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THESIS

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By:

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Title of the topic:

INDUSTRIAL TRANSFORMER DESIGN AND FAULT DETECTION

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Dedication

بسم الله الرحمن الرحيم

"رب أوزعني أن اشكر نعمتك التي أنعمت علي وعلى والدي وان اعمل صالحا ترضاه وادخلني برحمتك في عبادك الصالحين"

الآية **19**سورة النمل

I would like to express my heartfelt gratitude to God for granting me the strength to complete this work.

I extend my deepest appreciation to my beloved parents for their constant support and encouragement throughout this journey.

I would like to express my gratitude to my siblings for their unwavering support and love.

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Thank you all for your invaluable contributions to the successful completion of this work.

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05/2023

الملخص

هذا العمل يهدف إلى دراسة بنية محولات الطاقة ومبدأ عملها، وذلك كخطوة تمهيدية لدراسة أخطاء المحولات وطرق اكتشافها. يتم ذلك عن طريق استخدام برنامج ماتلاب لنمذجة وتحليل هذه الأخطاء، وتمثيلها .كما يتم استخدام برنامج بروتوس لتطوير نماذج لاكتشاف الأخطاء في الوقت الحقيقي، مما يساعد على تحديد الأخطاء واتخاذ التدابير اللازمة لمعالجتها في الوقت المناسب. تهدف هذه الدراسة إلى تحسين كفاءة واستقرارية محولات الطاقة وضمان عملها السليم.

Abstract

This work is a study of the structure and operating principles of power transformers, as a preliminary step towards studying transformer faults and detection methods. It involves modeling and analyzing these faults using the MATLAB software and real-time fault detection modeling using the Proteus software. The detailed analysis aims to identify and address faults in a timely manner, enhancing the efficiency and stability of power transformers.

Résumé

Ce travail est une étude de la structure et des principes de fonctionnement des transformateurs de puissance, en vue d'étudier les défauts des transformateurs et les méthodes de détection. Cela implique la modélisation et l'analyse de ces défauts à l'aide du logiciel MATLAB, ainsi que la modélisation de la détection des défauts en temps réel à l'aide du logiciel Proteus. L'objectif de cette étude approfondie est d'identifier et de résoudre les défauts de manière rapide, afin d'améliorer l'efficacité et la stabilité des transformateurs de puissance.

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LIST OF ACRONYMS

AC: Alternating current

EMF: Electric and magnetic fields

ϕ_m: the flux in the core

RMS: Root Mean Square

Bm: The maximum value of the flux density

K: The proportionality constant

f: frequency

V: The volume of the core

Pe: eddy current loss

t: the thickness of lamination

PC**:** Copper Loss

LV: a low voltage

HV: high voltage

MV: medium voltage

CM: the magnetic circuit

YN: Star coupling with neutral

ZN: Zigzag coupling with neutral

D: Delta coupling

MVA: Mega Volt-Ampere

KV: kilovolt

kVA: kilovolt Ampere

ONAN: Oil Natural Air Natural

ONAF: Oil Natural Air Forced

OFAN: Oil Forced Air Natural

OFAF: Oil Forced Air Forced

OFWF: Oil Forced Water Forced

ODAF: Oil Directed Air Force

ODWF: Oil Directed Water Forced

εr: Permittivity

Cp: the capacitance of a capacitor filled

C_o: the capacitance of the same empty capacitor

q: electric charge

d: distance

Ω.cm: ohm centimeter

tgδ: Tan Delta

RRM: Rogers Ratio Method

IEC: International Electrotechnical Commission

Rt : Winding resistance at temperature t

GISB: Groupe Industriel Sidi Bendehiba

LCD: Liquid crystal display

General Introduction

Industrial transformers play a crucial role in the reliable and efficient distribution of electrical power in various industries. These transformers are designed to handle high voltage and current levels, stepping up or stepping down the voltage as required. However, like any electrical equipment, industrial transformers are susceptible to faults and failures that can disrupt power supply and cause significant damage. Therefore, ensuring the proper design and effective detection of faults in industrial transformers is of utmost importance.

The objective of this thesis is to explore the field of industrial transformer design and fault detection. This research aims to analyze the key principles and considerations involved in the design of transformers for industrial applications, taking into account factors such as voltage levels, power ratings, insulation systems, cooling methods, and other design parameters. Additionally, the thesis focuses on the various types of faults that can occur in industrial transformers.

Furthermore, the thesis delves into the techniques and methods used for the detection and diagnosis of transformer faults. These techniques include both traditional and advanced approaches such as dissolved gas analysis, insulation resistance measurement, partial discharge monitoring, thermography, and condition monitoring systems.

By gaining a comprehensive understanding of industrial transformer design and fault detection, this thesis aims to contribute to the development of more robust and reliable power systems in industrial settings.

The titles of this thesis are to explore various aspects of transformer conception design and fault detection, including the generalities of transformers, fault detection methods, internship applications, and modeling and simulation.

Chapter 1 provides an introduction to the generalities of transformers, including their basic principles, construction, types, and applications. This chapter also discusses transformer ratings, losses, and efficiency, and the factors affecting transformer performance.

Chapter 2 focuses on fault detection methods, including traditional and modern techniques used in the power industry. This chapter also examines various types of faults that can occur in transformers and the importance of early fault detection and diagnosis in preventing catastrophic transformer failures.

Chapter 3 presents an overview of the internship application at the 'GISB' enterprise, which provides students with an opportunity to gain practical experience in the power industry. The chapter discusses the benefits of the GISB internship program, including industry-relevant skills and experience, the tests conducted on distribution transformers before and after the sales process and the protection methods applied to the transformers.

Chapter 4 deals with the modeling and simulation of transformers, which are critical tools for transformer conception design and fault detection. This chapter discusses various modeling and simulation techniques. It also explores the advantages and limitations of each technique and provides a case study on transformer modeling and simulation.

Overall, this thesis aims to provide a comprehensive understanding of transformer conception design and fault detection and how they can be applied in the power industry.

Chapter 1: Generalities about Transformers

1.1 Introduction

Transformers are essential electrical devices used in power systems and industries to transfer electrical energy between two or more circuits through electromagnetic induction. Transformers play a crucial role in stepping up or stepping down the voltage levels of AC power in power transmission and distribution systems. They are also used in various industrial applications, such as power supplies, welding equipment, and electric motors.

Studying transformers is crucial in the field of electrical engineering and power systems as they play a fundamental role in the transmission and distribution of electrical energy. The chapter provides a comprehensive overview of transformers, including their history, operation principles, theory, and types.

Understanding the EMF equation, transformer losses, winding coupling, and the magnetic circuit, as well as the different classifications of transformers, according to their use, cooling, insulating medium, and body construction, is essential for designing and maintaining efficient and reliable power systems.

1.2 Definition

A power transformer is a static device with two or more windings, which by electromagnetic induction, transforms an alternating voltage and current system into a different voltage and current system of generally different values at the same frequency for the purpose of transmitting electrical power. There are single-phase (Fig 1.1) and three-phase (Fig 1.2) transformers.

Figure 1. 1: Single-phase transformer

Figure 1. 2: three-phase transformer

- **Symbol**

Figure (1.3) indicates the transformer symbol.

Figure 1. 3:Transformer Symbol

1.3 History

The principle of electromagnetic induction was independently discovered by Michael Faraday and Joseph Henry in 1831. However, Faraday was the first to publish his experimental results, and thus he is credited with the discovery.

Alternating current electrical generators appeared in the 1870s, and it was realized that using them with an inductor made the circuit breaker ineffective. In 1882, the first system of iron magnetic circuits was introduced in London by Lucien Gaulard and John Dixon Gibbs, who named it the secondary generator.

However, in the fall of 1884, the company Ganz concluded that open magnetic circuits were not practical for use and voltage regulation. Also, in the same year, Ganz produced the first high-voltage transformer.

In 1889, the Russian engineer Mikhail Dolivo-Dobrovolsky built the first three-phase transformer at the German company AEG. [1]

Figure 1. 4:Faraday's first transformer

1.4 Operation principle:

1.4.1 Perfect or ideal transformer

An ideal transformer is a theoretical transformer that has no losses. It's used to model the actual transformers. Which are considered to be composed of a perfect transformer and various impedances. In the assumption that all losses and magnetic flux leaks are neglected, the ratio of the number of primary turns (N1) to the number of secondary turns (N2) completely determines the transformation ratio of the transformer. [2]

U1/U2 = N1/N2 = K = const. .... (I.1)

Where U1 is the voltage across the primary winding, U2 is the voltage across the secondary winding, and N1 and N2 are the number of turns in the primary and secondary windings, respectively. Neglecting losses, the power is transferred completely.

If I1is the primary current and I2 the secondary current, we have:

U1 I1 = U2 I2= K = const. .... (I.2)

and:

U1/U2 = I2/I1= K = const. .... (I.3)

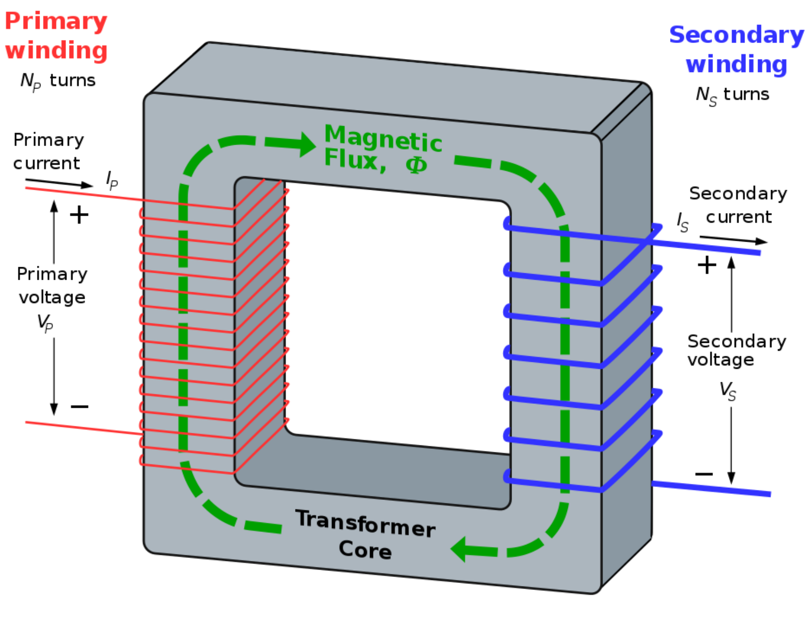


Figure 1. 5:Magnetic flux between windings

The magnetic flux between windings in a transformer refers to the flow of magnetic lines of force that pass through both the primary and secondary windings. It is the crucial link that allows the transfer of electrical energy from the primary winding to the secondary winding.

When an alternating current (AC) flows through the primary winding, it creates a changing magnetic field around the winding. This changing magnetic field induces a voltage in the secondary winding through electromagnetic induction. The magnetic flux, represented by the lines of force, is responsible for this induction process.

The amount of magnetic flux linking the primary and secondary windings depends on the design and configuration of the transformer, as well as the current flowing through the windings. The magnetic core, typically made of laminated iron or steel, helps guide and concentrate the magnetic flux, enhancing the efficiency of energy transfer.

By controlling the magnetic flux, transformers can step up or step down voltage levels while maintaining the same frequency. This enables efficient power distribution and voltage regulation in electrical systems.

It is important to ensure sufficient magnetic flux linkage between the windings to achieve efficient energy transfer and minimize losses in the transformer. Proper design and construction of the transformer core and winding arrangement play a critical role in optimizing the magnetic flux and overall performance of the transformer.

1.4.2 Equivalent circuit

Real transformer single phase electrical diagram shown below.

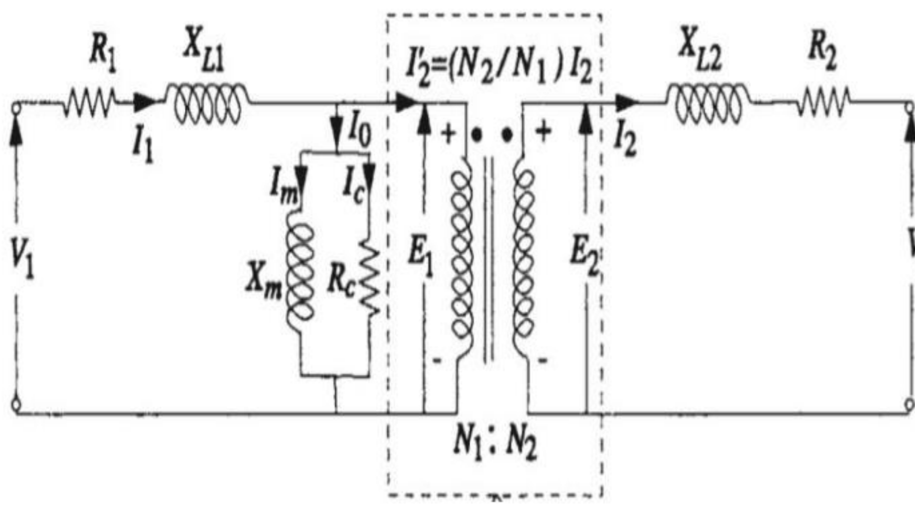


Figure 1. 6:Circuit diagram of a transformer

With:

Table 1. 1:Equivalent circuit.

V1 and V2	primary and secondary voltages
I1 and I2	primary and secondary currents
Io	no-load current
E1 and E2	primary and secondary ideal no-load voltages
N1 and N2	number of turns of the primary and secondary windings
R1 and R2	resistance of primary and secondary windings
XL1 and XL2	inductance of primary and secondary windings
Rc	iron losses
Xm	magnetizing reactance

Typical values of these parameters differ depending on the particular realization of a given transformer.

V1, V2, N1 and N2 set the nominal voltages and the no-load transformation ratio.

R1 and R2 are the electrical resistances of the windings, and the Joule losses will be mainly due to the passage of the currents I1 and I2 of load in these resistances.

The reactance's XL1 and XL2 correspond to the leakage fluxes of each of the windings.

It induces a voltage drop, depending on the load, representative of the short-circuit impedance of the transformer. It is strongly influenced by the geometric configuration of the windings between them.

1.5 Theory of transformer:

1.5.1 EMF Equation

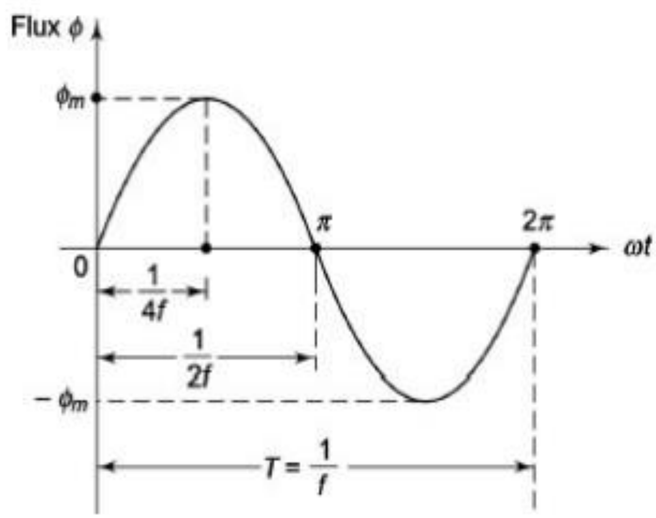


Figure 1. 7:Representation of alternating sinusoidal flows.

N2 = Number of turns in the secondary winding.

ϕ_m = Maximum flux in the core (Bm x A).

f = frequency of the AC supply (in Hz)

As shown in Fig. (1.7), the magnetic flux increases sinusoidally from zero to a maximum value of ϕ_m in one quarter of the period 1/4f.

Average rate of change of flux= ϕ_m / (1/4f) = 4f ϕ_m (Wb/s).

Induced EMF per turn = rate of change of magnetic flux per turn.

Therefore the average EMF per turn = 4f ϕ_m (volts).

The form factor = RMS value / average.

Therefore, RMS value of EMF per revolution = form factor x average EMF per revolution.

The flux ϕ_m varies sinusoidally, so the sinusoidal form factor is 1.11.

RMS value of EMF = 1.11 x 4f ϕ_m

RMS value of EMF per revolution = 4.44 f ϕ_m, where RMS value of EMF per turn is divided by the number of turns in the primary winding (N1) to give the primary winding (E1)

The total RMS value of the induced EMF can be derived:

E1= 4.44 f N1 ϕ_m.

In whole secondary winding (E2) can be derived as: E2= 4.44 f N2 ϕ_m.

From the above equations E1/N1 = E2/N2 = 4.44 f ϕ_m

Voltage transformation ratio (K)

E2/E1 = N2/N1 = K = const.

Notes:
- If N2 > N1, K > 1. The transformer is called step-up transformer.
- If N2 < N1, K < 1. The transformer is called step-down transformer

1.5.2 Transformer Loss

An ideal or perfect transformer has no energy loss. Therefore, the power on the primary side is equal to the power on the secondary side. However, practical transformers have small losses.

Therefore, power in primary coil = power loss + power in secondary coil

Today, power transformers are typically rated between 95% and 98% efficiency. The rest of this percent efficiency is a combination of different electrical losses in the transformer. Iron loss, copper loss, stray loss, and dielectric loss are types of transformer loss as shown in Figure (1.8) [2].

