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THEME **:**

Smart monitoring system design for voltage transformers using (Iot) and AI

In front of the jury composed of:

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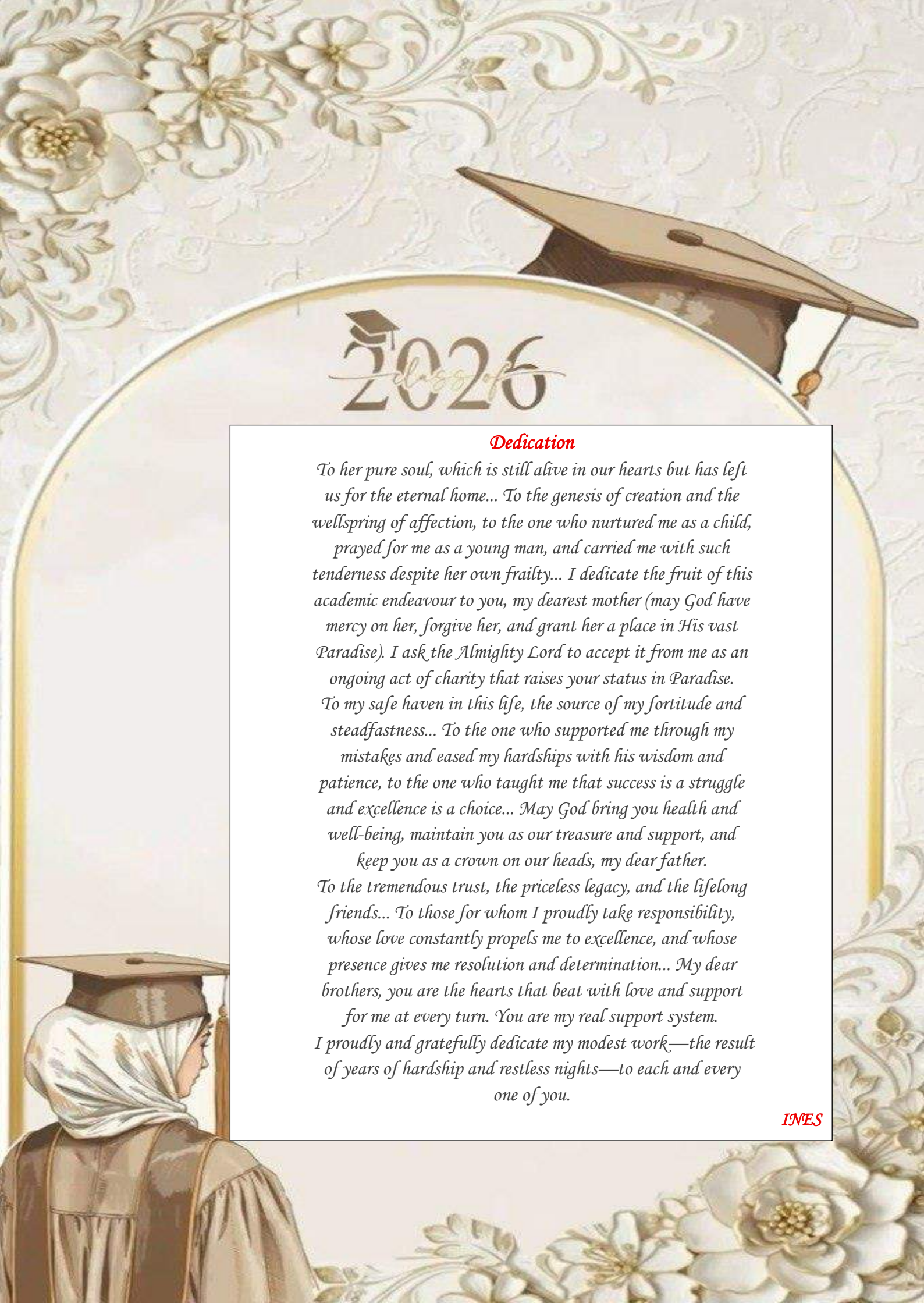
Praise be to God, by whose grace good deeds are accomplished, and peace and blessings be upon our Prophet Muhammad, his family, and his companions.

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As a token of our devotion, we pray that Almighty God will shower my beloved mother with His boundless kindness, give her a spot in His expansive Paradise, and reward her with this achievement.

We would like to extend our sincere gratitude to our father, who has been our source of strength and support, as well as to our brothers, who have helped us along the journey.We also thank everyone who helped us get to this point, including the distinguished members of the examination committee.



Dedication

To her pure soul, which is still alive in our hearts but has left us for the eternal home... To the genesis of creation and the wellspring of affection, to the one who nurtured me as a child, prayed for me as a young man, and carried me with such tenderness despite her own frailty... I dedicate the fruit of this academic endeavour to you, my dearest mother (may God have mercy on her, forgive her, and grant her a place in His vast Paradise). I ask the Almighty Lord to accept it from me as an ongoing act of charity that raises your status in Paradise.

To my safe haven in this life, the source of my fortitude and steadfastness... To the one who supported me through my mistakes and eased my hardships with his wisdom and patience, to the one who taught me that success is a struggle and excellence is a choice... May God bring you health and well-being, maintain you as our treasure and support, and keep you as a crown on our heads, my dear father.

To the tremendous trust, the priceless legacy, and the lifelong friends... To those for whom I proudly take responsibility, whose love constantly propels me to excellence, and whose presence gives me resolution and determination... My dear brothers, you are the hearts that beat with love and support for me at every turn. You are my real support system.

I proudly and gratefully dedicate my modest work—the result of years of hardship and restless nights—to each and every one of you.

INES



Dedication

To my beloved father,

Whose unwavering support, sacrifices, and guidance have been a constant source of strength throughout my life. Thank you for believing in me, encouraging me, and inspiring me to pursue my goals with determination and perseverance. I am deeply grateful for everything you have done for me.

To my beloved mother,

Whose endless love, patience, and prayers have been the foundation of my success. Your kindness, encouragement, and unconditional support have always given me the confidence to overcome challenges and continue moving forward. Words cannot fully express my gratitude and appreciation for all that you have done for me.

To my dear parents,

I dedicate this work to you as a humble expression of my love, respect, and gratitude. This achievement is the result of your sacrifices, support, and faith in me. I hope that this accomplishment brings you pride and happiness, just as your love and guidance have brought meaning and success to my life.

With deepest love, respect, and appreciation.

Mohamed Fouad

Abstract

In order to broaden its operational efficiency and decrease unplanned failures that could compromise the continuity of electrical grids, this project intends develop and design a smart system for monitoring electrical transformers using Internet of Things (IoT) and artificial intelligence (AI) technologies.

The main operational parameters of the electrical transformer, including temperature, humidity, voltage, current, oil level, and vibration, are measured by a set of sensors as part of the project concept. A microcontroller gathers and transmits this data in real time to a cloud platform, where it is stored, analysed, and displayed via an interactive control panel.

The practical part of this job entailed constructing and programming the proposed system and merging all of its parts after researching the types and components of electrical transformers as well as their basic laws and circuits. Additionally, artificial intelligence methods were used to evaluate data and anticipate possible problems before they arise, enabling early intervention.

The findings proved that the suggested method offers precise and efficient electrical transformer monitoring, lowers maintenance costs, increases the effectiveness of the monitoring and protection systems, and helps to improve the dependability of electrical

Summary

Afin d'améliorer son efficacité opérationnelle et de réduire les pannes imprévues susceptibles de compromettre la continuité des réseaux électriques, ce projet vise à développer et à concevoir un système intelligent de surveillance des transformateurs électriques utilisant les technologies de l'Internet des objets (IoT) et de l'intelligence artificielle (IA).

Les principaux paramètres de fonctionnement du transformateur électrique, notamment la température, l'humidité, la tension, le courant, le niveau d'huile et les vibrations, sont mesurés par un ensemble de capteurs dans le cadre du concept du projet. Un microcontrôleur collecte et transmet ces données en temps réel à une plateforme cloud, où elles sont stockées, analysées et affichées via un panneau de contrôle interactif.

La partie pratique de ce travail a consisté à construire et à programmer le système proposé, puis à intégrer tous ses composants après avoir étudié les types et les composants des transformateurs électriques ainsi que leurs principes de base et leurs circuits. De plus, des méthodes d'intelligence artificielle ont été utilisées pour évaluer les données et anticiper les problèmes potentiels avant qu'ils ne surviennent, permettant ainsi une intervention précoce.

Les résultats ont démontré que la méthode proposée offre une surveillance précise et efficace des transformateurs électriques, réduit les coûts de maintenance, augmente l'efficacité des systèmes de surveillance et de protection, et contribue à améliorer la fiabilité des réseaux électriques.

Key words:

Electrical Transformer

Smart Monitoring

Internet of Things (IoT)

Artificial Intelligence (AI)

Random Forest

Predictive Maintenance

Fault Detection

Real-Time Monitoring

Cloud Computing

Power Transforme

ESP 32

WiFi

Python

Voltage

Current

Alarm

DHT 22

Buzzer

Dashboard

Blynk

الملخص

بهدف تعزيز الكفاءة التشغيلية وتقليل الأعطال غير المتوقعة التي قد تهدد استمرارية شبكات الكهرباء، يهدف هذا المشروع إلى تطوير وتصميم نظام ذكي لمراقبة المحولات الكهربائية باستخدام تقنيات «إنترنت الأشياء» (IoT) و«الذكاء الاصطناعي» (AI).

يتم قياس المعلمات التشغيلية الرئيسية للمحول الكهربائي، بما في ذلك درجة الحرارة والرطوبة والجهد والتيار ومستوى الزيت والاهتزاز، بواسطة مجموعة من أجهزة الاستشعار كجزء من مفهوم المشروع. يقوم متحكم دقيق بجمع هذه البيانات ونقلها في الوقت الفعلي إلى منصة سحابية، حيث يتم تخزينها وتحليلها وعرضها عبر لوحة تحكم تفاعلية.

تضمن الجزء العملي من هذا العمل بناء وبرمجة النظام المقترح ودمج جميع أجزائه بعد البحث في أنواع ومكونات المحولات الكهربائية بالإضافة إلى قوانينها ودوائرها الأساسية. علاوة على ذلك، تم استخدام أساليب الذكاء الاصطناعي لتقييم البيانات وتوقع المشاكل المحتملة قبل حدوثها، مما يتيح التدخل المبكر.

أثبتت النتائج أن الطريقة المقترحة توفر مراقبة دقيقة وفعالة للمحولات الكهربائية، وتخفض تكاليف الصيانة، وتزيد من فعالية أنظمة المراقبة والحماية، وتساعد على تحسين موثوقية الشبكة الكهربائية

Symbols and Shortcuts

EMF : Measured the electromotive

$\emptyset$: Magnetic Flux

$\frac{d\emptyset}{dt}$: Rate of change of magnetic flux with respect to time

AC : Alternating current

LV : Low voltage

HV : High voltage

MV : Medium voltage

MC : Magnetic core

Kv : Voltage unit: kilovolt

AVID : Automatic voltage regulating device

PTs : Voltage transformers

CTs : Current transformers

TPOO : Ingress protection rating

MVA : Unit of apparent power: megavolt-amperes

ONAF : Oil Natural Air Forced

OFAN : Oil Forced Air Natural

OFAF : Oil Forced Air Forced.

OFWF : Water Forced by Oil

ODWF : Oil Directed Water Forced

ODAF : Oil Directed Air Forced

AN : Natural Air

AF : Air Forced

$\mathbf{N_p}, \mathbf{N_1}$: Number of turns in the primary winding

$\mathbf{N_s}, \mathbf{N_2}$: Number of turns in the secondary winding

$\mathbf{V_p}$: Primary winding voltage

$\mathbf{V_s}$: Secondary winding voltage

P : Electrical power

V : Electric voltage

I : Electric current

$\emptyset_\mathbf{m}$: Maximum magnetic flux

$\boldsymbol{\omega t}$: Angular frequency multiplied by time

$\mathbf{e_1}$: For the instantaneous electromotive force of the primary coil

$\mathbf{e_2}$: For the instantaneous electromotive force of the secondary coil

$\mathbf{E_{m1}}$: Peak value of the primary electromotive force

$\mathbf{E_{m2}}$:Peak value of the secondary electromotive force

F : frequence

α : transformation ratio

$\frac{1}{\alpha}$: current ratio

P_{in} : Input power

P_{out} : Output power

I_1 : primary current
I_2 : secondary current
Q_{in}: input reactive power
Q_{out} : output reactive power
P_0 : No-load power
V_0 : No-load voltage
I_0 : No-load current
Z_{eq} : Equivalent impedance
P_{cc} : short-circuit power loss
V_{cc} : short-circuit voltage
I_{cc} : short-circuit current
R_f : core loss resistance
X_m : magnetizing reactance
R_2' : Secondary winding resistance, referenced to the primary
X_2' : Secondary winding reactance, referenced to the primary.
Z_l' : Load impedance, referenced to the primary.
I_2' : Secondary winding current referred to the primary.
V_2' : Secondary winding voltage referred to the primary.
R_1' : Secondary winding resistance, referenced to the secondary
X_1' : Secondary winding reactance, referenced to the secondary.
Z_1' : Load impedance, referenced to the secondary.
I_1' : Secondary winding current referred to the secondary.
V_1' : Secondary winding voltage referred to the secondary
I_w' : Iron core loss current referred to the secondary.
I_m' : Magnetizing current referred to the secondary
I_0' : Total no-load current referred to the secondary.
R : Resistance
Z : Impedance
X : Reactance
AI : Artificial Intelligence
IOT :Internet of Things

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INTRODUCTION

General Introduction

One of the most important pillars supporting industrial and technical advancement in the current period is electricity, which is essential to many different economic and service sectors. Transformers, which are used to efficiently transport and distribute electricity by stepping up or down the voltage in accordance with use needs, are among the most crucial parts of electrical networks.

Transformers have a critical part in electrical grids, and their failure can result in large financial losses and power outages, thus it is necessary to design contemporary methods to continuously monitor and safeguard them. The development of artificial intelligence (AI) and the Internet of Things (IoT) has made it feasible to create intelligent systems that can monitor electrical transformers in real time and analyse data to anticipate defects before they occur.

The goal of this project is to design and implement an IoT and AI-based smart system for monitoring electrical transformers. The system uses a set of sensors to gather data, send it to a cloud platform for analysis, and display it via a professional monitoring dashboard. It will also provide an alert and warning system to improve operational efficiency and protection.

This project is broken up into three main sections: the first part deals with the theoretical study of electrical transformer types and components; the second part studies transformer-related calculations, laws, and circuits; and the third part deals with the project's practical aspects, including the design of the smart system and how it works.

Chapter I

State of the art

Chapter I State of the art

I.1.Introduction

Transformers are among the most important devices used in the transmission and distribution of electrical power. This section aims to provide a theoretical overview of electrical transformers by examining their types and components—including active and passive parts—as well as their classifications in terms of cooling, number of phases, insulation, and construction.... It also covers how they work, the main characteristics that affect their performance and stability, and the faults that can occur in them.

I.2 Definition of electrical Transformers

I.2.1 The concept of the transformer

An electrical transformer is a fixed, immobile electrical component. It is called static because it has no moving components. The transformer converts alternating voltage from one value to another (higher or lower) while providing a constant power output.

A transformer usually has two circuits: an electrical circuit and a magnetic circuit. An electrical circuit consists of two coils: the primary coil, which connects to the power source, and the secondary coil, which connects to the loads. The magnetic circuit consists of metal sheets produced from high-quality silicon iron. The transformer relies on a fixed electromagnetic tool that transfers electrical energy from one circuit to another by mutual induction between the windings, allowing voltage and current levels to be converted without changing the frequency of the system.[1]

A transformer is a very simple electrical device, but it is very important in the electrical network because it is an essential machine for transmitting electrical energy.

Transformers are used at the following levels:

- At the outlet of stations where the voltage is high for transmission.
- At connection or distribution stations.
- In distribution substations where the voltage is reduced to match the distribution voltage.
- In distribution stations where the voltage is reduced to match the level of usage voltage for businesses and homes. [2]



Figure I.1 : Single- phase transformer



Figure I.2 : Three –phase transformer

- Transformer symbols

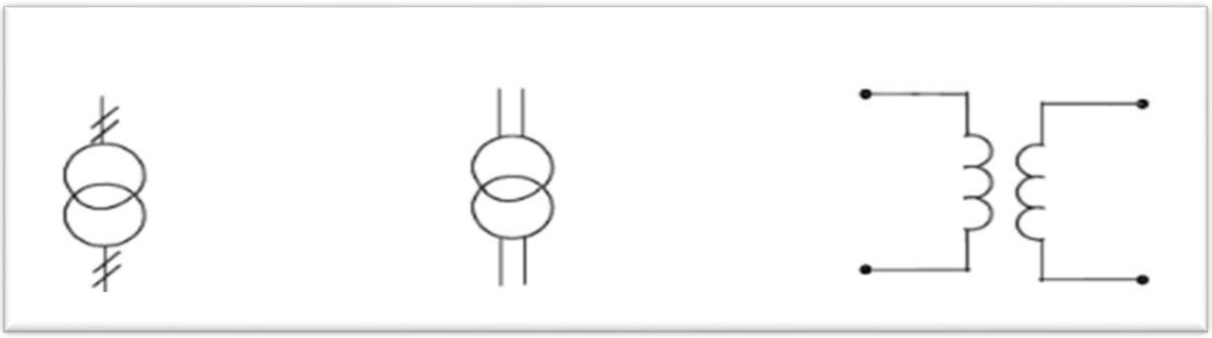


Figure I.3 : Transformer symbols of single - phase

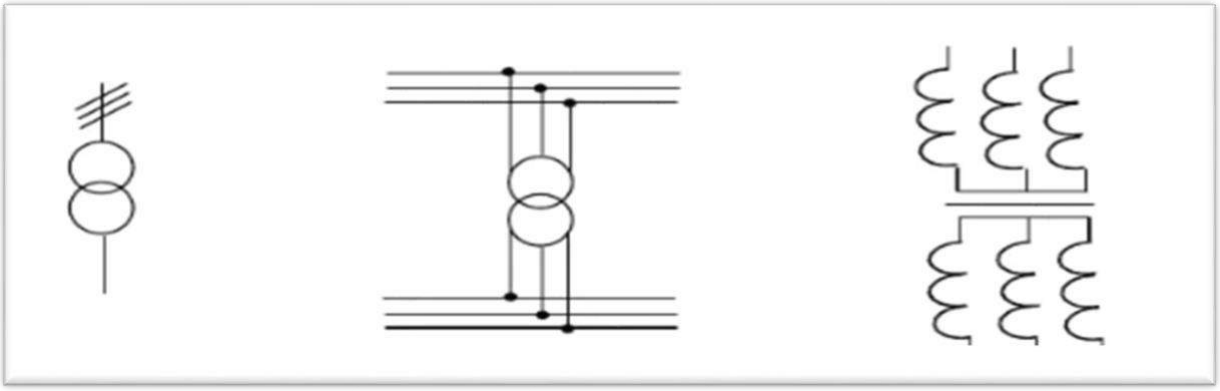


Figure I.4 : Transformer symbols of three - phase

- Transformer diagram

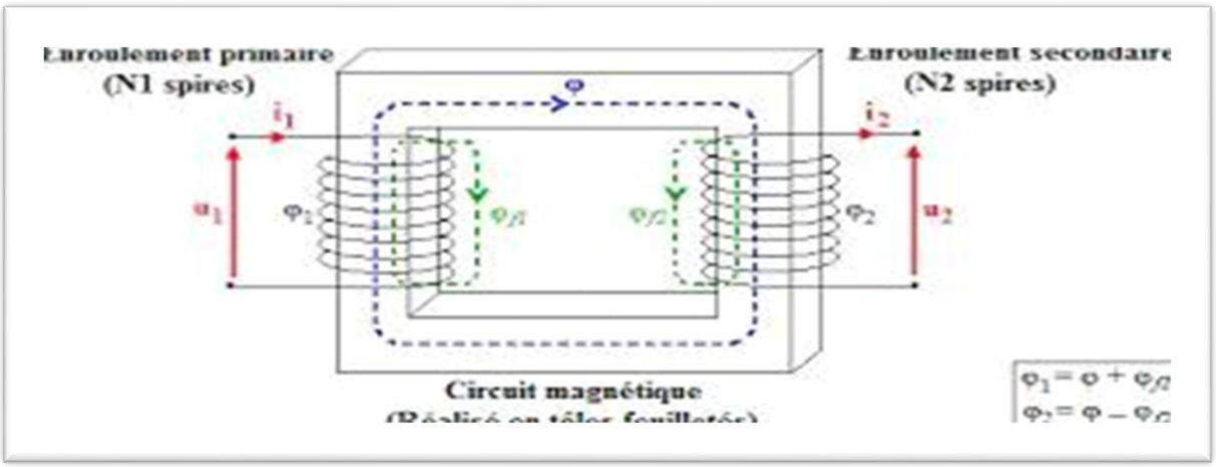


Figure I.5 : Transformer diagram of single- phase

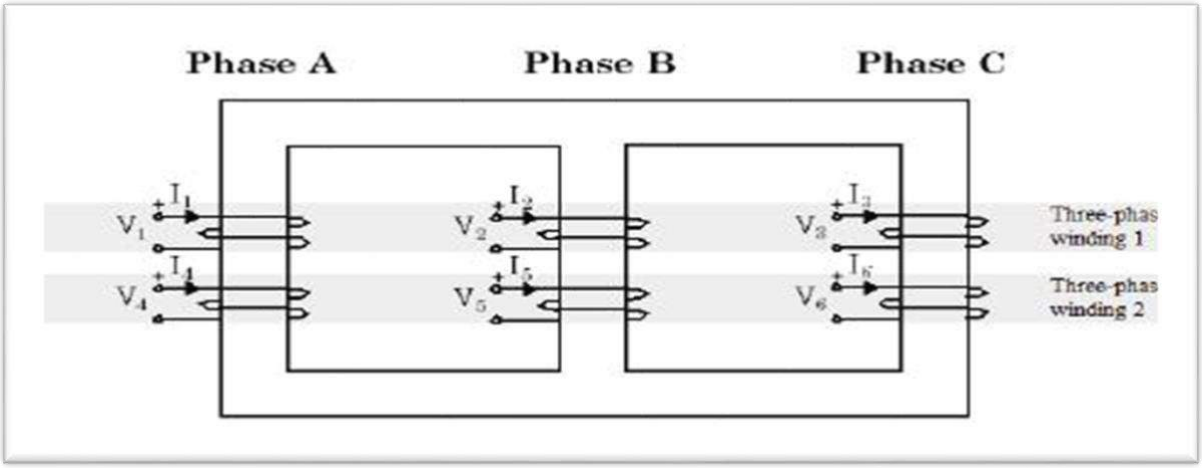


Figure I.6 : Transformer diagram of three- phase

I.2.2 Equivalent electromagnetic circuit of a single-phase transformer

According to Faraday's law, which states that when there is a variable magnetic induction flux Ø rotating in the magnetic circuit and generating a force in each of the windings (each current passing through an electric wire generates a magnetic field around), it generates a force in each of the windings and the direction of this magnetic field is determined according to the right-hand rule see Figure (I-7)

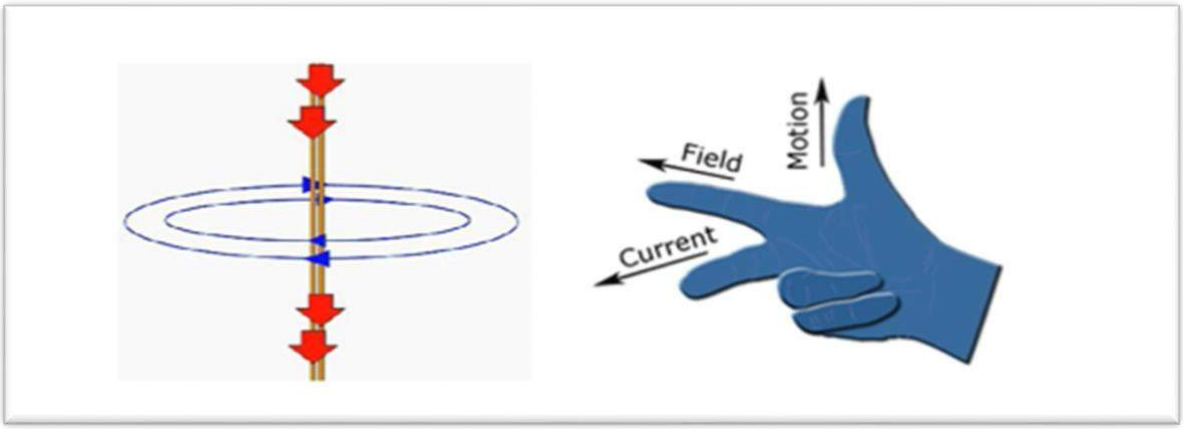


Figure I.7 : Direction of the magnetic field according to the right-hand rule

The electromotive force (emf) is proportional over time to the rates of change (dØ/dt) and to The number of cycles included in this winding. When the primary is executed by An alternative source, an alternating flow rotates equally in the magnetic circuit, which

The capacity depends on the number of turns of the initial coil and the voltage applied. This flow stimulates .The secondary coil has a voltage proportional to the number of cycles of the secondary coil. Closing the secondary to the load causes the secondary current to flow.

