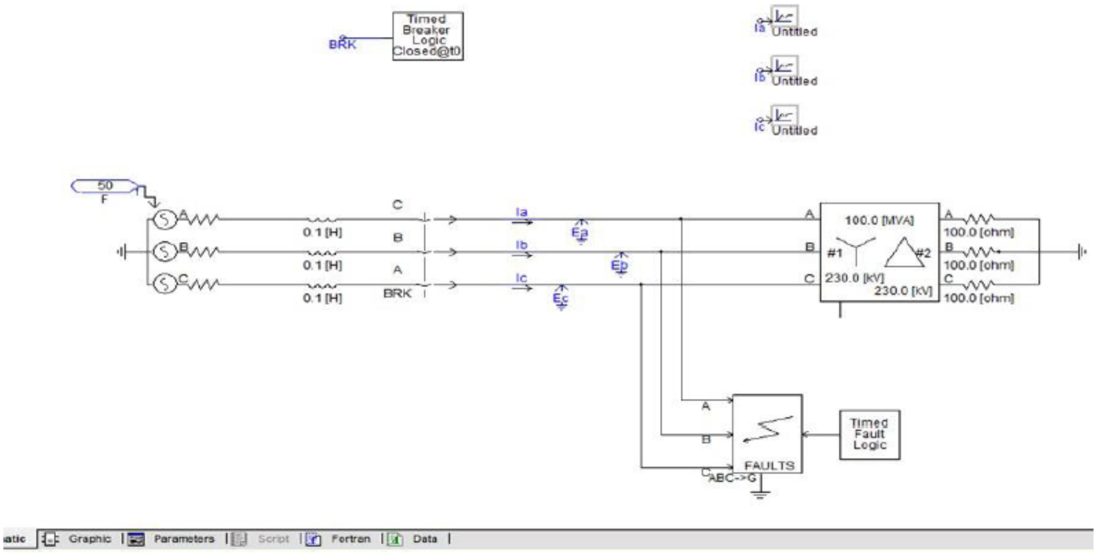


Figure 3.2: Simulation of Overcurrent protection of Three phase transformer - PSCAD

As shown in figure above the simulation of overcurrent scheme was carried out in PSCAD software. The specifications of the elements used are as under: A 230kV three phase voltage source of 50 Hz frequency is connected to a 100 MVA, 230kV/230kV, 50Hz, three phase, star-delta transformer. Each phase on the secondary side has a resistive load of 100 ohms.

With the help of a fault generating block in PSCAD, a LLLG fault is generated at an instant of 0.3 sec and for the duration of 0.2 sec.

Also we know that the instantaneous overcurrent relay should operate within 20ms to60ms time duration after the detection of fault.

The fault is occurring at 0.3 sec and we can see from fig. 5 that after the occurrence

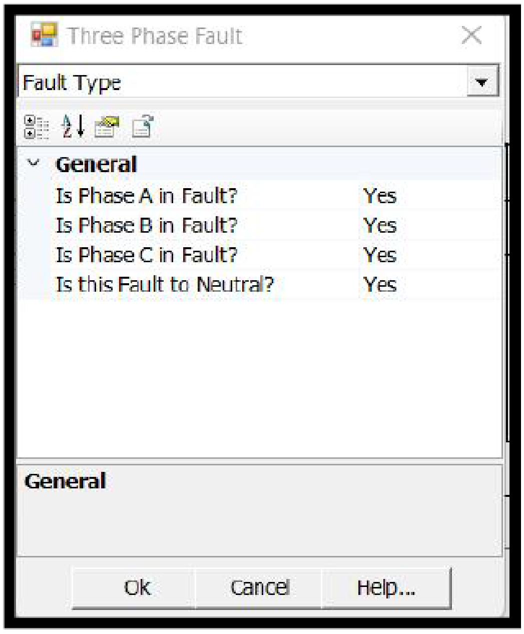


Figure 3.3: Details of fault generating block

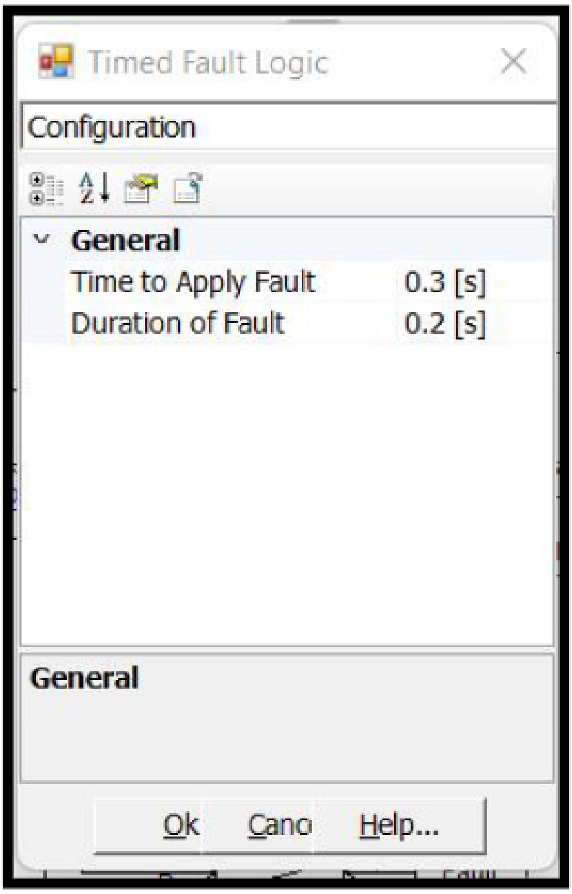


Figure 3.4: Timed fault logic

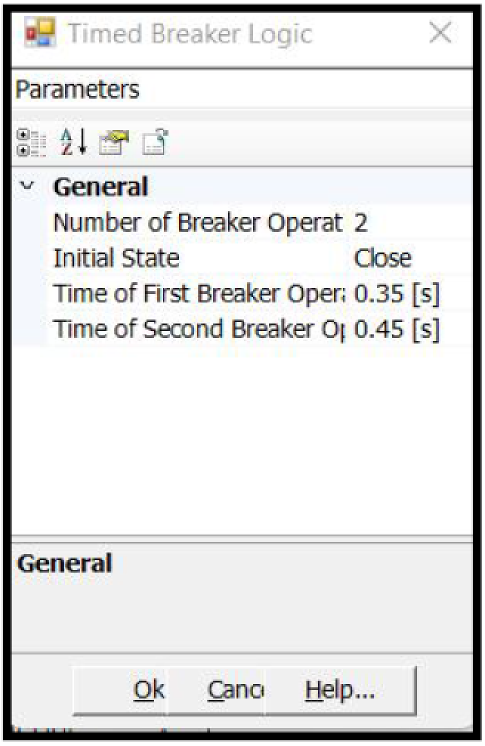


Figure 3.5: Timed breaker logic

of fault, within 50ms the circuit breaker has operated. The circuit breaker has operated again (closing) at time t = 0.45 sec and the system is restored by time t=0.5 sec.

3.2 DIFFERENTIAL PROTECTION

Differential protection is a unit protection and used for protection against internal Faults in the equipment to be protected. Different types of differential protection schemes used in practice are:

3.Circulating Current Differential Protection: It is also known as High Resistance Differential Scheme. It is applied for protection of generators, earth fault protection of transformers and motors.

