ELECTRICAL TRANSFORMER

Understanding Transformers: A Student Reference

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First Edition

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Acknowledgement

In the name of Allah, the Most Gracious, the Most Merciful.

It gives us immense pleasure to present this book, "Electrical Transformer: A Student's Reference," which is the culmination of dedicated effort and the support of many individuals. This book is intended to serve as a comprehensive and accessible resource for students delving into the fascinating world of electrical transformers. First and foremost,we are deeply grateful to Allah (SWT) for granting us the strength, knowledge, and perseverance to complete this work. Without His blessings, this book would not have been possible.
We would like to express our sincere gratitude to the mentors and colleagues, whose give their invaluable guidance and constructive feedback that have shaped the content and structure of this book.
Special thanks go to our students, who have inspired us with their curiosity and passion for learning. Their questions, insights, and enthusiasm have been instrumental in refining the focus of this book.
We extend my heartfelt appreciation to our family and friends for their unwavering support and understanding during the countless hours we dedicated to this project.
Finally, we wish to acknowledge all the authors, researchers, and educators whose work has provided the foundation and inspiration for this book. The field of electrical engineering is enriched by this contributions.
We hope this book serves as a useful reference for students and professionals alike, fostering a deeper understanding of electrical transformers and their applications. Any feedback or suggestions for improvement are most welcome, as learning is a continuous journey.Thank you for choosing this resource. we hope it inspires your learning and enhances your appreciation of these vital components in our electrical infrastructure.

With gratitude,

Authors;

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Preface

Welcome to "Electrical Transformers, Understanding Transformers: A Student Reference " This book is designed to serve as an essential reference for electrical engineering students and professionals alike, providing a thorough understanding of transformer principles and their practical applications in the industry.

Transformers are critical components in electrical systems, facilitating the efficient transmission and distribution of electricity. As technology evolves, so too do the demands placed on these devices, making it imperative for aspiring engineers to grasp their underlying principles and operational nuances.

This book begin with an introduction to the fundamental principles of transformers, laying a solid foundation for understanding how they operate. We explore various types of transformers, each serving unique functions in different applications, and delve into the key parameters that govern their performance. The calculations and tutorials included will enhance your problem-solving skills, preparing you for real-world challenges.

Additionally, the diverse applications of transformers in various industries, highlighting their significance in modern electrical systems. The challenges faced in transformer operation, providing insights into maintenance and troubleshooting were also addressed in this book.

This book aims to equip you with the tools and understanding necessary to navigate the complexities of electrical transformers either for the
student embarking on your journey in electrical engineering or a professional seeking to refresh their knowledge,

ELECTRICAL TRANSFORMER

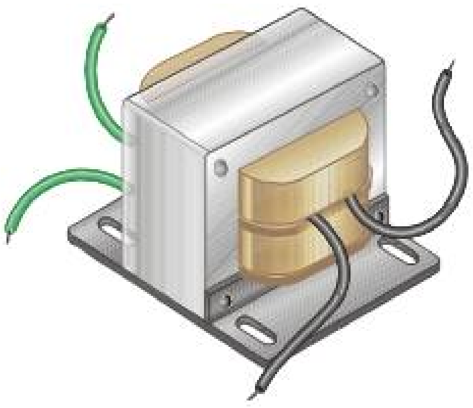
TOPIC OVERVIEW

INTRODUCTION TO TRANSFORMER

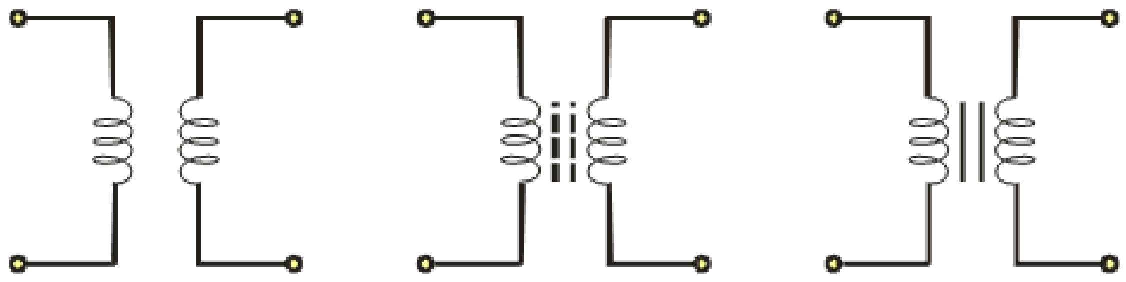
- Source voltage is applied to the primary winding
- The load is connected to the secondary winding
- The core provided a physical structure for placement of windings and a magnetic path so that the magnetic flux lines are concentrated close to the coils
- Typical core materials are : air, ferrite and iron

BASIC OF TRANSFORMER PRINCIPLES

- The basic transformer is formed from two coils that are usually wound on a common core to provide a path for the magnetic field lines.
- Schematic symbols indicate the type of core.