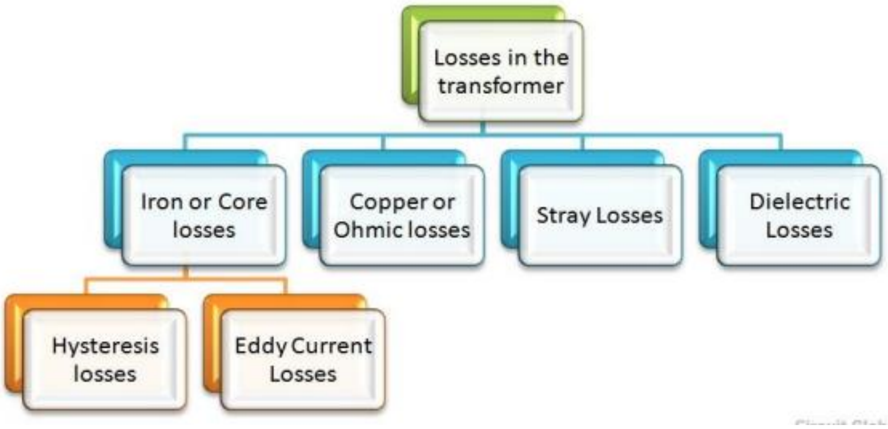


Figure 1. 8:Types of Losses in Transformer

1.5.2.1 Iron losses

Iron losses is occur in the core of the transformer, so it is known also as core losses.

Iron losses divided into the following:

a) Hysteresis loss:
This type of loss occurs due to magnetization reversal in the transformer core. The hysteresis loss depends on the amount and quality of iron used. It is the power dissipated in the form of heat and is given by the equation:
Wh = K Bmax f V (watts).
Which:
K: The proportionality constant.
f: frequency in HZ
Bmax: The maximum value of the flux density in T.
V: The volume of the core.

To reduce this type of loss, proprietary materials such as silicon steel are used in the construction of transformer cores.

b) Eddy current loss:
When an alternating current is supplied to the primary winding, it produces an alternating magnetizing flux in the core. Due to this flux, a voltage is induced in the secondary winding, which causes a current to flow to the load connected to it. Some of this alternating flux also links with the iron core of the transformer, causing an induced EMF. Due to this EMF, a current will circulate locally in the iron core of the transformer, not contributing to the output of the transformer, and dissipating as heat. This kind of power loss is called eddy current loss of transformer. The equation of eddy current loss is given by:
$Pe = K\ Bm^2\ t^2\ f^2\ V$ (watts).

Which:
K: co-efficient of eddy current.
Bm: the maximum value of the flux density.
t: the thickness of lamination in meters.

F: the frequency of reversal of magnetic field in Hz
V= the volume of magnetic material.

A key factor in minimizing eddy current losses is to make the core with thin laminations.

1.5.2.2 Copper Loss:

Copper loss is due to the ohmic resistance of the transformer windings.
The total copper loss of a transformer can be defined as:
$PC = I1^2R1 + I2^2R2$

1.5.2.3 Stray Loss:

The existence of a stray field causes stray loss. This type of loss is small compared to iron and copper losses. Therefore they can often be ignored.

1.5.2.4 Dielectric loss:

Dielectric loss happen in the transformer oil and other solid insulating materials in the transformer.

Losses occur in the transformer are core loss and copper loss. While stray and dielectric loss are very small. If these losses are decreased, it results in high efficient transformer.

1.6 Description of a power transformer

The transformer is composed of the following main elements.

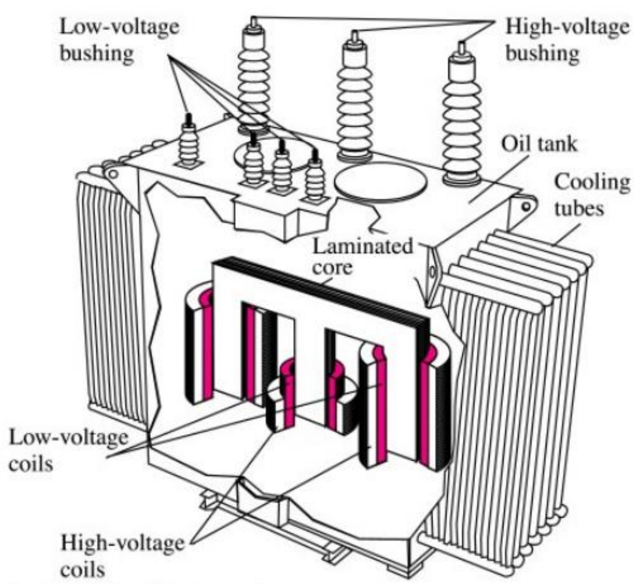


Figure 1. 9:power transformer components

The tank is a mechanically-welded steel assembly which protects the entire active part and allows it to be immersed in the dielectric oil. Cooling tubes are generally replaced by radiators or air coolers these days.

Some of the main elements of transformers are detailed below.

1.6.1 Windings

In the Figure below we can observe a single winding, with several turns which will be connected thereafter to the final connections of the transformer.

Figure 1. 10:Transformer winding

For a given phase of a transformer there is one winding per voltage level considered: a low voltage (LV) and a high voltage (HV), with sometimes an additional medium voltage (MV).

These different windings are nested one inside the other with generally the low voltage winding on the inside and the windings of higher voltage levels increasingly on the outside; all of these windings constituting a phase are installed on the cores of the magnetic circuit (CM).

1.6.1.1 winding coupling

In three-phase transformers, each phase contains its own windings, it is then necessary to connect the three phases, i.e. each single-phase element, together to form a three-phase system. The way these phases are connected together is called coupling.

The couplings are standardized and have a symbol which indicates the mode of electrical connection, and a time index which indicates the phase shift in voltage between the primary and secondary terminals of phase A.

The usual coupling symbols are:

➢ Star coupling: Y, with neutral point out (YN), or not (Y)

➢ Delta coupling: D

➢ Zigzag coupling: Z, with neutral point extended (ZN), or not (Z)

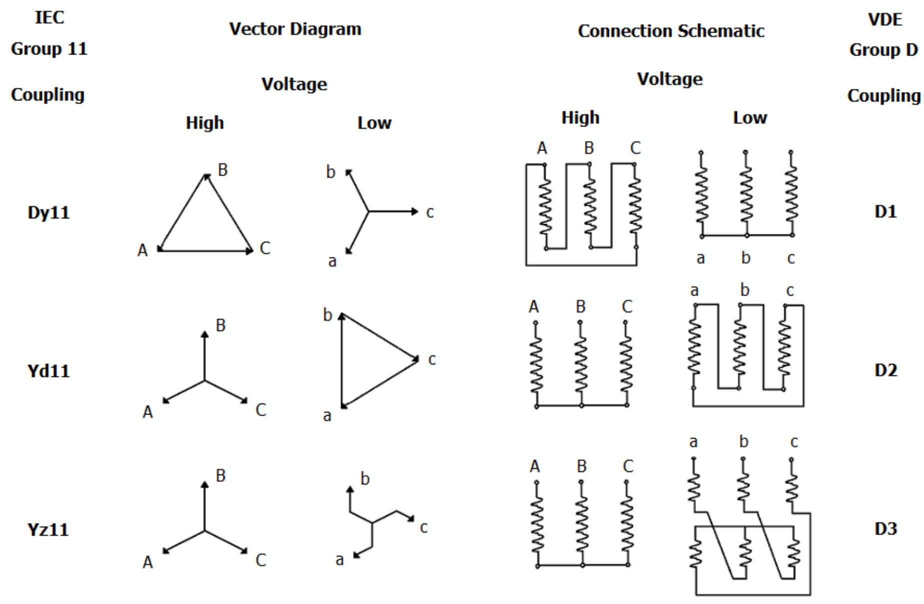


Figure 1. 11:The different types of coupling

The choice of coupling is based depends on several criteria:

- The load requires the presence of the neutral: The secondary must be connected either in star or zigzag.
- The operation is unbalanced: the secondary must be coupled in zigzag.
- On the high voltage side, it is better to choose star coupling (less turns to use).
- For high currents, triangle coupling is preferred than other couplings.

1.6.2 The magnetic circuit:

It is essentially composed of ferromagnetic sheets with oriented crystals, containing 6% of silicon. The magnetic circuit is formed of two parts, the core and the cylinder heads, to facilitate implementation during construction.

The core, which has a square or circular section depending on the type of transformer and the shape adopted for the coils, is made up of sheet metal bundled five to ten millimeters thick. Large transformers have cooling channels inside the cores.

The cylinder heads are located above and below the cores and are nested in the magnetic laminations of the core. [3]

Figure 1. 12:The magnetic circuit of transformer

The magnetic circuit is one of the heaviest elements of power transformers and can easily weigh a third of the total mass of a transformer. For example, in a 100 MVA transformer with a total mass of 120 tons, the circuit can weigh 45 tons

1.6.3 Dielectric oil: insulator and coolant

1.6.3.1 insulating role

All the windings are immersed in a tank filled with an insulating fluid whose dielectric strength conditions the distances between live parts. For example, a 400 kV transformer must be able to withstand brief shocks of 1425 kV during tests at the manufacturer. This fluid is typically mineral oil.

1.6.3.2 cooling role

The fluid also serves as a heat transfer agent from the active part, which is a hot source, to a cooling system. The thermal conductivity of this fluid and its specific heat must be as high as possible, and its viscosity ideally low. For example, in the largest transformers, losses can reach up to several MW, and efficient cooling is essential.

A new transformer having to withstand several decades of service, it is imperative that the quality of its oil be excellent, in particular its dielectric strength, its viscosity to effectively evacuate losses, and its stability over time (to oxidation basically).

Internal defects, thermal or electrical among others, leave traces in the oil, and analyzing oil samples from transformers can help detect these faults effectively.

1.6.4 Tap changer

On relatively stable networks, transformers are often equipped with an off-Load tap changer.

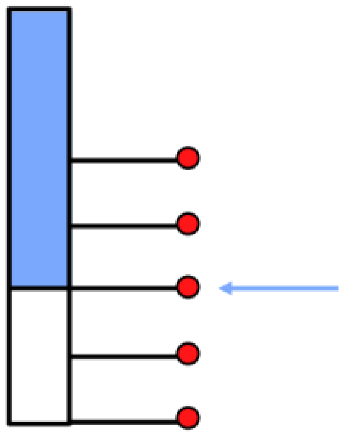


Figure 1. 13: Diagram of the off-Load tap changer

Figure shows the simplified diagram of a voltage tap changer with five taps in series on the considered winding. Here the third socket is in use.

These relatively simple devices are generally little manipulated, typically have three to seven sockets, and can be adapted to the network voltage if it changes significantly during the life of the transformer.

1.7 Types of power transformers:

Transformers are classified into different categories according to their [4]:

- Usage
- Cooling method
- Insulating medium
- Basic build

1.7.1 Classification of transformers according to their use [4]

Transformers are classified according to their use into the following categories:

- **Distribution transformers**

They are used in distribution networks in order to transmit energy from the medium voltage (MV) network to the low voltage (LV) consumer network.

Their nominal power generally varies from 50 to 1600kVA.

Figure 1. 14: Distribution transformer

- **Power transformers**

They are used in high power plants for voltage step-up and in transmission stations for step-up or step-down voltage, usually they are of power greater than 2MVA.

Figure 1. 15: Power transformer

- **Autotransformer**

Used for voltage conversion within relatively small limits, connecting power systems with different voltages, starting AC motors, etc.

Figure 1. 16:Autotransformer

- **Special power transformers**

They are used for special applications, for example, in ovens and welding.

Figure 1. 17:welding transformers

- **Telecommunication transformer**

They are used in telecommunications applications intended to produce a reliable signal over a wide frequency and voltage range.

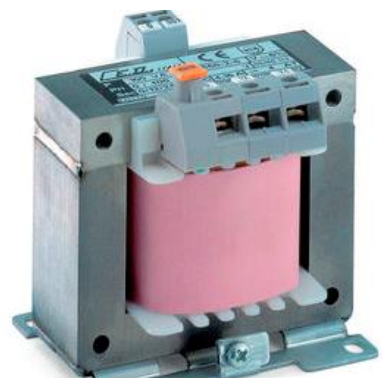


Figure 1. 18:Telecommunication transformer

1.7.2 Classification of transformers according to the method of cooling

The identification of oil-immersed transformers according to the cooling process is expressed by a four-letter code.

- The first letter designates the internal cooling fluid: **O** for mineral oil (99% of cases), **K** for insulating liquids with a fire point >300°C, **L** for liquids with an unmeasurable fire point

- The second letter designates the mode of circulation of the cooling fluid internal: **N** for natural, **F** for forced (presence of a pump, but the oil circulates freely), **D** for force and directed (pump and the oil is forced and directed through the windings).

- The third letter indicates the external coolant: **A** for air, **W** for water.

- The fourth letter designates the mode of circulation of the coolant external: **N** for natural, **F** for forced (fans).

In power transformers, various cooling methods are used, including circulation of oil by pumps or forced circulation of air by fans, or both of the above. As a result, the methods of following cooling's exist:

- ONAN: Oil Natural Air Natural

- ONAF: Oil Natural Air Forced

- OFAN: Oil Forced Air Natural

- OFAF: Oil Forced Air Forced

- OFWF: Oil Forced Water Forced

- ODAF: Oil Directed Air Force

- ODWF: Oil Directed Water Forced

For dry-type transformers:

- AN: Air Natural
- AF: Air Force

1.7.3 Classification of transformers according to the insulating medium

Transformers are classified according to their insulating medium in the categories following:

1. Oil-Immersed Transformers:

The insulating medium is mineral oil or synthetic (silicon) oil.

Figure 1. 19:Immersion type transformer

2. Dry type transformers

Cooling is implemented with natural air circulation and the windings are usually insulated with Class H or F materials. Class H materials are designed to operate under normal conditions at temperatures up to 180°C and Class F materials at temperatures up to 155°C.

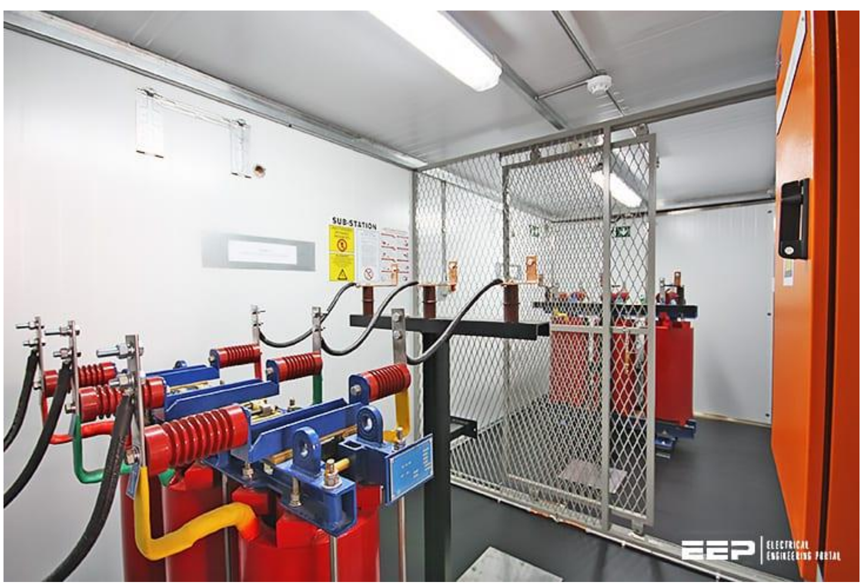


Figure 1. 20:Dry type transformer

1.7.4 Classification of transformers according to body construction (magnetic circuit)

a. Forms of magnetic circuits

Either in two columns formed by stacking sheets in staggered rows, or in shielded form, i.e. the windings are placed on the central column and the magnetic flux Φ [Wb] is closed on each side forming a breastplate.

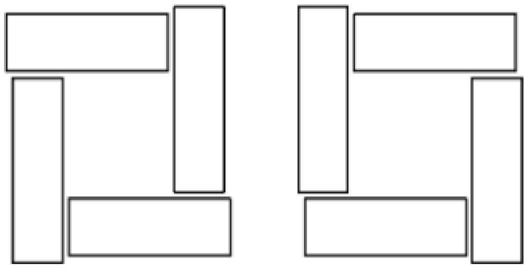


Figure 1. 22:Column type magnetic circuit

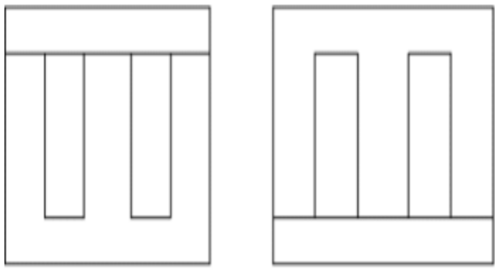


Figure 1. 21:shielded type magnetic circuit.

b. Different types of magnetic circuits

b.1. with three legs-vertical limbs:

The magnetic flux of a leg must circulate in the two other legs and also the flux passes through the coils of other phases, i.e. the transformer does not have flux free return.

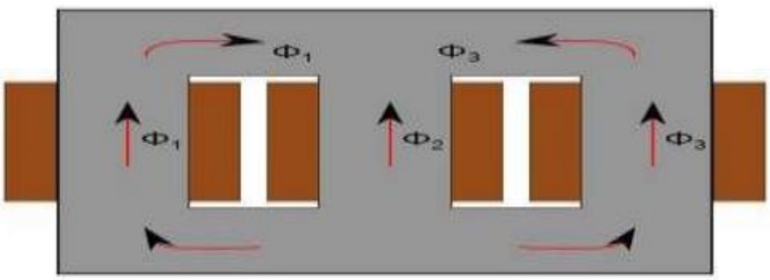


Figure 1. 23:magnetic circuits with three legs.

b.2. with five legs (vertical limbs):

A free flow return through the outer leg.