4.Opposed Voltage Differential Protection: This scheme is used in pilot wire unit protection of transmission lines

. 5.Biased or Percentage Differential Protection: This is usually applied for Protection of large power transformer.

a. Circulating Current Differential Protection

Under normal operation of the equipment being protected, I1 = I2 , i. e. the currents

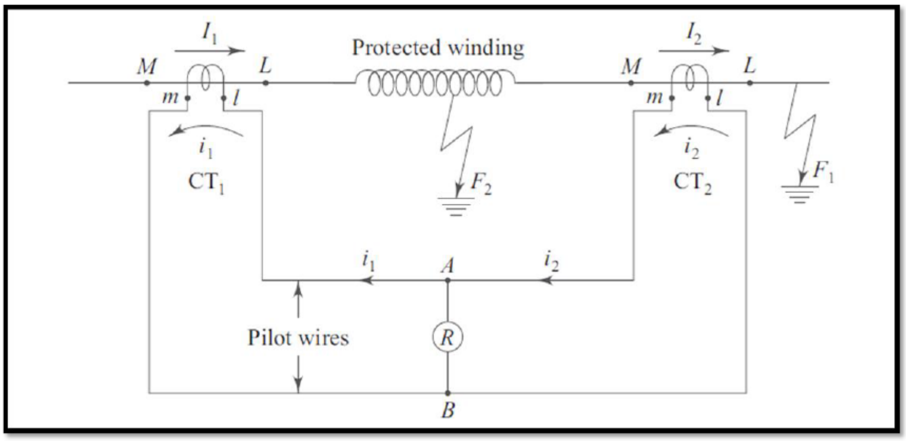


Figure 3.6: Schematic of differential relay

entering and leaving the equipment are equal. Therefore, their secondary equivalents are also equal, or i1 = i2 .

As i1 and i2 are equal, current i1-i2 flowing through a relay, R, shown in the circuit is zero. In case of external faults as at F1 , currents I1 and I2 will be much larger than that in case of normal operation but yet equal. Hence, i1= i2 and current through the relay is yet zero.

Therefore, the relay will not operate and a tripping signal to the breaker will not be sent. This is the requirement of the differential protection scheme, as differential protection has to be stable against external faults and very sensitive for internal faults within the equipment to be protected.

If there is an internal fault as at F2 , I1¿I2 .Hence, i1¿i2 , i1 -i2 0 and if i1 -i2¿ipu,i.e. the sensitivity threshold set, the relay R will operate issuing a tripping signal.

3.2.1 Differential Protection (Without Auto-reclose)

The MATLAB model of protection of three phase, star-star connected,11kV/33kV transformer using differential protection is shown above.

Here, as already mentioned above, the difference of primary and secondary currents of the transformer is taken(only magnitude). This value is further fed to the S-R flip flop which will issue commands to the circuit breaker to open,whenever a fault is detected. In SR Flip Flop the state of S=0, and the value of R is initially zero. So, the circuit breaker is closed initially. When an internal fault occurs (for example here LLLG), the value of difference of primary and secondary currents will be greater than 2 and this

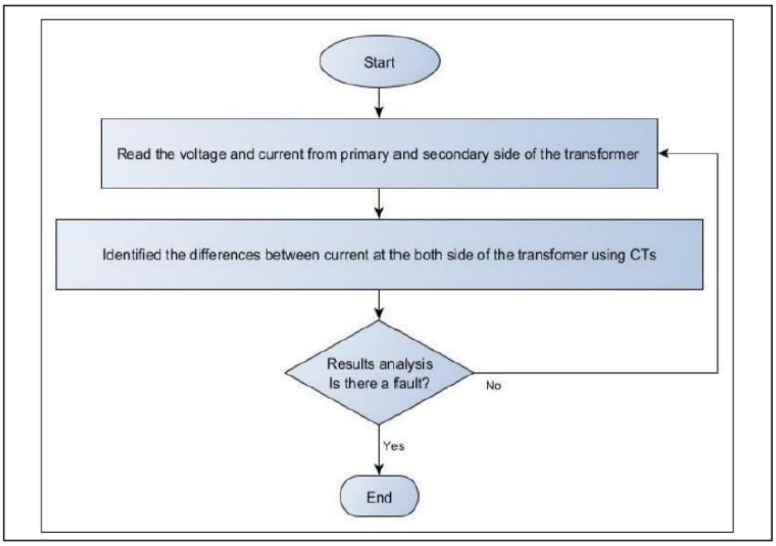


Figure 3.7: Flow chart of Differential Relay logic

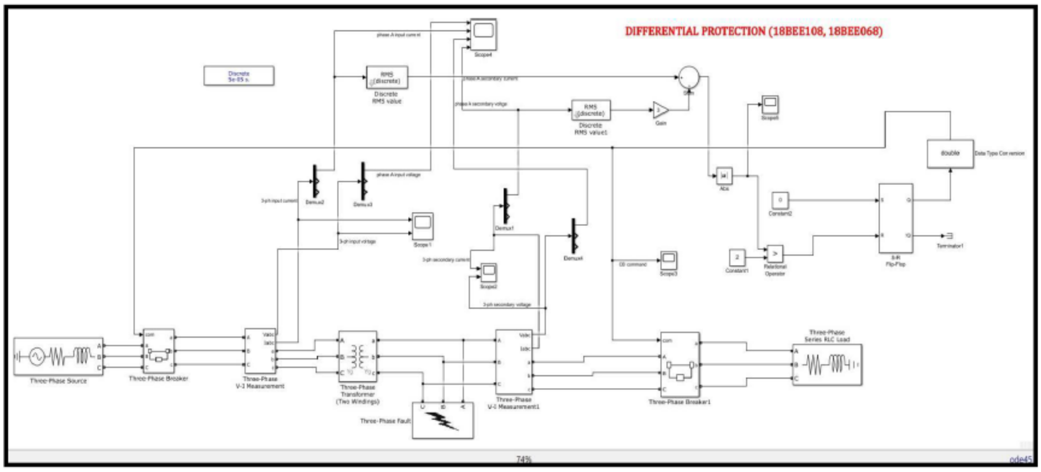


Figure 3.8: Differential Protection Simulink Model

difference is compared with the constant block with value 2.

Under normal conditions, this difference of currents is less than 2, so the value of R=0.But under fault conditions, the difference of currents will be greater than 2 and hence the value of R=1.

S	R	Q	State
0	0	Previous State	No Change
0	1	0	Reset
1	0	1	Set
1	1	X	Forbidden

Figure 3.9: Truth table of SR Flip Flop

Now, from the truth table of SR flip flop shown above, when S=0 and R=1, Q=0.Hence, the state of Q has changed and command is issued to CB to open and break the circuit. The result wave forms are shown below.