Small power transformer



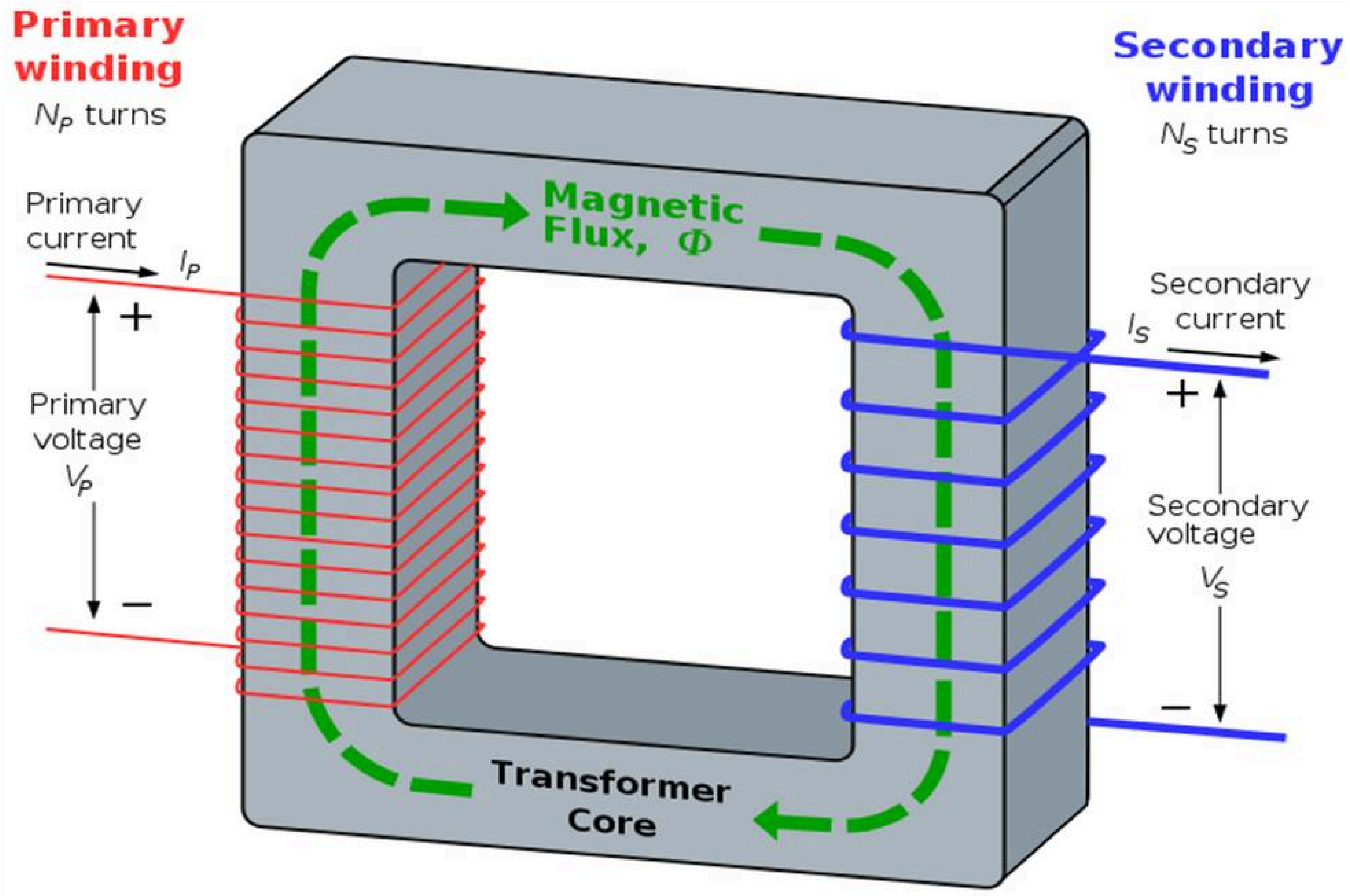
TRANSFORMER PRINCIPLES

•The transformer is based on two principles:

i. first, that an electric current can produce a magnetic field (electromagnetism)

ii. second that a changing magnetic field within a coil of wire induces a voltage across the ends of the coil (electromagnetic induction).