The ferromagnetic core provides a path to direct the magnetic flux as indicated according to Figure(I.8) [3].

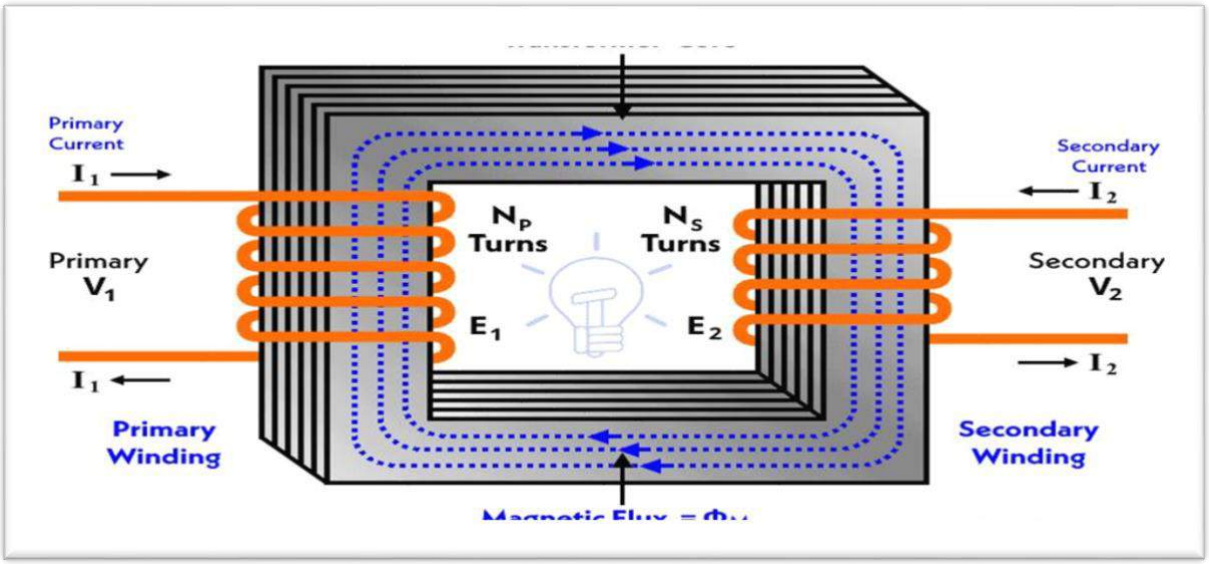


Figure I.8 : Electromagnetic equivalent circuit of a single-phase transformer

I.3 Operational Principle

The foundation of transformer operation is the idea that electrical energy can be effectively transferred from one circuit to another using magnetic induction. An alternating magnetic field is created in the transformer core when one winding of the transformer is powered by an alternating current (AC) source. "Flux," or alternating magnetic lines of force, move through the core. The alternating flux lines induce a voltage with a second winding around the same core. Current flows when a circuit is linked to the second windings terminals.

Two distinct coil windings coiled around a common core makeup each phase of a transformer. The high-voltage winding is positioned around both the low-voltage winding and the core after the low-voltage winding is positioned closest to the core. (Figure I.9) illustrates one phase's internal architecture. Usually, very thin steel laminations covered in insulation make up the core. Losses are decreased by insulating in between each lamination. Magnetic flux has a low resistance path thanks to the steel core. Low-voltage and high-voltage windings are separated from other windings and from the core, and leads. Are exposed by way too insulating bushings. High-voltage and low-voltage windings surround each of the three legs that make up a three-phase transformer's core. Internal structural support and insulation are provided by special paper and wood [4].

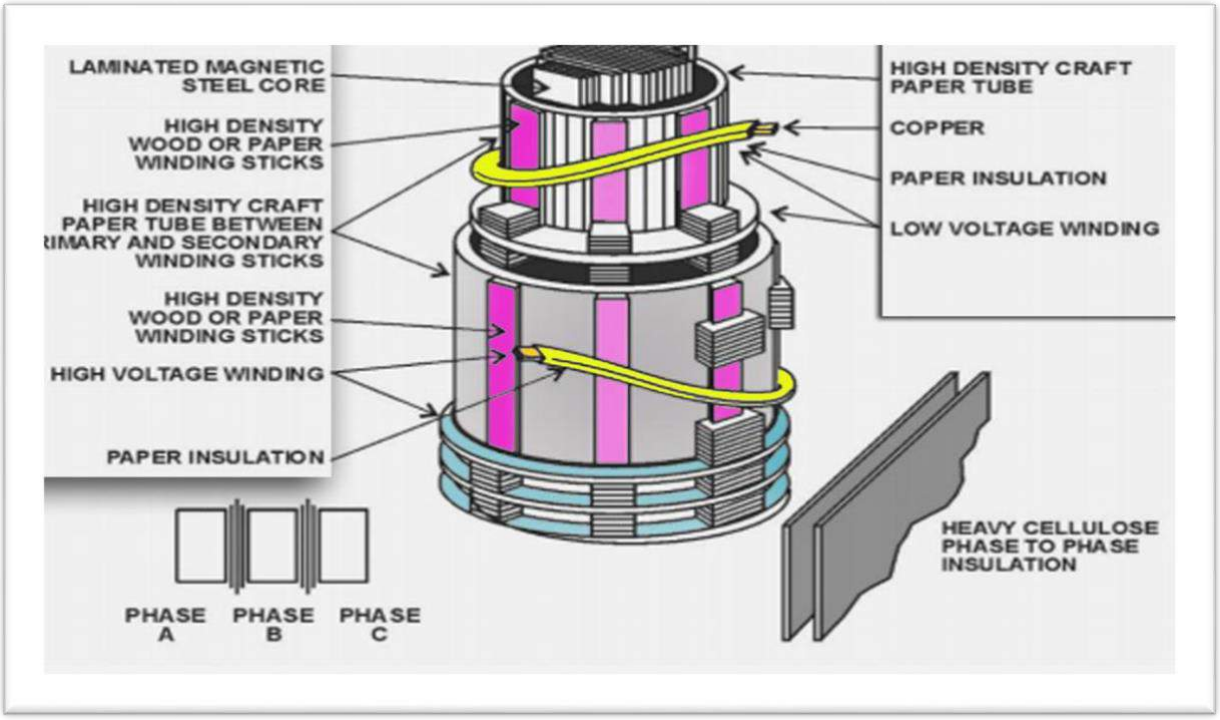


Figure I.9 : Transformer construction

I.4 Adapter Components

The transformer consists of two basic groups, the detailed elements of which are shown in Figure (I.10):

- Active Parts
- Inactive Parts

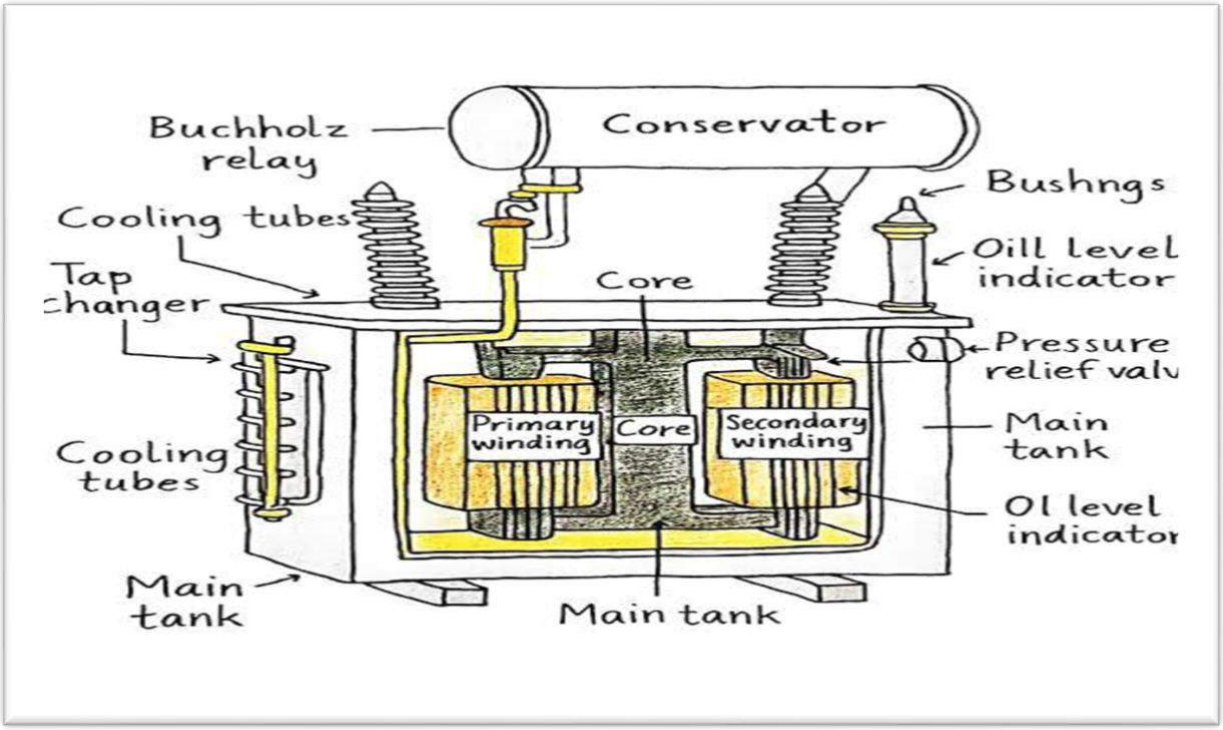


Figure I.10 : Interior view of a transformer, column type

❖ **Active Parts**

The active part of a transformer is defined as the magnetic circuit and the windings.

I.4.1 Circuit Magnetic

The magnetic circuit's function is to direct the magnetic flux produced by the primary winding's excitation in the direction of the secondary winding.

High-permeability, grain-oriented ferromagnetic sheets that are electrically isolated from one another make up the core. Eddy current and hysteresis losses that arise during the periodic change of the magnetic flux must be minimized in its design. The following actions are done to reduce losses [5] :

- The use of soft magnetic steel with low hysteresis loss and a short hysteresis loop region.
- The application of laminations whose thickness is selected to almost completely eliminate the impact of eddy currents.

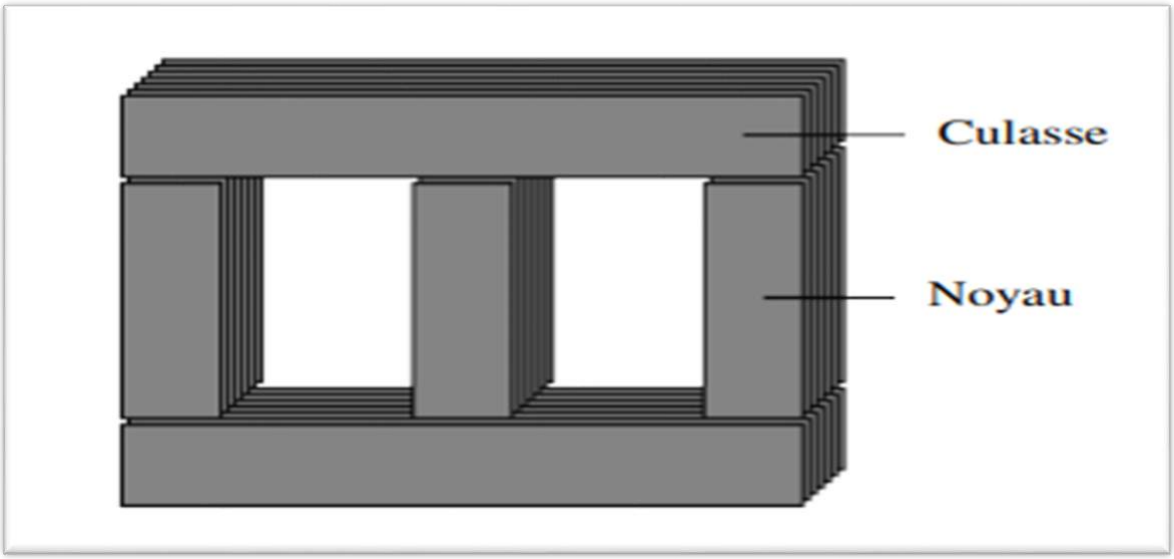


Figure I.11 : Magnetic circuit.

There are two primary configurations that depend on the magnetic circuit's shape:

I.4.1.1 Transformer of the shell type

This kind of transformer's magnetic circuit encircles the winding on both sides. The transformer that is produced has exceptional mechanical stiffness and a very small design since the tank keeps the unit together. Transient overvoltages are frequent in transmission and distribution networks, which are the main applications for these transformers. Shields are utilized to lessen the strains brought on by the electric fields inside the coils in order to remedy this.

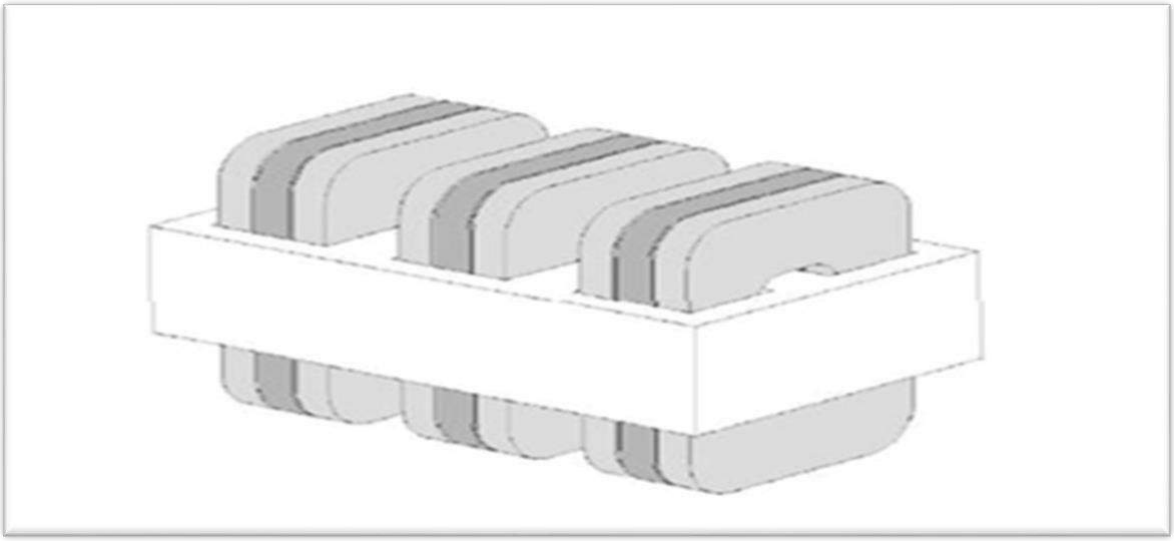


Figure I.12 : Shell-type transformer.

I.4.1.2 Transformers in columns

Everyone of the stages of a column transformer contains two concentric windings. A ferromagnetic core with closed ends supports these windings. By end plates to guarantee appropriate steering of magnetic flux.

This approach maximizes coupling while decreasing the bulk of the conductors by encircling the magnetic circuit with windings. High-voltage transformers and high-power applications employ this layout, which is more straightforward than the prior one. It is possible to organize the windings on a three-column magnetic circuit (cores). A flux-force circuit is the name given to this kind of magnetic circuit. Transformers with four or five columns three of which are coiled and the remaining ones act as flux return paths are employed if the imbalance is substantial [6].

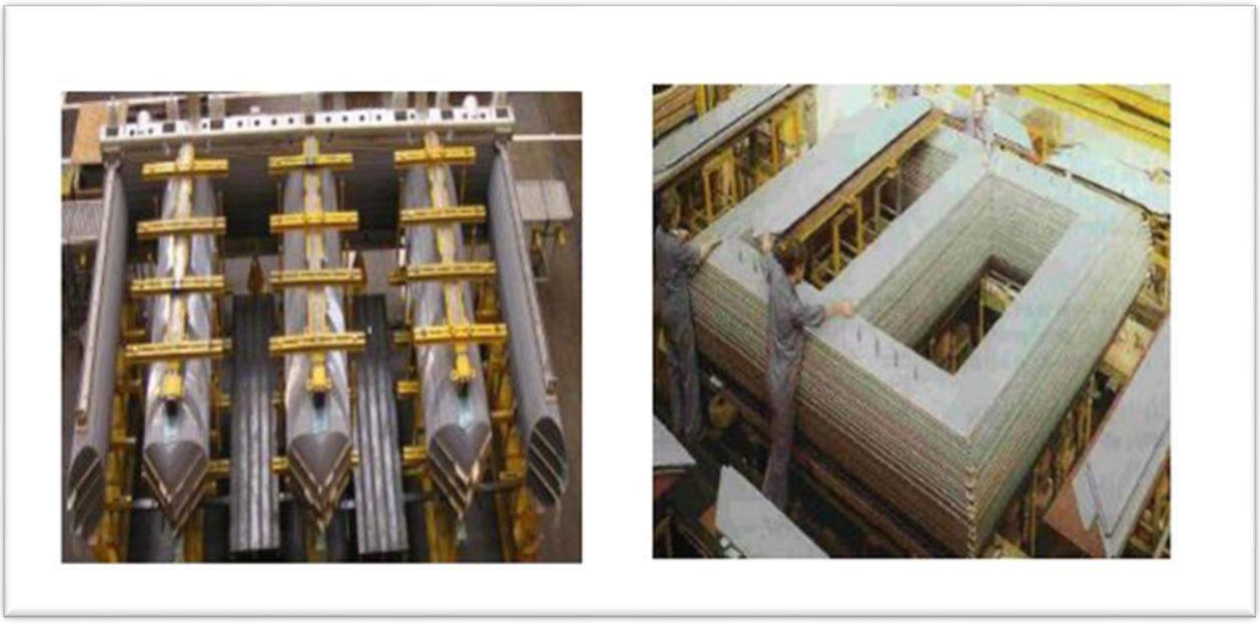


Figure I.13 : Three-phase magnetic circuit

I.4.2 Windings

A single, multi-turn winding that will eventually be linked to the transformer's terminal connections is seen in Figure (1-14).

A transformer's low-voltage (LV) and high-voltage (HV) windings, occasionally with an extra medium voltage (MV) winding, are one winding by voltage level for a certain phase. As shown in the cross-section of half-winding in Figure (I.15), these various windings are interleaved with one another, usually with the low-voltage winding on the inside and the windings of higher voltage levels organized in increasing order toward the outside. The magnetic circuit's (MC) cores hold the collection of windings that make up a phase [6].



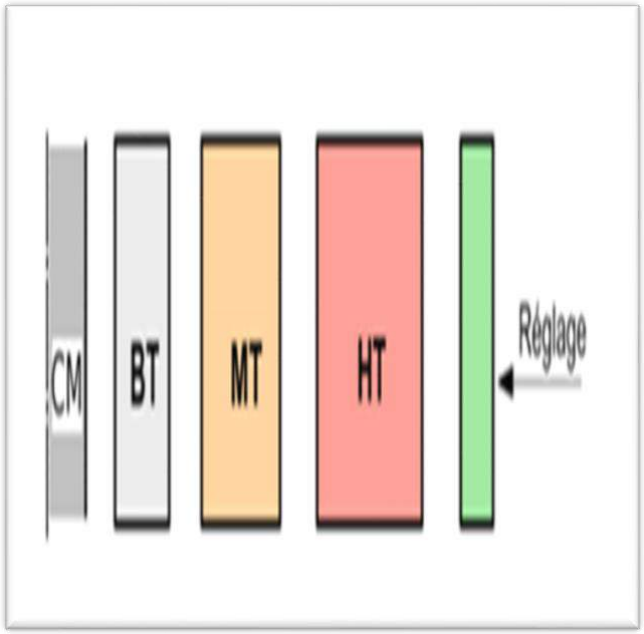


Figure I.14 : Transformer winding **Figure I.15:** Cross-section of a half-winding

- **Inactive Parts**

I.4.3 Insulation

There is a pair of insulation in a power transformer's active section

I.4.3.1 Insulation made of cellulosic

Cellulosic materials, which provide the best technological and financial compromise for the insulation of the impregnated system in power transformers, are used to make solid insulating materials like cardboard, compressed paper, and insulating cylinders [7].