BLOCKS

1.CIRCUIT

BREAKER:

2.TRANSFORMER

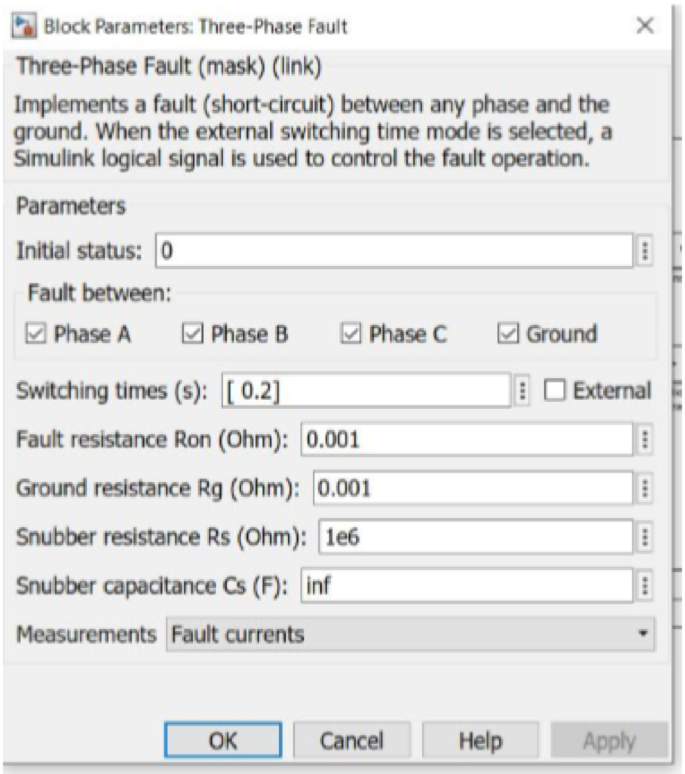


Figure 3.10: Three Phase Fault Block Parameters

3.2.2 Differential Protection (With Auto-reclose feature)

The previous Matlab model is modified to achieve auto reclosing of circuit breaker whenever the fault is cleared.

Here the state of S is changed with the help of a step signal. The state of S depends upon whether the value of step signal is greater than or equal to 1. So, for time t¡0.5s,

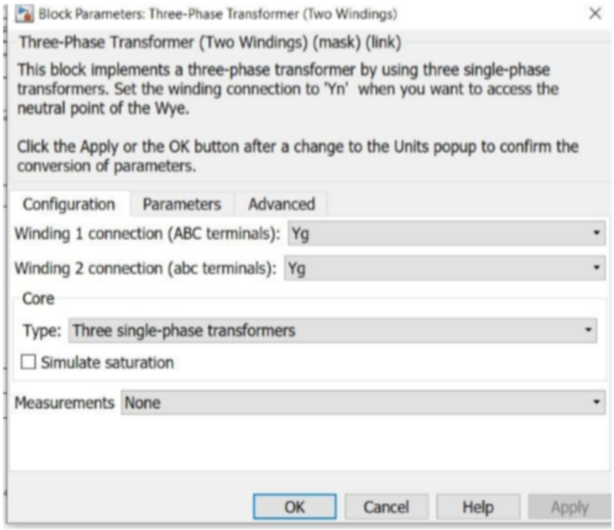


Figure 3.11: Three Phase Transformer Block Parameters

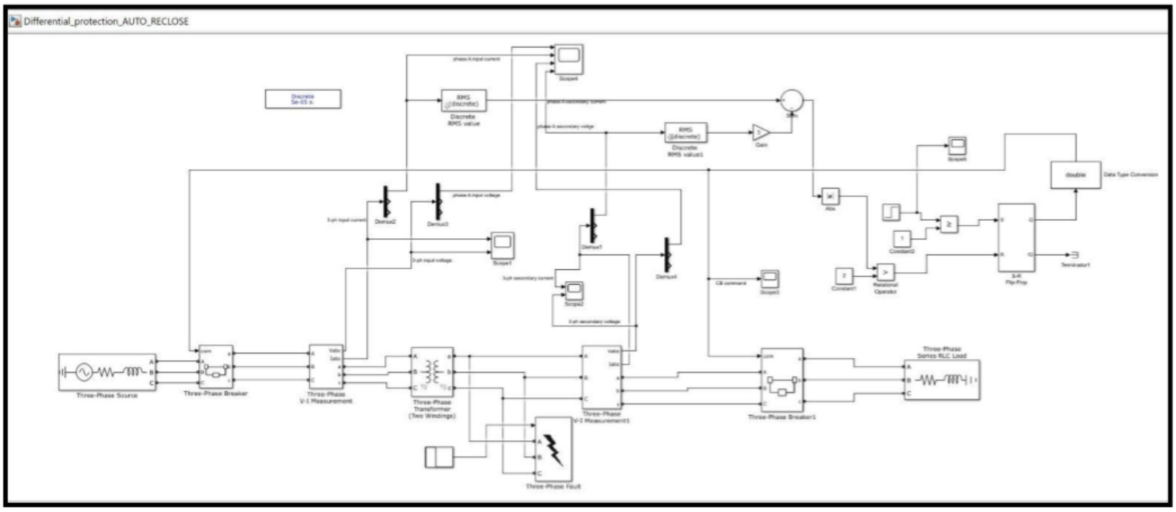


Figure 3.12: Differential Protection Simulink Model(With Auto Reclose

the step signal is kept 0 and hence S=0. The fault is CLEARED at t=0.5 sec and at this point the step signal changes to 1. So, S=1. And since, R=0, the state of Q changes and the closing command is issued to the circuit breaker. This way the system is restore.