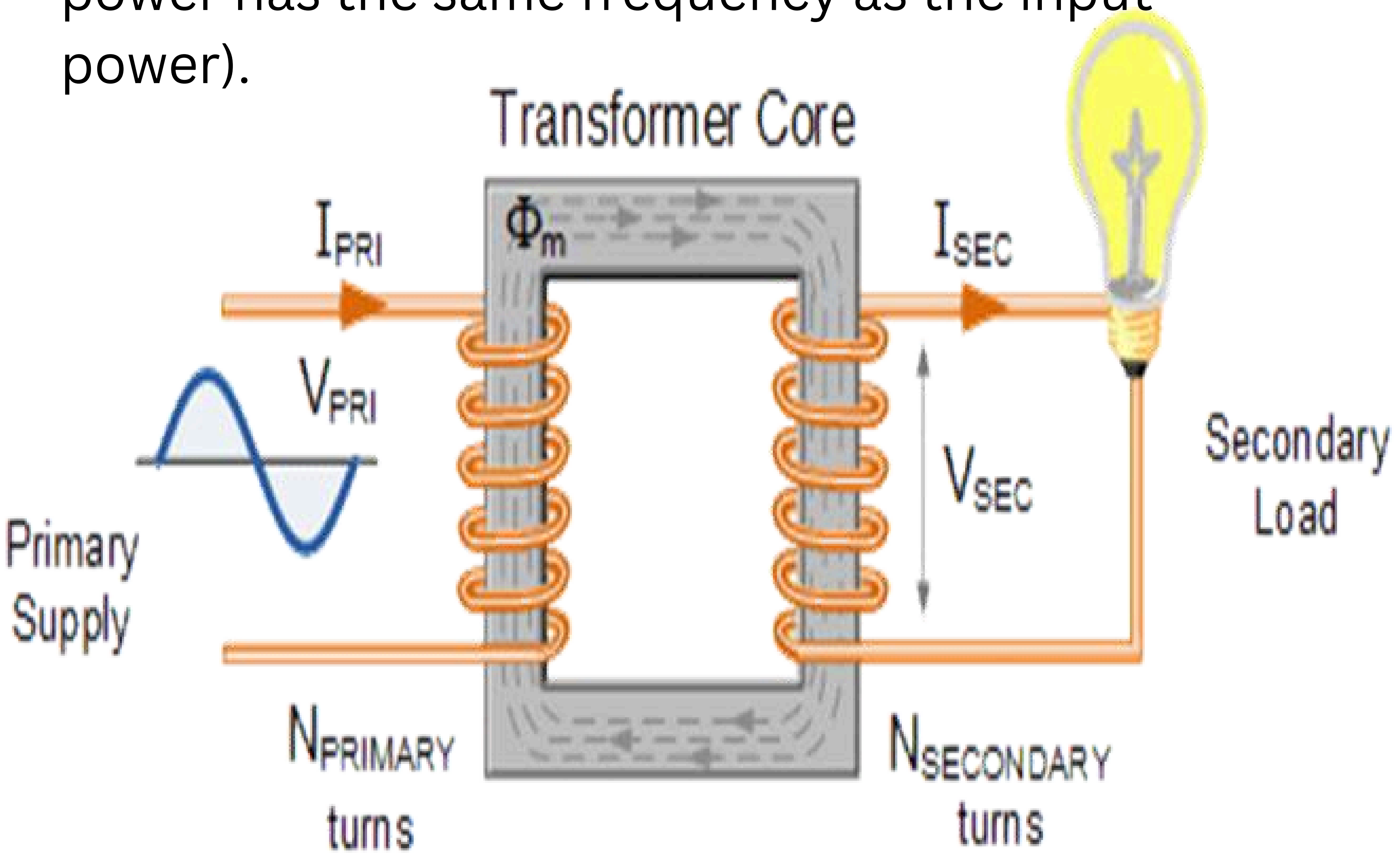
The parts of an ideal transformer



- Changing the current in the primary coil changes the magnetic flux that is developed.
- The changing magnetic flux induces a voltage in the secondary coil.
- Current passing through the primary coil creates a magnetic field.
- The primary and secondary coils are wrapped around a core of very high magnetic permeability, such as iron, so that most of the magnetic flux passes through both the primary and secondary coils.

OPERATING PRINCIPLES

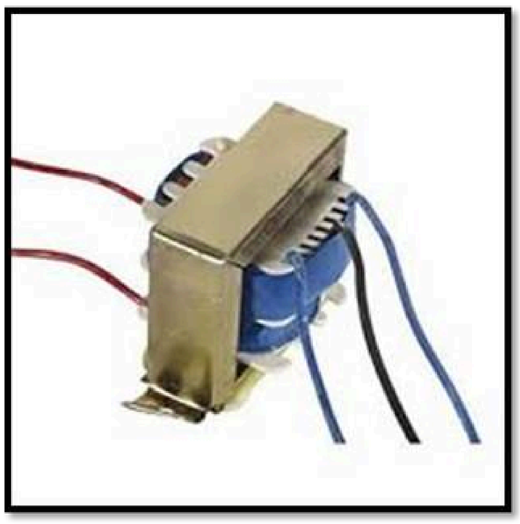
- Transformer action is based on the laws of electromagnetic induction.
- There is no electrical connection between the primary and secondary. The AC power is transferred from primary to secondary through magnetic flux.
- If an ac voltage is applied to the primary coil, magnetic flux will be created.
- When the magnitude of the applied flux changed, then the generated flux changed.
- This changing flux will link the primary and secondary coil and induce a voltage across the secondary windings.
- There is no change in frequency (output power has the same frequency as the input power).