I.4.3.2 Insulation with Liquid

Refined from crude oil, transformer oil is frequently a mineral oil made up of a blend of alkanes, naphthenes, and aromatic hydrocarbons. Acid treatment, solvent extraction, hydroprocessing, or a mix of these techniques are examples of refining procedures. When refining is finished, the mineral oil's properties can be brought up to the necessary standards. The oil's primary function is to cool the transformer and create dielectric insulation. Modern oils don't contain corrosive sulfur and are more resistant to deterioration. Additionally, they must to possess the following qualities:

- excellent flash point
- low pour point
- excellent dielectric strength
- low viscosity
- good resistance to static electricity

I.4.4 Tank

Thermal calculations typically take place to construct the transformer tank.

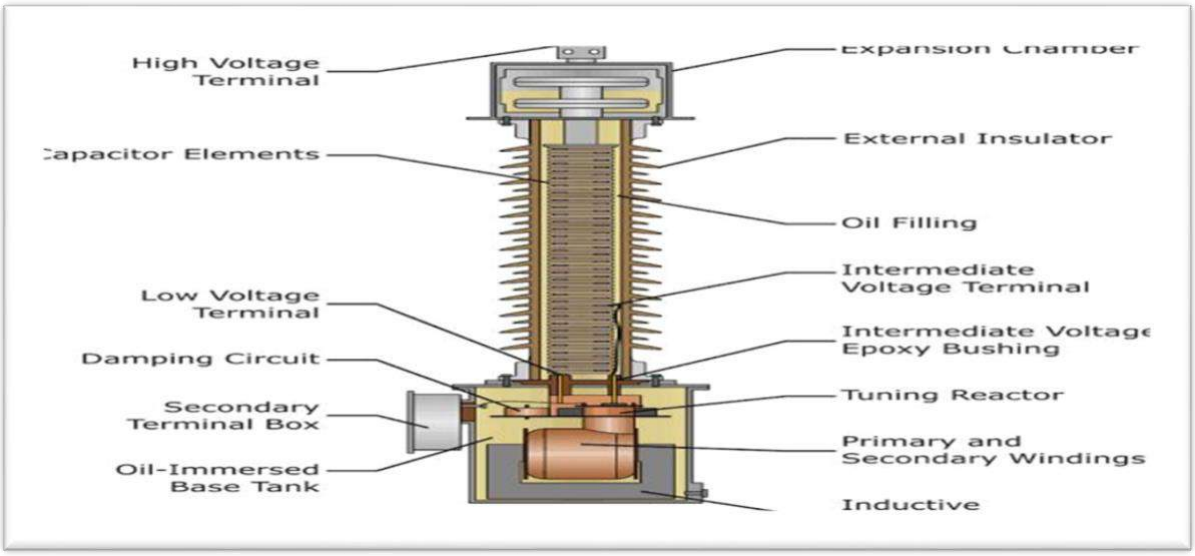
It's composed of steel.

The tank is perforated to facilitate natural air circulation around the transformer and protects the transformer's active component in turn, it retains the majority of the leakage flow within the tank [5,7].

I.4.5 Blushing with insulation

Bushings are used to connect the transformer's live components to the electrical grid. The electrical connection is provided by insulating bushings.

Bushings get their name from the connections between the ends of the primary and secondary winding and the incoming and outgoing lines via the cover.



Figuer I.16 : High-voltage Crossing

In order to prevent any external sparking in the case of a power surge (such as lightning), the insulator's length and notched profile enhance the distance from the power line by restricting the longitudinal electric field. There are several kinds of bushings. The body of the bushings is typically composed of a single block of porcelain, an insulating material, at voltages up to many tens of kV [8].



Figure I.17 : Crossbar Capacitor



Figure I.18 : Cross-cut porcelain

I.4.6 Tools

I.4.6.1 Tap switches

A series of windings that are sequentially electrified make up a tap changer. Using circuits with high-voltage windings. This enables you to alter the conversion ratio in and out of the load of the power transformer across a range of Tap-up and tap-down (AVID) are the two varieties of tap changers.

I.4.6.2 Cooling

Oil is used in power transformers to offer cooling. It moves in a closed loop from the active component, where losses take place, to a cold source, when heat is released [6]

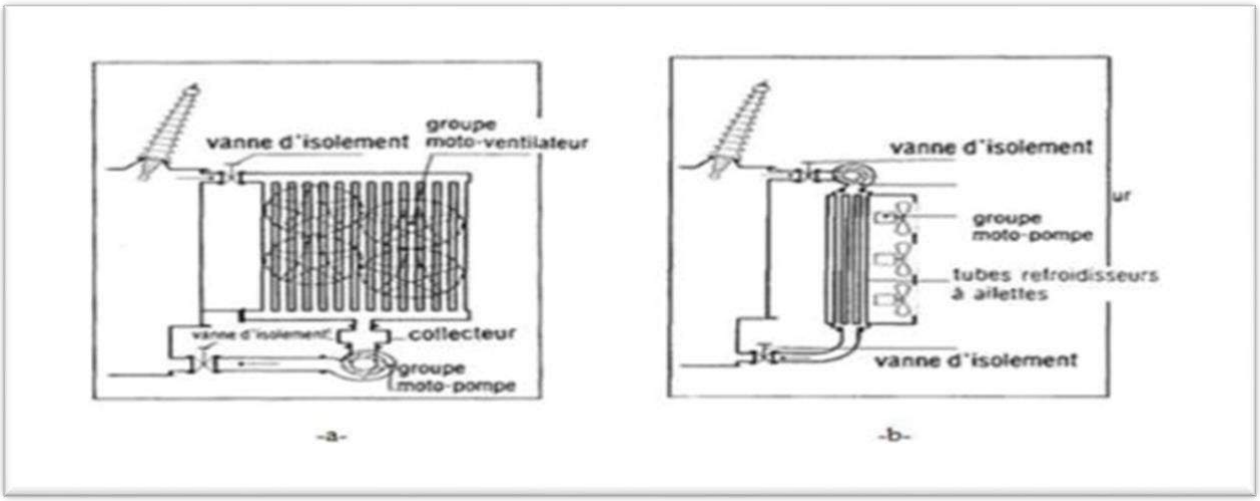


Figure I.19 : Cooling by forced oil circulation through fan-cooled radiators (a) or through air-cooled condensers (b)

I.4.6.3 Preservation

In so-called "breathing" transformers, the conservator (expansion tank) is employed to let the oil expand in reaction to temperature fluctuations.

The dielectric's surface can either be in touch with the surrounding air (traditional conservator) or kept apart by an airtight, flexible diaphragm (diaphragm conservator) [8].

I.4.6.4 Tap-changer control panel

This equipment is used to control the tap changers located inside the transformer tank [8].

I.5 Types of Transformers

I.5.1 Number of phases

I.5.1.1 Transformers of a single phase

For low-power residential applications, single-phase transformers are utilised [13].

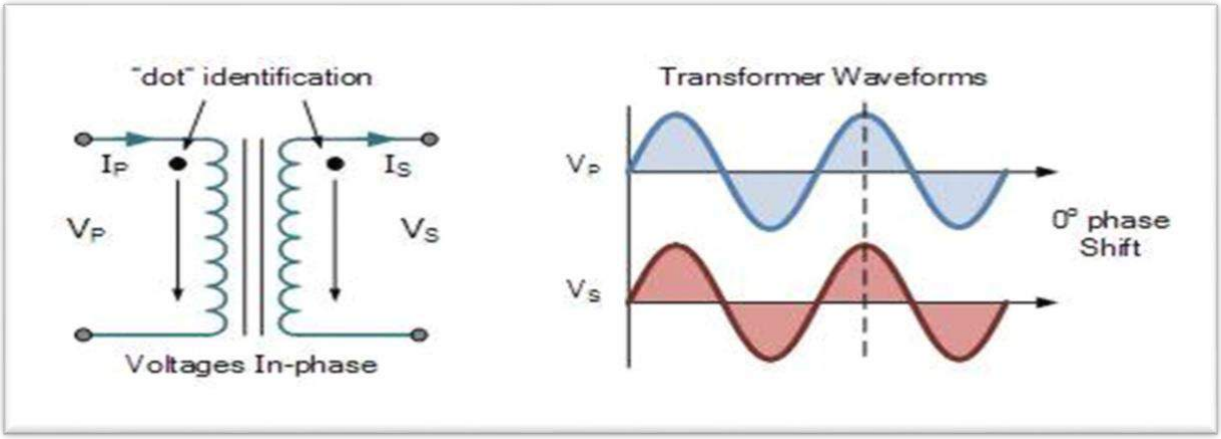


Figure I.20 : Schematic and diagram of a single-phase transformer

I.5.1.2 Transformers of three phases

Three-phase transformers are utilised in power transmission and industrial systems.[13]

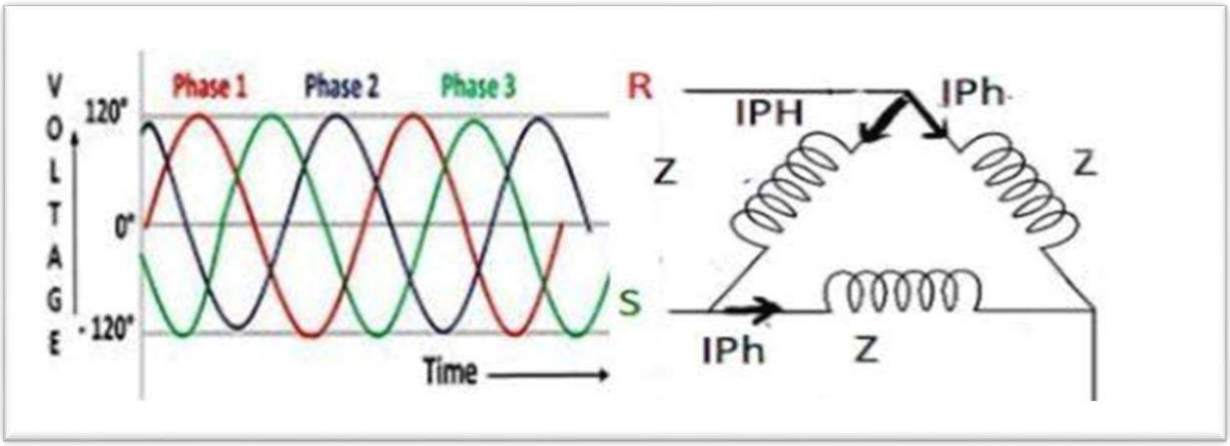


Figure I.21 : Schematic and diagram of a three-phase transformer

I.5.2 According to Function

I.5.2.1 Transformers for Power and Distribution

- **Transformers of Power**

Power plants use power transformers to generate and transmit electricity. They act as interconnections between two power plants and as step-up or step-down transformers to raise or lower the voltage level as needed.

- **Transformers of Distribution**

For both residential and commercial applications, distribution transformers are used to step down or lower a transmission line's voltage and current levels to a predefined level known as the end-user safety level [13].

I.5.2.2 Autotransformer

An autotransformer is a transformer where a single winding serves as both a primary and a secondary winding. An autotransformer's windings are coupled electrically and magnetically.

The transformer is referred to as a step-down autotransformer when the primary voltage is higher than the secondary voltage and a step-up autotransformer when the primary voltage is lower than the secondary voltage [13].

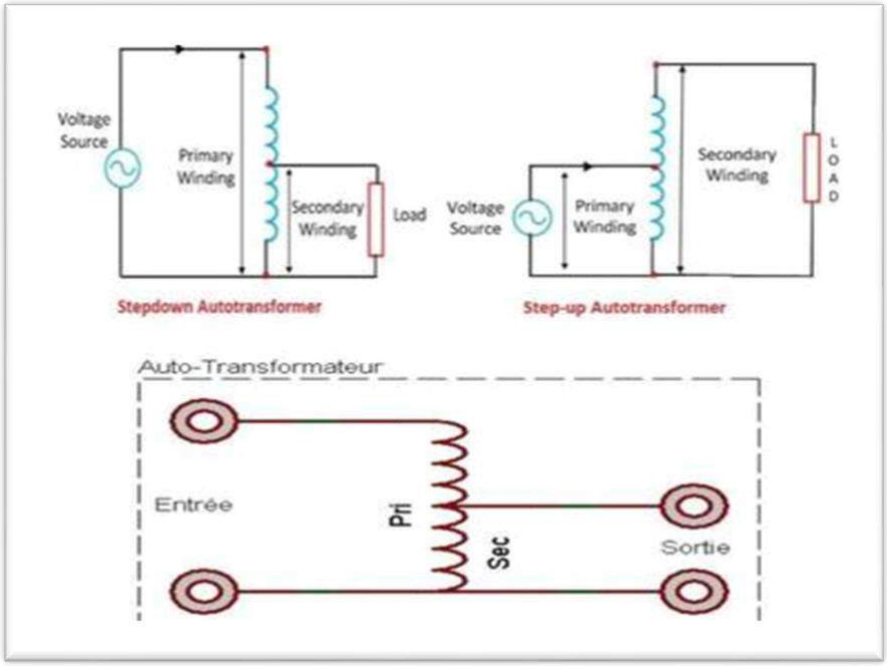


Figure I-22 : Autotransformer

I.5.2.3 Transformers for Isolation

An apparatus that transfers energy from the alternating current (AC) source to an electrical or electronic load is called an isolation transformer. To stop transmission, it isolates the windings. Specific kinds of harmonics [9].

I.5.2.4 Transformers of Instruments

Instrument transformers are employed for control and measurement (figure 10). They supply voltages and currents that are proportionate to the primary, but they pose less risk to personnel and equipment.

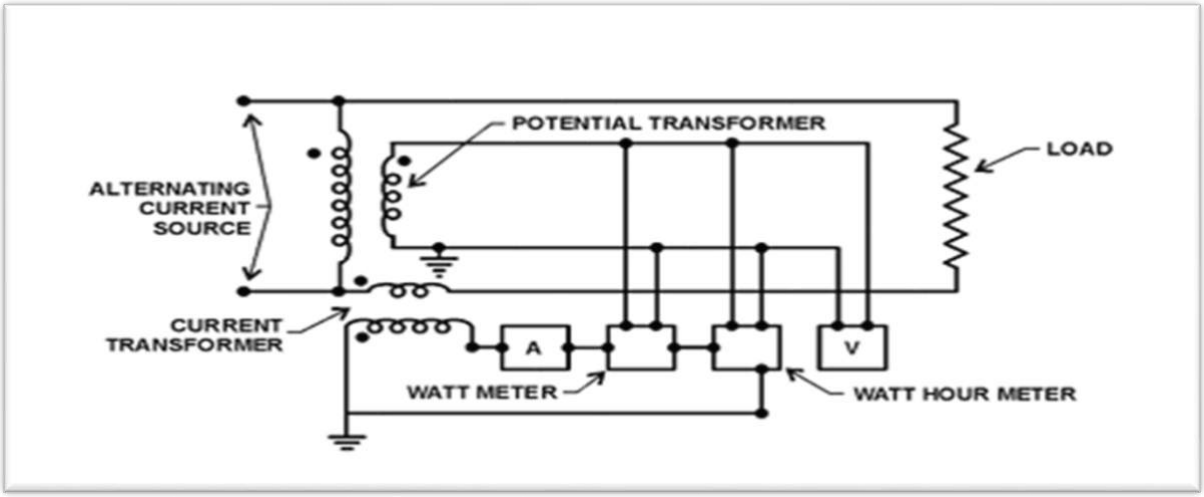


Figure I.23 : Connections of Instrument Transformers.

Potential transformers (PTs) are transformers that step voltage down, whereas current transformers (CTs) are transformers that step current down.

A CT is used to measure current on the primary, whereas a PT is used to precisely measure voltage on the primary [4].

I.5.3 According to Insulation

I.5.3.1 Transformers of the Dry Type

Dry-type transformers are ideal for indoor installations and are good for the environment.[10]

I.5.4 According to Cooling method

Power transformers employ a variety of cooling techniques, such as forced air circulation via fans, oil circulation via pumps, or a mix of the two. As a result, there are the following forms of cooling, which are [14] :

Table I.1 : Codes for cooling methods according to international standards(IEC)

Code	Cooling method
ONAF	Oil Natural Air Forced
OFAN	Oil Forced Air Natural
OFAF	Oil Forced Air Forced.
OFWF	Water Forced by Oil
ODAF	Oil Directed Air Forced
ODWF	Oil Directed Water Forced
AN	Natural Air
AF	Air Forced

I.5.5 According to Transformation ratio

I.5.5.1 Transformer step-up

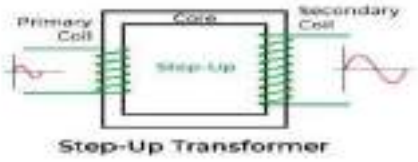
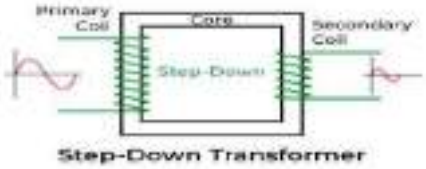
A step-up transformer raises the voltage [11].

I.5.5.2 Transformer step-down

A step-down transformer lowers the voltage [12]

Example :

Table I.2 : Comparison of Step-Down and Step-Up Transformers

	Step-up	Step-down
circuit	 Step-Up Transformer	 Step-Down Transformer
number of turns	$N_s > N_p$	$N_p < N_s$
Input voltage	$V_p = 220v$	$V_p = 220v$
Number of primary winding	$N_P = 100$ Round	$N_p = 1000$ Round
Number of secondary winding	$N_s = 500$ Round	$N_s = 50$ Round
Output voltage	$\frac{V_p}{V_s} = \frac{N_p}{N_s} = 1100v$	$\frac{V_p}{V_s} = \frac{N_p}{N_s} = 11\ v$

Note: In an ideal step-up transformer, as voltage increases, current decreases, and the opposite is true for a step-down transformer (they are directly proportional) in order to maintain a constant electrical power.(P=V.I)

I.5.6. According to Construction

I.5.6.1.Type of Transformer Core

The magnetic core of a core-type transformer is surrounded by windings [13].



Figure I.24 : core-type transformer

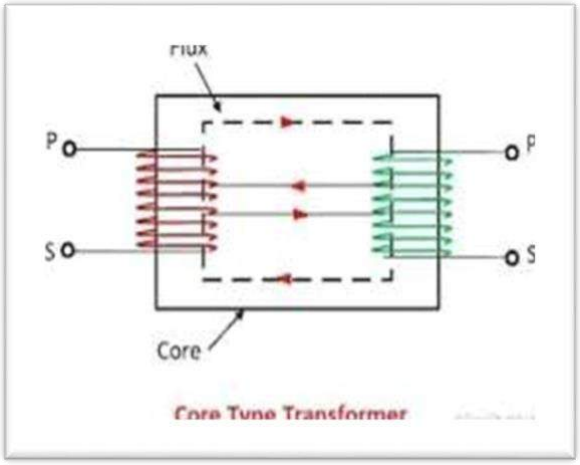


Figure I.25 : magnetic circuit of a core-type transformer

I.5.6.2. Transformer of the Shell Type

The windings are encircled by the magnetic core [13].

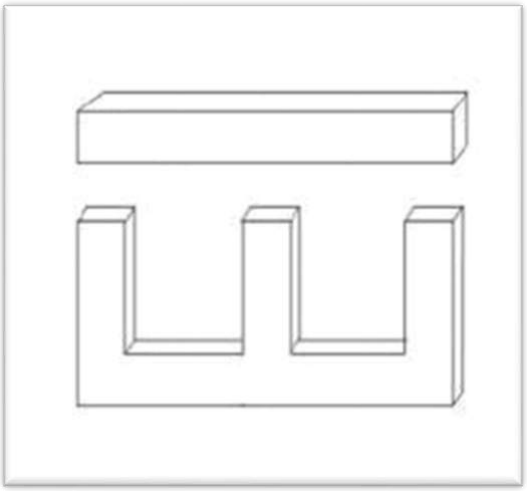


Figure I.26 : shell-type transformer

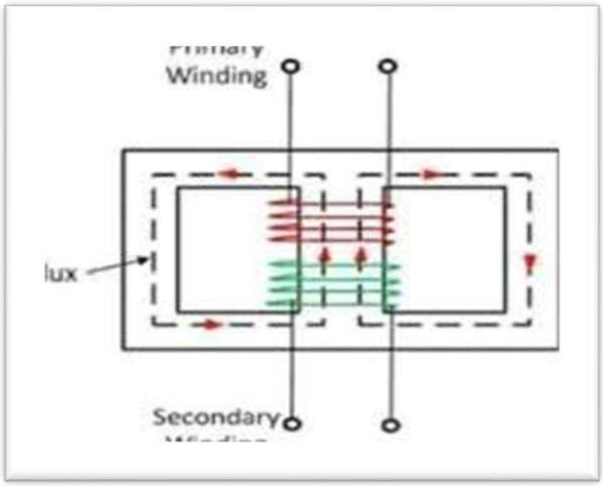


Figure I.27 : Magnetic Circuit of a Shell-Type Transformer

I.6.Transformer Major Faults

I.6.1.Faults in Mechanical Systems

The primary mechanical stress-related flaws are [14]:

- If tap changers are mechanically misaligned, they can have hot spots. Damage to internal insulation driven on by unusual vibrations, which are either the result of major collisions or improper internal tightening during construction.

- a decrease in dielectric clearances caused by a magnetic circuit's significant internal movement of several centimeters after a mechanical event, like a transformer falling (FigureI.28).

  Leaks that occur during installation and subsequent operation from joints that are mechanically a lot tight and/or hot (Figure I.29).



Figure I.28 : Transformer collapse



figure I.29 : Crushed bushing

I.6.2 Defects in Dielectrics

The capacity of a transformer's various components to tolerate voltage is characterized by dielectric flaws; this dielectric strength is correlated with the state of the insulation. In this category, the most prevalent flaws are:

- Partial discharge in live parts: either to ground or between turns (Figure 1-30) or windings.
- Partial discharges: usually solid in transformers, they occur inside an insulator. These micro-discharges have a specific location and have a tendency to spread over time .



Figure I.30 : clear gap between coils

Because carbon is conductive, all of these deficiencies have effects on the dielectric strength locally. It is impossible to reverse this occurrence because it is irreversible. Typical activity after dielectric failure[14].

I.6.3 Overcurrent-connected faults

There are the three main effects of these overcurrents[14]:

- The forces of electrodynamics, and High mechanical stresses are the result of Laplace forces in the windings. These forces may be particularly crucial when there is a short circuit. Up to several hundred tonnes. An obvious illustration of mechanical distortion of a winding is displayed in(Figure 1-31).
- Excessive heating of the windings causes solid insulators to deteriorate.
- Grid stability is disrupted by a drop in voltage on the secondary side.