BLOCKS

1.STAIR

GENERATOR

2.CIRCUIT BREAKER

3. THREE PHASE FAULT

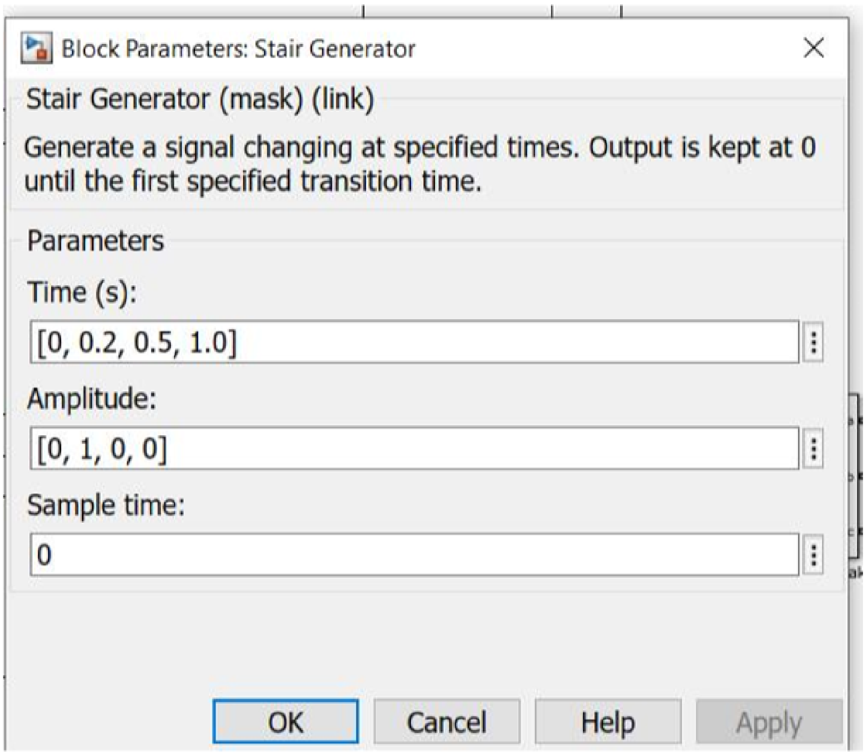


Figure 3.13: Stair Generator Block Parameters

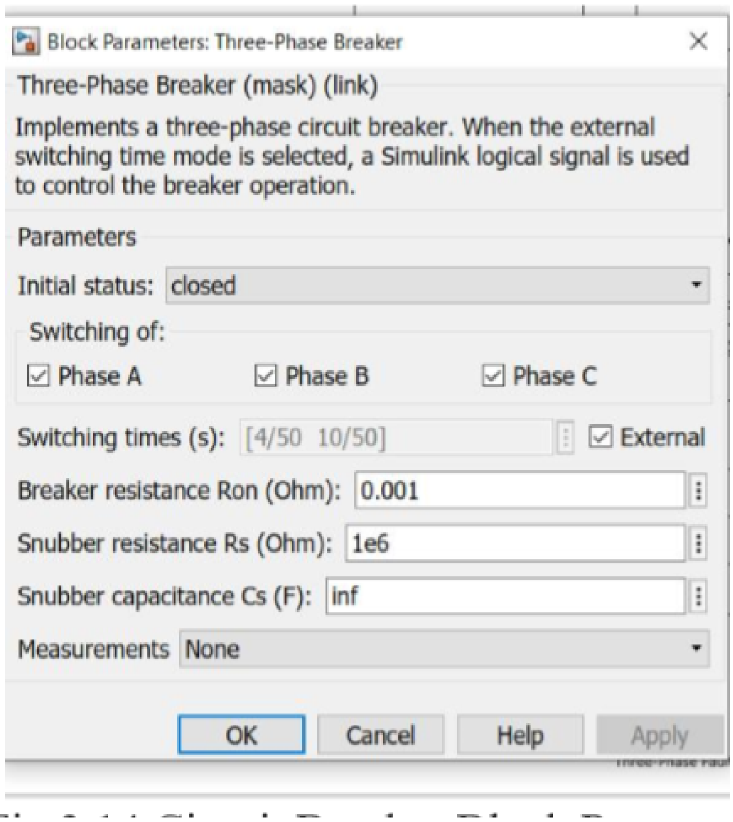


Figure 3.14: Circuit Breaker Block Parameters

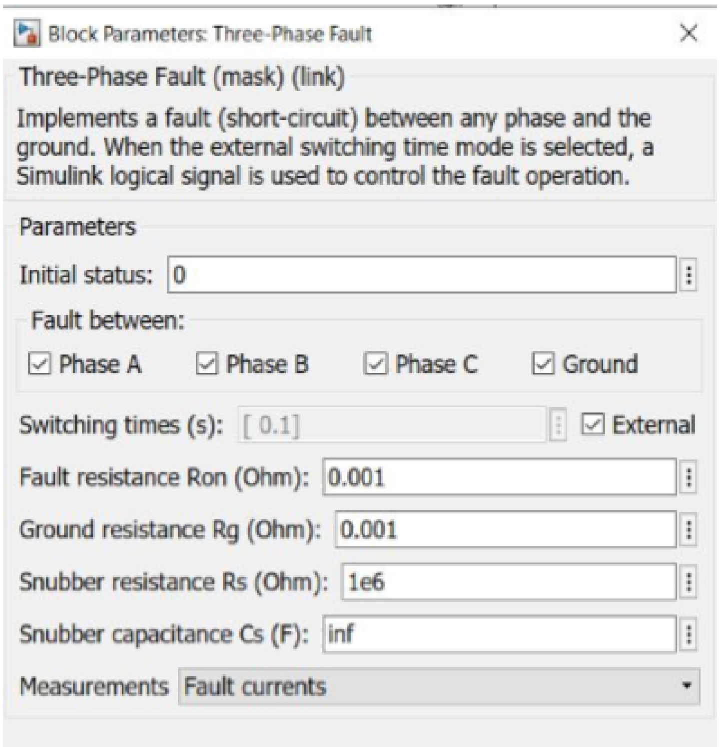


Figure 3.15: Three Phase Fault Block Parameter

3.2.3 EXTERNAL FAULT CONDITION

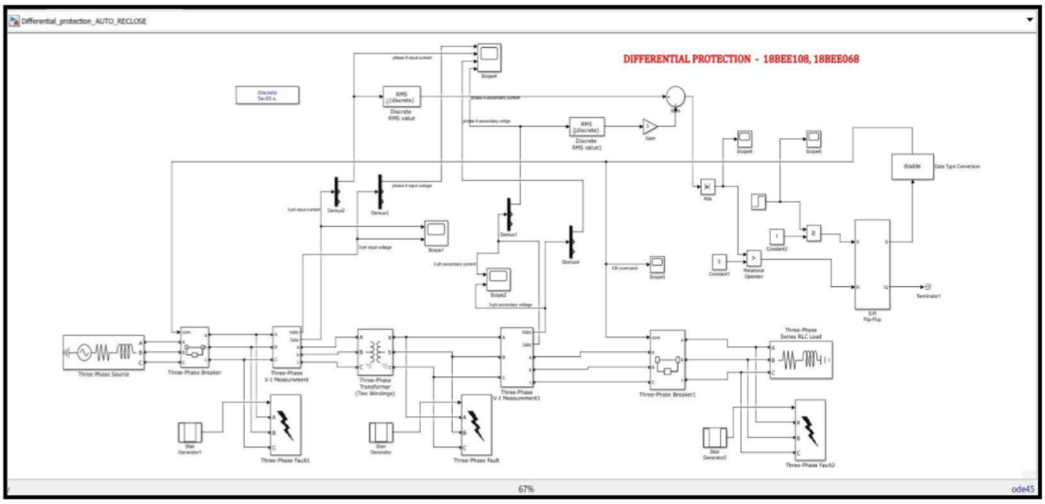


Figure 3.16: Differential Protection Simulink Model with Internal and External Faults

Here, we know that in case of internal fault the differential protection must operate but in case of external fault it should not operate

GRAPH OF PHASE ‘A’PRIMARY AND SECONDARY VOLTAGES AND CURRENT.

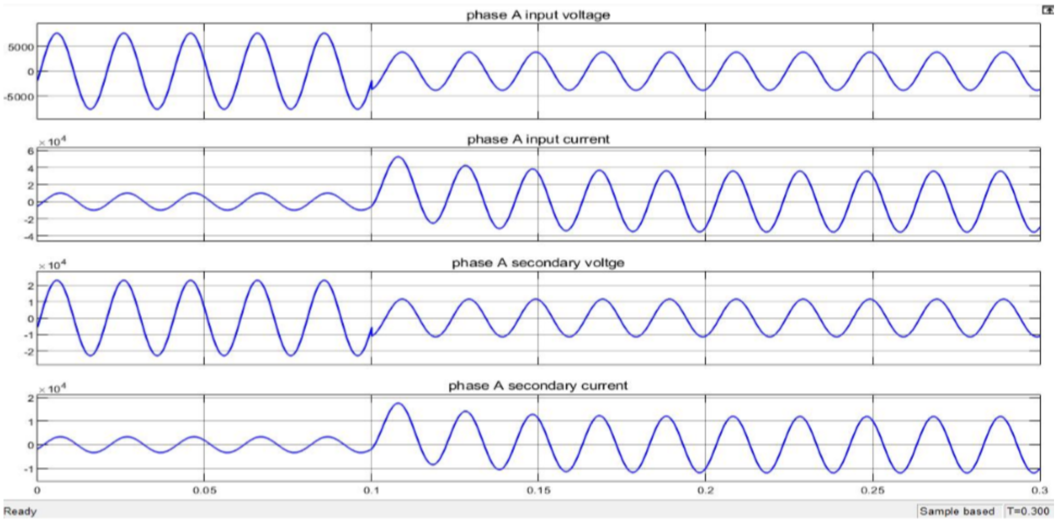


Figure 3.17: Graph of Phase A parameters(during external fault)

3.2.4 PROBLEMS IN APPLICATION OF DIFFERENTIAL PROTECTION

1) Non identical CT: In case of heavy external faults. CT has small ratio errors at normal rated current. But during external short-circuits in the transformer, the CT primary current is excessively charged. It may cause high spill current. The relay may give uncalled tripping.