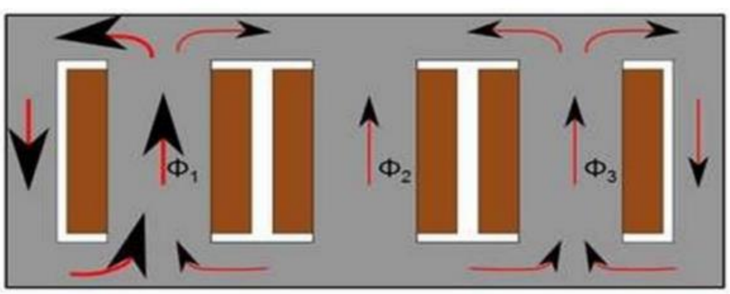


Figure 1. 24:magnetic circuits with five legs.

c. Two different materials are used for the construction of the core

c.1. Silicone steel sheet:

The silicon steel sheet which is used for the base construction it is an alloy consisting of 97% iron and 3% silicon. This material is crystalline. The silicon steel sheets have a thickness of 0.18 to 0.5mm. There are also silicon steel sheets for high magnetic induction operation.

c.2. Amorphous metal sheet:

The amorphous metal sheet which is used for the base construction it is an alloy consisting of 92% iron, 5% silicon and 3% boron. This material is not crystalline. It has 70% lower loss without filler than silicon steel. The thickness of the amorphous metal sheet is 0.025mm, that is to say, it is about 10 times less than the typical thickness of the steel sheet at the silicon.

1.8 Conclusion

In conclusion, transformers are essential devices used in many electrical applications to transfer electrical energy between circuits using magnetic flux. Their operation is based on the principle of electromagnetic induction and they are designed to operate at specific frequencies and made with different core materials to optimize their performance.

The next chapter will focus on the detection of faults in transformers and various methods used for fault diagnosis. Fault detection is an important aspect of transformer maintenance as it helps to prevent costly downtime and extend the transformer's lifespan. These methods play a crucial role in identifying and diagnosing transformer faults and will be discussed in detail in the upcoming chapter.

Chapter 2: Fault detection and various methods

2.1 Introduction

Like all electrical equipment, transformers can experience faults that lead to failure, one mistake can cause many problems, and a simple mistake on the part of the distributor can cause a widespread power outage. These faults can be dangerous because transformers contain large amounts of oil in direct contact with high voltage parts, increasing the risk of fire or explosion due to failure.

Different faults have various causes and effects on the power system. Transformers are one of the most expensive components in the network, making the study of transformer faults and detection very important. This chapter will introduce all the necessary concepts for detecting and locating faults in power transformers. The presented information can be significant for one or more faults, and they will be correlated with each other to diagnose faults.

2.2 External fault

External fault of the power transformer is an external short circuit of the power transformer.

The level of fault current is always high enough. It depends on the impedance of the circuit up to the point of failure and the short circuit voltage. The copper losses in the faulty feeder transformer increase sharply. This increased copper loss causes internal heating of the transformer. Large fault currents also create strong mechanical stresses on transformers. Maximum mechanical stress can occur during the first cycle of the symmetrical fault current.

In high voltage, there are two main types of faults in power transformers. Transient voltage surges and line frequency over voltages. [1]

a) Transient Overvoltage: High frequency overvoltage can occur in power systems due to any of the following:

- Arc grounding when the neutral is insulated.
- Switchover processing of various electrical equipment.
- Atmospheric lightning pulse.

Whatever the cause of an Overvoltage, it is ultimately a traveling wave with a high steep waveform and high frequency that spread through the mains, reaches the power transformer, and travels between adjacent windings. Breaks down the insulation of lead connections which can lead to short circuits between turns.

b) Overvoltage supply frequency: There can always be a risk of system overvoltage due to sudden disconnection of a large load, although the magnitude of this voltage is higher than its normal level, the frequency is the same as under normal conditions, an overvoltage in the system causes an increase in stress on the insulation of the transformer.

As we know, the tension:

$$v = 4.44\phi . f . T \Rightarrow v \propto \phi \quad \text{(II.1)}$$

Where v: voltage, ϕ: the flux in the core, f: the frequency of the supply, T: the number of turns in the winding.

Increased voltage causes a proportional increase in flux, so this causes an increase in iron loss and a proportionally large increase in magnetizing current, the increase flux is diverted from the transformer core to other parts of transformer steel structures.

Under such conditions, the bolt can be quickly heated and destroy its own insulation as well as the winding insulation.

$\propto \phi$/f .... (II.2)

From this equation, it is clear that if the frequency decreases in a system, the flux in the core increases, the effects are more or less similar to those of overvoltage.

2.3 Internal Faults

Internal faults are defects that occur inside a transformer that seriously affect the protection of the transformer, due to the complexity of the device, the visual confirmation of this type of fault remains complex and can cause the transformer to disconnect.

Therefore, the transformer should be immediately shielded from these disturbances. These problems are divided as electrical and mechanical faults.

Basic Internal faults can be found in the following:

- ✓ Over heating
- ✓ Winding faults
- ✓ Open circuits
- ✓ Over fluxing
- ✓ Earth faults
- ✓ Phase faults
- ✓ Inter turn faults
- ✓ Core faults
- ✓ Bushing faults
- ✓ Tank faults and cooling failure
- ✓ Tap changer fault

2.4 The main faults on a transformer [2]

2.4.1 Mechanical faults

The main faults related to mechanical stresses are:

- Degradation of internal insulation due to abnormal vibrations, themselves due to a lack of internal tightening in the construction, or following major shocks.
- The decrease in dielectric distances, due to the massive internal displacement of a magnetic circuit of several centimeters, following a mechanical shock such as when a transformer falls (Figure 2.2).
- Leaks from joints that are mechanically too tight and/or heated (Figure 2.1) during their installation and then their operation.
- Deformation of the magnetic circuit.
- Defects related to transport conditions.

Figure 2. 2:Transformer fall

Figure 2. 1:Leaks of joints

2.4.2 Electrical faults

These faults are the consequences of a short circuit or an open circuit in the primary or secondary winding.

• A short-circuit causes an increase in the temperature inside the transformer, which leads to the deterioration of the insulation of the conductors. The transformer is therefore unbalanced.

• Overvoltage due to bad contacts.

• Missing phases of the HV source.

• Power transformer overloads (Kch >100%).

• Load unbalance on the three phases LV. Ex: Short circuit between turns Figure (2.3).

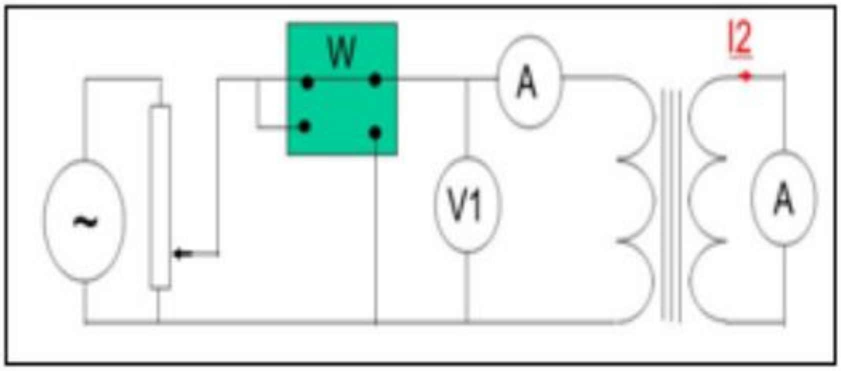


Figure 2. 3:Short circuit between turns [3]

2.4.3 Thermal faults

In all cases, these thermal stresses cause aging and degradation of various components:

• Insulating papers and the consequent degradation of their dielectric properties. For example, in the extreme case of (Figure 2.4), the entire coil is blackened from the inside due to operation at excessive temperatures.

• Insulating oil: Temperature, humidity, and oxygen accelerate the aging of the oil, which therefore loses its original qualities and can lead to defects.

Figure 2. 4:Overheating of a winding

2.4.4 Dielectric faults

The dielectric faults are characterized by the voltage withstand of the various transformer elements, this dielectric withstand is linked to the state of the insulators, the most known faults in this category:

- Active part isolation
- Dielectric ignition between turns, without short-circuit
- Short-circuit between turns
- Partial Discharges

Figure 2. 6:Dielectric ignition between turns

Figure 2. 5:Short-circuit between turns

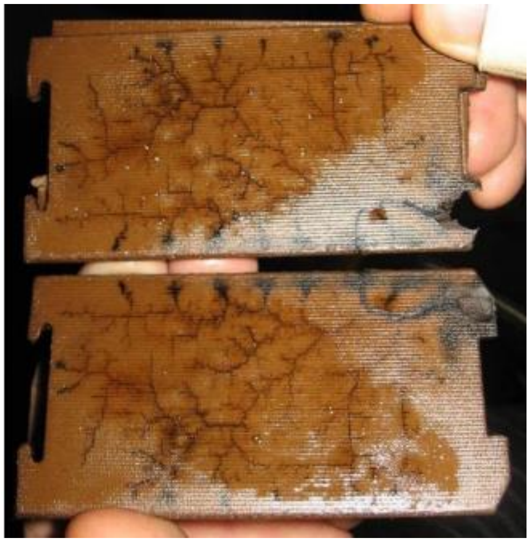


Figure 2. 7:Partial Discharges

2.4 Causes of defects

The causes of faults are multiple, mainly based on thermal, electrical and environmental effects. They can be classified into three groups:

➢ Fault initiators: transformer overheating, wear of contact elements, breakage of HV terminal insulators, LV fixings, electrical insulation problem in particular of the winding, transient overvoltage, etc.

➢ Contributors to faults: frequent overload, high ambient temperature, faulty ventilation, humidity, bad earth, ageing, etc.

➢ Underlying defects and human errors: manufacturing defects, defective components, unsuitable protections (fuses not calibrated), incorrect operations on the HV side, lack of maintenance, etc.

2.5 Fault detection methods

To detect faults, a transformer is equipped with sensing. The latter provides as output signal a usable physical quantity in response to another physical quantity specified as input signal. Sensors or detectors that provide as an output signal a usable electrical quantity in response to a quantity, property or physical condition to be measured. The principles of these transductions are based on the existence of various physical or chemical effects. Six main classes of signals can be distinguished [4].

➢ **Electrical**: voltage, current, load, resistance, inductance, capacitance, dielectric constant, polarization, electric field, frequency, dipole moment, potential,…etc.

➢ **Mechanical**: length, surface, volume, linear or angular speed, acceleration, mass flow, force, torque, pressure, wavelength and acoustic intensity, etc.

➢ **Chemicals**: composition, concentration, reaction rate, pH, oxidation, reduction, etc.

➢ **Thermal**: temperature, heat, cold, entropy, heat flux, state of matter, etc.

➢ **Magnetic**: field strength, flux density, magnetic moment, permeability, etc.

➢ **Optics**: intensity, wavelength, reflectance, transmittance, refractive index, etc.

2.6 Diagnostic techniques on SONELGAZ Transformers

The use of diagnostic techniques is very useful because it allows the assessment of the condition of the transformer components and the programming of preventive or corrective activities, thereby facilitating the scheduling of work and reducing downtime.

In this context, the diagnostic actions carried out by SONELGAZ-GRTE on power transformers include:

2.6.1 Oil analysis

The operation of transformers in good condition depends to a large extent on the quality of the mineral insulating oils used. The characteristics of oils are degraded by contamination, humidity, and aging. Insulating oil is one of the most important elements in a transformer that requires monitoring and maintenance because its function is to insulate and cool it. Oil is a fluid that penetrates all the internal parts of the transformer, and its circulation allows the evacuation of the heat produced by the windings through convection in the transformer tank [5]. Knowledge of the state of the oil and gases that can be dissolved in it is fundamental to ensure the correct operation of transformers, so it is necessary to carry out a regular check of the oil's condition.

2.6.1.1 Properties of oils:

The choice of an insulating oil is based on a large number of properties that can be grouped into three:

- Physical properties;
- Electrical properties;
- Chemical properties.

2.6.1.1.1 Physical properties

- **Viscosity:**

The viscosity of a fluid is defined as the property that characterizes its resistance to flow. More precisely, viscosity results from the resistance that the molecules of the fluid oppose to forces that tend to move them by relative sliding within it [6].

- **Pour Point :**

This is the lowest temperature at which oil will begin to flow under standard test conditions. The pour point of a transformer oil is an important property, especially in extremely cold climates. When the temperature of the oil drops below the pour point, the transformer oil stops convection, preventing cooling within the transformer. Paraffinic oils have a higher pour point than naphtha based oils.

The pour point of transformer oil mainly depends on the wax content in the oil. Paraffinic oils have a higher pour point due to their higher wax content.

If the liquid does not flow anymore. Two phenomena can be responsible for the loss of flow:

- Increase in viscosity at low temperature.
- The crystallization of certain components.

Insulating liquids in electrical engineering generally freeze at temperatures ranging from (-60°C to -30°C).

- **Flashpoint :**

The flash point of transformer oil is the temperature at which the oil releases enough vapor to form a flammable mixture with air. This mixture provides an instant flash when flame is applied under standard conditions. Flashpoint is important because it indicates the fire hazard in transformers.

Therefore, it is desirable that the transformer oil have a very high flash point. Usually over 140° [7].

- **Color appearance:**

The appearance, which is a visual test carried out on the oil, allows us to detect the presence of bodies in suspension (dust, humidity) and to evaluate its color and viscosity. A good visual condition of the oil means a clear appearance.

Color is an intrinsic property of new oil, and it has a relationship with the hydrocarbons that constitute it. It allows the quality of new oils to be assessed and is an effective means of monitoring their acidity in service. It also provides information about the oil's aging process. The appearance, color, and smell tell us about the general condition of the oil; a bad smell warns of the presence of electric arcs in the oil, a dark color indicates oil degradation, and the cloudy appearance means the presence of water and impurities [8].

Color comparator number	Color	Oil condition
< 7	Pale yellow	Good oil
7 - 10	Yellow	Proposition A oil
10 - 11	Bright Yellow	Service-aged oil
11 - 14	Amber	Marginal condition
14 - 15	Brown	Bad condition
16 - 18	Dark brown	Severe condition (reclaimed oil)
> 18	Black	Extreme condition (scrap oil)

Figure 2. 8:conditions of the transformer oil

2.6.1.1.2 Chemical properties

- **Humidity in Transformer Oil**

Initially, when the oil is new and treated, it has a low water content (<10 ppm for mineral oil), this content will increase during the life of the transformer following the penetration of humidity from the atmosphere but also with the degradation of the paper.

Humidity in transformer oil is highly undesirable as it adversely affects the dielectric properties of the oil.

Humidity in oil also affects the paper insulation of transformer windings and cores. Paper is highly hygroscopic. Paper absorbs the maximum amount of humidity from oil. This affects the paper's insulating properties and reduces its life. But in a loaded transformer, the oil gets hot. Therefore, the solubility of water in oil increases.

As a result, the paper releases humidity, increasing the humidity content of the transformer oil. Therefore, the temperature of the oil at which the sample is taken for testing is critical. Acids are formed in oils during oxidation. Acids cause dissolution of water in oil. Acids combined with more water will break down the oil, forming more acid and water. The rate of deterioration of this oil increases.

- **Transformer oil acidity**

Acidic transformer oil is a detrimental property. The more acidic the oil, the easier it is for the water in the oil to dissolve in the oil. The acidity of the oil reduces the insulating properties of the winding paper insulation. Acids accelerate the oxidation process of oils.

Acids also include rusting of iron in the presence of moisture.

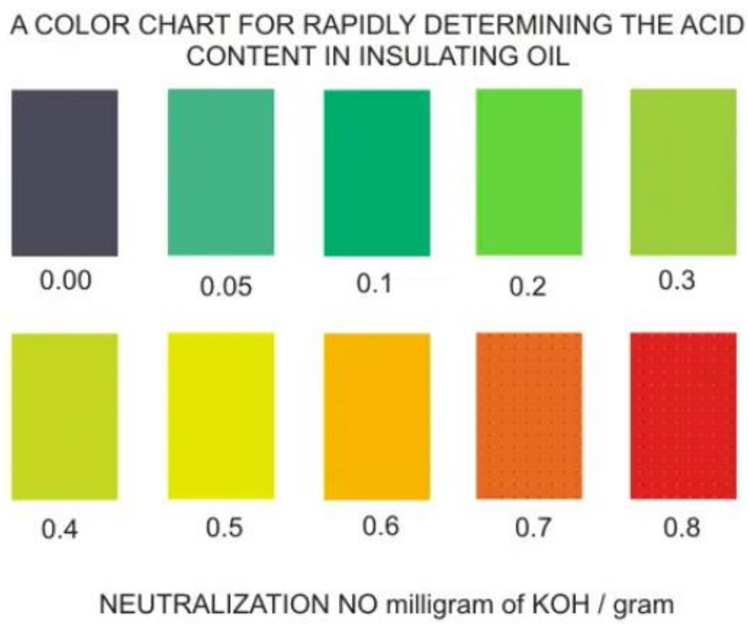


Figure 2. 9:Acidity Test of Transformer Insulating Oil

2.6.1.1.3 Electrical properties

- **Permittivity:**

The relative permittivity εr of a product is defined as the ratio between the capacitance of a capacitor filled with this product and the capacitance of the same empty capacitor:

$\varepsilon r = Cp/C_o$

In practice, εr is obtained by comparing the full capacitor to the capacitor in air. The error made on the determination of εr is small, since the relative permittivity of the air (at 25°C and under atmospheric pressure) is equal to 1.0005.

The absolute permittivity ε is the product of the relative permittivity εr by the vacuum permittivity:

ε_o=8, 85.10^-12 F/m, avec $\varepsilon=\varepsilon_o\ \varepsilon r$

The permittivity intervenes in the electrostatic force between electric charges q and q'

$F= K.q.q'/ \varepsilon.d^2$

d: distance between the charges.

- **Resistivity, Conductivity:**

An oil to be electrically insulating, must conduct as little electricity as possible when a voltage is applied to it. Its conductivity σ must therefore be as low as possible or conversely its resistivity ρ (Ω.cm) must be as strong as possible (ρ=1)

The conductivity of an insulating oil is due to the presence of positive and negative free charges (ions), in equal quantities. Under the effect of an electric field, these charges move, thus causing a conduction current [9].

The higher the temperature, the lower the viscosity of the oil and the greater the mobility of the ions, and therefore the higher the conductivity.

This is another important property of transformer oil, Oil resistivity is a measure of the DC resistance between two opposite sides of a cm3 oil block, as the temperature increases, the resistivity of the oil drops rapidly.