Figure I.31 : Net electrodynamic force

I.6.4 Electromagnetic Problems

If there are many grounded spots in the magnetic circuit (Figure I.32) or if the active part's metal, clamping bits are grounded; common issues could include hotspots brought on by [14]:

- unusually elevated induced eddy currents,
- These aberrant eddy currents cause internal insulation to decline.

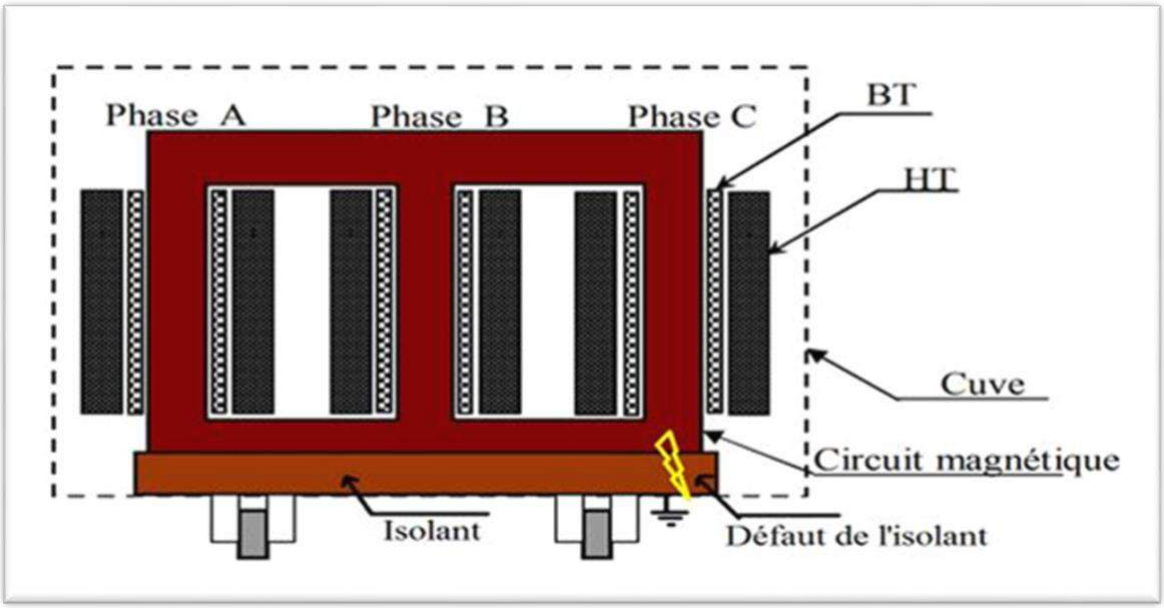


Figure I.32 : Schematic of a fault current loop with the CM magnetic circuit

I.6.5 Thermal Flaws

These thermal stressors always lead to ageing.

- The deterioration of insulation sheets' dielectric values. These are of the utmost significance since they cannot be changed during the transformer's operational life unless it is rebuilt. For instance, in the extreme scenario depicted in(Figure 1-33), the coil's interior is completely blackened as a result of operating at high temperatures.
- Insulating oil: Temperature, humidity, and gas cause the oil to age faster and lose its original qualities, which may end up in a failure [14].



Figure I.33: Excessive heating of a winding

I.6.6 Electrical Problems

Certain flaws can be brought on by current passing through the transformer's different contacts, such as:

- The creation of hot spots as part of some transformer components overheating, which causes insulation to deteriorate. Interruptions in electrical systems.
- Connections in some tap changers, primarily the diverter switch's movable contacts, may overheat if they are not used frequently and depending on the contact's quality and operating conditions.
- Despite continuously carrying the transformer's load current, a well-advanced hot spot on a bolted contact can be seen in (Figure 1-34).
- De-energized tap changer connections: Over time, the moving contacts in operating locations that are never moved could decline [14].



Figure I.34 : Hot spot on a bolted connection

I.7 Comparison of previous studies and the proposed system

Table I.3 : Comparison of previous studies and the proposed system

Authors	**Year**	**Main Contribution**
Chen and all	2011	Transformer fault diagnosis using random forest
Zhang and all	2020	IOT-based transformer monitoring and fault dig
Wang and all	2021	Real-time transformer monitoring using IoT
Equbal and all	2022	Online transformer fault classification
Tahir and tenbohlen	2023	Transformer condition assessment using random forest
Proposed system	2026	Real-time monitoring and fault prediction using IoT and AI.

The contrast shown in Table I.3 demonstrates that the majority of earlier research concentrated on either IoT-based monitoring or artificial intelligence methods independently. The suggested system offers real-time monitoring, early fault identification, and predictive maintenance of power transformers by combining machine learning and the Internet of Things.

I.8 Conclusion

We have covered the several kinds of electrical transformers and their fundamental parts in this section, emphasising the crucial function of transformers and outlining the significance of each component. The second portion of the research, which will cover electrical calculations, equivalent circuits, the fundamental rules regulating transformers, and the crucial mathematical relationships that affect their performance, is built upon this theoretical study.

Chapter II

Modeling and analysing of transformers

Chapter II Modeling and analysing of transformers

II.1 Introduction

It becomes necessary to look at the analytical and mathematical features that explain how these transformers work and their electrical characteristics during operation after the first section introduced the types of electrical transformers, their fundamental components, and common defects. The rules and equations regulating transformers are the focus of this section. It also covers calculations pertaining to current, voltage, and the turns ratio under both loaded and unloaded conditions, as well as an analysis of different electrical losses and how they affect transformer performance.

II.2 E.M.F equation of transformers

The primary winding draws a current when it is coupled to an alternating voltage source This primary sinusoidal current creates a sinusoidal flux φ that may be expressed as [1]

$$\emptyset = \emptyset_m \, \boldsymbol{sin\, wt} \quad \textbf{(II.1)}$$

Instantaneous emf induced in the primary winding is :

$$\boldsymbol{e_{1=}} -\boldsymbol{N_1} \frac{\boldsymbol{d\emptyset}}{\boldsymbol{dt}} \quad \textbf{(II.2)}$$

As well , the secondary winding's instantaneous *emf* is :

$$\boldsymbol{e_{2=}} -\boldsymbol{N_2} \frac{\boldsymbol{d\emptyset}}{\boldsymbol{dt}} \quad \textbf{(II.3)}$$

Substituting Equation (II.1) into the Equation (II.2) yields

$$\boldsymbol{e_1} = -\boldsymbol{N_1} \frac{\boldsymbol{d}}{\boldsymbol{dt}} (\emptyset_m \, \boldsymbol{sin\, \omega t}) \quad \textbf{(II.4)}$$

$$\boldsymbol{e_1} = -\boldsymbol{N_1 \omega \emptyset_m \, cos\, \omega t} \quad \textbf{(II.5)}$$

$$\boldsymbol{e_1} = \boldsymbol{N_1 \omega \emptyset_m (\omega t - 90°)} \quad \textbf{(II.6)}$$

The maximum value of e_1 is

$$\boldsymbol{E_{m1}} = \boldsymbol{N_1 \, \omega \emptyset_m} \quad \textbf{(II.7)}$$

The rms value of the primary *emf* is :

$$\boldsymbol{E_1} = \frac{\boldsymbol{E_{m1}}}{\sqrt{\boldsymbol{2}}} \quad \textbf{(II.8)}$$

Substituting Equation (2.7) into Equation (2.8) yields

Where : $\omega = \boldsymbol{2\pi f}$ **(II.9)**

$$\boldsymbol{E_1} = \frac{\boldsymbol{N_1 2\pi f \emptyset_m}}{\sqrt{\boldsymbol{2}}} \quad \textbf{(II.10)}$$

$$\boldsymbol{E_1 = 4.44 f \emptyset_m N_1} \quad \textbf{(II.11)}$$

- In a similar way , the secondary enf expression is : $\boldsymbol{E_2 = 4.44 f \, \emptyset_m N_2}$ **(II.12)**

II.3 Turns Ratio of transformers

Transformer turns ratio when creating an analogous circuit for a transformer , the turn ratio is a crucial factor , the step_up and step_down transform are identified using the turn ratio Faraday's laws state that the induced enf in the primary e_1 and secondary $e_2$winding's is

$$e_1 = -N_1 \frac{d\emptyset}{dt} \quad \textbf{(II.13)}$$

$$e_2 = -N_2 \frac{d\emptyset}{dt} \quad \textbf{(II.14)}$$

Dividing Equation (2.13) by Equation (2.14) yields

$$\frac{e_1}{e_2} = \frac{N_1}{N_2} = \alpha \quad \textbf{(II.15)}$$

Similar dividing Equation (2.11) by Equation (2.12) yields

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} = \alpha \quad \textbf{(II.16)}$$

When α is the turns ratio of a transformer

- If $N_2 > N_1 \rightarrow$ step_up transformer
- If $N_1 > N_2 \rightarrow$ step_ down transformer

Note : the losses are zero in an ideal transformer in the case the input power of the transformer is equal to its output power and this yields

$$V_1 I_1 = V_2 I_2 \quad \textbf{(II.17)}$$

Equation (II.17) can be rearranged as

$$\frac{V_1}{V_2} = \frac{I_2}{I_1} = \alpha \quad \textbf{(II.18)}$$

- The magnetic driving force produced by the primary current equal to the magnetic driving force produced by the secondary current and can be expressed as

$$N_1 I_1 = N_2 I_2 \quad \textbf{(II.19)}$$

$$\frac{I_1}{I_2} = \frac{N_2}{N_1} = \frac{1}{\alpha} \quad \textbf{(II.20)}$$

where $\frac{1}{\alpha}$ $current\ ratio$

Note : the ratio of primary to secondary current is inversely proportional to the transformes tuns ratio determined by Equation (II.19)

- the input and output power of an ideal transformer

$$P_{in} = V_1 I_1 cos\emptyset_1 \quad \textbf{(II.21)}$$

For an ideal condition the angle $\emptyset_1 = \emptyset_2$ and the output power can be rearranged as

$$P_{out} = \frac{V_1}{\alpha} \alpha I_1 cos\emptyset_1 \quad \textbf{(II.22)}$$

$$P_{out} = V_1 I_1 cos\emptyset_1 = P_{in} \quad \textbf{(II.23)}$$

$$P_{out} = P_{in} \quad \textbf{(II.24)}$$

- Seen that the input and output power are the same in case of an ideal transformer from Equation (II.23) similarly the input and output reactive power are :

$$Q_{out} = V_2 I_2 sin\emptyset_2 = V_1 I_1 sin\emptyset_1 = Q_{in} \quad \textbf{(II.25)}$$

$$Q_{out} = Q_{in} \quad \textbf{(II.26)}$$

II.4 Equivalent electrical diagram

II.4.1 Precise Equivalent Circuit

All of the parameters are moved from the secondary to the primary in (Figure II-2) identical equivalent circuit, which is referred to as the primary. These parameters are

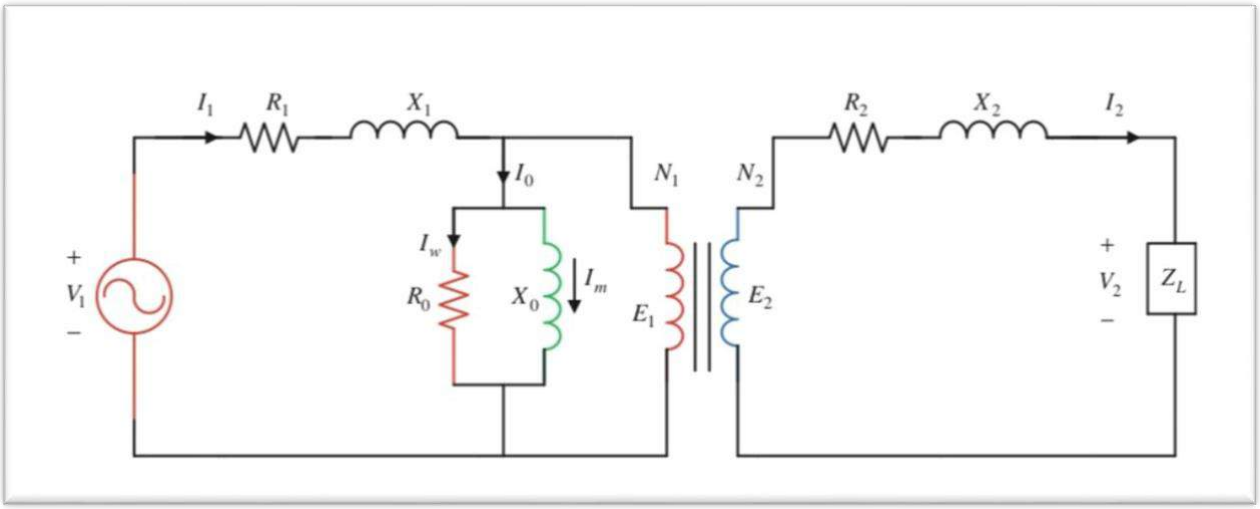


Figure II-1 : Two windings transformer

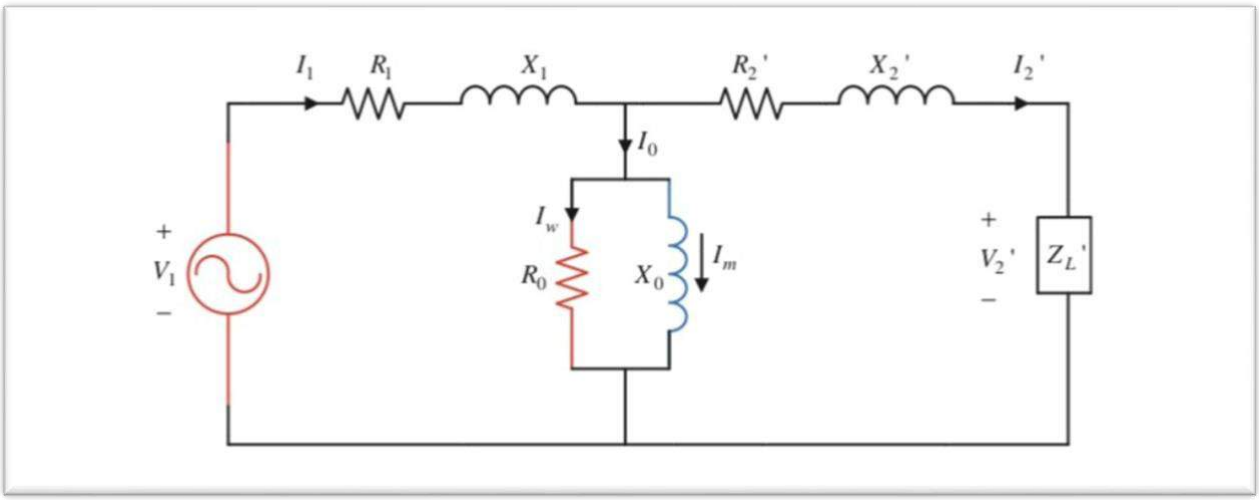


Figure II-2 : Exact equivalent circuit referred to primary

Equivalent circuit of a transformer

$$R_2' = a^2 R_2 \quad \textbf{(II.27)}$$

$$X_2' = a^2 X_2 \quad \textbf{(II.28)}$$

$$Z_L' = a^2 Z_L \quad \textbf{(II.29)}$$

$$I_2' = \frac{I_2}{a} \quad \textbf{(II.30)}$$

$$V_2' = aV_2 \quad \textbf{(II.31)}$$

The identical analogous circuit, referred to as the secondary, is seen in (FigureII-3), where all the parameters are moved from the primary to the secondary. These specifications are

$$R_1' = \frac{R_1}{a^2} \quad \textbf{(II.32)}$$

$$X_1' = \frac{X_1}{a^2} \quad \textbf{(II.33)}$$

$$I_1' = aI_1 \quad \textbf{(II.34)}$$

$$V_1' = \frac{V_1}{a} \quad \textbf{(II.35)}$$

$$I_w' = aI_w \quad \textbf{(II.36)}$$

$$I_m' = aI_m \quad \textbf{(II.37)}$$

$$I_0' = aI_0 \quad \textbf{(II.38)}$$

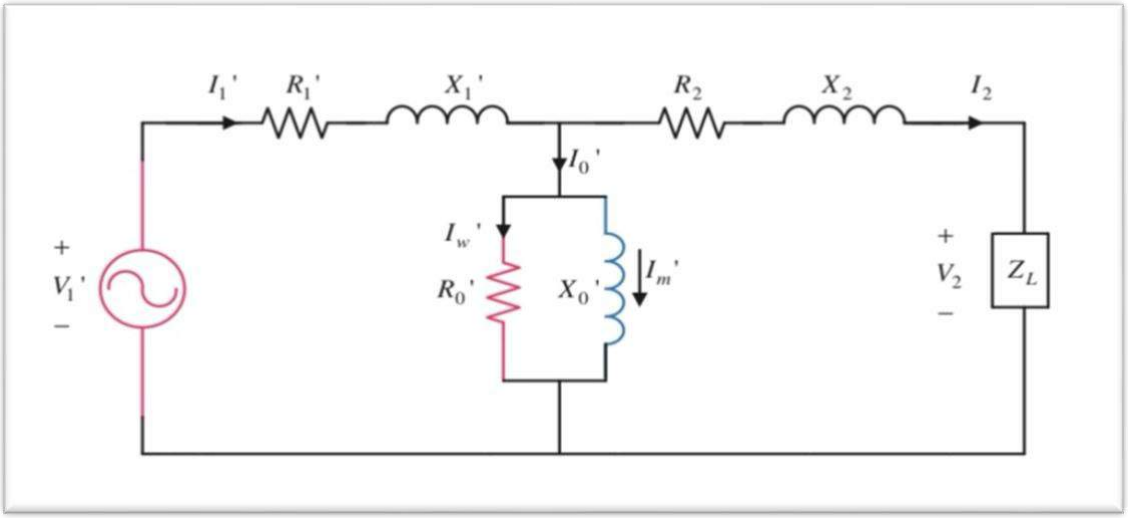


Figure II-3 : Exact equivalent circuit referred to secondary

II.4.2 Equivalent Circuit Approximation

When compared to the rated primary current, the no-load current is quite little. Consequently, R_1 and X_1Cause a very little voltage drop. Under these circumstances, it is reasonable to believe that the applied voltage and the voltage drop across the no-load circuit are identical. The no-load circuit may be shifted across the supply voltage, V_1, to create the nearly equivalent circuit, which is referred to as the primary in(Figure II-5)The primary's total resistance, reactance, and impedance are

$$R_{01} = R_1 + R_2' = R_1 + a^2R_2 \quad \textbf{(II.39)}$$

$$X_{01} = X_1 + X_2' = X_1 + a^2X_2 \quad \textbf{(II.40)}$$

$$Z_{01} = R_{01} + jX_{01} \quad \textbf{(II.41)}$$

The no-load circuit resistance and reactance are

$$R_0 = \frac{V_1}{I_w} \quad \textbf{(II.42)}$$

$$X_0 = \frac{V_1}{I_m} \quad \textbf{(II.43)}$$

An approximate analogous circuit, known as the secondary, is seen in (Figure II-4) The secondary's total resistance, reactance, and impedance are:

$$\boldsymbol{R_{02} = R_2 + R_1' = R_2 + \frac{R_1}{a^2}} \quad \textbf{(II.44)}$$

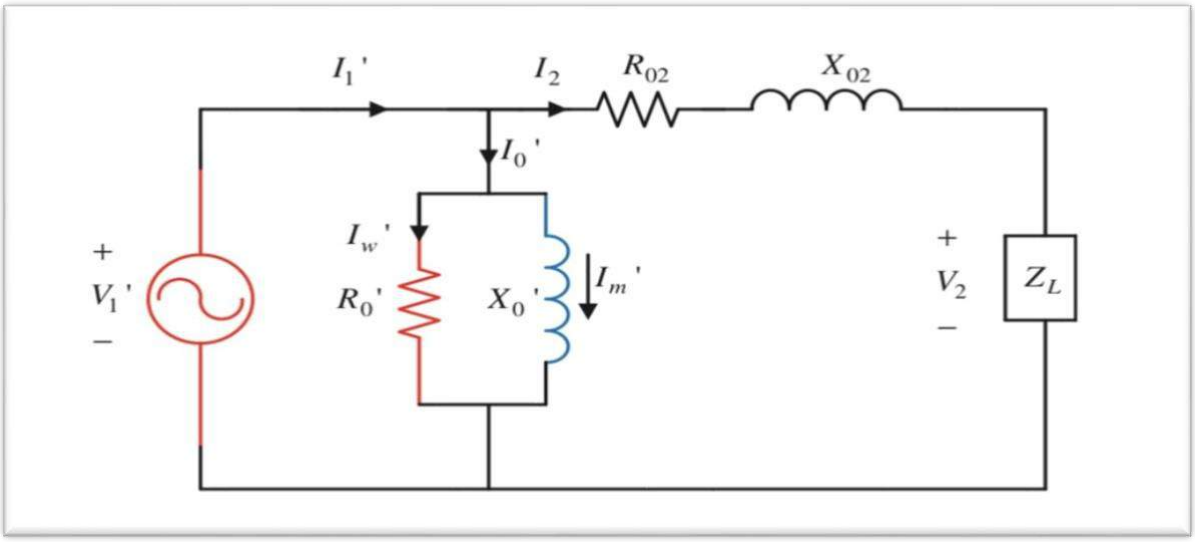


Figure II.4 : Approximate equivalent circuit referred to primary

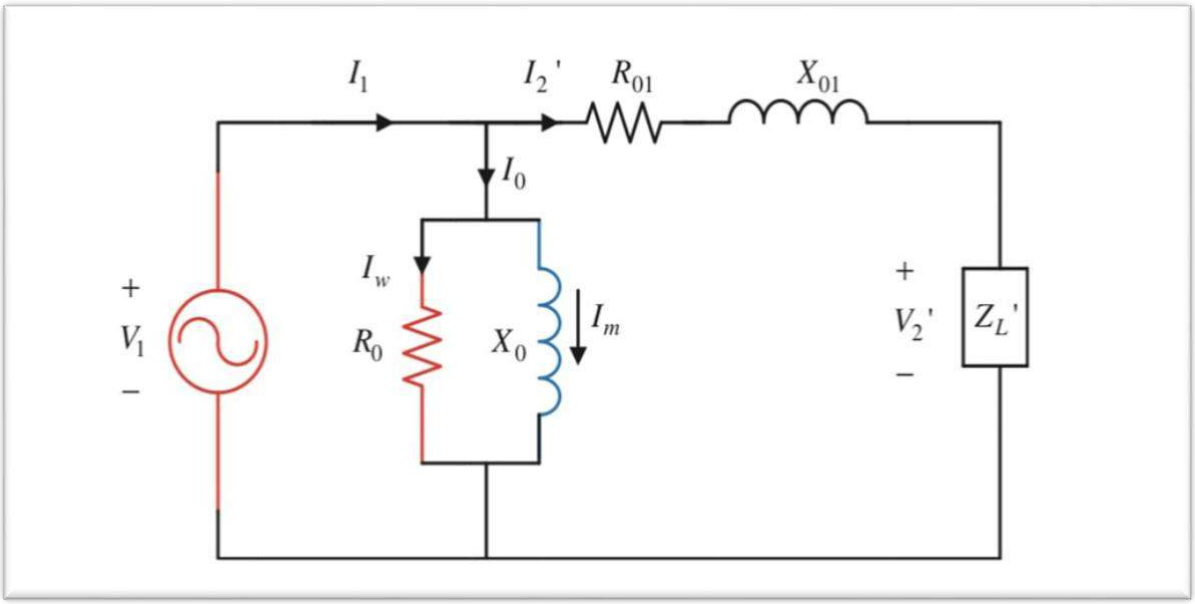


Figure II.5 : Approximate equivalent circuit referred to secondary

$$\boldsymbol{X_{02} = X_2 + X_1' = X_2 + \frac{X_1}{a^2}} \quad \textbf{(II.45)}$$

$$\boldsymbol{Z_{02} = R_{02} + jX_{02}} \quad \textbf{(II.46)}$$

The no-load circuit resistance and reactance and reactance referred to the secondary are

$$\boldsymbol{R_0' = \frac{V_1'}{I_w'}} \quad \textbf{(II.47)}$$

$$\boldsymbol{X_0' = \frac{V_1'}{I_m'}} \quad \textbf{(II.48)}$$

II.5 Test transformers

The parameters of the equivalent circuit for the transformers depicted in figure (II.6) can be determined through these which are listed below [13]