2) Tap changing : As required by the loading conditions, the output voltage may be regulated. Ratio of CTs on both sides are set on the basis of normal tap. Due to the change in load, the ratio of CTs will not set on normal tapping. Due to this relay may give an uncalled trip.

3) Magnetizing inrush current: When an electrical power is switch is on from the primary side, with keeping its secondary circuit open. The largest inrush current will be found in the transformer, when the transformer is not connected to loader is energized. Due to this in rush current the relay will give an uncalled trip single-space of any faults.

4)CT saturation: CT saturation is a term used to describe the state where in a CT is no longer able to reproduce an output current in proportional to its primary current. The basic reason for CT saturation is due to the property of the core which goes to magnetic saturation due to number of reasons like large primary current or high burden at the secondary or an open circuit in the secondary.

3.3 Biased or Percentage Differential Protection:

Another method to guarantee stability in case of external faults is to use biased differential relay. The biased differential relay has two coils. One coil is known as restraining coil or bias coil, which restrains the operation of a relay. The other coil, operating coil, produces the operating torque.The relay operates when

• Operating coil current i1 - i2 ¿ ipu, which is known as basic setting or sensitivity threshold.

•The pick-up ratio(1 2)/((1+ 2/)2)¿m,the bias setting.The characteristic of such a relay is shown in the figure of the next slide. The biased differential relays are usedfor the differential protection of large power transformers and generators.

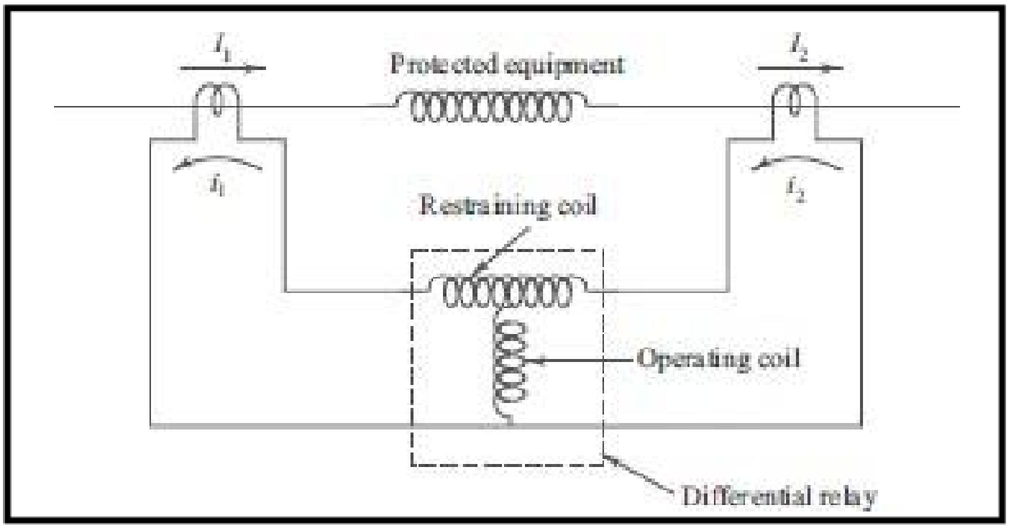


Figure 3.18: Biased Differential Relay

BIASED DIFFERENTIAL RELAY

As shown in the figure above, a biased differential relay is used for protection of three phase transformers. Here the bias setting is given as:(i1-i2)*2/(i1+i2) orm.

The magnitude of this value is compared with the constant block of value 0.5.If it is greater than0.5the R=1.

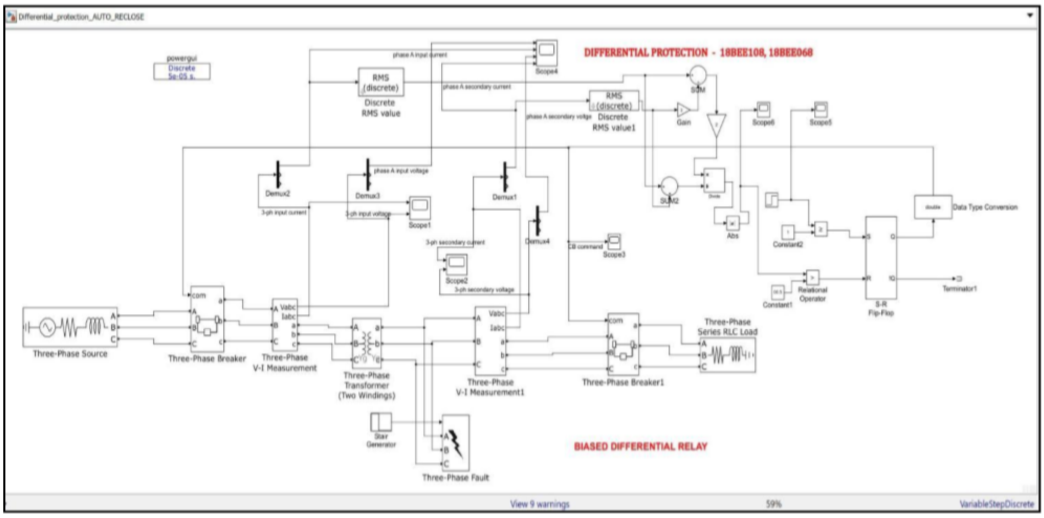


Figure 3.19: Biased Differential Relay

Similarly,the value of step signal is compared with constant block of value1.If it is greater than or equal to 1 the S=1. Under normal conditions, for time t¡0.5, the value of step signal is 0, so the value of S=0.The value of m is less than0.5s oR =0. Hence, no signal is issued to the circuit breaker.

Under fault conditions,the value of m¿0.05,s oR =1 and hence,at rip signal will be issued to the circuit breaker and it will break the circuit. The result wave forms are shown below.