Immediately after charging the transformer after a long standstill, the oil temperature is ambient and very hot at full load. Overload can reach up to 90°C. The resistivity of insulating oil should be high at room temperature and have good value at high temperature.

Therefore, the resistivity or specific resistance of transformer oils should be measured at 27 °C and 90 °C.

The minimum typical resistivity of transformer oil is 35 x 1012 ohm-cm at 90°C and 1500 x 1012 ohm-cm at 27°C.

- **Tan Delta Dissipation Coefficient**

The dissipation factor or dissipation factor (tgδ) is directly related to AC resistivity and permittivity tgδ=1/R.C

The dissipation factor is also known as transformer oil dissipation factor or tan delta. Leakage current flows when an insulator is placed between the live part of an electrical device and the ground part. Since an insulator is a dielectric, the current through it ideally leads the voltage by 90°. Voltage here means the instantaneous voltage between the live part and the device ground. But in reality, no insulating material is inherently a perfect dielectric.

If the loss angle is small, the resistive component of the current IR is small, indicating high resistive properties of the insulating material. High resistance insulation is a good insulator. Therefore, one should try to keep the value of tanδ as small as possible. This high value of tanδ indicates the presence of impurities in the transformer oil.

In a nutshell, tanδ is a measure of the dielectric imperfections of insulating materials such as oils [7].

2.6.1.2 Analysis of gases dissolved in oil

2.6.1.2.1 Formation of gas dissolved in the oil during a fault

We begin by examining the rate of combustible gas production, which increases as fault conditions worsen. The relative composition of the gases then provides a means of detecting changes in fault conditions. For example, as the temperature of an oil fault increases, the relative composition changes from predominantly methane and ethane to greater amounts of ethylene. When the fault temperature rises sufficiently, acetylene begins to form. When this occurs, the failure temperature around the cellulose paper insulation increases, often accelerating the production of carbon dioxide gas and reducing carbon dioxide.

This diagnostic technique is one of the most reliable predictive methods and has the advantage of being able to be carried out without leaving the transformer out of service.

Table 2. 1:Gases of Interest [10]

Gas	**Generation**
Oxygen	Typically present from residual air, air ingress, can be generated from electrolysis of free water
Nitrogen	Typically present from inert nitrogen pressure system, residual air, air ingress
Hydrogen	Partial discharge activity, overheating of oil, electrolysis of free water
Methane	Partial discharge activity, overheating of oil
Ethane	Overheating of oil
Ethylene	Overheating of oil, associated with higher temperature overheating
Acetylene	Arcing in oil, very high temperature overheating of oil (typical starting around 700^{o} C
Carbon monoxide	Overheating of paper, CO_2/CO ratio provides additional information
Carbon dioxide	Overheating of paper, CO_2/ CO ratio provides additional information

2.6.1.2.2 Methods of interpreting the results

The analysis of gases dissolved in transformer oils is a well-known diagnostic technique in the industry and several criteria have been established. The best-known common criteria are those of Rogers, Dornenburg, IEC 60599 and Duval's triangle.

- **Dornenburg ratio method**

This method uses the ratio of gas concentrations to indicate the fault type. The gas ratio method uses a coding scheme that assigns specific combinations of codes to specific fault types. A fault condition is recognized when a gas combination matches a specific fault code. The code is generated by calculating the ratio of gas concentrations and comparing the ratio to predefined values that are derived from experience and changed continuously. The

Dornenburg ratio method uses four gas concentration ratios such as CH4/H2, C2H2/C2H4, C2H2/CH4 and C2H6/C2H2 to identify thermal damage, corona discharge and flashover.

Each consecutive ratio is compared to a specified value, and the diagnosis is confirmed if all four consecutive ratios for a particular disorder fall within the given value. In this scheme, the ratio method is considered correct if the H2, CH4, C2H2, and C2H4 gas concentrations of (ppm) are more than twice the relevant L1 concentrations shown in Table 2. However, this procedure can lead to a large number of "no interpretation" results due to incomplete ratio ranges [11].

Table 2. 2:Concentration of Dissolved Gas.

Key Gas	L1 Concentrations (ppm)
Hydrogen (H2)	100
Methane (CH4)	120
Carbon monoxide (CO)	350
Acetylene (C2H2)	35
Carbon monoxide (CO)	50
Acetylene (C2H2)	65

Doernenburg gas analysis attempts to identify the following anomalies:

- Thermal faults

- Partial discharge (Corona)

- Arc discharge

Table 2. 3:Dornenburg Ratio Method Concentration Ratios.

Suggested Fault Diagnosis	CH4/H2	C2H2/C2H4	C2H6/C2H2	C2H2/CH4
Thermal Decomposition	>1	<0.75	<0.3	>0.4
Corona	<0.1		<0.3	>0.4
Arching	>0.1, <1	>0.75	>0.3	<0.4

- **Rogers Ratio Method (RRM)**

The most common gas ratio method is the Rogers ratio method, which distinguishes more thermal fault types compared to the Donenberg ratio method. The Rogers method analyzes four gas ratios:

CH4/H2, C2H6/CH4, C2H4/C2H6, and C2H2/C2H4. Disorders are diagnosed using a simple coding scheme based on ratio ranges. The Rogers ratio is a simple scheme based on ratio ranges used for fault diagnosis. The four recognizable conditions for oil-insulated transformers are normal aging, partial discharge with or without tracking, and electrical and thermal failures of varying severity. This method, based on the thermal degradation principle. This method is useful for correlating the results of multiple damage investigations with their respective gas analyses. However, some ratio values do not match the diagnostic codes associated with various failures of this procedure. This method also does not consider dissolved gases below normal concentration levels, so even an accurate implementation of the method may misinterpret the data [12].

Table 2. 4:Rogers Ratios Method.

Case	R2 C_2H_2/ C_2H_4	R1 CH_4/ H_2	R5 C_2H_4/ C_2H_6	Suggested Fault Diagnosis
0	<0.1	>0.1 to <1	<1	Unit normal
1	<0.1	<0.1	<1	Low-energy density arcing- PD
2	0.1 to 3	0.1 to 1	>3	Arcing – High-energy discharge
3	<0.1	>0.1 to <1	1 to 3	Low temperature thermal
4	<0.1	>1	1 to 3	Thermal less than 700°C
5	<0.1	>1	>3	Thermal exceeding 700°C

This method is useful for correlating the results of multiple damage investigations with their respective gas analyses.

- **IEC Ratio Method**

This method uses the same three ratios as the Rogers ratio method, but suggests different ratio ranges and interpretations. The fault diagnosis scheme recommended by the International Electrotechnical Commission (IEC) [13] identifies four conditions: normal aging, low and high energy density partial discharges, thermal faults, and electrical faults of varying intensity.

IEC 60599-1999 directly uses the ratio ranges. The 3D graphical representation of ratio ranges is another improvement, Plot the non-diagnostic faults on a graph so that you can observe the closest distance to a specific fault region.

The six major defects classes are shown below in the form of interpretation tables.

Table 2. 5:IEC Ratio Method Diagnosis.

Case	Characteristic fault	C2H2/C2H4	CH4/H2	C2H4/C2H6
PD	Partial discharges	Not significant	<0.1	<0.2
D1	Discharges of low energy	>1	0.1-0.5	>1
D2	High energy discharges	0.6-2.5	0.1-1	>2
T1	Thermal faults<300°C	Not significant	>1 but Not significant	<1
T2	Thermal faults>300°C and <700°C	<0.1	>1	1-4
T3	Thermal faults>700°C	<0.2	>1	>4

➢ **Duval Triangle Method**

This method uses values of only three gases CH4, C2H2 and C2H4 and their location in a triangular map [14]. Gases are transformed into triangular co-ordinates.

This method is easily performed but careless implementation can obtain false diagnosis. The permissible amount of dissolved gases should be determined before using this method to analyze transformers.

A weakness of ratio techniques is that they do not cover all ranges of data and often overlook data that are ratios outside the thresholds determined in the tables. It always provides a diagnosis, with a low percentage of wrong diagnosis. Figure (2. 10) shows the coordinates and fault zones of Duval Triangle.

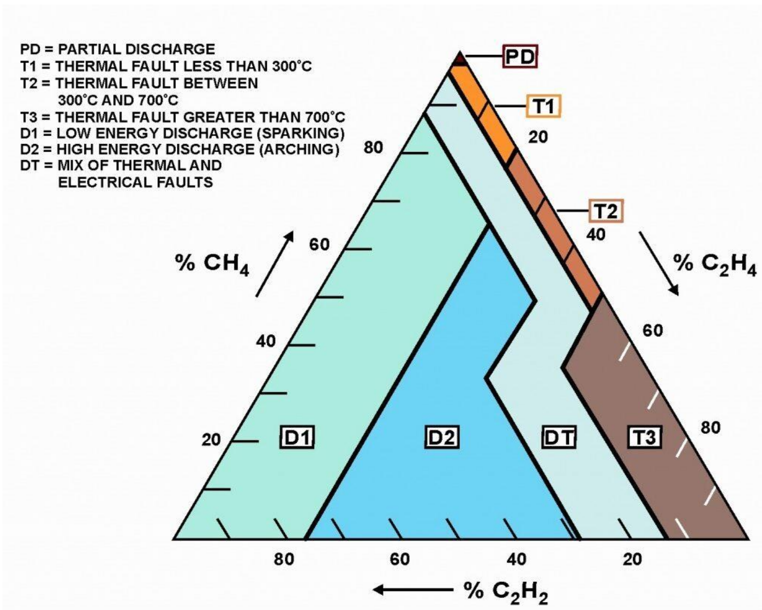


Figure 2. 11:Fault Zones in the Duval Triangle Method

2.6.2 Dielectric measurements

The electrical insulators of equipment are subject to aging giving rise to a progressive loss of their dielectric characteristics which can be the cause of transformer faults.

The objective of dielectric measurements is to detect possible degradation in the insulation of the transformer in order to be able to intervene before the occurrence of an incident due to damage.

The insulation condition is an essential factor in the operational reliability of transformers. To assess its condition, the following parameters must be measured:

• Power factor measurement.

• Capacity measurement.

• DC insulation resistance measurement.

2.6.2.1 Loss factor and capacitance measurement

This type of test is applied to windings and terminals, allowing clear identification of sources of short-term problems in the transformer.

The measurement of the loss factor and the capacity of the windings is a good tool to determine the quality and the condition of the insulation of the equipment, especially those which incorporate in their manufacture paper or oil insulation.

• F.P loss factor measurement

The loss factor test or called 'tag δ' makes it possible to assess the quality and integrity of the capacitive insulation of the windings, by indicating the existence of insulation deterioration (aging of the paper, the presence water in the paper, poor condition of the oil, electric shock) [15].

• Winding capacitance measurement

Capacitance provides general information about the insulation loss in the core or the windings. The capacitance measurement is made between tank and winding or between winding.

Thus, a variation in the insulation capacity proves the existence of abnormal conditions, such as the presence of humidity, short-circuited or interrupted conductor sections, winding deformation.

•Terminal capacitance measurement

High voltage bushings are an important accessory which, in the event of damage, can be a major cause of the transformer's indispensability, which means that particular attention must be paid to their maintenance.

The measurement of the capacitance of the terminals can provide information on the state of the terminals, which will make it possible to avoid damage (explosion) to the bushings.

If the terminals are of the capacitive type, they normally have a test tap, a capacitive terminal of typical construction has two insulations C1 and C2, the value C1 represents the capacitance between the center conductor of the terminal and the capacitive tap, and C2 indicates the capacitance between the capacitive tap and the ground, see Fig (2.11).

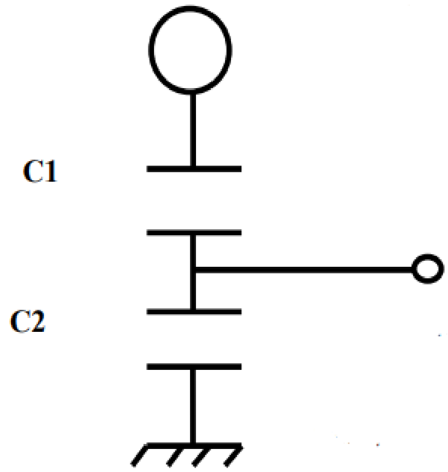


Figure 2. 12:Diagram of a capacitive type terminal

Certain precautions to reduce the causes of errors:

-carry out the measurements if the atmospheric humidity is low.

- ensure the depollution of the crossings before measuring.

- The measurements must be carried out at a temperature close to that of the factory test.

2.6.2.2 DC insulation resistance measurement

It mainly corresponds to the measurement of the surface conductivity of the insulation and used in the detection of an impending fault. It consists of checking the insulation between windings, between winding and tank, between tank and earth.

• Principle of measurement

Consists of short-circuiting all the terminals of the tested winding and applying a voltage of 5000 V to it with a measuring device called a Megohmmeter and the other windings are short-circuited and connected to earth. It is advisable to make sure that the tank and the core are connected to the earth.

• Polarization Index

The polarization index PI is the ratio between the measurement of the insulation resistance at 10 minutes and the insulation resistance at 1 minute [16].

$$R = \frac{R_{10}\text{min}}{\text{R}_1\text{min}} \quad \text{...} \quad \text{(II.3)}$$

The acceptance criteria for the PI are:

Table 2. 6:Domain of PI.

Polarization Index (10 min/ 1 min)	criteria
<1	Dangerous
<1.5	Poor
1.5- 2	Doubtful
2-3	Acceptable
3- 4	Good
>4	Excellent

2.6.3 Electrical measurements

The electrical measurements carried out on the transformers are:

2.6.3.1 No-load current measurement

The excitation current of a transformer is the current drawn when one of the windings is supplied with a voltage while the second is open. This total no-load current has a magnetization component and a loss component.

The excitation current test is used to evaluate the magnetized circuit of the transformer:

-problem associated with the core (cut sheets, defective seals).

-problem associated with the coils (short-circuited or open-circuit turns).

• Principle of measurement

The test technique consists of injecting an alternating voltage of reduced value (up to 12 kV) of different levels, and carrying out a measurement of the magnetization current.

2.6.3.2 Transformation ratio measurement

It consists of measuring the transformation ratios in the different taps of the tap changer and comparing them with the design values to validate the interior connections. Deviations indicate inter-turn shorts, an open circuit, connection problems or a fault in the tap changer [17].

The measurements are carried out:

- On commissioning.

- During a detailed interview.

- In the event of a failure.

- After a repair.

The test technique consists of injecting alternating voltages into the high voltage winding, measuring the resulting voltages in the others.

2.6.3.3 Winding resistance measurement

The purpose of the resistance measurement is to determine the existing deviations from the design values of the resistances in each winding. Among other things, this measurement determines the Joule effect losses in the windings and connections.

The measurement is performed by applying direct current to the winding, then measuring the voltage drop and therefore its resistance. By taking care to raise the temperature of the windings in order to be able to bring the measured values back to values at the reference temperature.

The corrected resistance is calculated by the following equation:

$$R75 = \mathrm{Rt}\left(\frac{235+75}{235+t}\right) \quad \text{(II.4)}$$

235 for copper and 225 for aluminum

Winding Resistance at standard temperature of 75^{o}C

Rt = Winding resistance at temperature t

t = Winding temperature

2.6.3.4 Leakage reactance measurement

The measurement of the leakage reactance or short-circuit impedance, allows by comparison with the values of the measurements during factory tests of the transformer to detect very significant changes (> ±5%) which should lead to more extensive investigations; an open circuit or short circuits between turns, or between windings and tank.

2.7 220/60 KV Power Transformer failure history:

The following table summarizes the breakdown history of Substation power transformer GRTE Ghardaïa from the year 2010 until the year 2019[18].

Table 2. 7:History of Substation power transformer GRTE

<table>
<tr><th rowspan="2">Ranks</th><th rowspan="2">N0</th><th colspan="2">Reasons to stop</th><th rowspan="2">Outage start date</th><th rowspan="2">Outage end date</th><th rowspan="2">Break time (h)</th></tr>
<tr><th>Intervention following an anomaly</th><th>Systematic Maintenance Action</th></tr>
<tr><td>1</td><td>1</td><td></td><td>Annual maintenance</td><td>15/12/2011</td><td>17/12/2011</td><td>37</td></tr>
<tr><td>2</td><td>2</td><td>Malfunction of fans</td><td></td><td>14/07/2012</td><td>14/07/2012</td><td>4</td></tr>
<tr><td>3</td><td>3</td><td>Cracked insulators</td><td></td><td>24/12/2012</td><td>24/12/2012</td><td>1,5</td></tr>
<tr><td rowspan="2">4</td><td>4</td><td>TR regulation level fault</td><td rowspan="2"></td><td rowspan="2">13/05/2013</td><td rowspan="2">13/05/2013</td><td>1</td></tr>
<tr><td>5</td><td>Oil leak at Terminal 220 / 60 KV</td><td>21</td></tr>
</table>

5	6		Annual maintenance	02/12/2013	04/12/2013	37
6	7	Regulator blockage (Blockage following a mechanical strain at the level of the tap changer)		17/08/2014	17/08/2014	1
7	8	cooling system fault		25/11/2014	25/11/2014	8
	9	Thermal overload on the winding				34
8	10	Thermostat failure		17/01/2015	17/01/2015	2
	11		Oil drying			8
9	12	Low oil level at terminal 60KV Phase 8		02/11/2015	02/12/2015	25
10	13		Annual maintenance	22/12/2015	24/12/2015	36
11	14	Malfunction of fans		05/06/2016	05/06/2016	3
12	15	Buchholz relay fault		21/11/2016	21/11/2016	8
	16	Regulator blockage (Blockage following a mechanical strain at the level of the tap changer)				1
13	17	damaged sprocket of the tappet gear		08/04/2017	08/04/2017	31
	18	Cracked insulators				2
14	19	Malfunction of fans		31/08/2017	31/08/2017	4
15	20		Annual maintenance	15/12/2017	17/12/2017	37
16	21	cooling system fault		18/02/2018	18/02/2018	8
	22	TR regulation level fault				1
17	23	Buchholz relay fault		09/08/2018	09/08/2018	6
	24	Oil leak at the radiator				20
18	25	Thermostat failure		01/12/2018	01/12/2018	2
19	26	Pressure relief valve burst		07/03/2019	07/03/2019	35
	27	Cracked insulators				1.5
20	28	Malfunction of fans		19/08/2019	19/08/2019	3
21	29		Annual maintenance	10/12/2019	12/12/2019	37

2.8 Conclusion

In this chapter, we have presented the significance of utilizing diagnostic techniques in power transformers to obtain valuable information and reduce the likelihood of failures or service degradation while increasing their life expectancy. Analysis of dissolved gas in the oil can indicate the presence of an anomaly such as a hot spot at high temperature, which enables assessment of the degree of aging of the cellulosic and dielectric insulation, and analysis of contamination levels. Electrical and dielectric measurements should be carried out systematically on transformers to determine their condition and prevent damage.