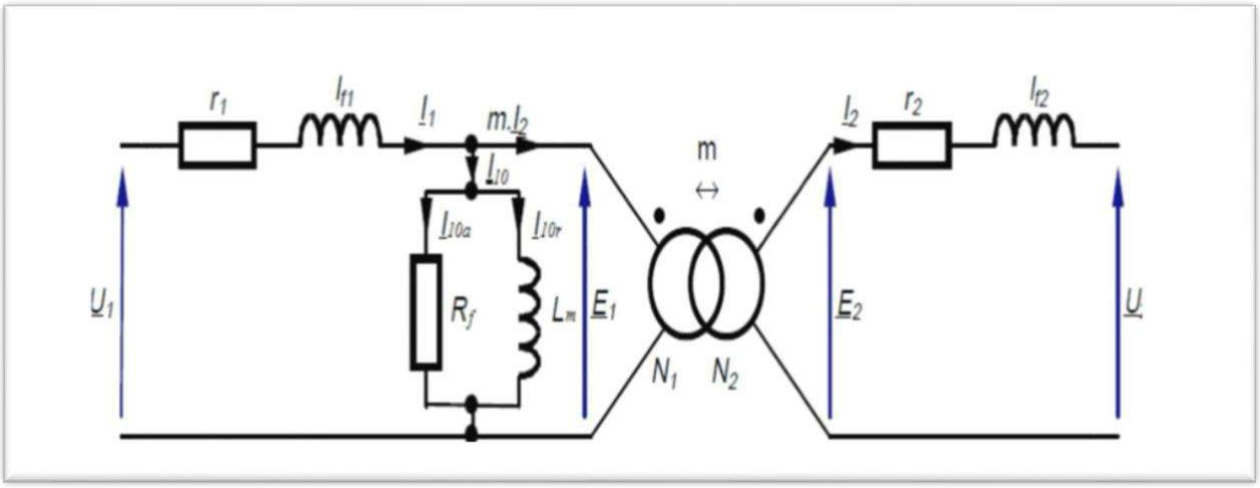
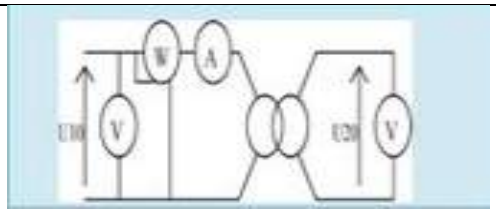
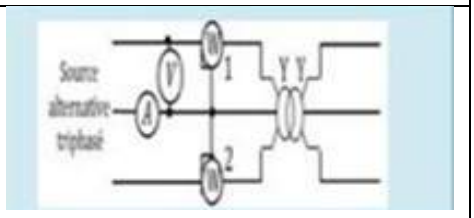


Figure II.6 : Equivalent circuit of transformer on the primary side

II.5.1 No- load tests

In the no-load test,the secondary part is kept under vacuum while the rated voltage is applied . it is possible to determine parameters and iron losses ($I_2 = 0$) by determining current power and voltage .

Table II.1: No- load tests

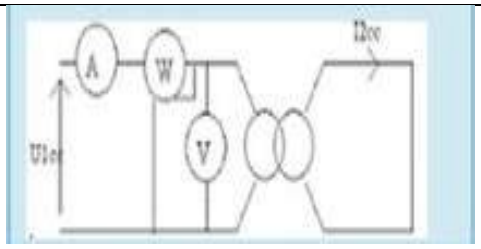
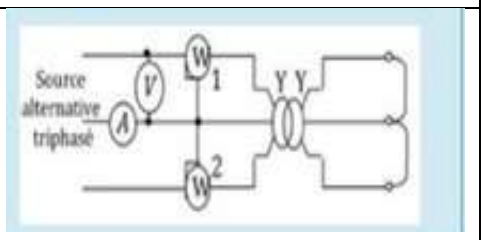
	Single-phase case	**Three-phase case**
Test circuit		
Power factor	$\cos\varphi = \frac{P_0}{V_0 I_0}$	$\cos\varphi = \frac{P_0}{\sqrt{3}V_0 I_0}$
Resistance and shunt	$\frac{1}{R_f} = \frac{I_0}{V_0}\cos\varphi$	$\frac{1}{R_f} = \frac{I_0 - phase}{V_0 - phase}\cos\varphi$
Shunt reactance	$\frac{1}{X_m} = \frac{I_0}{V_0}\cos\varphi$	$\frac{1}{X_m} = \frac{I_0 - phase}{V_0 - phase}\cos\varphi$

II.5.2. Tests for Short Circuits

To find parameters and Joule losses, a short-circuit test is employed, which entails giving the primary winding a lower voltage (minimum value) while maintaining the shorted the secondary

winding. After then, the main voltage is raised until the rated value of the secondary current is reached.

Table II.2 : Tests for Short Circuits

	Single-phase case	**Three-phase case**
Test circuit		
Power factor	$\cos\varphi = \frac{P_{cc}}{V_{cc}I_{cc}}$	$\cos\varphi = \frac{P_{cc}}{\sqrt{3}V_{cc}I_{cc}}$
Equivalent impedance	$Z_{eq} = \frac{V_{cc}}{I_{cc}}\cos\varphi$	$Z_{eq} = \frac{V_{cc}-phase}{I_{cc}-phase}\cos\varphi$ $R_{eq} = \frac{P_{cc}}{3I_{cc}^2}$
Series reactance	$X_{eq} = \frac{V_{cc}}{I_{cc}}\sin\varphi$	$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2}$

By expressing them in terms of the primary or secondary side, the equivalent series parameters can be computed.

II.5.3 Power Balance Sheet

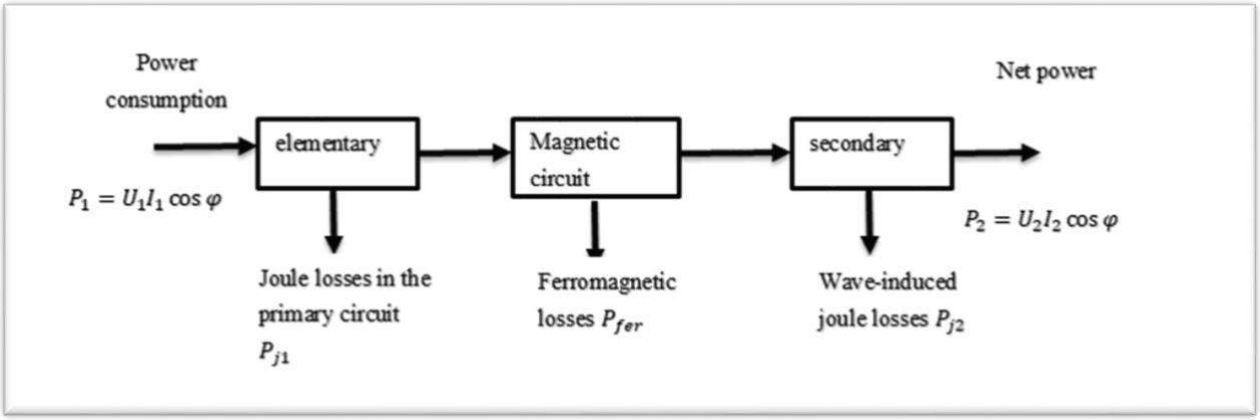


Figure II.7: Balance of power

- Balance of power

$$\boldsymbol{P_1 = P_{j1} + P_{fer} + P_{j2} + P_2} \qquad \textbf{(II.49)}$$

II.5.4. Effectiveness

Transformer efficiency is defined as the ratio of the power drawn by the primary winding to the power supplied by the secondary winding [13] .

$$\eta = \frac{P_2}{P_1} = \frac{\textit{powre supplied by the secondary circuit}}{\textit{primary power}} \quad \textbf{(II.50)}$$

$$\eta = \frac{P_2}{P_1} = \frac{P_2}{P_j + P_{fer} + P_2} \quad \textbf{(II.51)}$$

II.6 ConfiguringConnections

The primary and secondary windings can be connected in a star or delta pattern, just like in any three-phase system. A third alternative is to create a single phase by joining two half-windings, each on a separate corps, in series. The three phases that are thus created are then connected in a star configuration. We refer to this type of connection as a zigzag connection. Three-phase transformer connections are often described using an uppercase letter for the primary and a lowercase letter for the secondary. The following letters are utilized [2]:

- The first letter, which is printed in uppercase, indicates the high-voltage connection. (D: delta, Z: zigzag, Y: star)
- The second letter is printed in lowercase and indicates the low-voltage connection. (d: delta, z: zigzag, y: star)
- If present, the letter "n" denotes the existence of a neutral

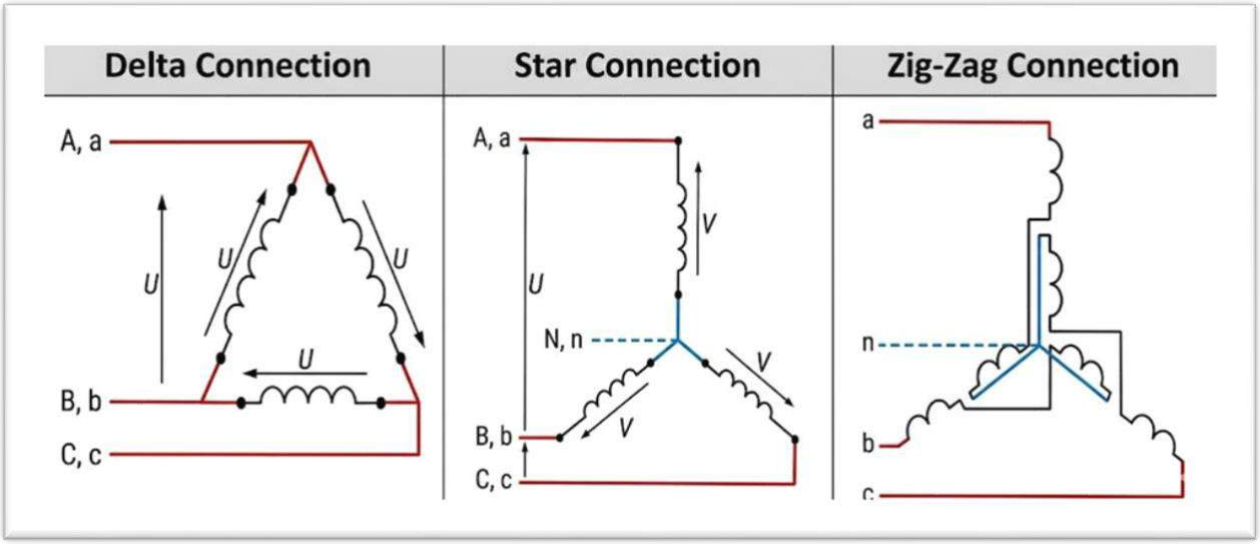


Figure II.7 : Methods for connecting transformer winding

II.6.1 Vector GroupLinkage

The term "vector connection" describes the relationship between a transformer's internal windings, particularly the phase angle difference between the transformer's main and secondary windings. This is a thirty-degree angle. However, why is the angle thirty degrees? The explanation is that the angle between each hour and the next is 30 degrees when a circle is

divided into hours. The maximum angle, 360, can be found by dividing the same circle by the number 12.

Directional groups are classified into four categories based on the angle of displacement, as shown in the following table [3] :

Table II.4 : Polar Group and Phase Angle

Directional Pattern	Angle Measure	Connection Method
Group 1	0°	$Yy_0 - Dd_0 - Dz_0 - Zd_0$
Group 2	180°	$Yy_6 - Dd_6 - Dz_6 - Dz_6$
Group 3	-30°(late)	$Dy_1 - Yd_1 - Yz_1 - Zy_1$
Group 4	+30°(early)	$Dy_{11} - Yd_{11} - Yz_{11} - Zy_{11}$

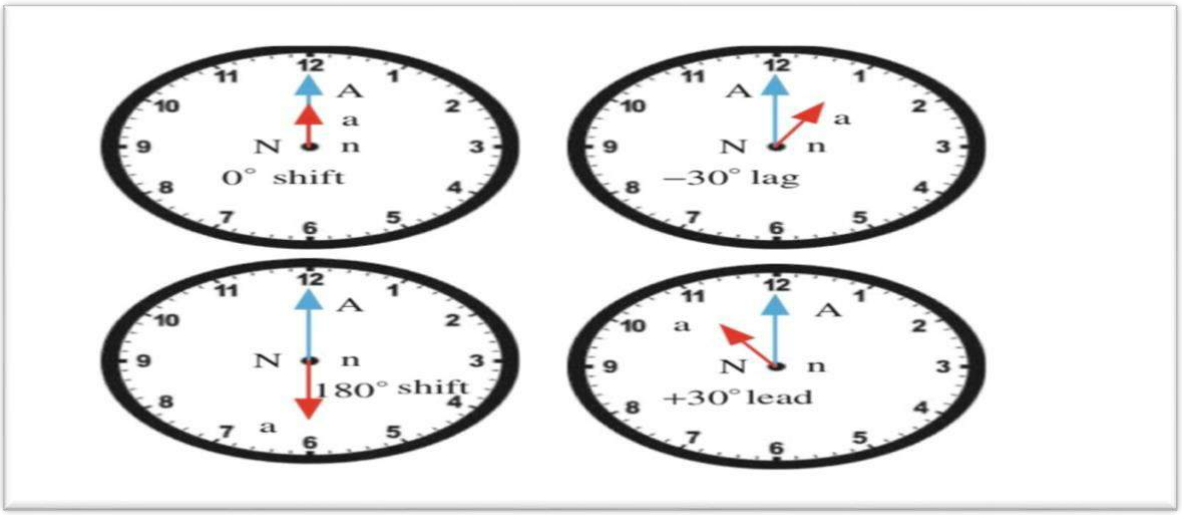
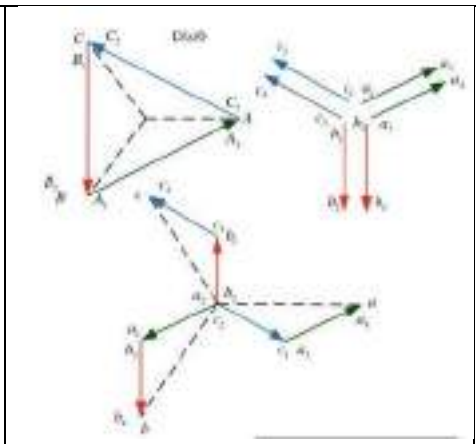
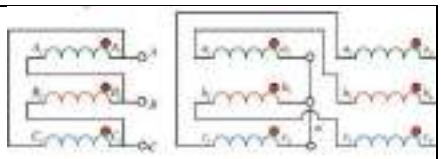
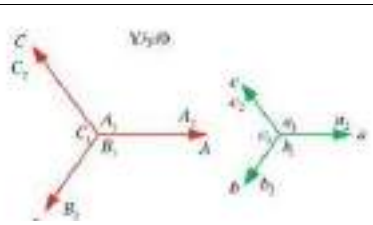
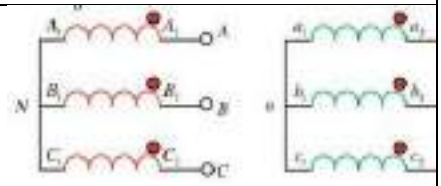
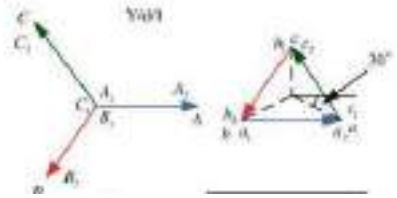
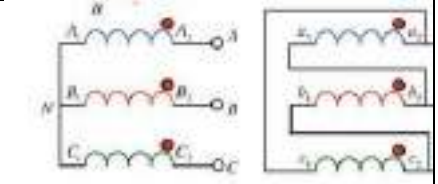
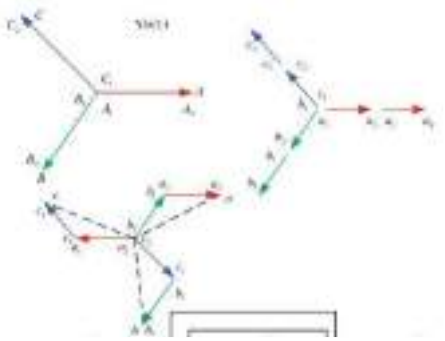
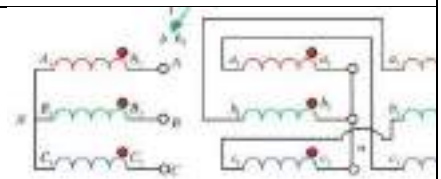
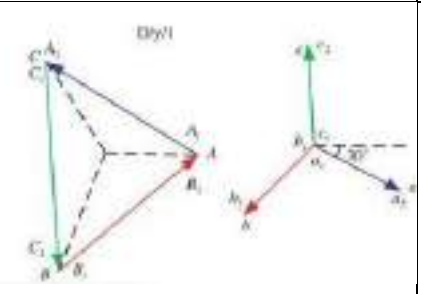
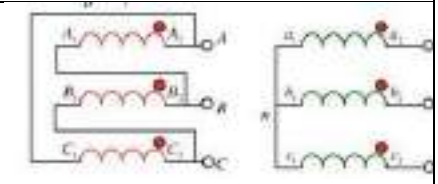


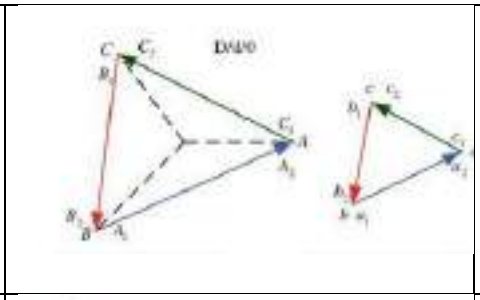
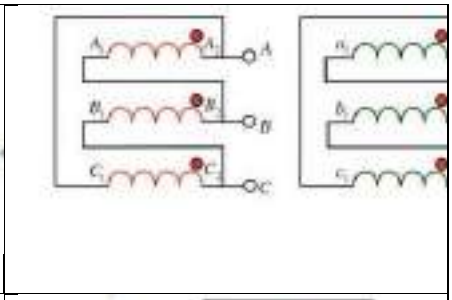
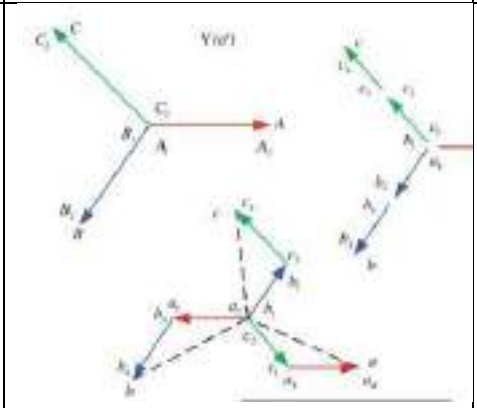
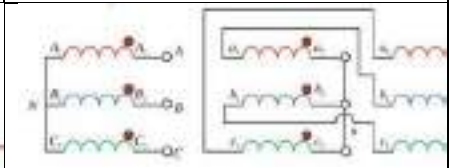
Figure II.8 : Representation of vector groups with the clock

II.6.2 Characteristics of transformer radial coupling groups and their transformation ratios

Table II.5 : Schematic Diagram and Coil Connections for Connection sets

Connection Group	**Conversion Ratio**	**Radial Diagram**	**Engineering Diagram**

Dz0	$\frac{\sqrt{3}N_2}{2N_1}$		
Yy0	$\frac{N_2}{N_1}$		
Yd1	$\frac{N_2}{\sqrt{3}N_1}$		
Yz11	$\frac{\sqrt{3}}{2}\frac{N_2}{N_1}$		
Dy1	$\sqrt{3}\frac{N_2}{N_1}$		

Dd0	$\frac{N_2}{N_1}$		
Zy1	$\frac{2}{\sqrt{3}}\frac{N_2}{N_1}$		

- The Relationship Between Connections in Terms of Current and Voltage

Table II.6 : Relationship Between Connections in Terms of Current and Voltage

Connection type	Line current	Line voltage
Delta_ delta	$I_L \rightarrow \frac{I_L}{n}$	$V_L \rightarrow nV_L$
Star_ delta	$I_L \rightarrow \frac{I_L}{\sqrt{3n}}$	$V_L \rightarrow \sqrt{3}nV_L$
Delta_ Star	$I_L \rightarrow \sqrt{3}\frac{I_L}{n}$	$V_L \rightarrow \frac{nV_L}{\sqrt{3}}$
Star_ Star	$I_L \rightarrow \frac{I_L}{n}$	$V_L \rightarrow nV_L$

- The relationship between line current, phase current, and voltage

Table II.7 : Relationship between line current, phase current, and voltage

Connection	phase voltage	Line voltage	phase current	Line current

Star	$V_P = V_L \div \sqrt{3}$	$V_L = \sqrt{3} \times V_P$	$I_P = I_L$	$I_L = I_P$
Delta	$V_P = V_L$	$V_L = V_P$	$I_P = I_L \div \sqrt{3}$	$I_L = \sqrt{3} \times I_P$