GRAPH OF THREE PHASE CURRENT AND VOLTAGE

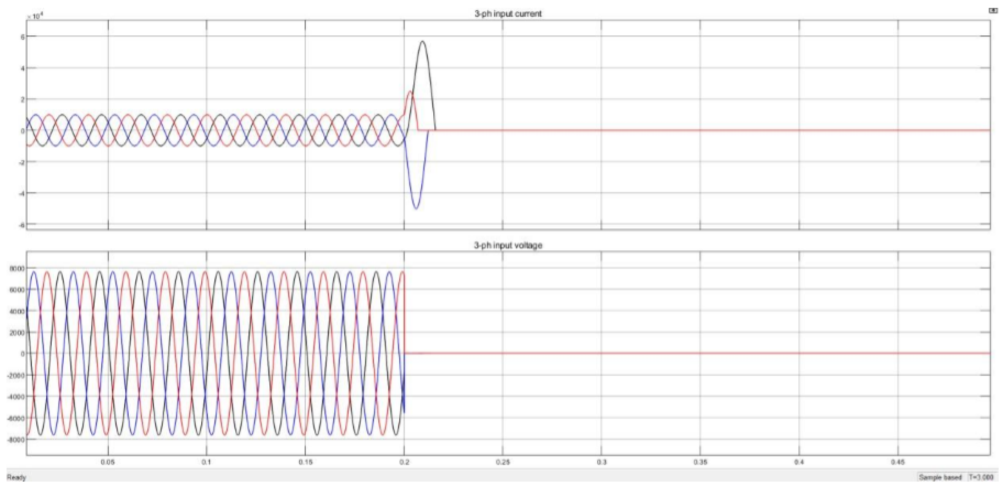


Figure 3.20: Graph of Three phase Current and Voltage

THREE PHASE SECONDARY CURRENT AND VOLTAGE

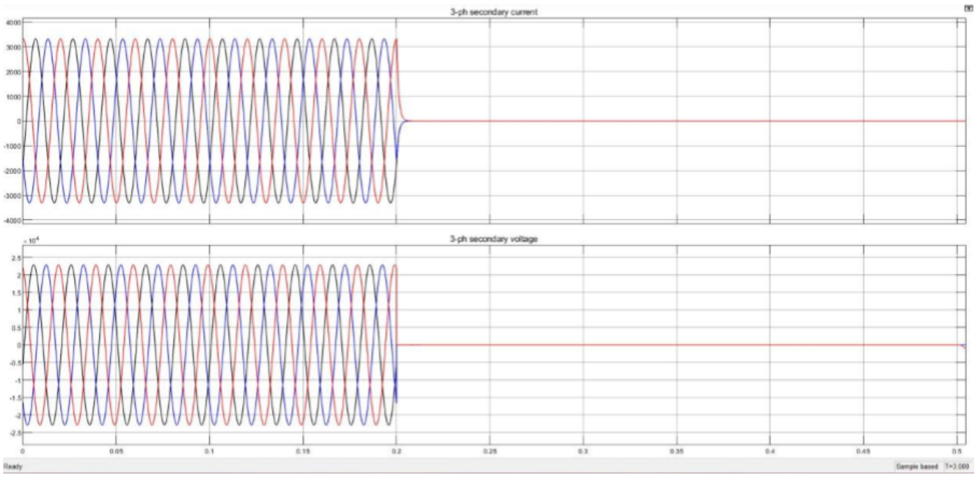


Figure 3.21: Graph of Three Phase Secondary Current and Voltage

PHASE A CURRENT AND VOLTAGE

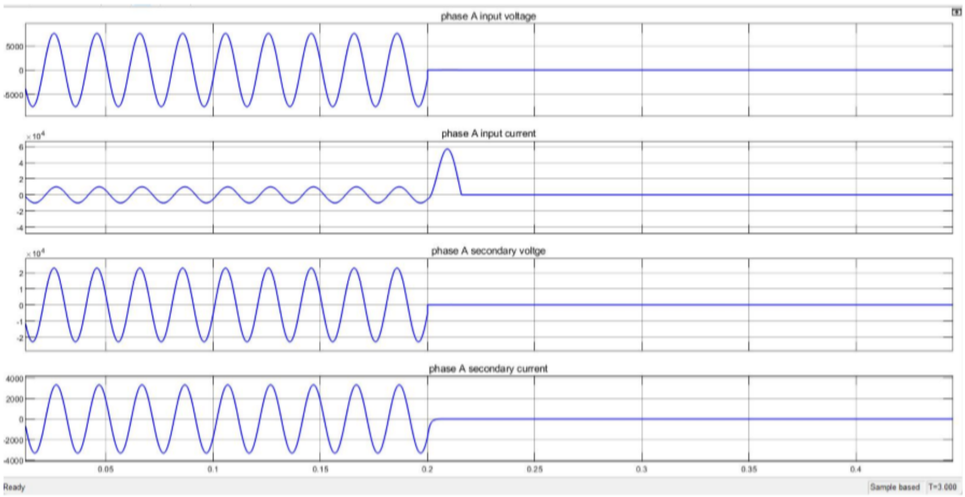


Figure 3.22: Graph of Phase A Current and Voltage

Chapter 4

RESULT AND DISCUSSION

4.1 Software Used for Analysis

Simulation for protection scheme of three phase, star- star connected, 11kv/33kv transformer using differential protection is done for the required application. The required model is implemented using MATLAB/SIMULINK, R2021a / March 17, 2021 version.

4.2 Control Strategy

This research presents a model and simulation of differential protection scheme for a three phase two-winding transformer using MATLAB/Simulink software. It is modelled to guide against faults in auxiliary equipment of the transformer, internal faults in transformer winding, external faults. It also presents a fast response and fault clearing time of the protection scheme using the Simulink work tool. A 100 MVA transformer was used as a case study. The digital differential protection scheme was incorporated using related Simulink block components. From the simulated results, it was observed that the differential protection scheme gave a good response by discriminating between through faults and inrush magnetizing current. During the inrush magnetizing current there was no tripping of the relay. When fault was induced within the transformer, the relay gave a fast switching response of 0.52 msec after the fault had occurred.