Chapter 3Internship application

3.1 Presentation of the GISB

GISB subsidiary of in the Mesra Wilaya of Mostaganem business area.

GISB has been working in the energy sector since 2009. In order to meet the quantitative requirements for ISO 9001 qualified low voltage electrical cables, distribution transformers and newly manufactured light bulbs of the highest quality.

Figure 3. 1:Location of GISB on Google Maps

GISB is an industrial company specializing in the manufacture of many areas such as:

• Cables of different types

• Transformers & MV cells

• Renewable energies

• LED lighting

• Electrical accessories

3.2 GISB ENERGY section

Since its establishment in 2018 as a company dedicated to the manufacture of distribution transformers, GISB ENERGY has followed an uninterrupted development trajectory, both at the technological level and at the level of the expansion of the company, including: Transformers immersed in dielectric fluids ranging from a power of 100 kVA up to a power of 5000 Kva, as well as 24 kv, 36 kv modular cells and MV double isolation circuit breaker cell.

One of the hallmarks of GISB ENERGY is the ability to achieve high levels of quality and reliability throughout its manufacturing range, thanks to qualified personnel, cutting-edge technology employed in the design, manufacture and control. Of the process and the finished product, in its test laboratories, as well as in its after-sales service for monitoring customer satisfaction.

All this, united with an internal policy of respect for the environment and sustainability, as well as the prioritization of the well-being and health of our staff in the workplace [1].

3.3 30/0.4KV distribution transformer for GISB Company

The transformer produced by this company is a distribution transformer with a power rating of 1000 KVA. It has a high voltage rating of 30 KV and a low voltage rating of 400 V with a Dyn11 coupling. The short circuit voltage of the transformer is 5.64%, and the rated current is 19.245 A. The transformer operates at a frequency of 50 Hz and can withstand high temperatures of 60/65°C. The type of oil used in the transformer is mineral oil, and the cooling mode is ONAN.

This type of transformer is commonly used in electrical power systems for step-down voltage applications, such as in commercial and residential areas. The high voltage rating of 30 KV makes it suitable for transmitting power over long distances, while the low voltage rating of 400 V is ideal for distributing power to end-users. The Dyn11 coupling is a popular configuration for distribution transformers as it provides good voltage regulation and reduces losses.

The short circuit voltage of 5.64% indicates the ability of the transformer to handle short circuit currents. The high-temperature rating of 60/65°C ensures that the transformer can operate in harsh environments without overheating. The mineral oil used in the transformer provides good insulation properties and serves as a cooling medium. The ONAN cooling mode is a common cooling method for distribution transformers as it is simple and cost-effective.

Overall, this distribution transformer is a reliable and efficient solution for distributing electrical power in various applications.

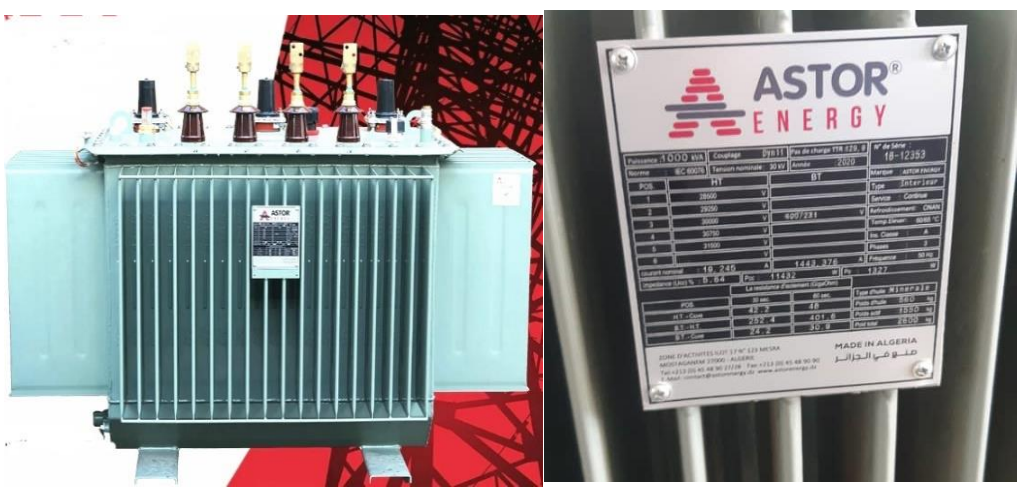


Figure 3. 2:1 3:30/0.4KV GISB's transformer

Table 3. 1 : 30KV/0.4KV transformer nameplate

Power	1000 KVA
HV voltage	30 KV
LV voltage	400 V
Coupling	Dyn11
Short circuit voltage	5.64%
Rated current	19.245 A
Frequency	50 Hz
High temperature°c	60/65°c
Type of oil	Minerale
Cooling mode	ONAN

3.3.1 30/0.4KV Transformer construction:

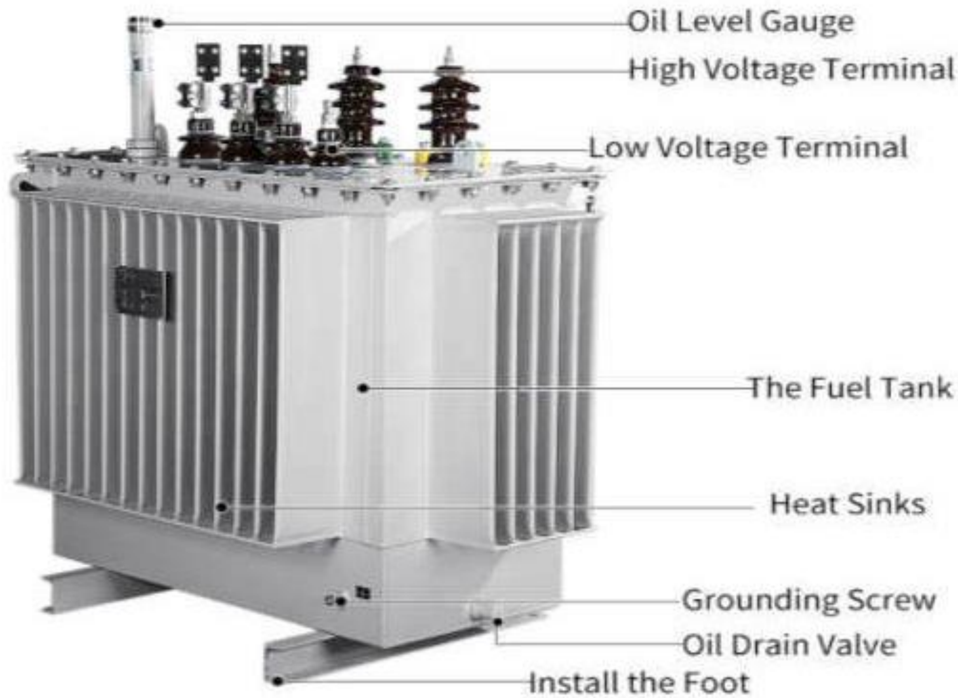


Figure 3. 3:Description of Transformer.

3.4 Different types of Protections for 30/0.4KV oil transformers

3.4.1 External Protection

3.4.1.1 Maximum current relay RSf 5

- **Applications:**

For instant tripping of the switch in case of overcurrent's due to overload or short-circuit. Designed primarily for installations requiring a high percentage of return, low consumption, and high resistance to short circuits. The operation of the relay is indicated by a signaling device in the form of an annunciator panel. To obtain delayed tripping, the RSf 5 can be used in combination with a time-delay relay [2].

- **Operating mode:**

When the current intensity passing through the relay winding reaches or exceeds the set value, the pivoting armature moves to the action position, activating the contact and signaling device. When the current falls below the return value, the pivoting armature and contact return to the starting position. The signaling device must be manually reset.

Figure 3. 4:Maximum current relay RSf 5.

3.4.1.2 Relay with independent delayed maximum current RSZ 3f2

- **Applications:**

These relays are used for delayed tripping of switches in case of overload or short-circuit. The relays are distinguished by low consumption and a relatively high return percentage, accompanied by remarkable operating accuracy and high resistance to short-circuit. That is why they are particularly suitable for the protection of generators and alternators, transformers, and power lines. They allow the adjustment of very small-time steps [2].

- **Operating mode:**

In case of overcurrent, the maximum current excitation systems of the affected conductor close the timing system circuit. The timing system instantly closes the auxiliary contact and at the end of the set time, the main contact triggers the switch. In case the current takes

Figure 2. 13:RSZ 3f2

3.4.1.3 Differential Protection

Differential protection is achieved by comparing the sum of the primary currents to the sum of the secondary currents. The difference between these currents should not exceed a value of i0 for a time longer than t0, beyond which there is a tripping action. Transformer differential protection is a main protection system that is as important as internal transformer protections. This protection has absolute selectivity and, in addition, is required to be very stable against external faults. The principle of operation of the protection is based on the comparison of incoming and outgoing currents of the transformer [3].

This protection is used:

- To detect fault currents that are less than the rated current,
- To provide instantaneous tripping since selectivity is based on detection rather than on time-delay.

Figure 3. 5:Differential relay.

3.4.2 Internal protection

3.4.2.1 Buchholz protection

Arcs that originate inside a transformer decompose a certain amount of oil and cause gas to be released. The gas produced rises to the upper part of the transformer tank and from there to the conservator through a mechanical relay called the Buchholz relay, this relay is sensitive to any movement of gas or oil. If this movement is weak, it closes a signaling contact (Buchholz alarm). In addition, a tripping order is issued by means of another contact that closes in case of significant movement.

The gases remain trapped in the upper part of the relay, from where they can be sampled, and their examination allows some assumptions to be made about the nature of faults [3]:

- If the gases are not flammable, it can be said that it is air that comes either from an air pocket or from oil leakage.
- If the gases ignite, there has been destruction of the insulating materials, and the transformer must be taken out of service.

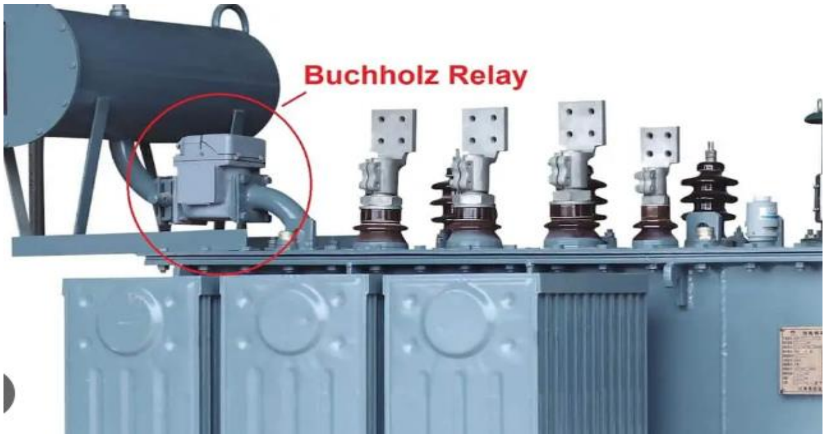


Figure 3. 6:Buchholz Relay.

3.4.2.2 Thermal protection

Thermal protection is used to protect power transformers against overloads. To detect the presence of an overload, it estimates the heating of the primary and secondary coils to be protected based on the measurement of the current.

Figure 3. 7:Manometer.

3.5 Conclusion

This chapter allowed us to practically study the various types of protection for one type of GISB MOSTAGANEM transformers, mainly the distribution transformer.

In the next chapter, we will focus on modeling some of the protection methods for three-phase transformers.

Chapter 4: Modeling and Simulation

4.1 Differential Relay Protection Modeling in MATLAB

4.1.1 Introduction:

Differential protection is the main part of transformer protection. Our goal in this chapter is to better understand its operation for different operating scenarios. Short circuits are the major faults that affect the transformer and result in high current. The protection system includes mechanisms for detecting and isolating all faults inside the transformer.

4.1.2 Components of the System:

This approach was achieved using the MATLAB environment, which allowed us to simulate power systems in different operating modes to analyze the physical phenomena corresponding to these systems.

Simulink is a program within MATLAB for simulating systems. It is a multi-domain simulation platform for dynamic systems, in which model definition is done by block diagrams (structural diagrams). It highlights the structure of the system and allows for visualizing the interactions between the different internal and external quantities. Simulink has a graphical interface for viewing results in graphical or numerical form.

4.1.2.1 Simulated system

The simulated system consists of:

- A three-phase voltage source representing the generator (11KV 500MVA).
- The step-up transformer (11 KV/33KV), representing the transformer under study.
- Two three-phase breakers controlled upstream and downstream of the transformer.
- Current and voltage measuring tools.
- Differential protection.
- A load (R, L, C) representing nominal consumption.
- Generator of the different three-phase, two-phase, single-phase faults, with a time input to specify the fault duration.

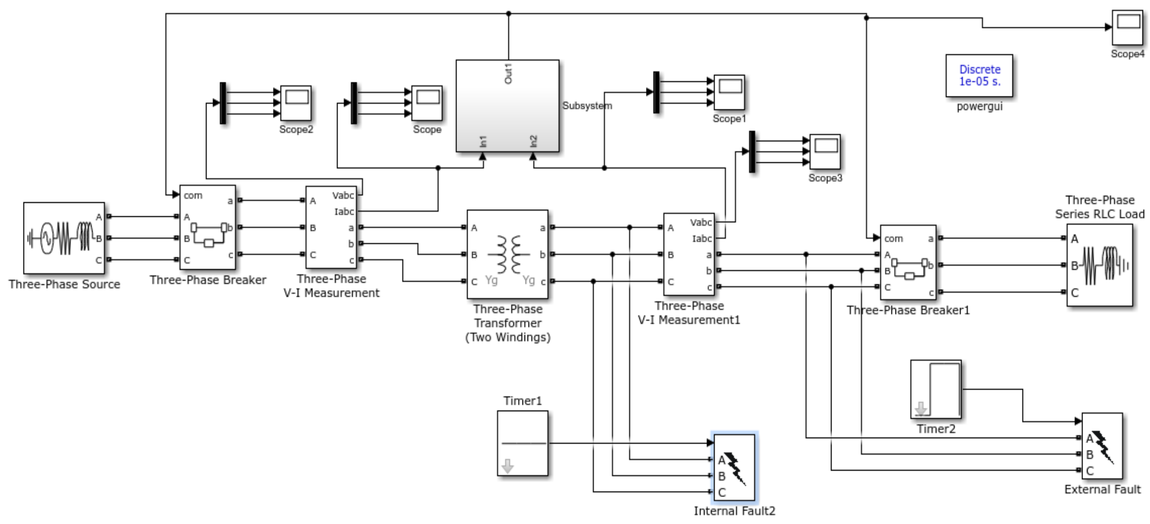


Figure 4. 1:Simulated Model.

4.1.2.2 Differential Protection:

The differential protection block was implemented by approaching its operating mode using several Simulink blocks.

The difference between the two primary and secondary currents is calculated after amplitude compensation. If this difference exceeds a predetermined threshold, an order will be given to trip the breakers.

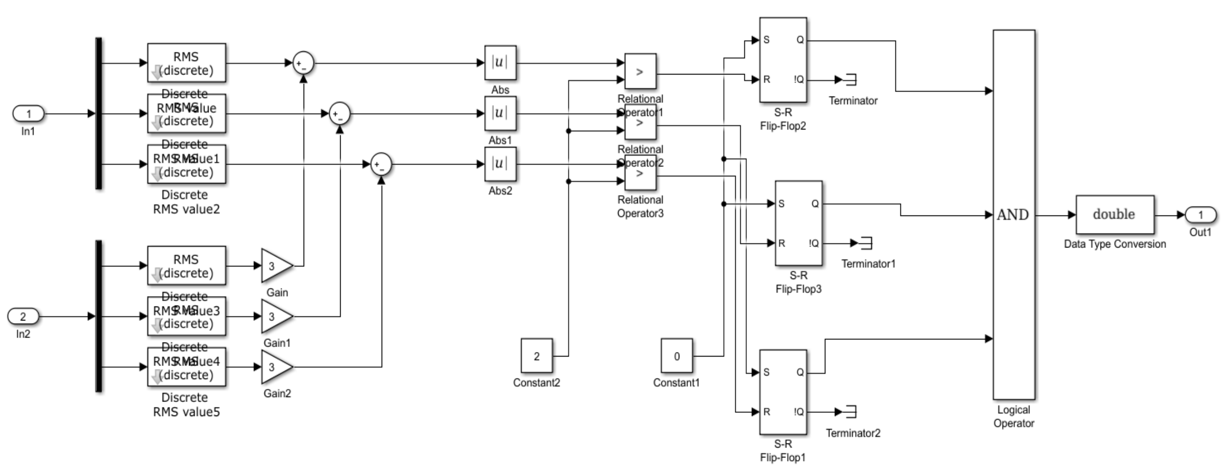


Figure 4. 2:Differential Protection Subsystem.