II.7 Capacity in Electrical Transformers

Transformers are electromagnetic devices that transfer energy. During this process, three types of capacity emerge that reflect the efficiency and operating characteristics of the transformer. These can be summarized in the following table [4] :

Table II.8 : The types Capacity in Electrical Transformers

	Symbol	equation	Unit of measurement
Apparent power	S	S=V.I	KVA
Active power	P	P=V.I.	KW
Reactive power	Q	Q=V.I	KVAR

II.8 Data sheet for a three-phase transformer

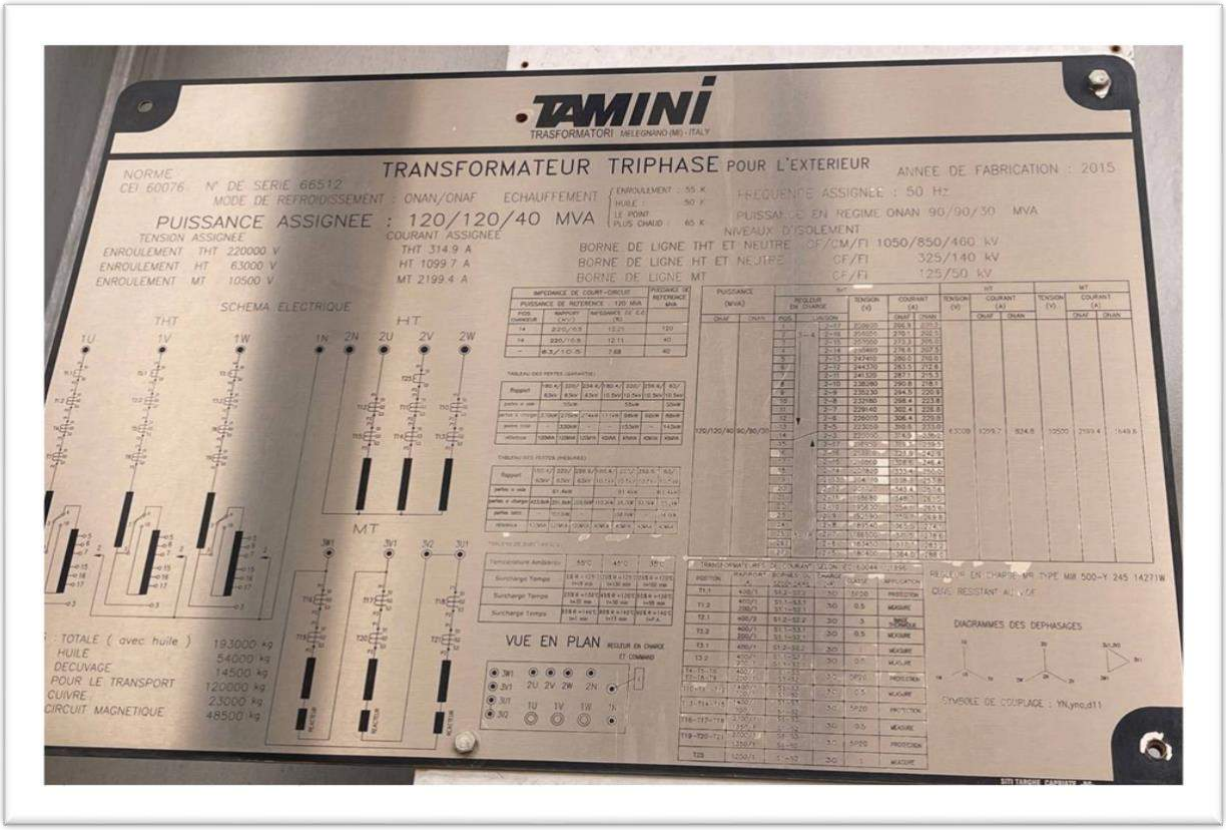


Figure II.9 : Technical Data Sheet for the 220 kV Power Transformer

(SONELGAZ Ouargla)

Manufacturer : TAMINI

Transformer type : three-phase outdoor

Year of manufacture : 2015

Approved standard : CET60076

Serial number : 66512

Table II.8 : Nominal data from the nameplate

Technical parameter	Value	Unit
Rated power	120/120/40MVA	MVA
Voltage	220/63/10.5KV	KV
Rated current	314.9/1099.7/2199.4A	A
Frequency	50HZ	HZ

Cooling system	ONAN/ONAF	-
Connection type	YN,yn0,d11	-
Insulation levels	1050/850/460KV 325/140KV 125/50KV	KV
Gross weight	193000 Kg	Kg

II.9 Conclusion

This section examines the various laws and mathematical relationships pertaining to electrical transformers, as well as the analysis of equivalent circuits and the fundamental calculations that explain transformer performance under various operating conditions. This theoretical and mathematical knowledge forms the foundation for moving on to the practical phase of the project, where the third section will involve the design and implementation of a smart system for monitoring using artificial intelligence and the Internet of Things, along with an explanation of how the system works.

Chapter Three

Applied design and integration of AI and IOT technologies

III.1 Introduction :

This section focuses on the practical application of the project by designing and implementing a smart system for monitoring voltage transformers using the Internet of Things (IoT) and artificial intelligence after going over the theoretical aspects of electrical transformers and talking about the fundamental calculations and laws associated with them. This section's goal is to create a system that can use a variety of sensors, including temperature, humidity, current, voltage, oil level, and vibration sensors, to gather transformer data in real time. The data will then be sent to a cloud platform for analysis and presentation via a control panel. Additionally, it uses artificial intelligence methods to anticipate issues before they happen.

III.2 The Role of the Internet of Things and Artificial Intelligence in Electrical Transformers

III.2.1 Artificial intelligence

In the real world, artificial intelligence is a broad area with several axes and different meanings based on the perspective taken.

- Artificial intelligence is a collection of methods used to create machines that can carry out particular activities and address human issues.
- The science of artificial intelligence (AI) aims to use human intelligence to enable a computer to carry out tasks.
- Research on human intellectual activity for which there is no established methodology
- Information processing is the focus of computer science; artificial intelligence (AI) is interested in any situation where this processing cannot be reduced to a straightforward, exact, or algorithmic approach.

« The capacity that humans have given robots to think, create, talk, judge, and make decisions, as well as to memorize and learn through experience »[18]

- Machine learning and deep learning are the two main ways that an Al system "develops" to do complete a job when it comes to its construction.

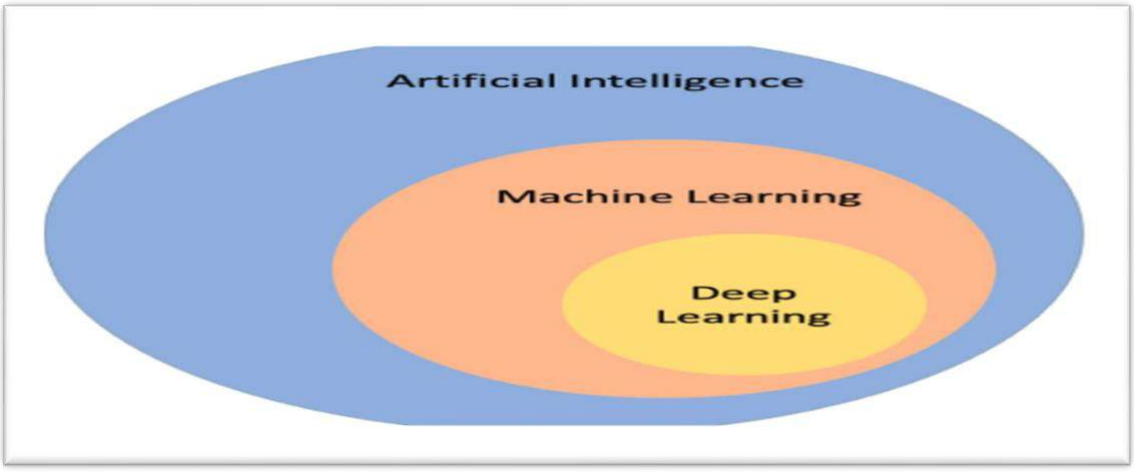


Figure III.1 : The Interconnected Relationship Between Artificial Intelligence Machine Learning And Deep Learning

Deep Learning (DL) : is an advanced subset of Machine Learning that employs intricate processes modeled after the human brain, known as Artificial Neural Networks (ANN).

This "Introduction to AI" study does not cover how neutral networks operate, nor deep learning systems, can do exceptionally well at challenging jobs like creating original artwork and finding new medications.

Machine Learning: When handed more and/or better training data, machine learning (ML) systems may learn from massive volumes of data and gradually improve their performance. AI systems driven by machine learning use this "knowledge" acquired from training data, can then identify patterns in data (for example, picture and speech recognition) or generate predictions (for example, weather forecasting) .[19]

III.2.1.1 AI and other disciplines

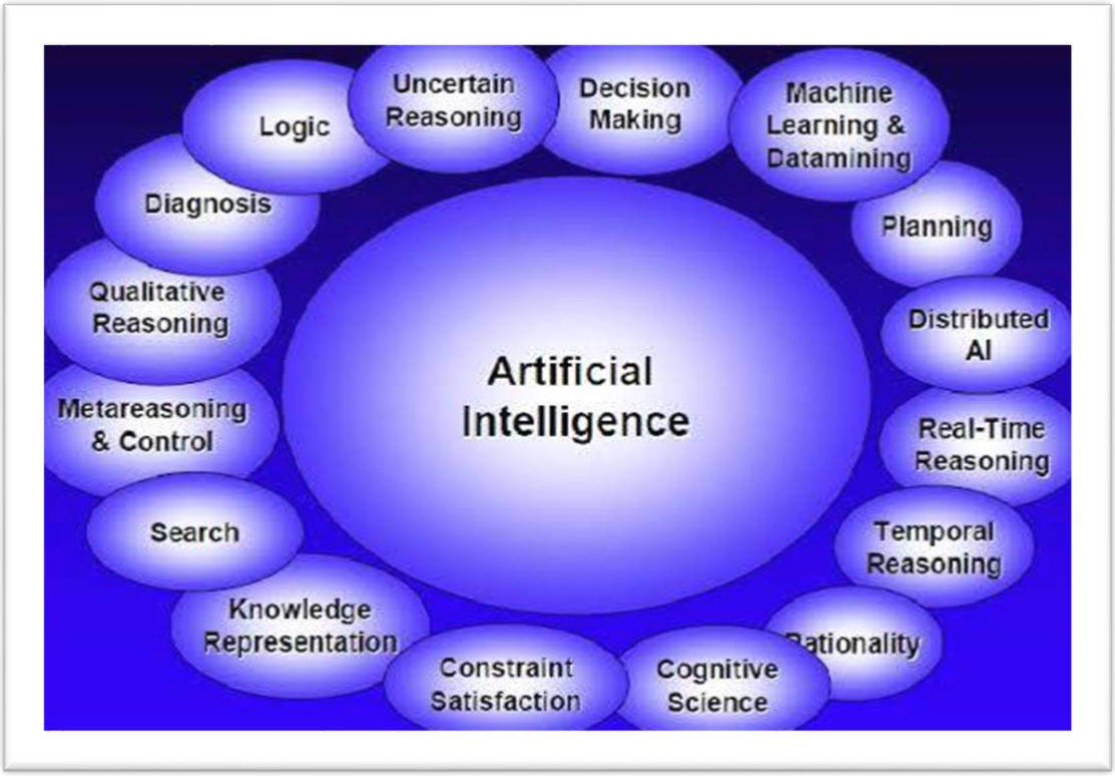


Figure III.2 : AI and other disciplines

III.2.1.2 Applications of AI

- Algorithmic

  -Writing and demonstrating algorithms
- The theory of complexity

  -The complexity of the issues
- Vision in computers
- -Identifying irregularities (fraud)
- -Shape recognition (picture, object, etc.)

- Reasoning

  -Predicate logic and propositional logic

  -Other reasoning (not monotonic, by default, etc.)

- Databases

  -Acquiring knowledge

  -Mining data

- Natural language

  -Automated examination of semantics

  -Translation by machine

  -Voice recognition

- Robotics

  Task Scheduling**[18]**

III.2.1.3 The role of artificial intelligence in electrical transformers



- Cut down on malfunctions and outages by identifying and fixing problems early to maintain service.
- Predictive maintenance: Use ongoing data analysis to foresee problems before they arise
- Increase transformer longevity: By lowering electrical and thermal stress, smart monitoring helps increase transformer lifespan.
- Boost operational efficiency: Transformer efficiency rises as a result of data analysis
- High-precision data analysis: Use artificial intelligence to process data and find subtle, hard-to-find patterns.
- Remote monitoring: Real-time monitoring improves response times and saves time and effort
- Lower operational expenses: When performance is improved and outages and emergency repairs are decreased, operating and maintenance costs are significantly lowered.
- Quick and astute decision-making, such as removing or shifting the load to safeguard the transformer

III.2.2 Internet of Things

However, it wasn't limited to PCs using the Internet. Simple computing and networking capabilities were among the many other kinds of gadgets that started. The phrase "Internet of Things" was first used in the early 2000s to refer to the increasing number of Internet-connected devices and their applications. The phrase was officially recognised by the International Telecommunication Union (ITU) in 2005. The ITU describes the IoT as a "consisting of smart objects that connect to the Internet and communicate with each other with minimal or no human intervention." These items often connect through a gateway to an Internet of Things platform, which is made up of services and software tools that gather data from sensors, controllers, and other devices.

Connecting a wide range of objects to the Internet, including sensors, hands-free controllers, and remote monitoring devices, is what the Internet of Things is all about these days. Cisco claims that we have already surpassed the threshold at which there are significantly more

"things" or objects linked to the Internet than people; in truth, this goal was reached more than ten years ago.

The situation is summarised in Figure III.3 The platform links IoT hardware to network applications that process and store data at the Sense & Connect Layer. The Platform Layer, which is in the center, is where the data is processed, analysed, stored, and secured. It links to end-user apps at the End-User Layer, where they monitor and analyse data from IoT devices and transmit commands to the devices.[20]

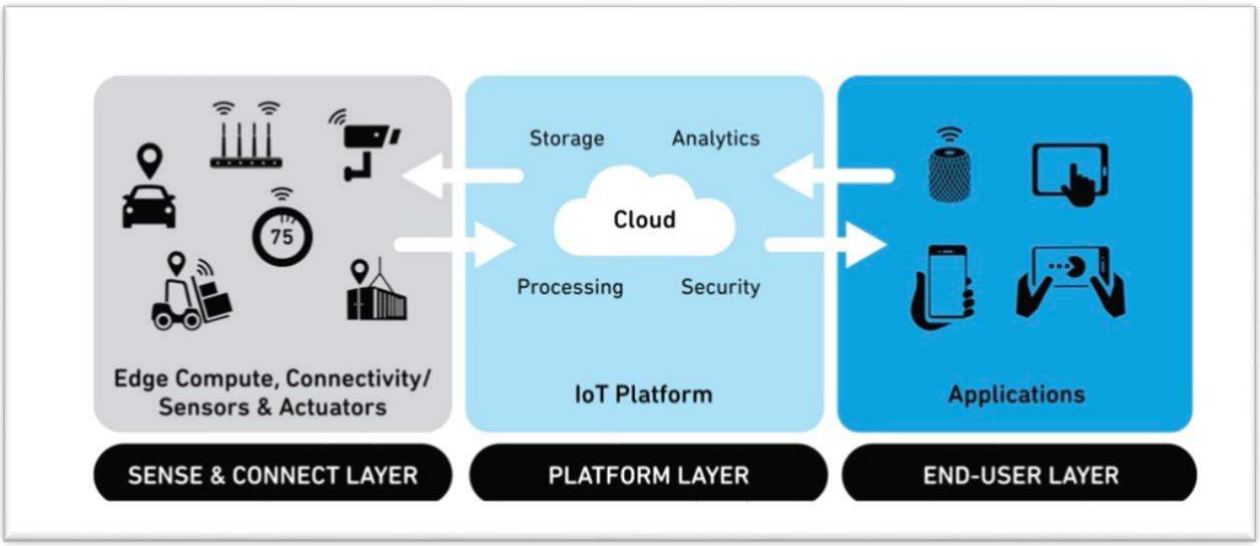
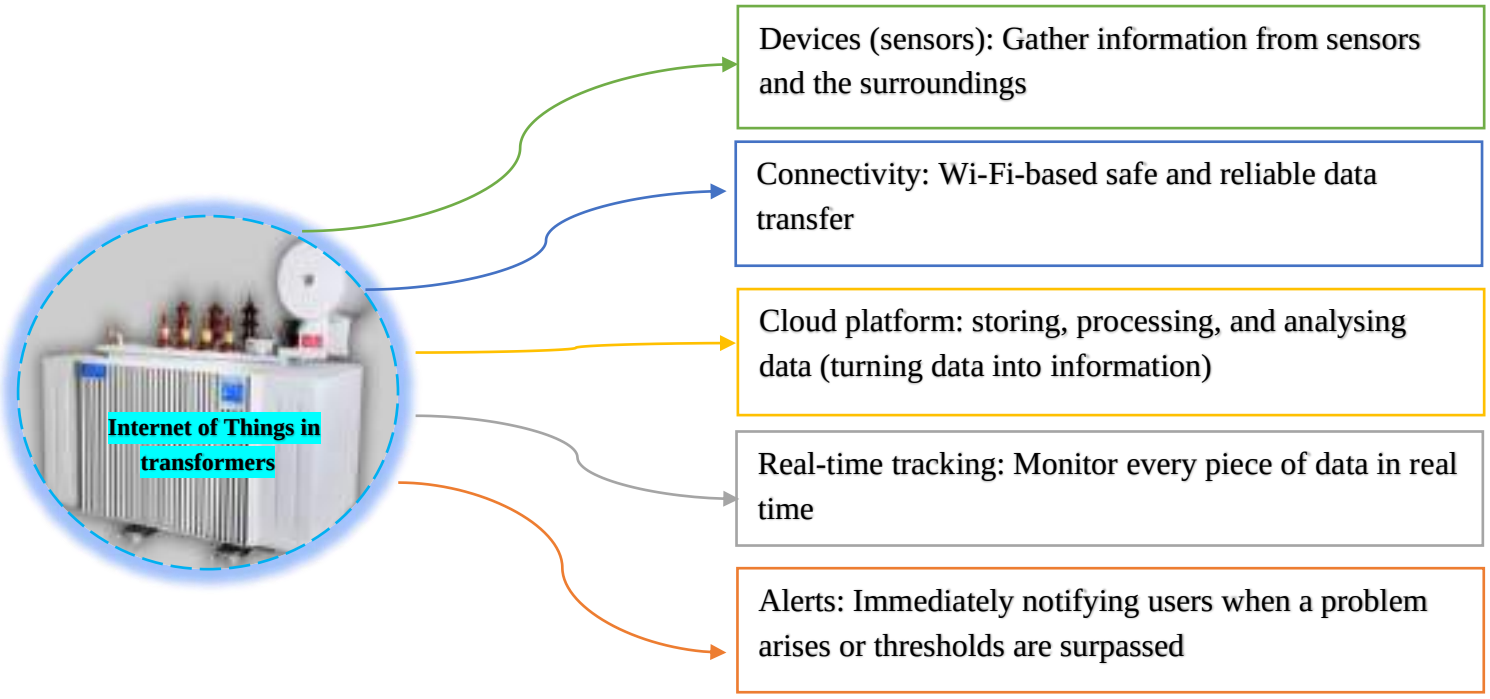


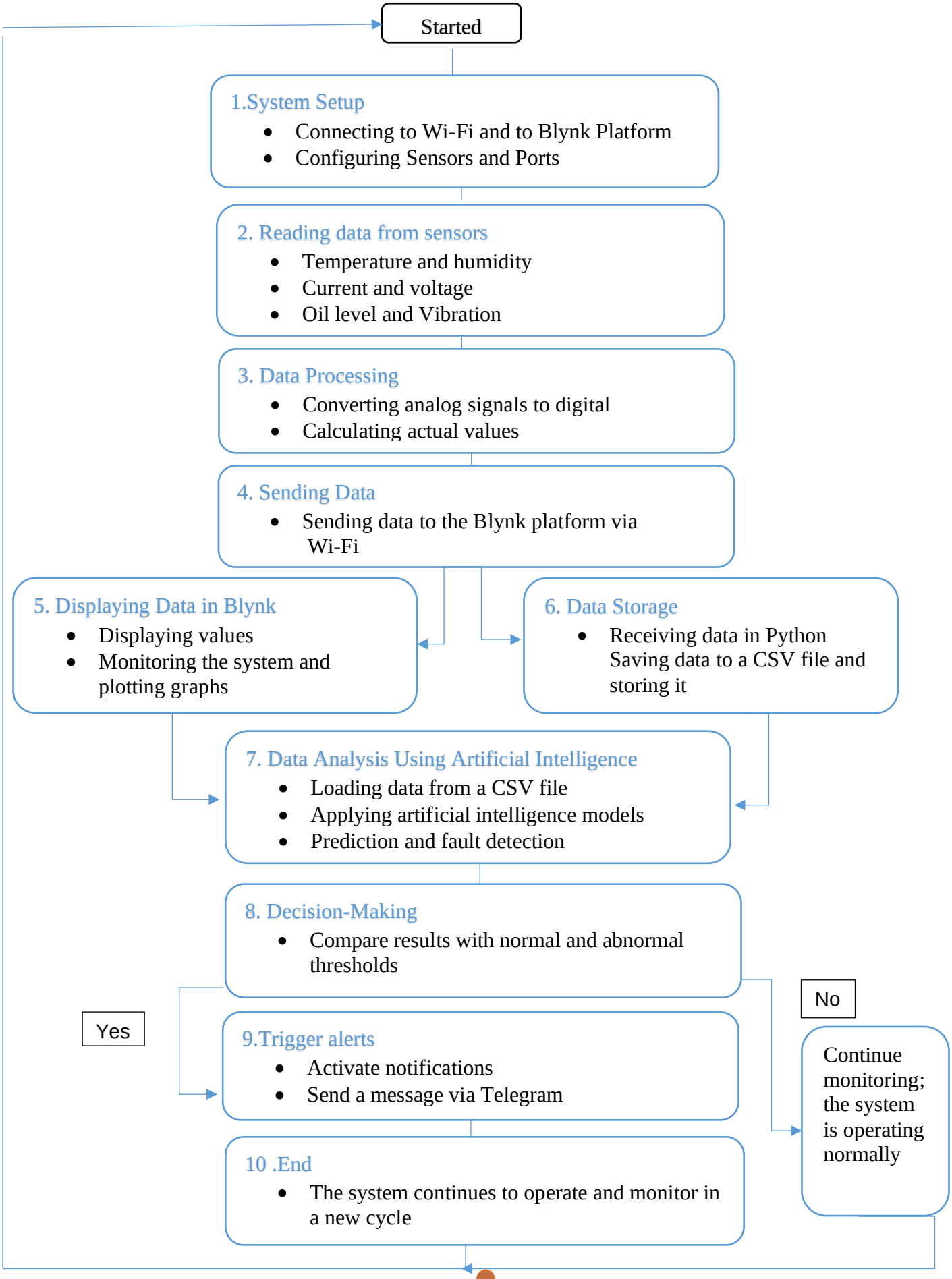
Figure III.3 : The layers of the IOT

III.2.2.1.The role of Internet of Things in electrical transformers



III.3 Phases of Project Implementation (Desing of a voltage Transformer Monitoring System Using AI and IOT)