4.2.1 Differential Protection (Without Auto - reclose)

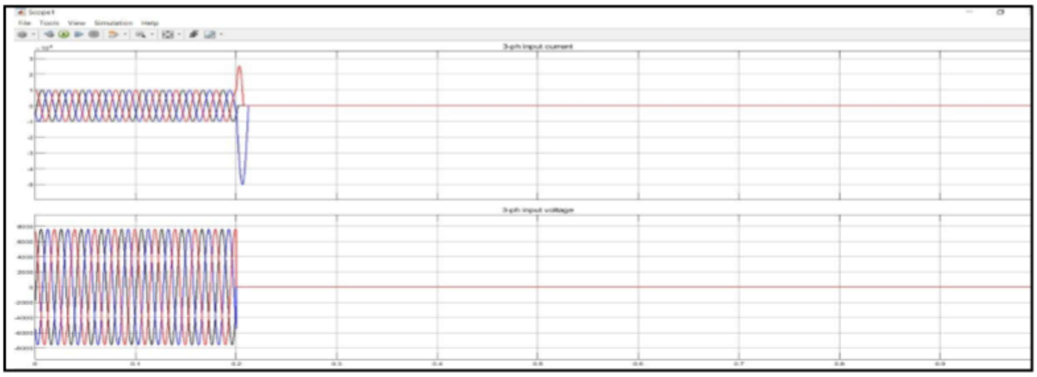


Figure 4.1: Three phase input current and input voltage

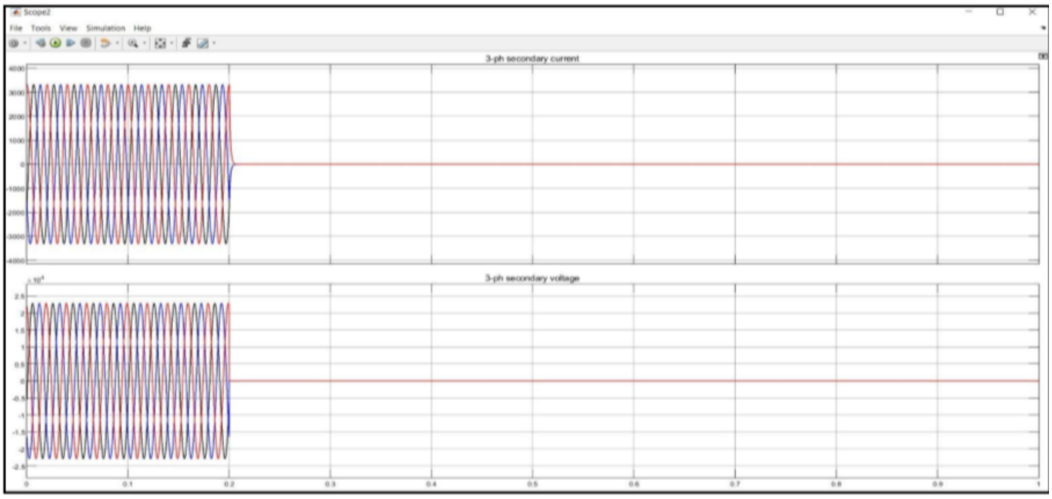


Figure 4.2: Three phase secondary current and voltage

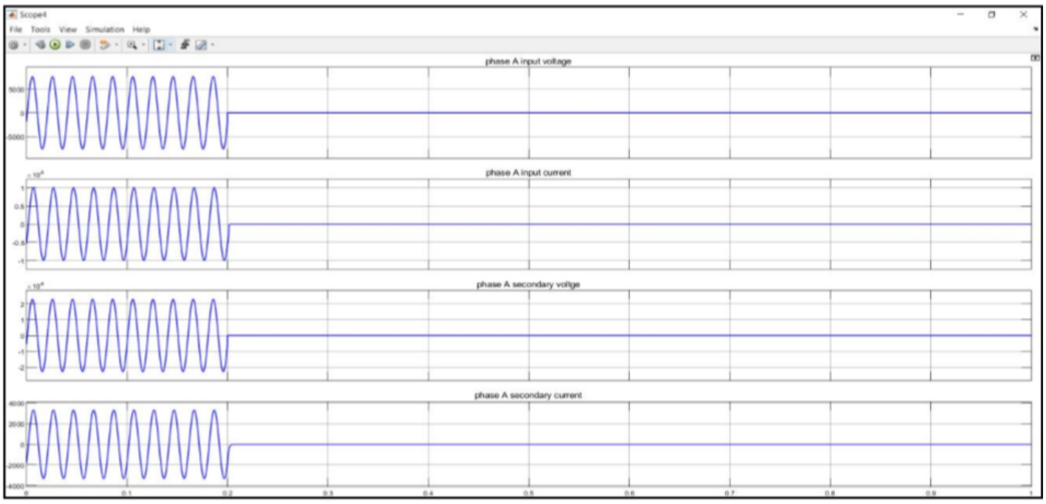


Figure 4.3: Phase A(Primary and Secondary Voltages and Currents)

Here in this Differential protection the Circuit breaker opens up when the fault occurs inside the Power transformer and it will remain in the same state, as this is the condition for Differential Protection Without auto-reclose.

4.2.2 Differential Protection (With Auto-reclose feature)

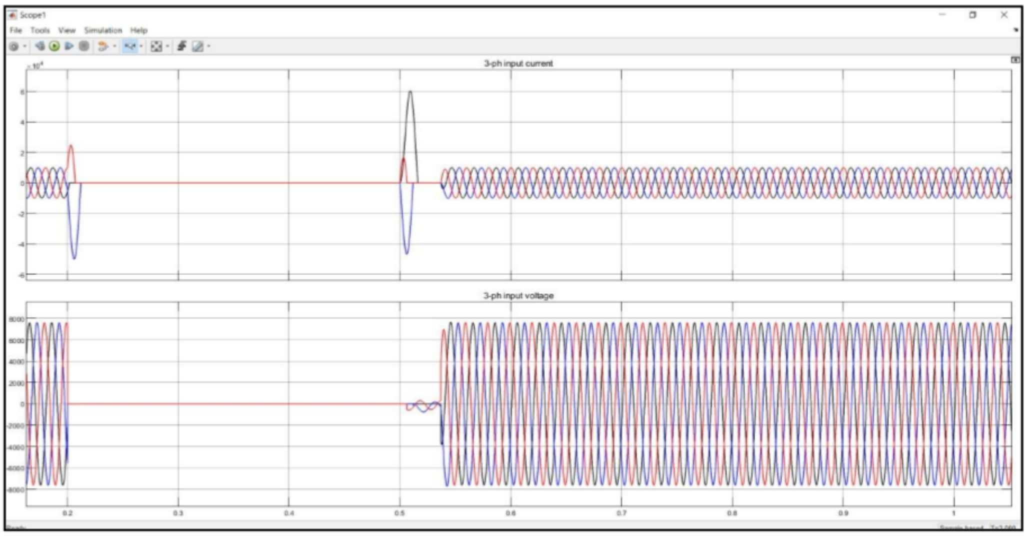


Figure 4.4: Three phase input current and input voltage

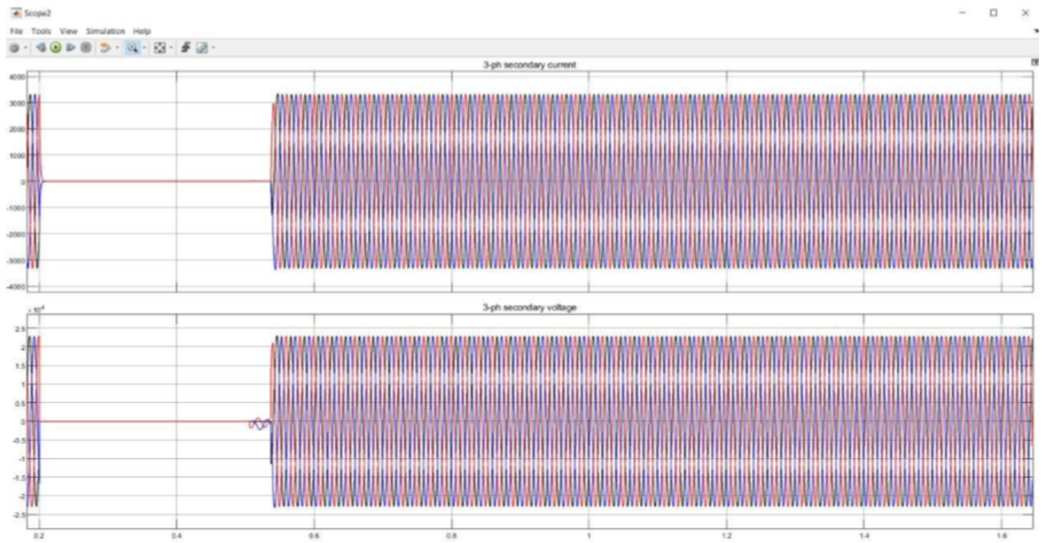


Figure 4.5: Three phase secondary current and voltage

The previous Matlab model is modified to achieve auto reclosing of circuit breaker when ever the fault is cleared. Here the state of S is changed with the help of a step signal. The state of S depends upon whether the value of step signal is greater than

Figure 4.6: Phase A(Primary and Secondary Voltages and Currents)

or equal to 1. So, for time t¡0.5s,the step signal is kept 0 and hence S=0. The fault is CLEARED at t=0.5 sec and at this point the step signal changes to 1. So, S=1. And since, R=0, the state of Q changes and the closing command is issued to the circuit breaker.This way the system is restored.