The differential protection model is executed for the following cases:

- Normal operation.
- External fault.
- Internal fault.

4.1.3 Simulation

4.1.3.1 Normal operation

a) The waveforms of the primary and secondary currents of the three-phase system.

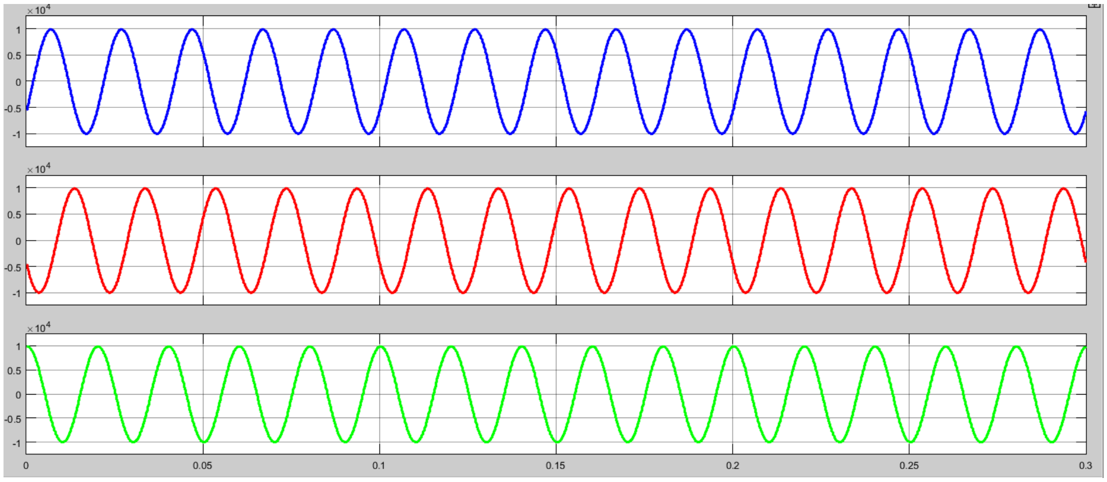


Figure 4. 3:primary current without fault.

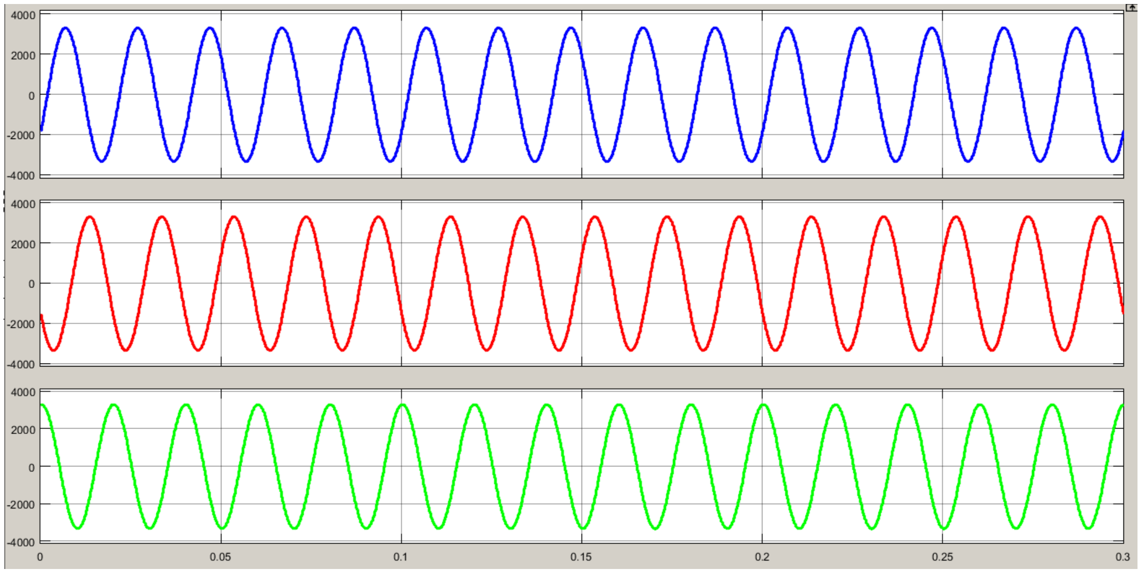


Figure 4. 4:Secondary current without fault.

b) Primary and secondary voltage:

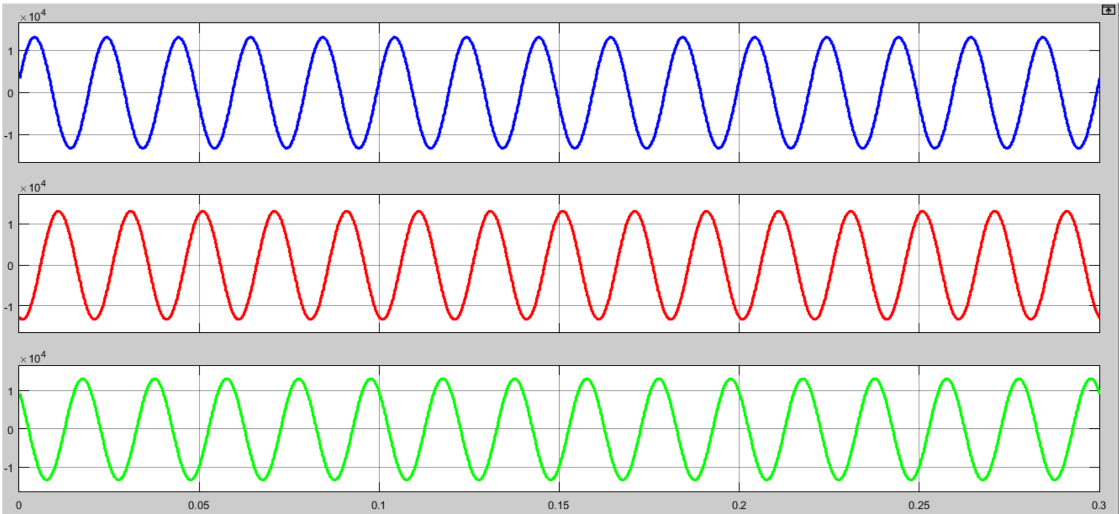


Figure 4. 5:Primary voltage without fault.

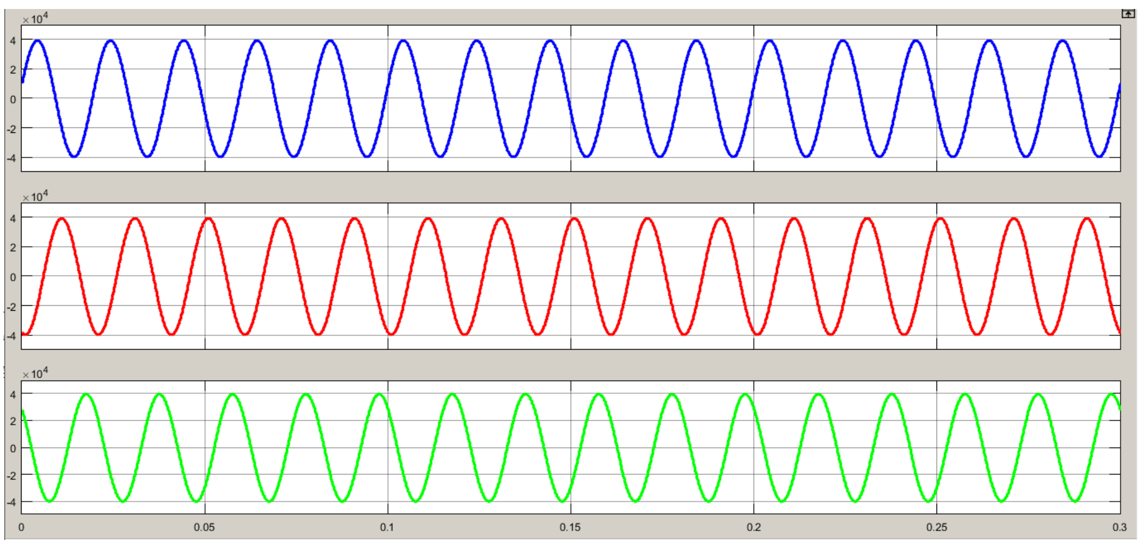


Figure 4. 6:Secondary voltage without fault.

c) Differential relay:

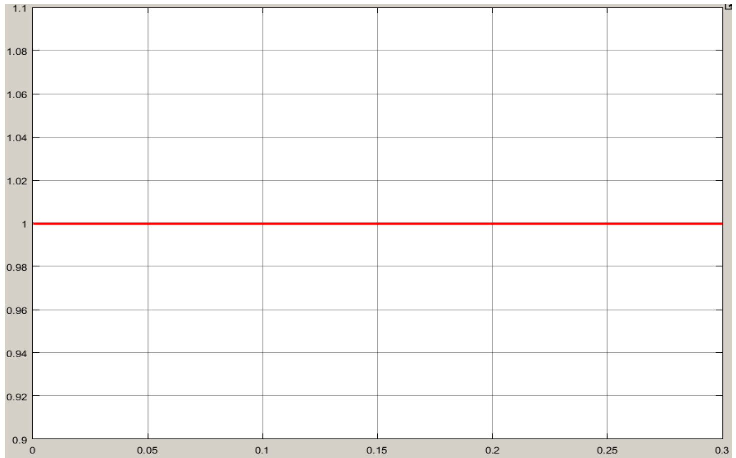


Figure 4. 7:Differential current.

In normal operation, the primary and secondary currents are at nominal values Fig (4.3) Fig (4.4), the differential current should be negligible, indicating that the currents entering and leaving the transformer are nearly equal. Any deviation from this balanced condition could indicate an internal fault or an external fault affecting the transformer, Fig (4.7) and no fault has affected the transformer.

4.1.3.2 Internal fault:

An internal fault is applied in the transformer secondary at time t=0.1s and for a duration of 0.2s.

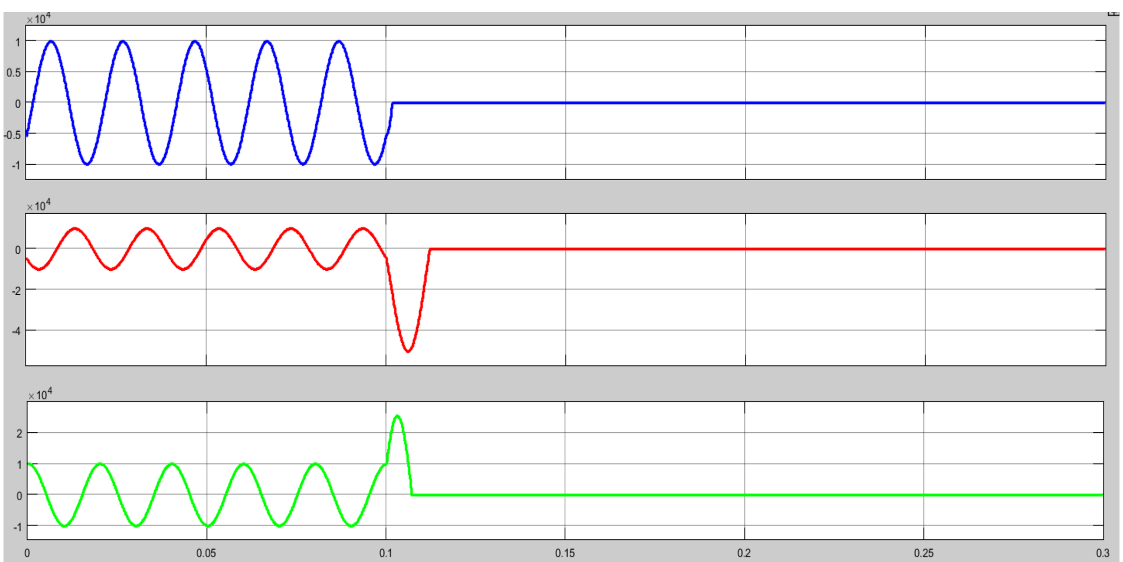


Figure 4. 8: Primary current for each phase.

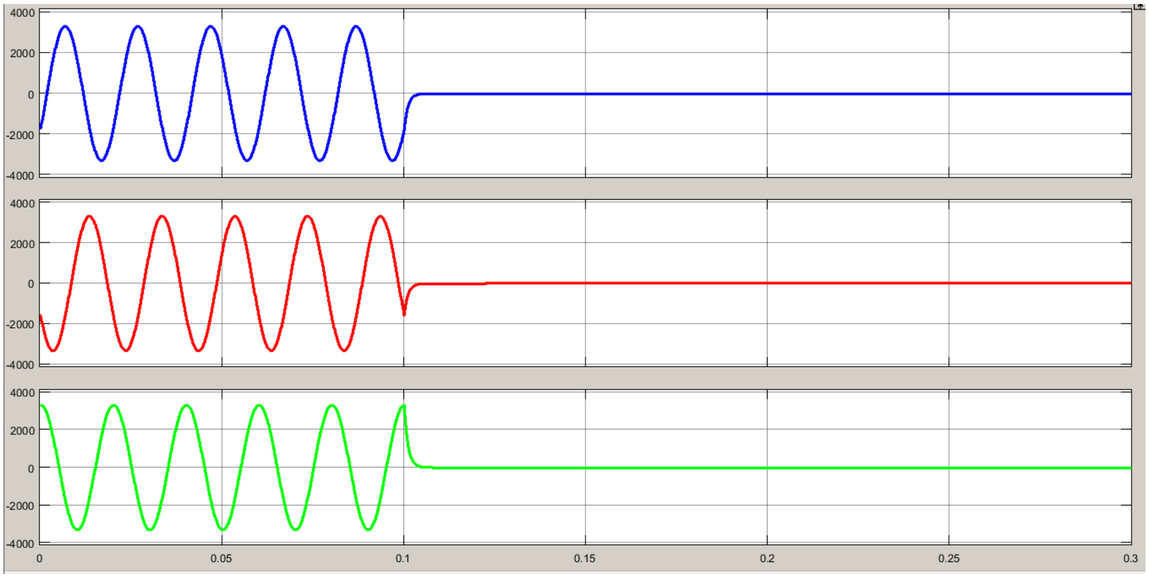


Figure 4. 9:Secondary current for each phase.

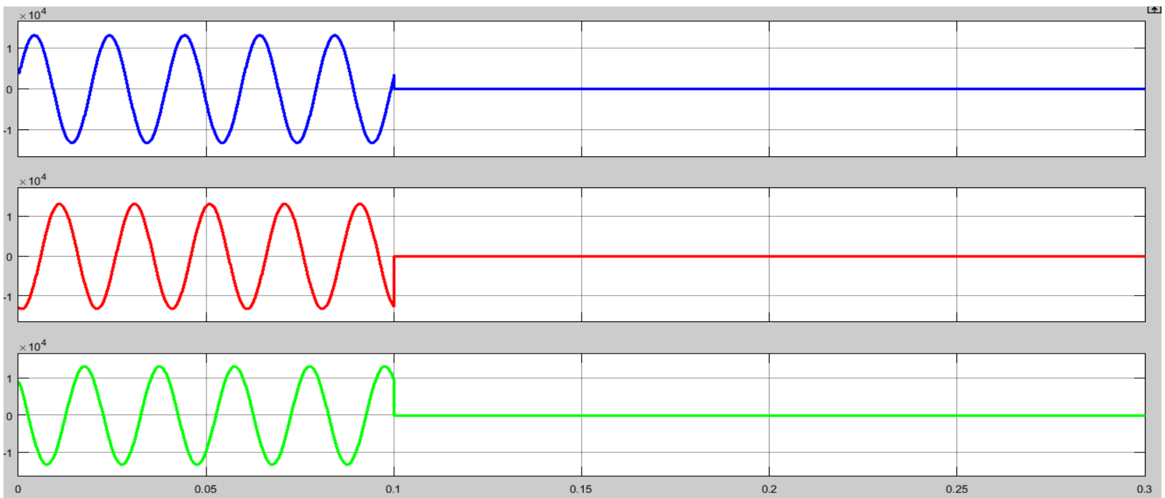


Figure 4. 10:Primary voltage of each phase.

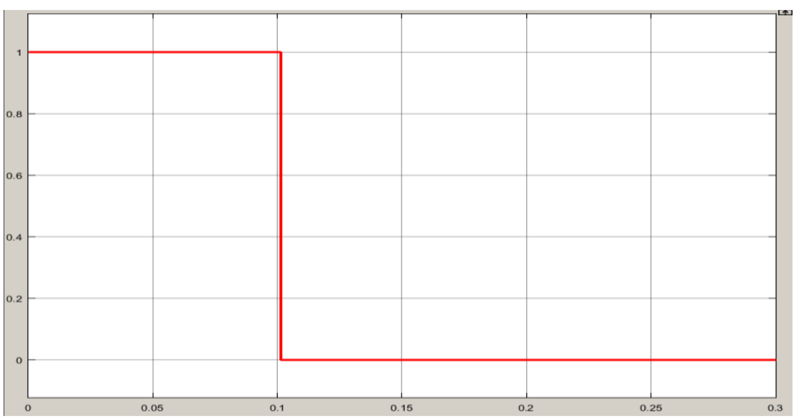


Figure 4. 11:Differential current.

The occurrence of a fault in the transformer leads to an increase in differential current, and this value is too high and exceeds the operating thresholds for a short period of time.

The circuit breakers receive a trip signal and the transformer is isolated, as seen in the interruption in each phase Fig (4.8), Fig (4.9).

Similarly, if a two-phase or phase-to-ground fault is applied, since the same process detects the fault, the differential current will be too high and the protection system must intervene.

4.1.3.3 External fault:

We now apply a fault outside the protected zone, either upstream or downstream of the transformer, the fault is applied for 0.2s at t=0.1.