III.3.1 Flowchart of system operations


Started
1.System Setup
Connecting to Wi-Fi and to Blynk Platform
Configuring Sensors and Ports
2. Reading data from sensors
Temperature and humidity
Current and voltage
Oil level and Vibration
3. Data Processing
Converting analog signals to digital
Calculating actual values
4. Sending Data
Sending data to the Blynk platform via Wi-Fi
5. Displaying Data in Blynk
Displaying values
Monitoring the system and plotting graphs
6. Data Storage
Receiving data in Python
Saving data to a CSV file and storing it
7. Data Analysis Using Artificial Intelligence
Loading data from a CSV file
Applying artificial intelligence models
Prediction and fault detection
8. Decision-Making
Compare results with normal and abnormal thresholds
Yes
No
9.Trigger alerts
Activate notifications
Send a message via Telegram
Continue monitoring; the system is operating normally
10 .End
The system continues to operate and monitor in a new cycle

III.3.2 The system's electrical circuit

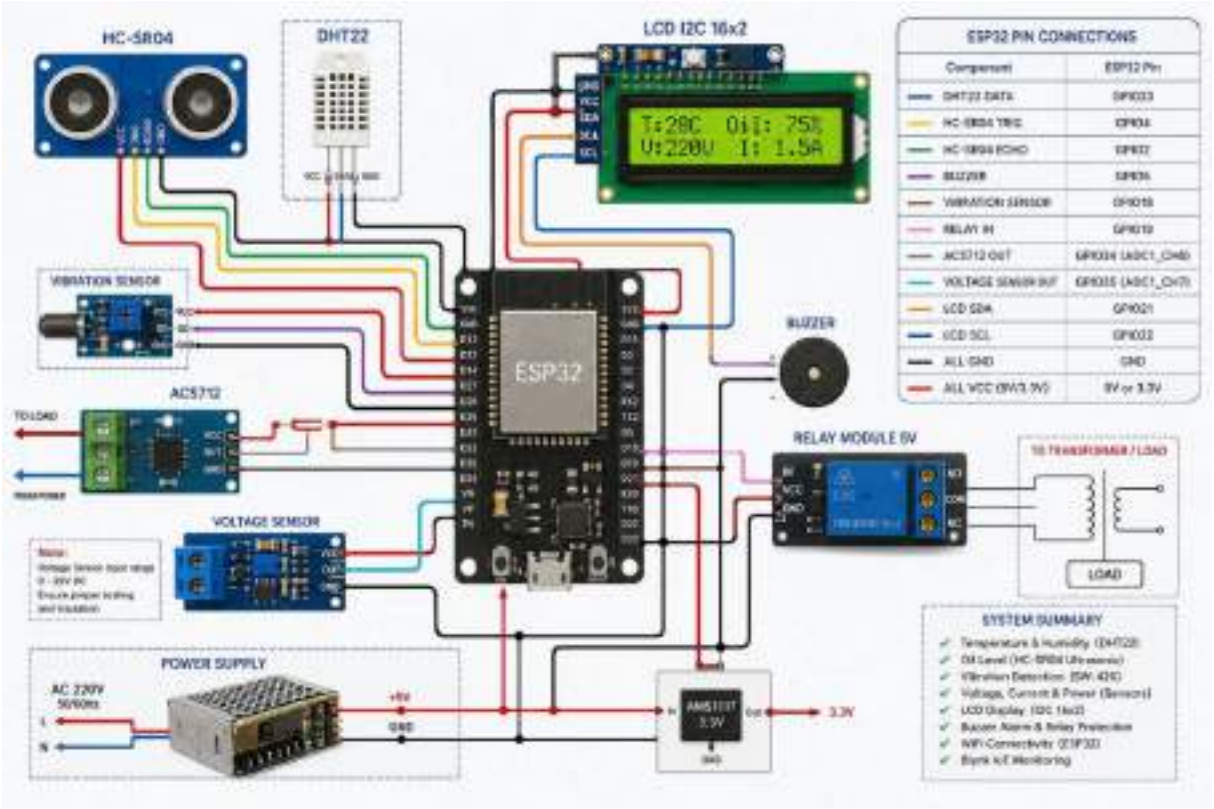


Figure III.4 : System's electrical circuit

III.3.3 General System Architecture

Initially, a smart system utilising artificial intelligence (AI) and the Internet of Things (IoT) was created to monitor electrical transformers. To gather information on the transformer's condition, the system uses a number of sensors that are linked to an ESP32 controller. The system measures a number of important variables, such as:

- Temperature
- Humidity
- The voltage
- Current
- The vibration
- The amount of oil

Following collection, the data is sent to the Blynk IoT platform over Wi-Fi for monitoring and presentation in real time.

Table III.1 : Materials used for the project

Number	Component Name	Electronic component	Functional
1	ESP 32		Collects data from all sensors, processes information, executes monitoring algorithms, and manages communication with external modules.
2	ACS712		Measures the current flowing through the transformer circuit and sends an analog signal to the microcontroller
3	Voltage Sensor Module		Continuously monitors the transformer's operating voltage
4	DHT22		Monitors the temperature and humidity surrounding the transformer.

5	AJ-SR04M		Detects transformer oil level and identifies low-oil or leakage conditions.
6	SW-420 Vibration swith Module		Monitors unusual vibrations caused by transformer operation or internal faults.
7	Buzzer		Audio alert if a blockage is detected
8	Connecting Wires		Transfer power and signals between sensors, the microcontroller, and the communication module
9	Breadboard		Assembling and wiring
10	LCD 16*2		View results

11	Relay		Turn off the power to the transformer otherwise , the alarm will continue
12	Power Transforme r		POWER TRANSFORME R INPUT : AC220-240V 50HA OUTPUT : AC 10.5V/550MA

III.3.4 Component Connection

The following pin assignments were used to link the sensors to the ESP32 controller:

Table III.2 : Component Connection

Component	VCC	GND	GPIO
DHT22	3.3V	GND	GPIO 23
SW-420	3.3V	GND	GPIO 19
Voltagr sensor	5V	GND	GPIO 34
ACS712	5V	GND	GPIO 35
AJ-SR04M	5V	GND	TRIG GPIO 33 ECHO GPIO 32
Buzzer	3.3V	GND	GPIO 25
LCD	5V	GND	SDA GPTO 21 SCL GPIO 22
Relay	GPIO 26	GND	-

III.3.5 ESP32 Controller Programming

The Arduino IDE was used to program the ESP32 controller, and the program carries out

the following functions:

Examining sensor data

- Electrical power calculation (The following formula was used to determine electrical power: P=V.I)
- Recognising risky circumstances
- Data transmission to the Blynk platform
- Turning on the buzzer when a threat is identified
- Send a messages to Telegram

III.3.6 Configuring the Blynk system

On the Blynk IoT platform, a project was developed to :

- Show sensor information
- Create graphs in real time
- Send notifications
- Remotely check the switch's condition

Additionally, each sensor in the app was given a virtual pin.

Table III.3 : Port Distribution in Blynk

Virtual Pin	Sensor / Data Type
V1	Temperature
V2	Humidity
V3	Voltage
V4	Oil level
V5	Power
V6	Current
V7	Vibration state
V8	Alarm

- System interface via the Blynk app on your phon

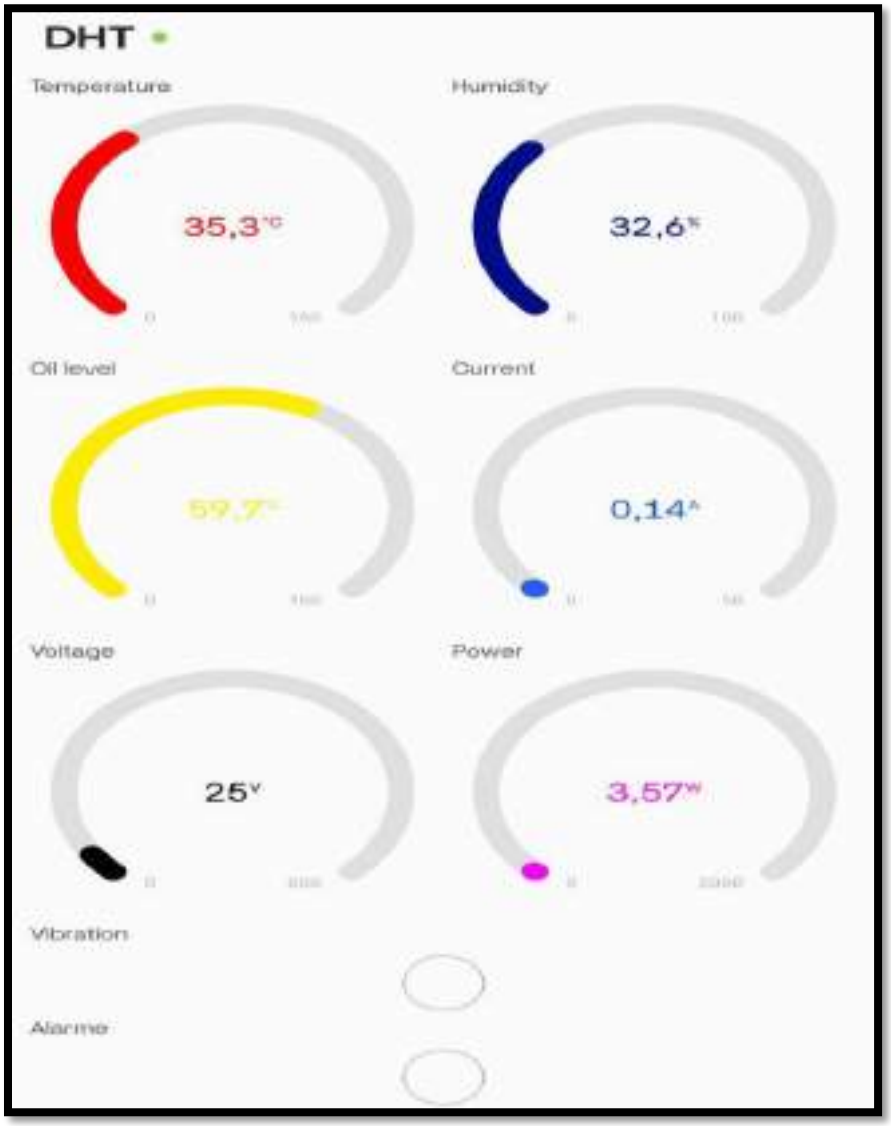


Figure III.5 : The phone ‘s user interface

III.3.7 Keeping Information in a CSV File

Sensor data was saved using Python in a CSV file that is periodically updated with data from the Blynk platform.The following are possible with the CSV file:

- Preserving past information
- Examining the performance of the system
- AI model training
- Forecasting failures

III.3.8.Artificial Intelligence-Based Fault prediction

III.3.8.1.Data collection

Data is collected continuously by the proposed monitoring system from a number of

sensors mounted on the transformer prototype.

The parameters gathered are:

- Temperature and Humidity
- Voltage
- Current
- Oil Level
- Vibration
- Power

These metrics are sent by the ESP32 via the Blynk platform. For additional research and model training, the gathered data is subsequently saved in CSV files.

III.3.8.2 Data Preprocessing

To increase prediction accuracy, the gathered data is preprocessed before the machine learning model is trained.

Among the preprocessing procedures are:

- Elimination of missing values.
- Removal of erroneous measurements.
- Data transformation into numerical values.
- The dataset is divided into input and output variables.

This step guarantees that the model gets accurate and clean data.

III.3.8.3 Variables of Input and Output

The following input features are employed in training:

- The temperature
- Humidity
- The voltage
- Current
- Vibration Power and Oil Level

The transformer's operational condition is represented by the output variable:

- State of normalcy (0)
- State of fault (1)

III.3.8.4 The Random Forest Method

For this investigation, the Random Forest algorithm was used since it offers:

- High accuracy in classification.
- Excellent results with tiny datasets.
- Resistance to measurement mistakes and noise.
- The ability to manage several input variables at once.

Python's Scikit-learn module was used to implement the model.

III.3.8.5 Training Models

Two subsets of the dataset were created:

Set of training (80%)

20% of the testing set

One hundred decision trees were used to train the Random Forest classifier:

RandomForestClassifier(n_estimators=100)

The model discovered the connection between transformer operating parameters and fault conditions following the training phase.

III.3.8.6 Model Evaluation

Classification measures like these were used to assess the model's performance:

- Accuracy
- Precision
- Recall the F1-score

The model's capacity to differentiate between typical and anomalous operating situations can be evaluated thanks to these indicators.

III.3.8.7 Model Saving

Following training, the model was stored in a file called:

- transformer_model.pkl

This makes it possible to predict faults in real time using the learned model without having to go through the training procedure again.

III.3.8.8 Forecasting in Real Time

New measurements obtained by the sensors are sent to the trained model while the system is operating.

After analysing these observations, the model forecasts the transformer's operational condition.

The system takes the following measures if it detects abnormal conditions:

- The buzzer is activated.
- Warning notifications are displayed.
- Notifying Telegram users.
- Blynk dashboard update.

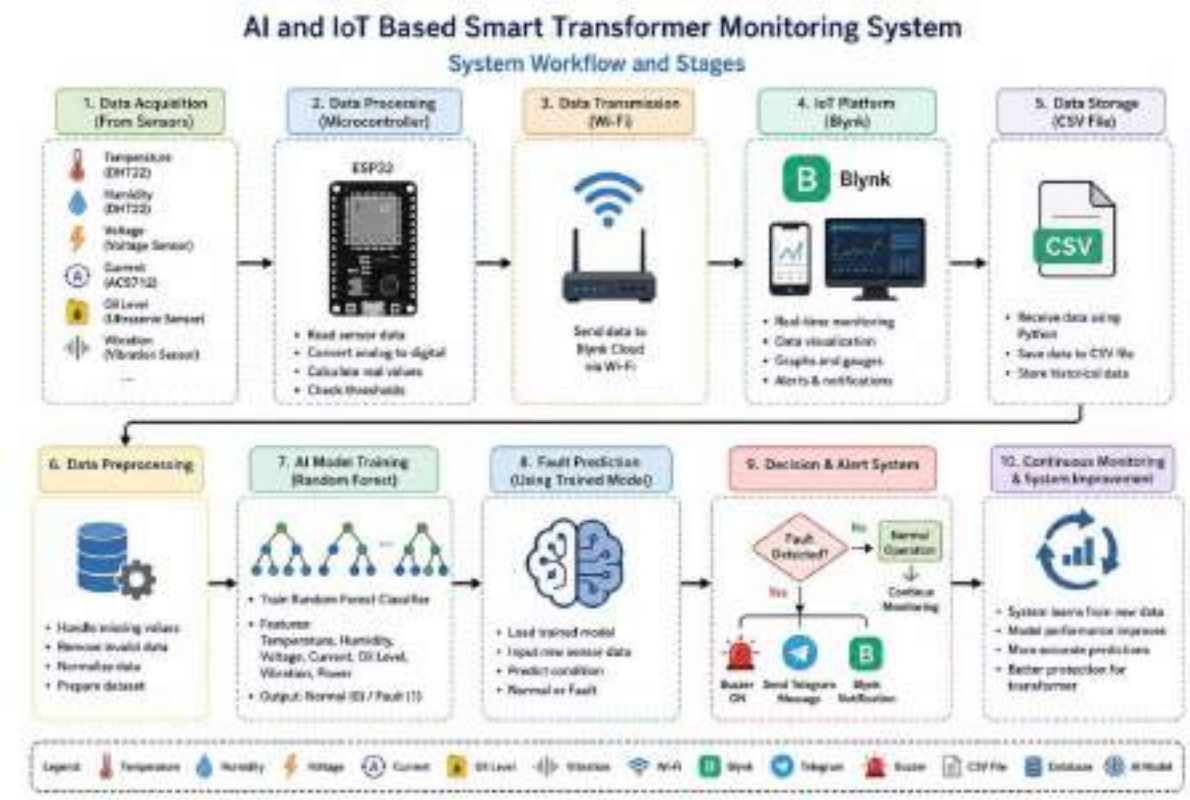


Figure III.6 : AI and IOT Based smart Transformer Monitoring System

III.4 Alarm System

III.4.1 Principle of Operation

The alarm system keeps an eye on the data that the sensors are measuring.

The system determines that the transformer is operating abnormally when one or more parameters surpass the established safety limits.

There are two ways to set off the alarm:

- Values of the threshold.
- prediction using artificial intelligence.

III.4.2 Alarm Conditions

The following circumstances cause the alert to sound:

- Elevated temperature.
- Too much current.
- Unusual vibration.

- Low level of oil.
- Anomalies in voltage.
- The AI model predicts faults.

III.4.3 Alarm Actions

The system does the following when it detects a fault:

- The buzzer is activated.
- The relay is turned on.
- Warning notifications are displayed on Blynk.
- Notifying Telegram users.
- Notifying the operator.

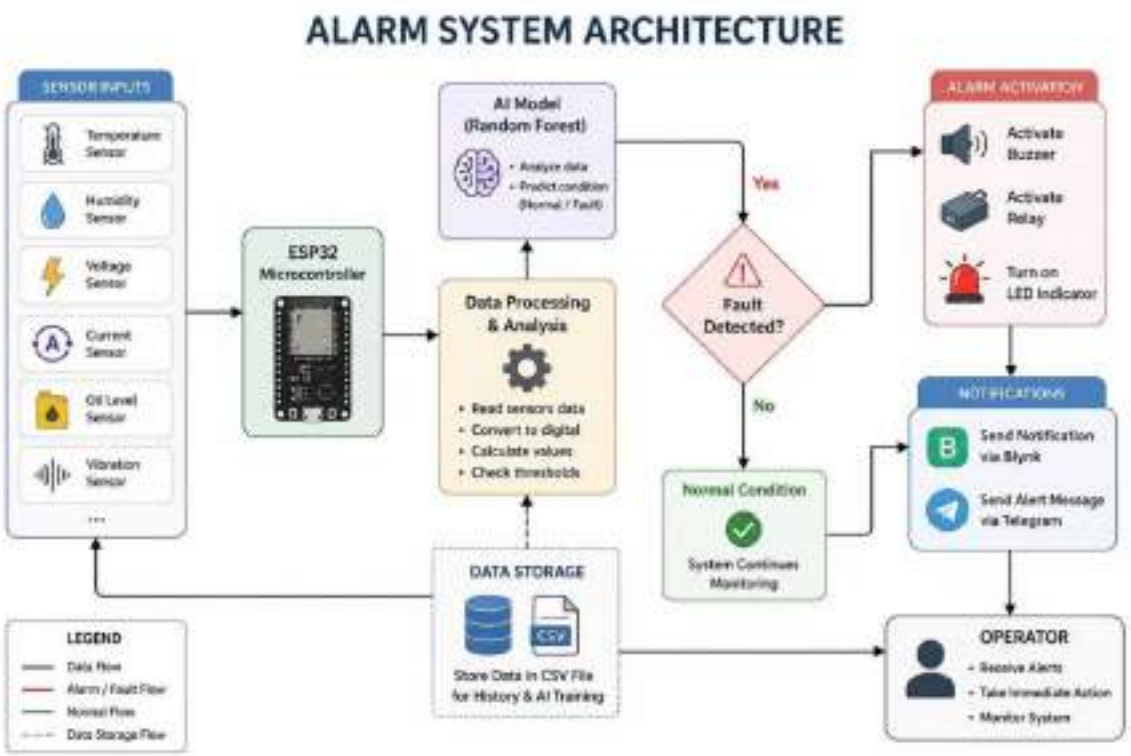


Figure III.7 : Alarm system Architecture

III.5 Project Results

- ✓ Transformer monitoring system in Serial monitor (Arduino IDE in C++)

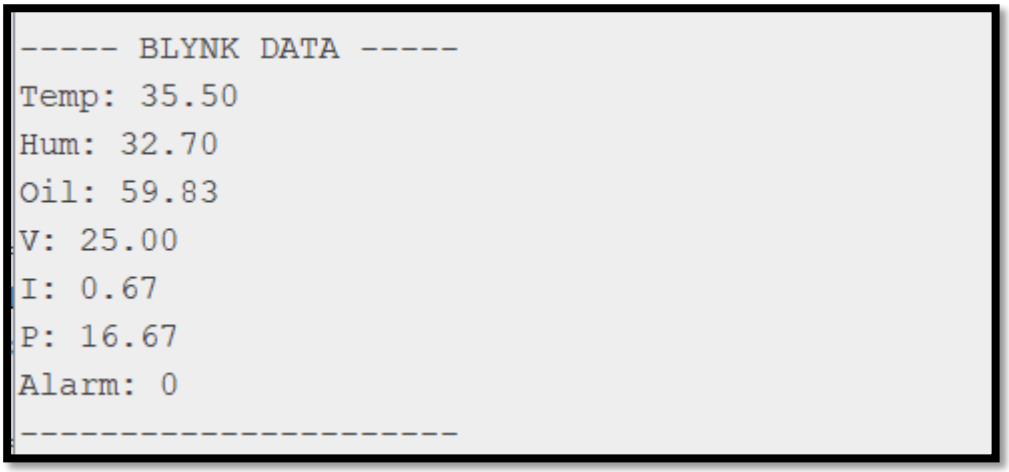


Figure III.8: Transformer monitoring system in Serial monitor

- ✓ Setting up an IOT system to retrieve data feom Blynk

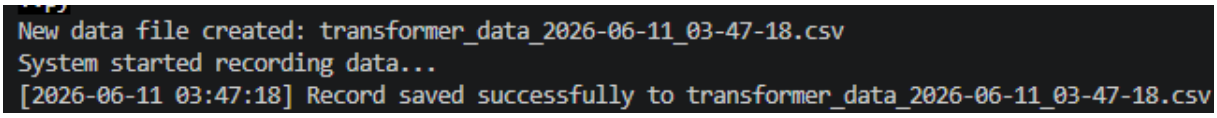
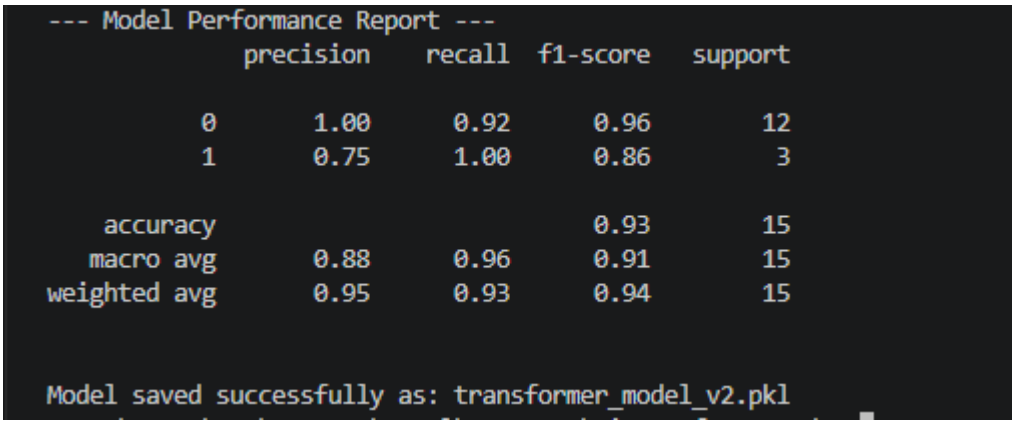


Figure III.9: Result of retrieving data from Blynk

- ✓ Model training and accuracy



Firure III.10 : Training resulta and model accuracy

- ✓ User interface for predictive analytics (random forest) and sending Telegram alerts .