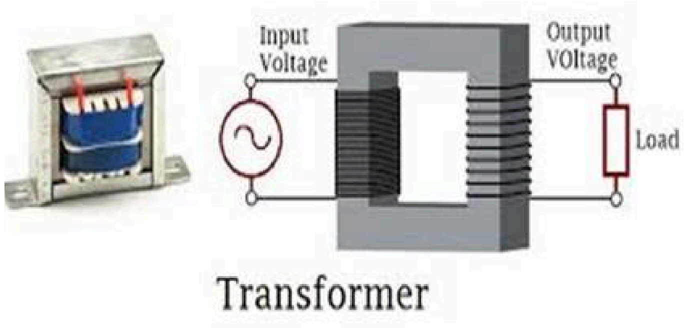


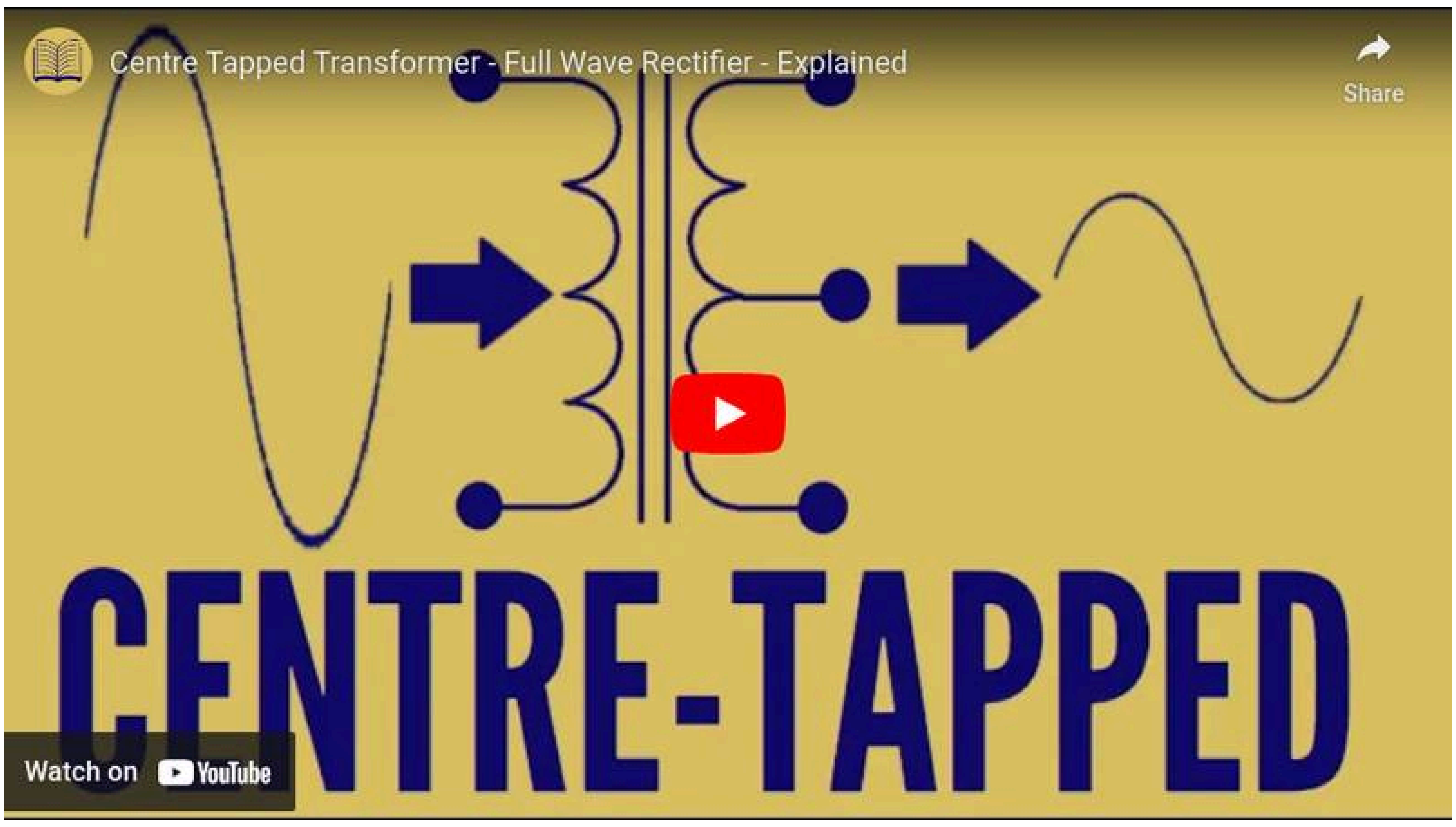
Scan to watch the video

TYPES OF TRANSFORMER

- Center tapped transformer
- Multiple winding transformer
- Auto transformer



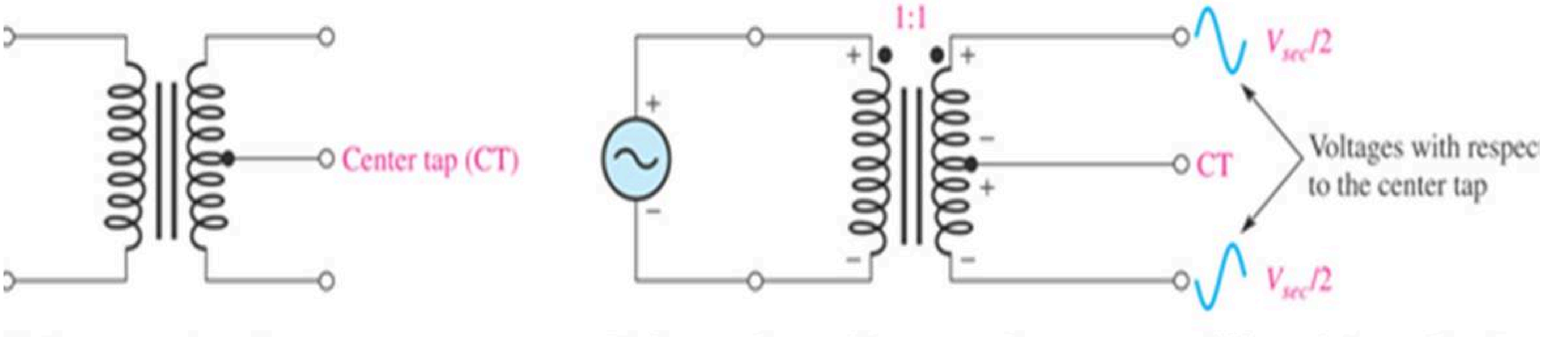



https://youtu.be/Wq-QEDR3w0g

A.CENTER TAPPED TRANSFORMER

- The center tap (CT) transformer is equivalent to two secondary windings with half the voltage across each
- Center tap windings are used for rectifier supplies and impedance-matching transformers

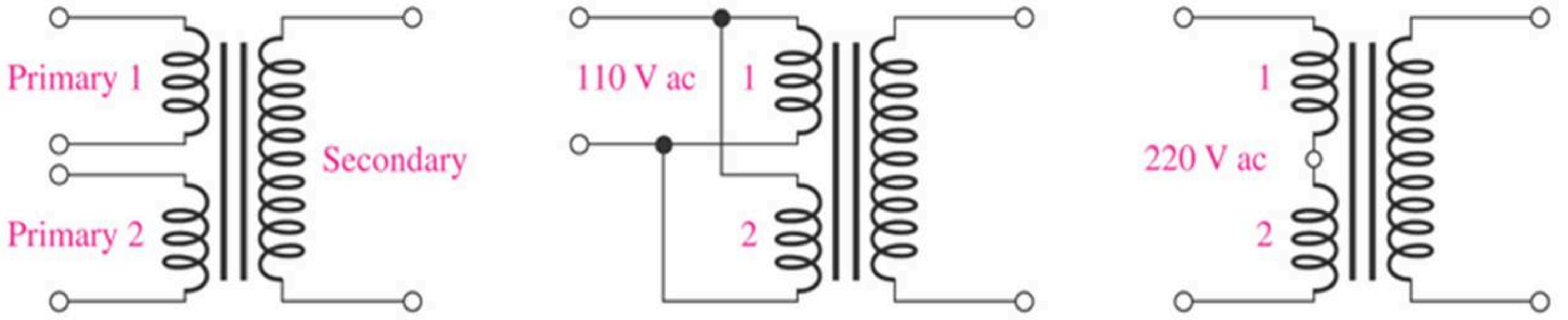


(a) Center-tapped transformer

(b) Output voltages with respect to the center tap are 180° out of phase with each other and are one-half the magnitude of the secondary voltage.

B.MULTI WINDING TRANSFORMER

Multiple-winding transformers have more than one winding on a common core. They are used to operate on, or provide, different operating voltages