4.3 Components Used

1.Buchholz Relay Buchholz relay is the protection equipment which is used in the transformer. Basically, the buchholz relay protection is a mechanical fault detector for electrical faults in oil immersed transformers.Buchholz relay in the transformer is located in between piping of the oil conservator and main tank. For reliable operation shape of the conservator pipe is slightly inclined. Buchholz relay works independently. The relay is not affected by the number of transformer windings, tap changer position, and instrument transformer. When tap changer is located on the top of the tank then, conservator has its own oil enclosure. At that time, tap changer had its dedicated Buchholz relay. The Buchholz relay is very accurate and highly sensitive detector. A Buchholz relay consists of two main parts pivoted float and pivoted vane.Both the pivoted float and pivoted vane consist of mercury switch. The casing of the buchholz relay is occupied with oil as well as mercury switches are open simultaneously. When small faults occur in the transformer at that time in between the fault location and top of the transformer some gases are produced. The gas bubbles are tapped in the casing of the buchholz relay protection, in the casing of the transformer oil is exchanged by gases. When the oil level in the buchholz relay decreases simultaneously the float will float and mercury switch tilts, resulting in closure of an alarm circuit. Large faults occur between the windings or phases of the earth within the transformer. When the large faults occurs at that time it causes to produce a huge volume of the gas and oil vapour which are difficult to move out from the transformer, so it produces the pressure and removes oil. This produces the fast flow towards the conservator from the transformer which is further responded by the vane. In the pipe to the conservator, the vane is responded to the high oil and gas flow. Then the circuit will trip which is closed by the mercury switch. The tripping time totally depends upon the fault location and magnitude of the fault current. According to certain tests, the tripping time of the circuit must be in the range of 0.050 – 0.10 seconds. The tripping time should not be greater than 0.3 seconds. The gas accumulator relay protects the different parts of the insulation systems and transformer conductors from the overheating. It gives the long-term accumulation of gases. It also indicates the fault sources at early stage of the circuit which prevents the system from damage. When the transformer comes into service, at that time air which is present in the winding may give rise to sudden alarm indications. At this time, the tank of the transformer is filled with oil. The air in the winding of the power transformer is removed by vacuum treatment. The Buchholz relay also indicates the reduction in the oil level due to leakage from the transformer tank.

The following are some limitations of the Buchholz relay:

1)It only detects faults under the oil level.

2) The mercury switch is not too sensitive, because it helps to operate relay during false conditions like earthquakes, presence of birds on the pipe, mechanical shocks to the pipe.

3)The tripping time of the relay is equal to 0.1 second, which is acceptable.It should not be more than 0.1 seconds because the average time is0.2 seconds under fault conditions. It is accepted till relay that indicates the failure of equipment.

4)Buchholz relay cannot be fitted to the transformer below rating of 500KVA.

2.Winding Temperature Indicator

The winding of the transformer is a component which has the highest temperature.When the load is simultaneously increasing, the temperature of the wind also increases. The temperature of winding and top oil is measured to control the temperature parameters o the transformer. This temperature is measured using Winding Temperature Indicator and the temperature of Transformer oil is measured using Oil Temperature Indicator. Winding Temperature Indicator indicates the winding temperature of HV and LV winding of the transformer and triggers the cooler unit, it also gives the alarm of temperature rise. An indirect system is used to measure winding temperature, since it is dangerous to place a sensor close to the winding near to high voltage. The indirect measurement is done by means of the Thermal Image. The measuring system is filled with liquid which changes its volume with rising temperature.Inside the instrument,it is fitted with a heating resistance which is fed by a current proportional to the current following through the transformer winding. To do this we connect the terminal of the heating resistance with the bushing current transformer so that the reflection of change in load is reflected in winding temperature indicator. The heating resistance is fed by a current transformer associated to the loaded winding of the transformer. The increase in the temperature of the resistance is proportional to that of the winding. The sensor bulb of the instrument is located in the hottest oil of the transformer, therefore the winding temperature indicates the temperature of the hottest oil plus the winding temperature rise above hot oil level. The winding temperature of the transformer may rise due to increased loading of the transformer or due to some internal fault.Normally the Winding temperature indicator gives an alarm at 85 degrees Celsius and trip signal at 95 degrees Celsius(General practice in India).

3.Oil Surge Relay

OSR protection is basically used to protect the internal fault in the On Load Tap Changer Circuits. It monitors the oil level in the OLTC Conservator Tank and then the force oil enters into or leaves from OLTC. OSR provided with the single element oil surge relay has been specially designed to operate with OLTC. OSR does not operate during change of Transformer Taps. It will operate when the surge is developed in the OLTC. Under normal conditions, the OLTC OSR relay reads normal pressure, since the relay becomes active. A heavy fault inside of the OLTC incidentally generates pressure wave or Oil surge or Oil move in the direction of OLTC tank. If this flow rate exceeds the operating threshold of the damper, then the flap moves the flow direction. Due to this movement, the red switch will be actuated and it gives trip signal to the circuit breaker and hence,the fault will be removed. The main purpose of the OSR is to limit the damage to the OLTC during fault condition.

4.Pressure Release Valve

In case of a serious fault inside the Transformer, Gas is rapidly produced. This gaseous pressure must be relieved immediately otherwise it will damage the Tank and cause damage to neighboring equipment. This relay is mounted on the top cover or on the side walls of the Transformer. This valve has a corresponding port which will be sealed by a stainless steel diaphragm. The movement of the diaphragm lifts the spring and causes a micro switch to close its contacts to give a trip signal to the HV and LV circuit breakers and isolate the transformer. A visual indication can also be seen on the top of the relay. For smaller capacity transformer,an Explosion vent is used to relieve the excess pressure but it cannot isolate the Transformer from the fault.

Chapter 5

FUTURE SCOPE

5.1 CONCLUSION

In conclusion, the protection scheme of three phase transformer simulations: over current protection scheme and differential relay protection scheme had been successfully done. In three phase faults, as faults happen, the transformer is consequently isolated from the grid. Simulations studies are performed and the relay's performance with different system parameters and conditions is investigated. The obtained result illustrates that the proposed protection scheme(over current and differential)represents an appropriate action.

5.2 Future scope

In future the following modifications can be made: In the next few years GSM service can be added to this system, when a fault occurs. The fault is automatically detected but by extending this we can automatically clear the fault in future. A modern transformer protection and control system has many functions reflecting the technical trends of function integration. The integrated transformer protection and control system could also include adaptive functions such as the adaptive measurement with analogue inputs during the frequency change in power systems, on load tap changer position compensation for increased sensitivity of the differential protection and adaptive voltage control function. The adaptive voltage control function has a feature in which once the voltage control command is issued, the expected change of voltage amplitude is checked and the next operation will be temporarily blocked if the expected change of voltage amplitude cannot be confirmed in the previous action. This feature provides a positive effect in avoiding voltage collapse when the power system is short of reactive power supply.

Numerical relays can be designed to include abilities for changing their settings automatically so that they remain attuned to the system operating state as it changes. Some of the functions that can be made adaptive are as follows.

- Using the most appropriate algorithm during a disturbance
- Changing settings of relays of a distribution network as the system loads or configuration change
- Changing the settings of second and third zone distance relays as the system operating state changes
- Compensating for the CT and VT errors
- Changing the circuit auto - reclosers delays to ensure that the circuit is reclosed after the arc is extinguished.

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