Figure III.11 : Automatic fault detdction and smart transformer monitoring



Figure III.12 : The Telegram mobile app inerface now displays real-time and critical alerts for the converter

- System Control and Monitoring Dashboad

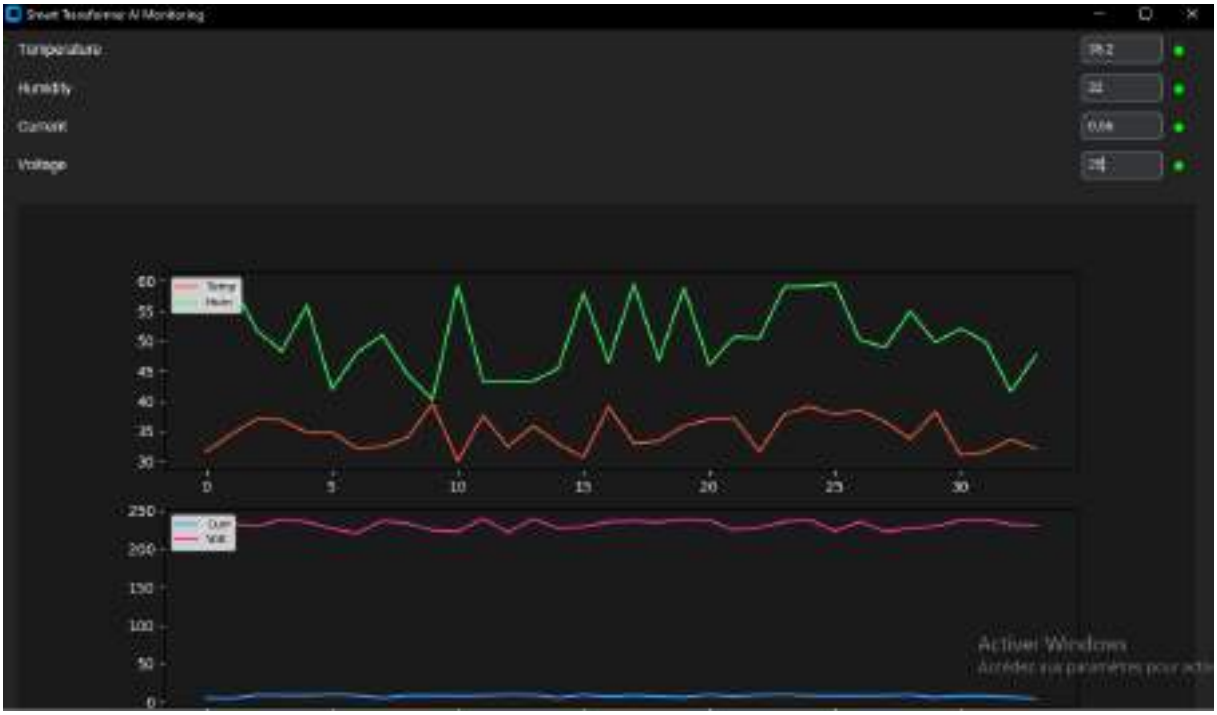


Figure III.13 : Dashboard



Figure III.14 : Final rendering of the project

III.6 Conclusion

This section describes the architecture of a smart system that uses artificial intelligence (AI) and the Internet of Things (IoT) to monitor electrical transformers. The system makes it possible to monitor the transformer's status in real time and gather a variety of crucial operational condition data. Additionally, the process of data analysis and abrupt failure prediction showed how well the suggested system works to provide precise and intelligent electrical transformer monitoring, which lowers maintenance costs and increases operational efficiency. In order to stay up with technical improvements, this initiative is seen as a significant step toward creating smart electrical systems based on contemporary technologies.

Conclusion

General Conclusion

This dissertation tackled a major challenge in contemporary electrical power systems: guaranteeing the dependable functioning and ongoing surveillance of electrical transformers. Transformers, as essential components in transmission and distribution networks, need diligent oversight to avoid unforeseen breakdowns, minimize maintenance expenses, and ensure continuous power delivery.

The project started with an in-depth theoretical exploration of transformer technology, encompassing operational principles, design, classifications, insulation systems, and cooling techniques. This study offered a robust insight into transformer operation and underscored the essential factors that affect performance, efficiency, and service life.

Thereafter, mathematical models and analytical techniques were examined to assess transformer performance across different operating conditions. The examination of equivalent circuits, electrical laws, losses, efficiency, and voltage regulation revealed a significant connection between operating conditions and transformer reliability. These analyses highlighted the significance of ongoing condition monitoring to identify unusual circumstances before they escalate into major failures.

Leveraging this theoretical framework, a sophisticated monitoring system utilizing Internet of Things (IoT) and Artificial Intelligence (AI) technologies was developed and executed. The suggested approach allows for real-time collection of transformer operational data via various sensors that monitor temperature, humidity, voltage, current, oil level, and vibration. The gathered data is sent to a cloud platform for continuous storage, visualization, and analysis.

The incorporation of Artificial Intelligence provides considerable benefit to the system by facilitating predictive maintenance features. Instead of depending only on regular inspections or fixing issues post-fault, the suggested method examines operational trends and detects early indicators of deterioration, enabling proactive planning of maintenance activities. This helps to decrease outage lengths, boost maintenance effectiveness, prolong transformer lifespan, and improve the overall dependability of the electrical grid.

Additionally, the system enhances operational safety by reducing the frequency of on-site inspections, especially in remote or dangerous areas.

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Appendices

- Code Arduino IDE

```
#define BLYNK_TEMPLATE_ID "TMPL2ig-4fhoG"
#define BLYNK_TEMPLATE_NAME "DHT"
#define BLYNK_AUTH_TOKEN "1nfntXVYoDpS_R0EtvhCv8LW6cLUkPvB"
#include <WiFi.h>
#include <BlynkSimpleEsp32.h>
#include <DHT.h>
#include <Wire.h>                  // إضافة مكتبة الـ I2C
#include <LiquidCrystal_I2C.h>     // إضافة مكتبة الشاشة
// ================= WIFI =================
char ssid[] = "Idoom 4G_10259";
char pass[] = "23769287";
// ================= PINS =================
#define TRIG_PIN 4
#define ECHO_PIN 2
#define BUZZER_PIN 5
#define VIBRATION_PIN 18
#define CURRENT_PIN 34
#define VOLTAGE_PIN 35
#define RELAY_PIN 19
// ================= DHT =================
#define DHTPIN 23
#define DHTTYPE DHT22
DHT dht(DHTPIN, DHTTYPE);
// ================= LCD I2C =================
LiquidCrystal_I2C lcd(0x27, 16, 2);
// ================= TANK =================
const float tankHeight = 50.0;
// ================= TIMER =================
unsigned long dangerStartTime = 0;
bool dangerActive = false;
BlynkTimer timer;
void setup() {
  Serial.begin(115200);
```

```
  // إعداد الشاشة وتشغيل الإضاءة الخلفية
  lcd.init();
  lcd.backlight();
  lcd.setCursor(0, 0);
  lcd.print("System Loading...");
  pinMode(TRIG_PIN, OUTPUT);
  pinMode(ECHO_PIN, INPUT);
  pinMode(BUZZER_PIN, OUTPUT);
  pinMode(RELAY_PIN, OUTPUT);
  digitalWrite(BUZZER_PIN, LOW);
  digitalWrite(RELAY_PIN, HIGH);
  pinMode(VIBRATION_PIN, INPUT_PULLDOWN);
  dht.begin();
  Blynk.begin(BLYNK_AUTH_TOKEN, ssid, pass);
  timer.setInterval(2000L, sendData);
  // مسح الشاشة وكتابة أن النظام جاهز
  lcd.clear();
  lcd.setCursor(0, 0);
  lcd.print("System Started!");
  delay(1000);
  lcd.clear();
}
void loop() {
Blynk.run();
  timer.run();
}
// ================= MAIN FUNCTION =================
void sendData() {
  // ========== OIL ==========
  digitalWrite(TRIG_PIN, LOW);
  delayMicroseconds(2);
  digitalWrite(TRIG_PIN, HIGH);
  delayMicroseconds(10);
```

```
digitalWrite(TRIG_PIN, LOW);
long duration = pulseIn(ECHO_PIN, HIGH, 30000);
float distance = duration * 0.0343 / 2.0;
if (distance <= 0 || distance > tankHeight) distance = tankHeight;
float oilLevel = ((tankHeight - distance) / tankHeight) * 100.0;
oilLevel = constrain(oilLevel, 0, 100);
// ========== DHT ==========
float temperature = dht.readTemperature();
float humidity = dht.readHumidity();
// ========== VIBRATION ==========
int vibration = !digitalRead(VIBRATION_PIN);
// ========== POWER ==========
float voltage = (analogRead(VOLTAGE_PIN) / 4095.0) * 25.0;
float currentVoltage = (analogRead(CURRENT_PIN) / 4095.0) * 3.3;
float current = (currentVoltage - 2.5) / 0.1;
if (current < 0) current = 0;
float power = voltage * current;
// ========== ALARM LOGIC ==========
bool alarm = false;
if (oilLevel < 40) alarm = true;
if (!isnan(temperature) && temperature > 80) alarm = true;
if (!isnan(humidity) && humidity > 60) alarm = true;
if (vibration == HIGH) alarm = true;
if (voltage > 1000 || current > 200) alarm = true;
// ========== TIMER + RELAY ==========
if (alarm) {
  digitalWrite(BUZZER_PIN, HIGH);
  if (!dangerActive) {
    dangerActive = true;
    dangerStartTime = millis();
  }
  if (millis() - dangerStartTime >= 120000) {
    digitalWrite(RELAY_PIN, LOW); // cut power
  }
```

```
} else {
  digitalWrite(BUZZER_PIN, LOW);
  dangerActive = false;
  dangerStartTime = 0;
  digitalWrite(RELAY_PIN, HIGH);
}
// ========== LCD DISPLAY ==========
// عرض البيانات على الشاشة وتحديثها كل ثانيتين
lcd.clear();
if (alarm) {
  lcd.setCursor(0, 0);
  lcd.print("!! DANGER !!    ");
  lcd.setCursor(0, 1);
  lcd.print("Check System!   ");
} else {
  // السطر الأول: درجة الحرارة ومستوى الزيت
  lcd.setCursor(0, 0);
  lcd.print("T:");
if(!isnan(temperature)) lcd.print((int)temperature); else lcd.print("--");
  lcd.print("C ");
  lcd.print("Oil:");
  lcd.print((int)oilLevel);
  lcd.print("%   ");
  // السطر الثاني: الجهد والتيار
  lcd.setCursor(0, 1);
  lcd.print("V:");
  lcd.print((int)voltage);
  lcd.print("V ");
  lcd.print("I:");
  lcd.print(current, 1); // طباعة رقم عشري واحد للتيار
  lcd.print("A    ");
}
```

```
        // ========== SEND TO BLYNK ==========
        Blynk.virtualWrite(V1, temperature);
        Blynk.virtualWrite(V2, humidity);
        Blynk.virtualWrite(V3, oilLevel);
        Blynk.virtualWrite(V4, current);
        Blynk.virtualWrite(V5, voltage);
        Blynk.virtualWrite(V6, power);
        Blynk.virtualWrite(V7, vibration);
        Blynk.virtualWrite(V8, alarm);
        // ========== SERIAL ==========
        Serial.println("----- BLYNK DATA -----");
        Serial.print("Temp: "); Serial.println(temperature);
        Serial.print("Hum: "); Serial.println(humidity);
        Serial.print("Oil: "); Serial.println(oilLevel);
        Serial.print("V: "); Serial.println(voltage);
        Serial.print("I: "); Serial.println(current);
        Serial.print("P: "); Serial.println(power);
        Serial.print("Alarm: "); Serial.println(alarm);
    Serial.println("----------------------\n");
}
```

- Python code to save sensor data to to a CSV file

```python
import requests
import csv
import time
import os
from datetime import datetime

# --- الإعدادات ---
TOKEN = "1nfntXVYoDpS_R0EtvhCv8LW6cLUkPvB"
FILE_NAME = "transformer_data.csv"
BASE_URL = f"https://blynk.cloud/external/api/get?token={TOKEN}"

# تعريف الأعمدة
FIELDS = ["Time", "Temperature", "Humidity", "Oil_Level",
"Current","Voltage", "Power", "Vibration", "Alarm"]

# --- دالة جلب البيانات من Blynk ---
def get_blynk_data(pin):
    try:
```

```
        response = requests.get(f"{BASE_URL}&{pin}", timeout=5)
        if response.status_code == 200:
            return response.text.strip('"')
        return "Error"
    except:
        return "N/A"

# --- التأكد من وجود الملف وإنشاء العناوين ---
if not os.path.exists(FILE_NAME):
    with open(FILE_NAME, 'w', newline='', encoding='utf-8') as f:
        writer = csv.DictWriter(f, fieldnames=FIELDS)
        writer.writeheader()
    print(f"تم إنشاء الملف: {FILE_NAME}")

print("بدأ النظام في تسجيل البيانات...")

# --- حلقة التكرار الرئيسية ---
try:
    while True:
        # جمع البيانات
        data = {
            "Time": datetime.now().strftime("%Y-%m-%d %H:%M:%S"),
            "Temperature": get_blynk_data("V1"),
            "Humidity": get_blynk_data("V2"),
            "Oil_Level": get_blynk_data("V3"),
            "Current": get_blynk_data("V4"),
            "Voltage": get_blynk_data("V5"),
            "Power": get_blynk_data("V6"),
            "Vibration": get_blynk_data("V7"),
            "Alarm": get_blynk_data("V8")
        }

        # حفظ البيانات في الملف بنمط الإضافة (Append)
        with open(FILE_NAME, 'a', newline='', encoding='utf-8') as f:
            writer = csv.DictWriter(f, fieldnames=FIELDS)
            writer.writerow(data)

        print(f"[{data['Time']}] تم حفظ السجل بنجاح.")

        # الانتظار 5 ثواني قبل الطلب التالي
        time.sleep(5)

except KeyboardInterrupt:
    print("\nتم إيقاف النظام بواسطة المستخدم.")
except Exception as e:
    print(f"حدث خطأ غير متوقع: {e}")
```

- Python code for training the Moudel

```
import pandas as pd
import glob
import os
import joblib
from sklearn.model_selection import train_test_split
from sklearn.ensemble import RandomForestClassifier
from sklearn.metrics import classification_report

# 1. دمج جميع ملفات البيانات الموجودة في المجلد
all_files = glob.glob("transformer_data_*.csv")
df_list = [pd.read_csv(file) for file in all_files]
df = pd.concat(df_list, ignore_index=True)

# 2. تنظيف البيانات
df = df.replace(['N/A', 'Error'], pd.NA)
df = df.dropna()

# تحويل الأعمدة الرقمية (للتأكد من معالجتها كأرقام)
cols_to_numeric = ["Temperature", "Humidity", "Oil_Level", "Current",
"Voltage", "Power", "Vibration", "Alarm"]
for col in cols_to_numeric:
    df[col] = pd.to_numeric(df[col])

# 3. تحديد المدخلات (X) والمخرج (y)
features = ["Temperature", "Humidity", "Oil_Level", "Current", "Voltage",
"Power", "Vibration"]
X = df[features]
y = df["Alarm"]

# 4. تقسيم البيانات وتدريب النموذج
X_train, X_test, y_train, y_test = train_test_split(X, y, test_size=0.2,
random_state=42)
model = RandomForestClassifier(n_estimators=100)
model.fit(X_train, y_train)

# 5. عرض النتائج
print("--- تقرير أداء النموذج ---")
predictions = model.predict(X_test)
print(classification_report(y_test, predictions))

# 6. حفظ النموذج لاستخدامه لاحقاً في نظام التنبيهات
joblib.dump(model, 'transformer_model_v2.pkl')
print("\nتم حفظ النموذج بنجاح باسم: transformer_model_v2.pkl")
```

- code fault detection in real time and AI predictive maintenance

```
import joblib
import requests
```

```
import time

# --- الإعدادات ---
# تأكد من وضع الـ Token والـ ID التي حصلت عليها من الصور
TELEGRAM_TOKEN = "8552702849:AAFAvSLttL1Adz_4RlKGt46L-L1Gv7wHCp8"
CHAT_ID = "5642294829"
BLYNK_TOKEN = "1nfntXVYoDpS_R0EtvhCv8LW6cLUkPvB"

# تحميل النموذج الذي قمت بتدريبه
model = joblib.load('transformer_model.pkl')

def send_telegram_msg(message):
    url =
f"https://api.telegram.org/bot{TELEGRAM_TOKEN}/sendMessage?chat_id={CHT
_ID}&text={message}"
    try:
        requests.get(url, timeout=5)
    except Exception as e:
        print(f"خطأ في إرسال تلغرام: {e}")

def get_blynk_data():
    pins = ["V1", "V2", "V3", "V4", "V5", "V6", "V7"]
    data = []
    for pin in pins:
        url =
f"https://blynk.cloud/external/api/get?token={BLYNK_TOKEN}&{pin}"
        try:
           val = requests.get(url, timeout=5).text.strip('"')
          data.append(float(val) if val not in ["N/A", "Error", ""]else
0.0)
        except:
            data.append(0.0)
    return data

print("نظام التنبيهات يعمل الآن... (راقب تلغرام)")

while True:
    try:
        current_data = get_blynk_data()
        prediction = model.predict([current_data])

        if prediction[0] == 1:
            msg = "⚠️ خطر! تم اكتشاف خلل في المحولة. يرجى الفحص فوراً."
            send_telegram_msg(msg)
            print(msg)
            time.sleep(60) # انتظر دقيقة قبل إرسال تنبيه آخر لتجنب الإزعاج
        else:
            print("✅ الحالة طبيعية.")
            time.sleep(10)
```

```
    except Exception as e:
        print(f"حدث خطأ في النظام: {e}")
        time.sleep(10)
```

- Analyser

```
import pandas as pd
import joblib
import requests
import time

# ==============================================================================
# 1. الإعدادات (Config)
# ==============================================================================
TELEGRAM_TOKEN = "8552702849:AAFAvSLttL1Adz_4RlKGt46L-L1Gv7wHCp8"
TELEGRAM_CHAT_ID = "5642294829"
BLYNK_TOKEN = "1nfntXVYoDpS_R0EtvhCv8LW6cLUkPvB"
MODEL_PATH = r"C:\Users\pc1\Desktop\transformer_model.pkl"

# تحميل النموذج
model = joblib.load(MODEL_PATH)

# ==============================================================================
# 2. الدوال المساعدة
# ==============================================================================
def send_telegram_alert(message):
    url = f"https://api.telegram.org/bot{TELEGRAM_TOKEN}/sendMessage"
    payload = {"chat_id": TELEGRAM_CHAT_ID, "text": message, "parse_mode":
"Markdown"}
    try:
        requests.post(url, json=payload, timeout=15)
    except Exception as e:
        print(f"خطأ في إرسال تلغرام: {e}")

def get_blynk_data():
    # الترتيب: Temp, Hum, Vib, Oil, Volt, Curr, Pwr
    pins = ["V1", "V2", "V3", "V4", "V5", "V6", "V7"]
    data = []
    for pin in pins:
        url =
f"https://blynk.cloud/external/api/get?token={BLYNK_TOKEN}&{pin}"
        try:
            val = requests.get(url, timeout=5).text.strip('"')
            data.append(float(val) if val not in ["N/A", "Error", ""] else
0.0)
        except:
            data.append(0.0)
    return data
```

```
# ==============================================================================
# 3. دالة التحليل الهندسي والذكي
# ==============================================================================
def analyser_transformateur(data):
    temp, hum, vib, oil, volt, curr, pwr = data

    # القواعد الهندسية (Thresholds)
    is_critical = False
    defauts = []
    if temp > 80: defauts.append(f"Temp High: {temp} > 80°C")
    if oil < 40: defauts.append(f"Oil Low: {oil} < 40 cm")
    if hum > 60: defauts.append(f"Humidity High: {hum} > 60%")
    if volt > 240: defauts.append(f"Voltage High: {volt} > 240V")
    if curr > 20: defauts.append(f"Current High: {curr} > 20A")
    if vib > 4.5: defauts.append(f"Vib Abnormal: {vib} mm/s")

    if defauts: is_critical = True

    # التنبؤ بالذكاء الاصطناعي
    input_df = pd.DataFrame([data], columns=['Temperature', 'Humidity',
'Vibration', 'OilLevel', 'Voltage', 'Current', 'Power'])
    prediction = model.predict(input_df)[0]

    print(f"📊 الحالة: Temp:{temp}, Oil:{oil}, Volt:{volt}, Curr:{curr} | AI
Prediction: {'CRITICAL' if prediction == 1 else 'SAFE'}")

    if prediction == 1 or is_critical:
        alert_msg = (
            "⚠️ *تنبيه خطر في المحولة* ⚠️\n\n"
            f"❌ *الحالة:* {', '.join(defauts) if defauts else ' تنبؤ ذكاء اصطناعي
بخطر'}\n"
            "💡 *الإجراء: يرجى الفحص الفوري!*"
        )
        send_telegram_alert(alert_msg)
        return True
    return False

# ==============================================================================
# 4. الحلقة الرئيسية (Main Loop)
# ==============================================================================
print("✅ نظام المراقبة الصناعي يعمل الآن...")
while True:
    try:
        current_data = get_blynk_data()
        if analyser_transformateur(current_data):
            time.sleep(60) # تهدئة بعد التنبيه
        else:
            time.sleep(10)
```

```
    except Exception as e:
        print(f"خطأ: {e}")
        time.sleep(10)
```