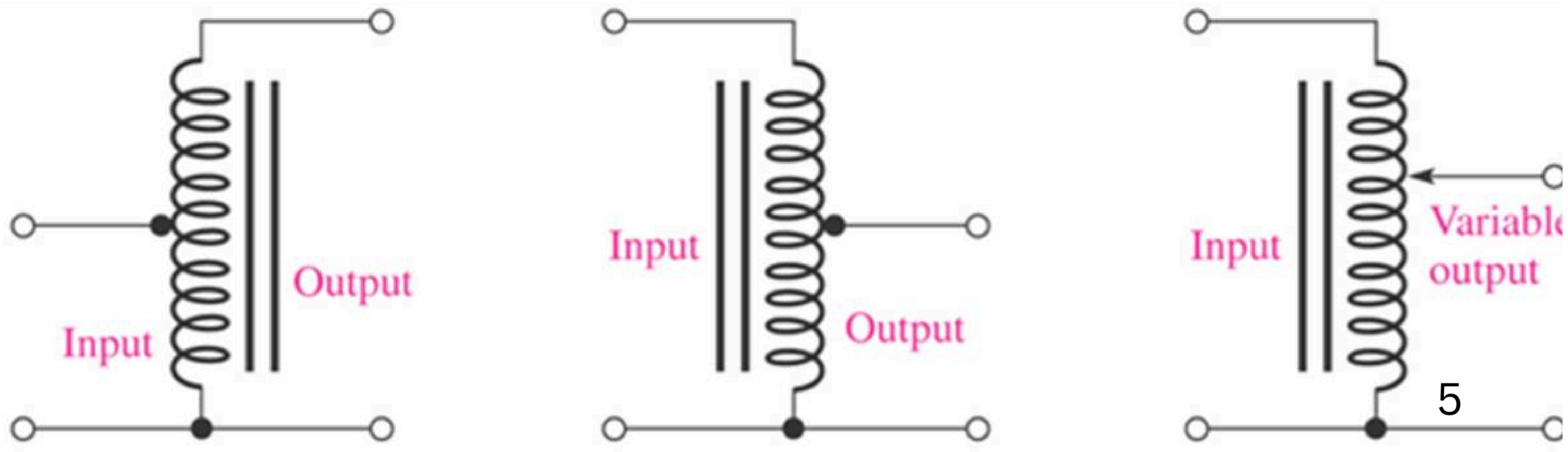
(a) Two primary windings

(b) Primary windings in parallel for 110 V ac operation

(c) Primary windings in series for 220 V ac operation

C.AUTO TRANSFORMER

- In an autotransformer, one winding serves as both the primary and the secondary. The winding is tapped at the proper points to achieve the desired turns ratio for stepping up or down the voltage



(a) Step-up

(b) Step-down

(c) Variable

PRACTICAL TRANSFORMER

- Power Transformers
- Distribution Transformers
- Instrument Transformers
- Isolation Transformers
- Autotransformers
- Toroidal Transformers
- Three-Phase Transformers
- Single-Phase Transformers
- Buck-Boost Transformers
- Oil-Cooled- Dry Transformers

1. Power Transformers

Power transformers are primarily used in high-voltage transmission networks to step up (increase) or step down (reduce) the voltage level. These transformers are designed to handle large quantities of electrical energy and are typically used in transmission networks between power plants and distribution systems. Power transformers are most effective when operating at full load and are used for voltage regulation across long distances.

Subcategories of Power Transformers:

a) **Step-up Transformer**: Converts low-voltage, high-current electricity into high-voltage, low-current electricity for efficient long-distance transmission.
b) **Step-down Transformer:** Lowers high-voltage electricity for distribution to residential or commercial areas. It is used at substations near end users.

Applications:
Electrical power generation and transmission networks.
Substations in power grids.

2. Distribution Transformers

Distribution transformers are designed to provide the final voltage transformation in an electrical power distribution system, stepping down the voltage used in transmission lines to a level suitable for consumer use. These transformers typically operate at lower voltages and are used to distribute electrical power to residential, commercial, and industrial consumers.

Key Characteristics:

Operate at low to medium voltage levels (11kV, 6.6kV, 3.3kV).

Function under varying load conditions.

High efficiency in partial loads.

Applications:

Electrical distribution networks.

Supplying power to homes, offices, and industrial facilities.

3. Instrument Transformers

Instrument transformers are designed to scale down the current and voltage levels for measurement, control, and protection in electrical systems. They ensure the safety of measuring instruments and provide isolation from high voltages.

Types of Instrument Transformers:

Current Transformer (CT): Steps down high current to a lower, measurable level. It's widely used in ammeters, relays, and protective devices.

Potential Transformer (PT): Also called a voltage transformer, it scales down high voltage to a lower level for safe measurement in voltmeters and protective relays.

Applications:

Electrical metering and protective circuits.

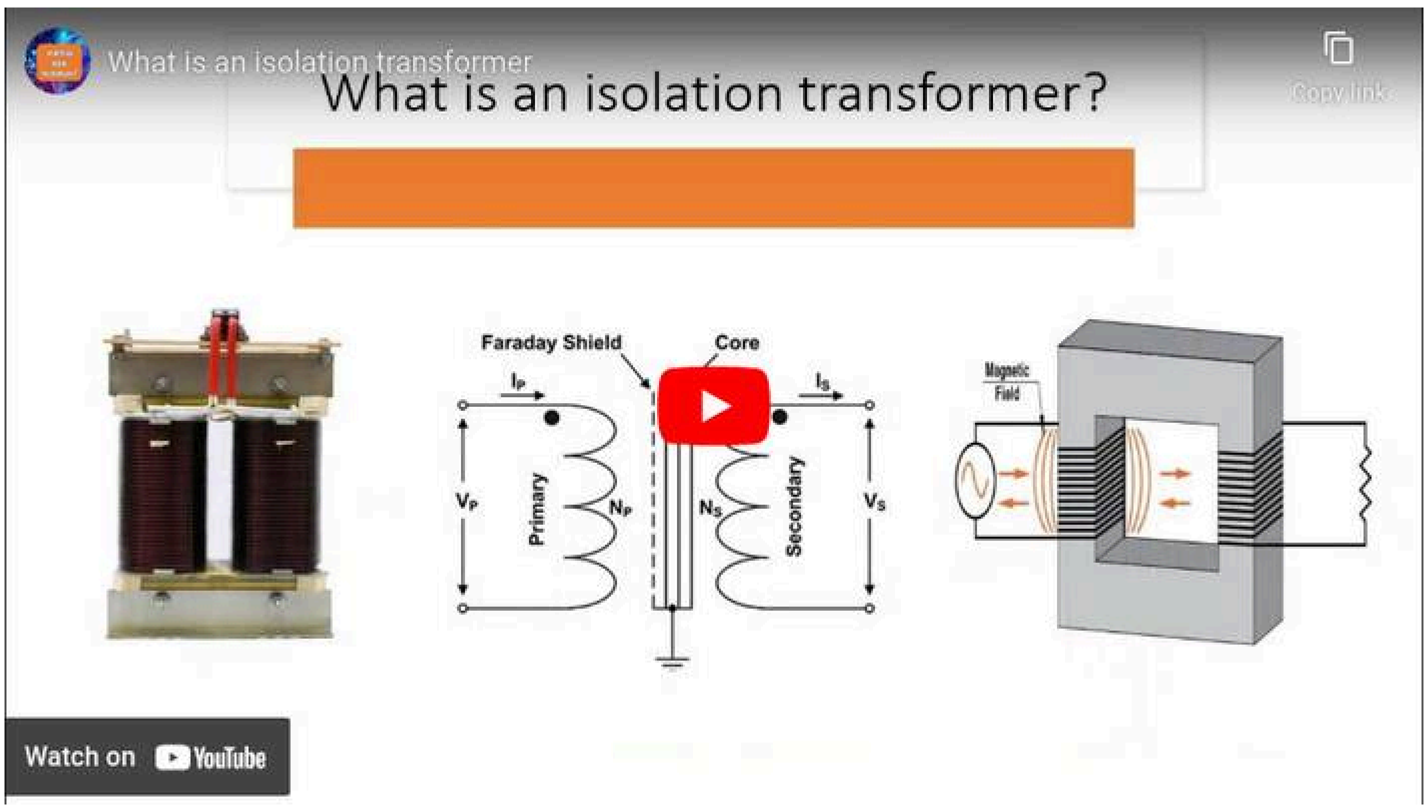
Control systems in substations and distribution networks.