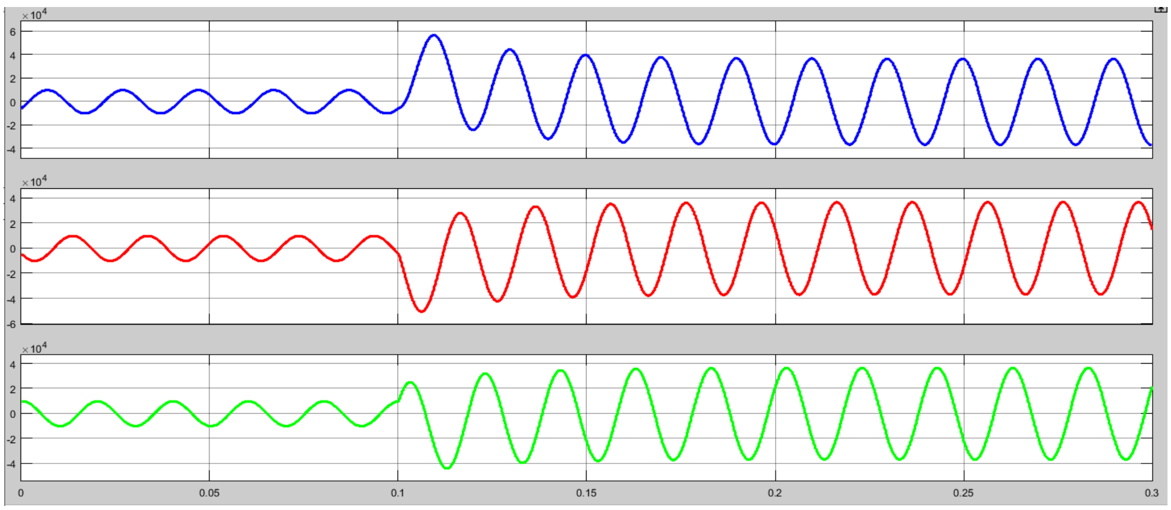


Figure 4. 12:Primary current for each phase.

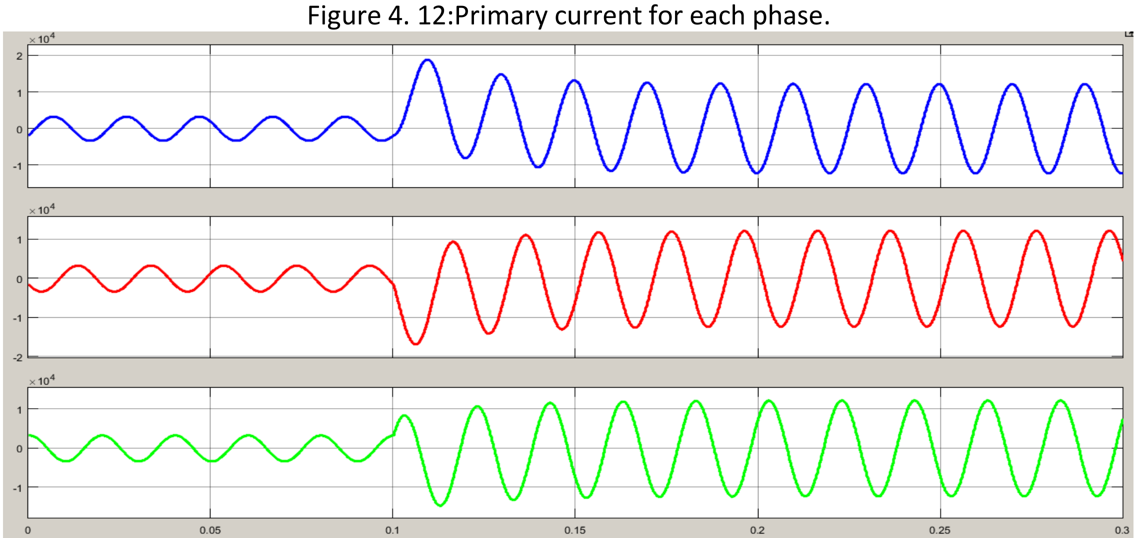


Figure 4. 13:Secondary current for each phase.

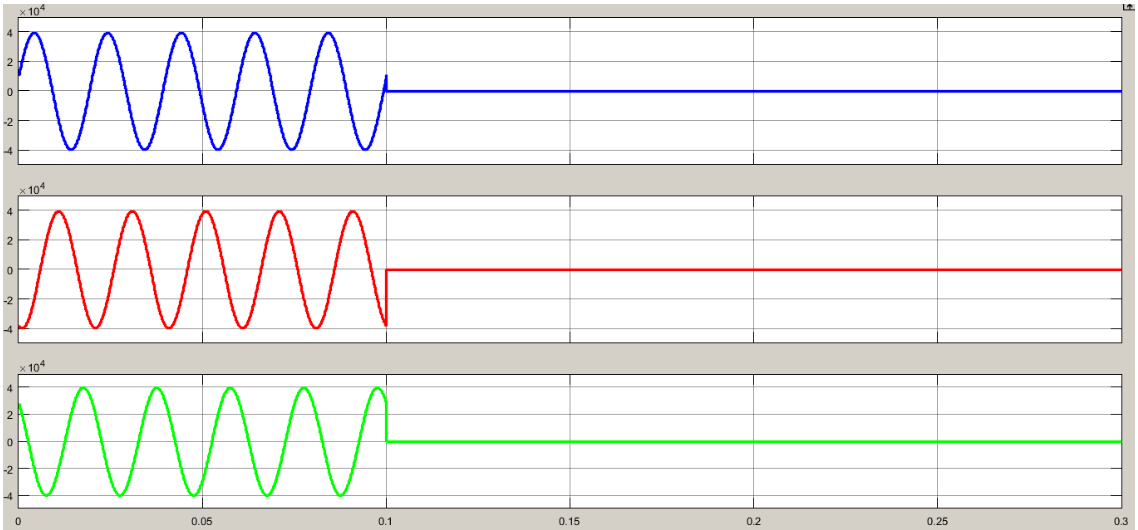


Figure 4. 14:Secondary voltage of each phase.

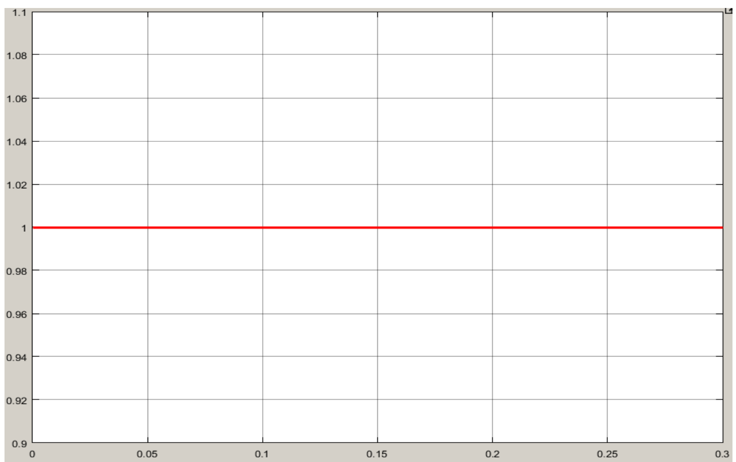


Figure 4. 15:Differential current.

As soon as the fault occurs, the current reaches values of up to 60 kA at the primary Fig (4.12). At external fault, no trip signal sent from the differential relay to the circuit breaker because the fault occurred out of the transformer protected zone as the turn ratio is the same Fig (4.15).

The voltage drops during the fault period Fig (4.14) because the system cannot supply such a quantity of current.

In this case, the phase overcurrent protection should operate to protect the transformer against external faults, as the transformer cannot withstand such high currents without the risk of damage.

4.2 Transformer faults detection in real time (Modeling in Proteus 8 Professional)

4.2.1 Introduction

Protection of distribution transformers is a subject of increasing interest and in recent years we have seen many systems providing this control, sending written texts is very popular among mobile phone users.

Anomalies in distribution transformers are accompanied by variations in various parameters but we focused in our research on some faults such as rising or decreasing in oil level, temperature and earth faults.

The online monitoring system consists of sensors installed in embedded systems, GSM modems, mobile users, GSM networks, transformer sites. A sensor is installed on the transformer side to read and measure the physical quantity from the distribution transformer and convert it to an analog signal.

These received analog signals are processed by the ADC and fed to the microcontroller. A pre-programmed microcontroller sends signals to the GSM module. User receives her SMS from her GSM module.

The convenience of being able to control the transformer from a specific location has become essential as it saves a lot of time and effort. So we have to do this systematically and that's what we're trying to do with our system.

4.2.2 Objectives:

- To notify the operators during the occurrence of any faults via GSM Networking.
- To isolate the faulty portion in the system.
- To control the distribution system more efficiently and conveniently**.**
- To provide proper monitoring system in 3-phase distribution transformer.

4.2.3 Operation principle

The code is an Arduino sketch that monitors the condition of a transformer. The code measures three parameters: temperature, oil level, and earth current. It uses an ultrasonic sensor to measure the oil level, an analog temperature sensor to measure the temperature, and an analog current sensor to measure the earth current.

The code starts by initializing the necessary libraries, pins, and variables. Then it initializes the LCD and sends an introduction message. In the main loop, the code measures the three parameters and displays them on the LCD. It also checks if any of the parameters are outside a certain range. If they are, it sends an SMS to a predefined number.

The condition function contains the logic for checking if the temperature, oil level, or earth current is outside its acceptable range. If the temperature is above 75 degrees Celsius, the ‘lcd_tempPrint’ function is called, which clears the LCD, displays the temperature, and sends an SMS to a predefined number using the sms function.

If the oil level is above 800 cm, the ‘lcd_oilLevelFULLPrint’ function is called, which clears the LCD, displays "OIL TANK FULL," and sends an SMS to a predefined number using the sms1 function.

If the oil level is below 300 cm, the ‘lcd_oilLevelLOWPrint’ function is called, which clears the LCD, displays "LOW OIL LEVEL," and sends an SMS to a predefined number using the sms2 function.

If the earth current is above a certain threshold, the ‘lcd_EarthFaultPrint’ function is called, which clears the LCD, displays "EARTH FAULT CURRENT," and sends an SMS to a predefined number using the sms3 function.

4.2.4 Requirement analysis:

4.2.4.1 Block Diagram:

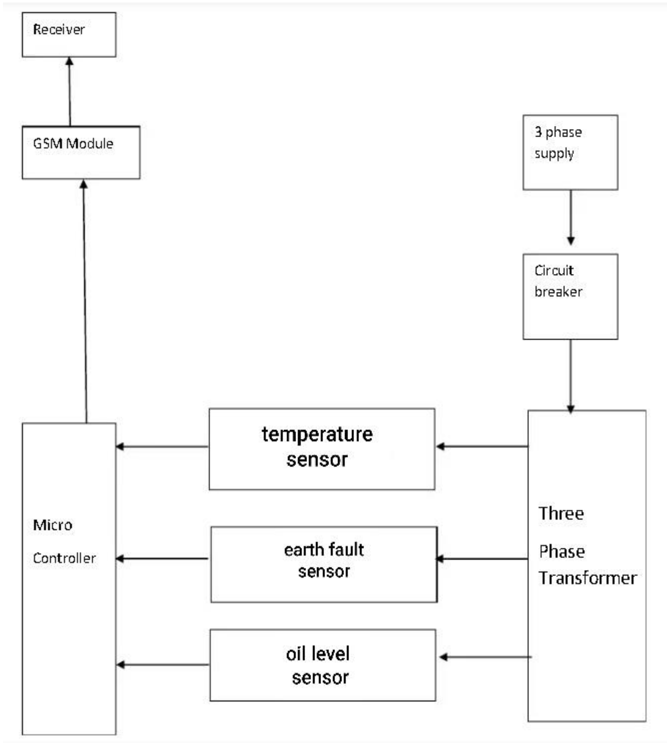


Figure 4. 16:Block Diagram.

4.2.4.2 Components:

1. LM-35 (Temperature Sensor)

- Calibrated directly in Celsius
- Suitable for Remote Applications
- Operation from 4V- 30V
- Low Impedance output, 0.1 Ohm for 1mA load

Figure 4. 17:LM-35.

2. GSM Module

- Use extremely popular SIM 900
- Operating Voltage: 5V-15V DC
- Provides serial TTL interface for easy and direct interface to microcontroller
- Can be controlled through standard AT command
- Low power consumption of 0.25A during normal operation and 1Aduring transmission
- Comes with an onboard wire antenna for better reception

Figure 4. 18:GSM Module.

3. LCD

Liquid crystal display is the abbreviation for liquid crystal display. It is a type of electronic display module that is utilized in a wide range of circuits and devices such as mobile phones, calculators, computers, television sets, and so on.

Voltages Vcc and Vss are supplied from +5V and ground respectively, and Vee is used to control the contrast of the LCD. Sets the character contrast on the LCD screen using a variable voltage between ground and Vcc.

Figure 4. 19:LCD Display.

4. Arduino UNO

Arduino is an open-source electronics platform that uses simple hardware and software to make it easy to use. Arduino boards can take inputs - such as light from a sensor, a finger on a button, or a Twitter message and convert them to outputs such as turning on an LED, triggering a motor, or publishing anything online.

It has 14digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button [1].

Figure 4. 20:Arduino UNO.

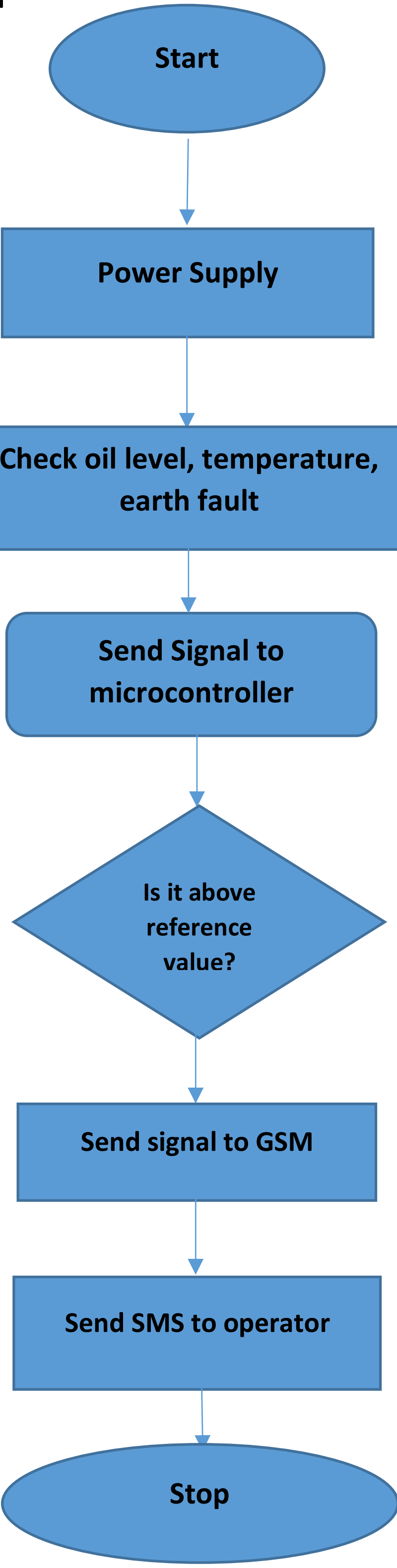
5. Potentiometer

Potentiometers are used in a very wide range of industries and applications. It can be used as a control input, position measurement or calibration component and much more.

Figure 4. 21:Potentiometer.

4.2.5 Methodology

4.2.5.1 Flowing Diagram



4.2.5.2 Circuit Diagram

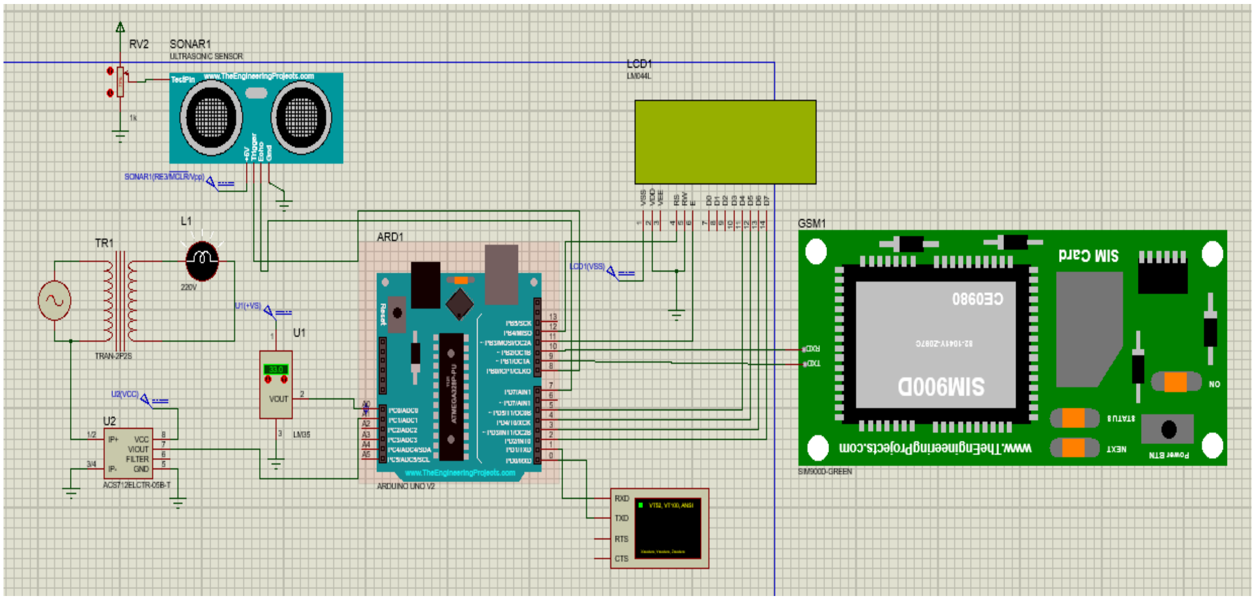


Figure 4. 22:Circuit Diagram.