https://www.youtube.com/watch?v=Ik2r-TImy5Y&t=128sg

4. Isolation Transformers

An isolation transformer is a transformer used to transfer electrical power from a source of alternating current (AC) power to some equipment or device while isolating the powered device from the power source, usually for safety reasons or to reduce transients and harmonics.

In transmission and distribution systems, isolation transformers are employed to adjust voltage levels by stepping up or down, ensuring that voltage and current capacities match between the coils. A crucial role of these transformers is to mitigate voltage spikes in supply lines, which could otherwise disrupt service or damage equipment if they reach the load.
When placed between power supply lines, an isolation transformer helps diminish voltage spikes before they impact the load. Additionally, it prevents grounding issues on the secondary side, thereby reducing ground loop interference and minimizing noise effects in the load equipment.



ihttps://www.youtube.com/watch?v=9j0OrMAFi2c

5. Auto-Transformers

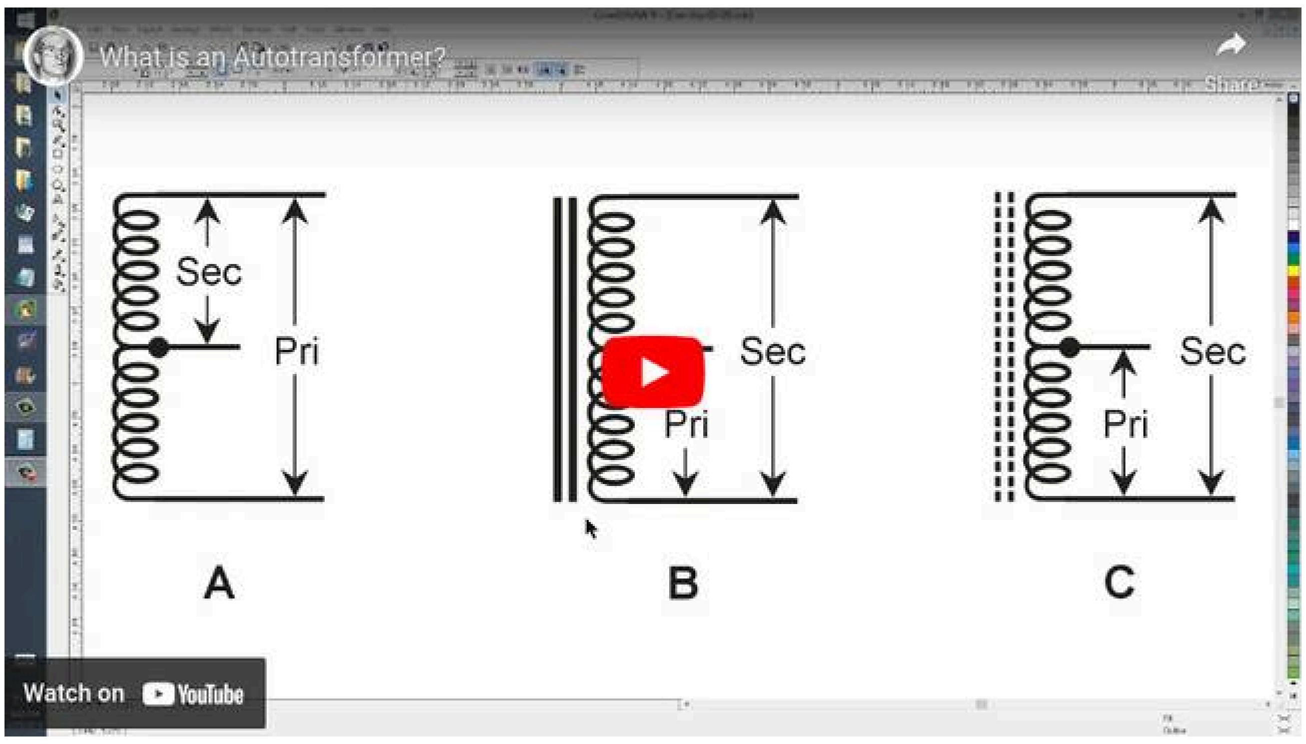
An autotransformer (or auto transformer) is a type of electrical transformer with only one winding. The "auto" prefix refers to the single coil acting alone (Greek for "self") – not to any automatic mechanism. An auto transformer is similar to a two winding transformer but varies in the way the primary and secondary winding of the transformer are interrelated.

The advantages of an auto transformer include:

For transformation ratio = 2, the size of the auto transformer would be approximately 50% of the corresponding size of two winding transformer. For transformation ratio say 20 however the size would be 95 %. The saving in cost of the material is of course not in the same proportion. The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2. Thus auto transformer is smaller in size and cheaper.

An auto transformer has higher efficiency than two winding transformer. This is because of less ohmic loss and core loss due to reduction of transformer material.

Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.



https://www.youtube.com/watch?v=To2AEqeeFVwe bit of body text

6. Toroidal Transformers

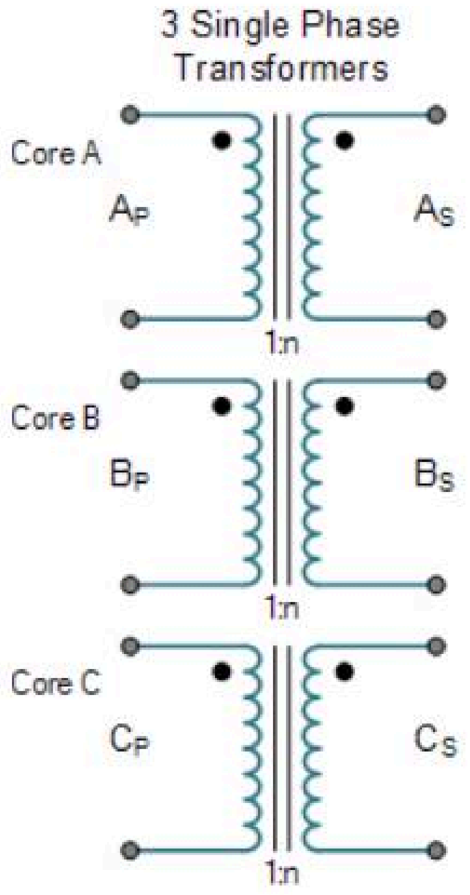
A toroidal transformer features a core shaped like a torus or donut. The primary and secondary windings are wrapped around the entire surface of this toroidal core, with an insulating material in between. This design significantly reduces magnetic flux leakage, making the toroidal core an optimal choice for transformer cores.

https://www.youtube.com/watch?v=TPXtiJaSiKA

7. Three Phase Transformers

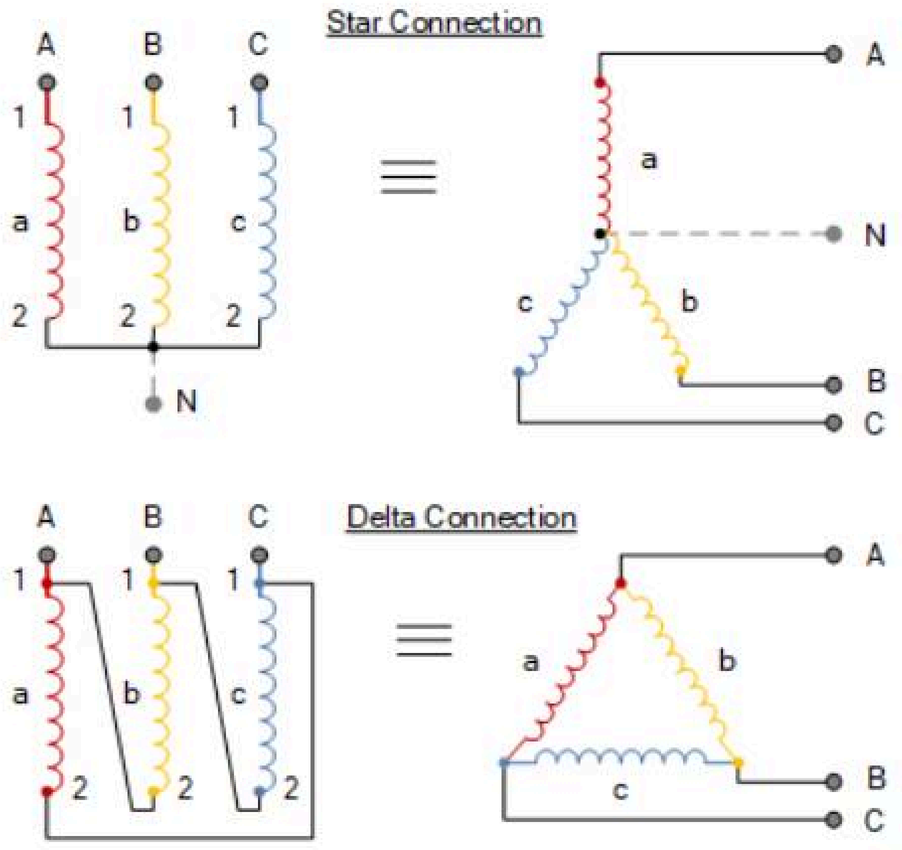
A three-phase electrical system in used to generate and transmit electric power over long distances for use by offices and industry. Three-phase voltages (and currents) are raised or lowered by means of three phase transformers as the three phase transformer can have its windings connected in various ways.

Three Phase Transformer Connections



Primary Configuration	Secondary Configuration
Delta (Mesh)	Delta (Mesh)
Delta (Mesh)	Star (Wye)
Star (Wye)	Delta (Mesh)
Star (Wye)	Star (Wye)
Interconnected Star	Delta (Mesh)
Interconnected Star	Star (Wye)

Transformer Star and Delta Configurations



IDEAL TRANSFORMER EQUATIONS

For an ideal transformer, the $P_{Primary}$ is equal to the $P_{Secondary}$, or the **power input is equal to the power output**.

$$P_{out} = P_{in}$$

$$V_s I_s = V_p I_p$$

$$I_s / I_p = V_p / V_s$$

$$P_{out} = P_{in} \times \text{Efficiency Rating}$$

$$\eta = \text{Pout / Pin} = \text{Pout / (Pout+ losses)}$$

$$\eta = \frac{\text{VsIs x P.F}}{\text{(VsIs x P.F) + copper loss + core loss}}$$

Scan here to understand the equations!!!

INDUCTION LAW

•The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

$$V_s = N_s \frac{d\Phi}{dt}$$

•where Vs is the instantaneous voltage, Ns is the number of turns in the secondary coil and Φ is the magnetic flux through one turn of the coil.