4.2.6 Result and Analysis

The project circuit is designed and simulated in the proteus software. The coding is coded in the Arduino software. The code is compiled and uploaded in the Arduino Uno. Then, the simulation is run by the use of the run button.

4.2.6.1 Normal operation

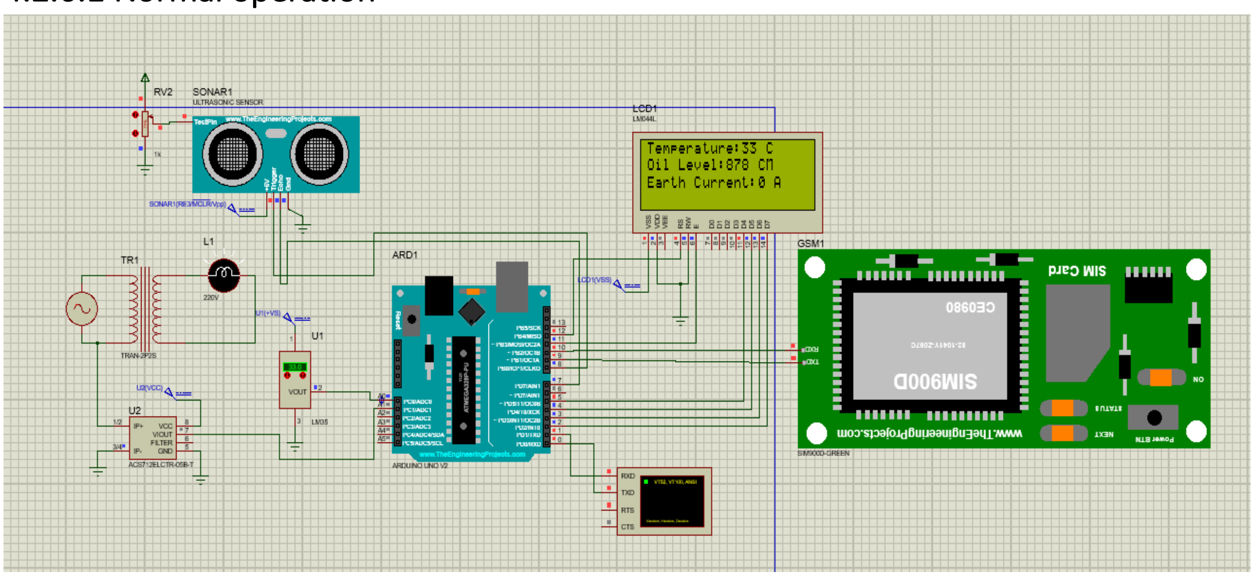


Figure 4. 23:When there is no fault.

Figure shows that after running the simulation when there is no fault occurred the LCD shows the detection is no-fault and it shows the normal state of the transformer.

4.2.6.2 Transformer oil fault

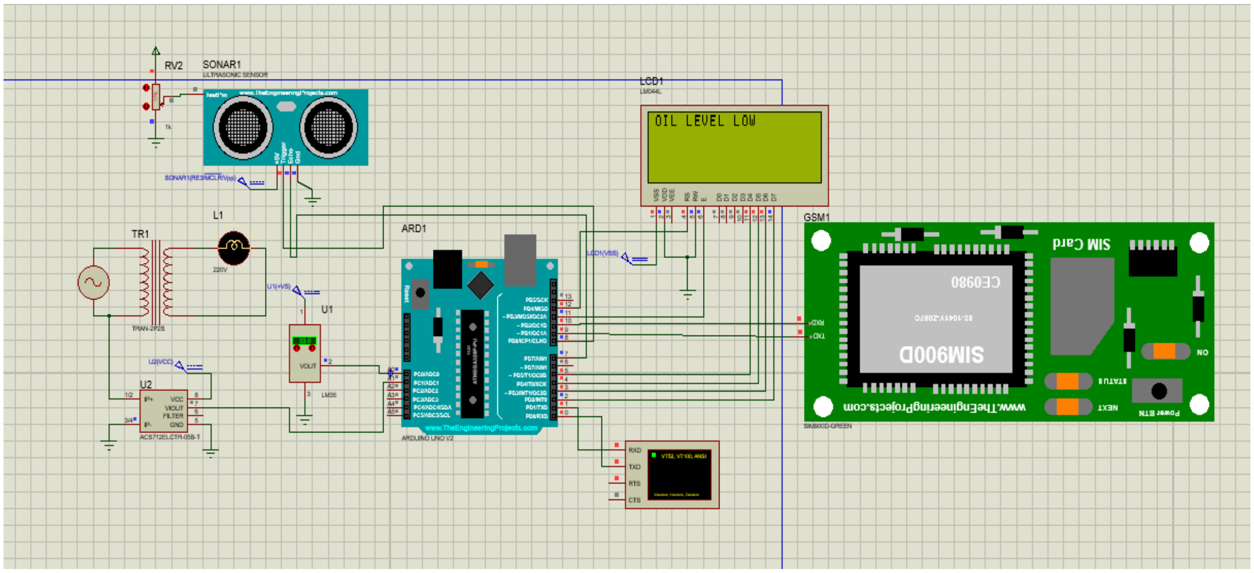


Figure 4. 24:Transformer oil fault.

Figure shows that the fault has occurred in the oil level of transformer, and it is shown on the transformer LCDs.

Because this is defined in the system, if the oil level is less than 300cm, then it appears on the LCD screen that there is a fault, and please review that.

4.2.6.3 Transformer temperature fault

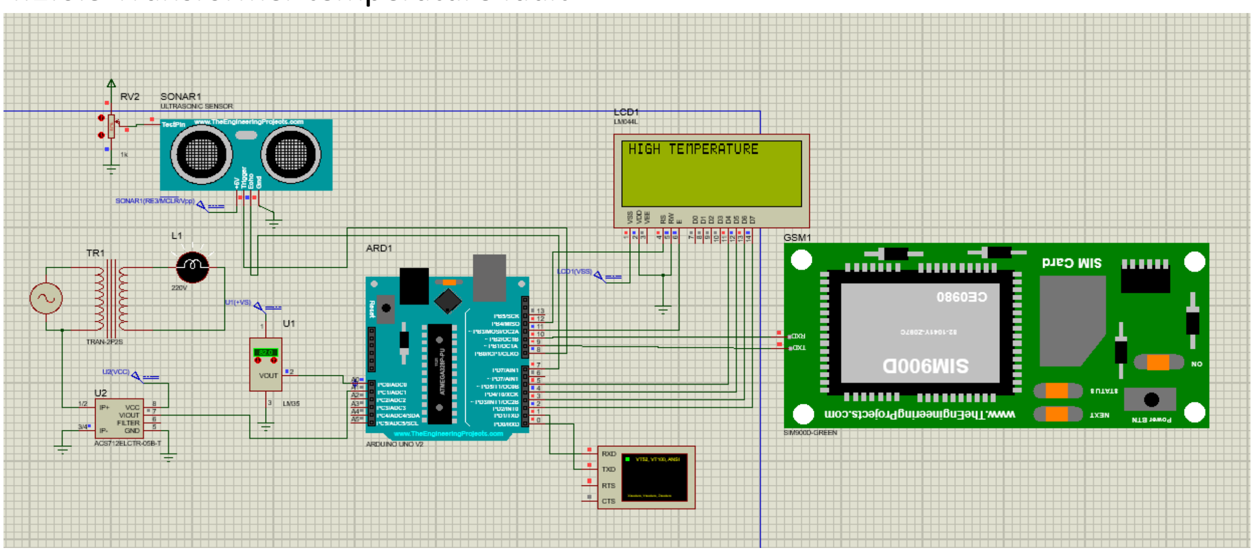


Figure 4. 25:Transformer temperature fault.

Figure shows that the fault has occurred in the temperature of transformer, because that's defined in the system, if the temperature is higher than 75, then it appears on the LCD screen that there is a fault, and please review that.

4.2.6.4 Transformer earth fault

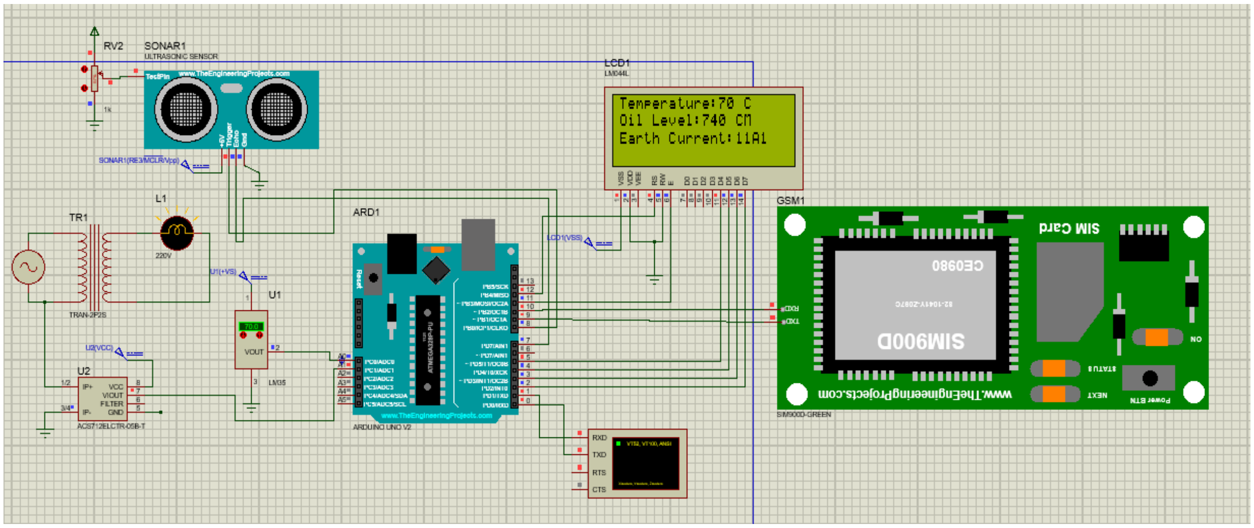


Figure 4. 26:Earth fault.

Figure shows that the fault has occurred in the earth, and it is shown on the transformer LCDs.

4.2.6.5 Outputs from LCD

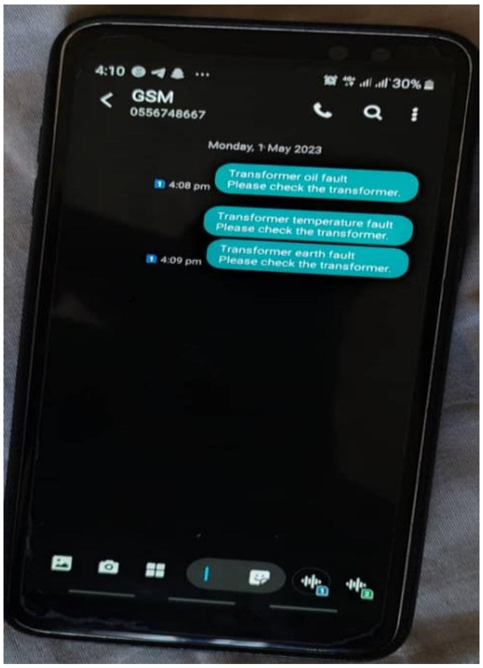


Figure 4. 27:SMS

4.3 Conclusion

In conclusion, protecting distribution transformers is crucial for ensuring the stability and reliability of the electrical network. The use of protection relays is important for detecting internal and external faults and preventing catastrophic failures. Additionally, the implementation of GSM-based monitoring systems provides a reliable and efficient method for detecting abnormalities in distribution transformers. This system allows for real-time monitoring and quick response to any faults detected, minimizing downtime and reducing the risk of damage to the transformer. Compared to manual monitoring methods, GSM-based monitoring is more efficient, less time-consuming, and provides a higher level of reliability. Overall, the advantages of GSM-based monitoring systems make them a valuable tool for transformer fault detection in distribution networks.

General conclusion

In conclusion, this thesis has explored various aspects of industrial transformer conception design and fault detection. The generalities of transformers were introduced, including their construction, types, and applications, as well as factors affecting transformer performance. Additionally, fault detection methods were discussed, including traditional and modern techniques used in the power industry, and the importance of early fault detection and diagnosis was emphasized.

An overview of internship applications was also provided, highlighting the benefits of practical experience in the power industry. Finally, the modeling and simulation of transformers were examined, including various techniques used in transformer conception design and fault detection.

This thesis has contributed to the knowledge and understanding of transformer conception design and fault detection and has demonstrated the significance of these areas of research in the power industry. Through the exploration of these topics, this thesis has provided insights into improving transformer efficiency and reliability, which are critical for a sustainable and reliable power system network.

Overall, this thesis has highlighted the importance of transformer conception design and fault detection in the power industry and the need for continued research and development in these areas. The knowledge gained from this research will contribute to the design of more efficient and reliable transformers and enhance the overall performance and sustainability of the power system network.

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ANNEX

Arduino Code:

```
//FINAL YEAR PROJECT WORK
#include <Wire.h>
#include <LiquidCrystal.h>
#include<SoftwareSerial.h>
LiquidCrystal lcd(12, 11, 5, 4, 3, 2);
SoftwareSerial SIM900(9, 10);
const int trigPin = 8; // Trigger Pin of Ultrasonic Sensor
const int echoPin = 7; // Echo Pin of Ultrasonic Sensor
long duration;
int OilLevel;
int delayTime = 700;
int EarthCurrent;
float SensorReadEarth;
float sensitivity = 0.185;
int temp;
float TempSensorPin = A0;
float vout;
void setup() {
  // put your setup code here, to run once:
pinMode(TempSensorPin,INPUT);
pinMode(trigPin, OUTPUT);
pinMode(echoPin, INPUT);
 Serial.begin(9600);
 SIM900.begin(9600);
 delay(100);
Serial.println(" REMOTE TRANSFORMER MONITORING");
```

```
lcd.begin(20,4);
lcd.print("PROJECT WORK");
lcd.setCursor(2,1);
lcd.print("REMOTE");
lcd.setCursor(9,1);
lcd.print("MONITORING");
lcd.setCursor(4,2);
lcd.print("TRANSFORMER");
delay (delayTime);
lcd.clear();
}
void loop() {
//temperature//
vout = analogRead(TempSensorPin);
vout = (vout * 500) / 1023;
temp = vout;
//EARTH CURRENT//
SensorReadEarth = analogRead(A1)*(5.0 / 1023.0);     //We read the sensor output
EarthCurrent = (SensorReadEarth - 2.5)/sensitivity;   //Calculate the current value for earth
// SENSING OIL LEVEL//
digitalWrite(trigPin, LOW);
delayMicroseconds(2);
digitalWrite(trigPin, HIGH);
delayMicroseconds(10);
digitalWrite(trigPin, LOW);
duration = pulseIn(echoPin, HIGH);
OilLevel = duration * 0.034 / 2;
//LCD PRINTING//
```

```
lcd.setCursor(0,0);
lcd.print("Temperature:");
lcd.setCursor(12,0);
lcd.print(temp);
lcd.setCursor(15,0);
lcd.print("C");

lcd.setCursor(0,1);
lcd.print("Oil Level:");
lcd.setCursor(10,1);
lcd.print(OilLevel);
lcd.setCursor(14,1);
lcd.print("CM");

lcd.setCursor(0, 2);
lcd.print("Earth Current:");
lcd.setCursor(14, 2);
lcd.print(EarthCurrent,2);
lcd.setCursor(16, 2);
lcd.print("A");
delay(600);
condition();
}
void sms()
{
SIM900.print("AT+CMGF=1\r");
SIM900.println("AT + CMGS = \"+233558254026\"");// recipient's mobile number
```

```
Serial.println("AT + CMGS = \"+233558254026\"");// recipient's mobile number
SIM900.println("HIGH TRANSFORMER TEMPERATURE"); // message to send
Serial.println("HIGH TRANSFORMER TEMPERATURE");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
void sms1(){
SIM900.print("AT+CMGF=1\r");
SIM900.println("AT + CMGS = \"+233558245026\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+233558245026\"");// recipient's mobile number
SIM900.println("OIL TANK FULL"); // message to send
Serial.println("OIL TANK FULL");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
void sms2(){
SIM900.print("AT+CMGF=1\r");
SIM900.println("AT + CMGS = \"+233558245026\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+233558245026\"");// recipient's mobile number
SIM900.println("LOW OIL LEVEL"); // message to send
Serial.println("LOW OIL LEVEL");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
void sms3(){
```

```
SIM900.print("AT+CMGF=1\r");
SIM900.println("AT + CMGS = \"+233558245026\"");// recipient's mobile number
Serial.println("AT + CMGS = \"+233558254026\"");// recipient's mobile number
SIM900.println("EARTH FAULT CURRENT"); // message to send
Serial.println("EARTH FAULT CURRENT");
SIM900.println((char)26); // End AT command with a ^Z, ASCII code 26
Serial.println((char)26);
SIM900.println();
}
//CONDITIONS
void condition()
{
  if (temp > 75)
{
lcd_tempPrint();
sms();
 delay(300);
  }
if (OilLevel > 800)
{
 lcd_oilLevelFULLPrint();
 sms1();
 delay(1000);
  }else if (OilLevel < 300)
{lcd_oilLevelLOWPrint();
 sms2();
 delay(300);
 }
```

```
 }
// LCD PRINTING CONDITION//
void lcd_oilLevelFULLPrint()
{
lcd.clear();
lcd.setCursor(1,1);
lcd.clear();                      //if condition temp for it to print.
lcd.print("OIL TANK FULL");
}
void lcd_oilLevelLOWPrint()
{
lcd.clear();
lcd.setCursor(0,2);
lcd.clear();                      //if condition temp for it to print.
lcd.print("OIL LEVEL LOW");
}
void lcd_tempPrint()
{
lcd.clear();
lcd.setCursor(0,0);
lcd.clear();                      //if condition temp for it to print.
lcd.print("HIGH TEMPERATURE");
}
```