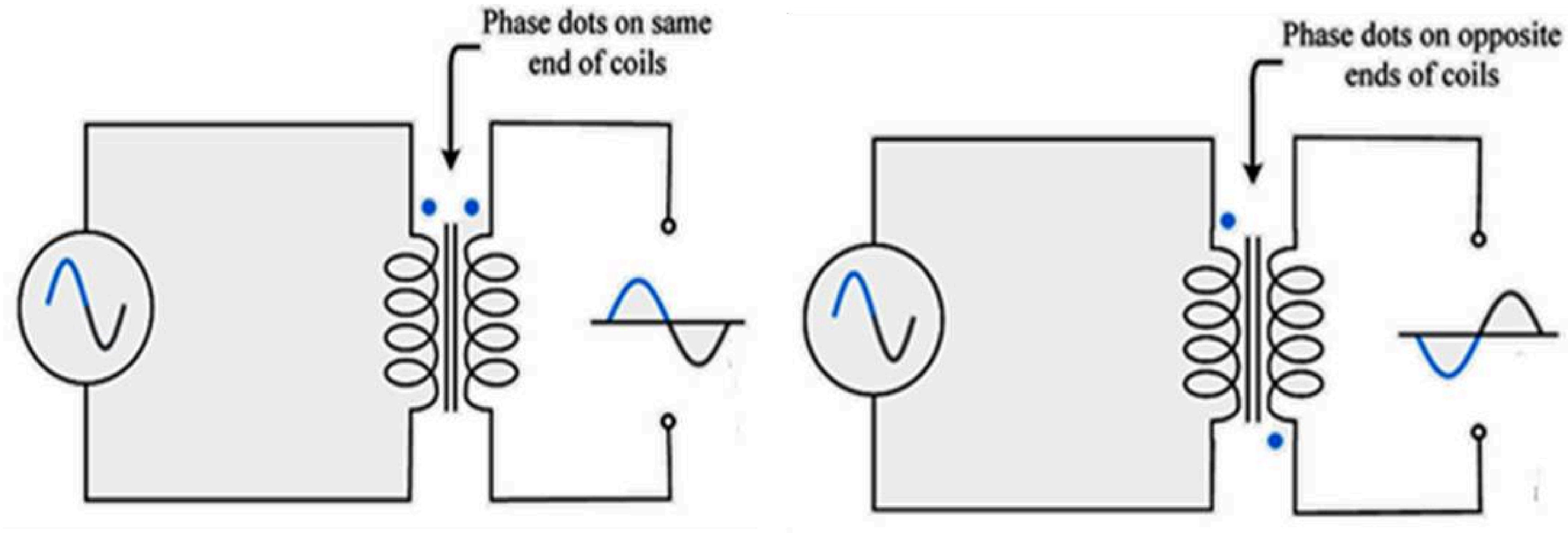
•Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer, the instantaneous voltage across the primary winding equals to:

$$V_p = N_p \frac{d\Phi}{dt}$$

TRANSFORMER CONSTRUCTION

- The transformer consists of core, surrounded by at least two series of coils.
- The core is used as to aid in linking the flux from the primary coil to the secondary coil.
- From the principle of mutual induction, when two coils are inductively coupled and if the current in one coil is change uniformly, an emf (electromagnetic force) is induced in the other coil.
- If a closed path is provided at the secondary circuit, this induced emf at the secondary drives a current.
- Dots are used in diagrams of transformers to indicate the current polarities for the windings.
- Dotted terminals have the same polarity.

TRANSFORMER DOT NOTATION

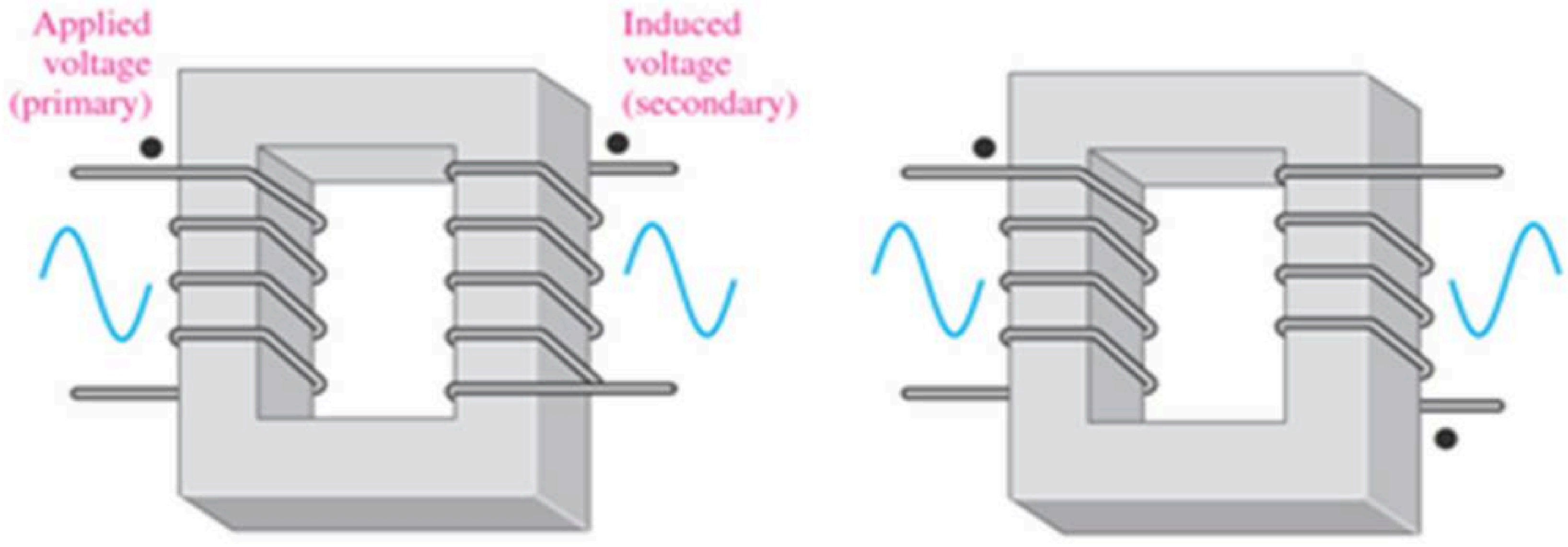


(a) Voltage are in phase

(b) Voltage are out of phase

DIRECTIONS OF WINDINGS

- The direction of the windings determines the polarity of the voltage across the secondary winding with respect to the voltage across the primary section
- Phase dots are used to indicate the polarities.

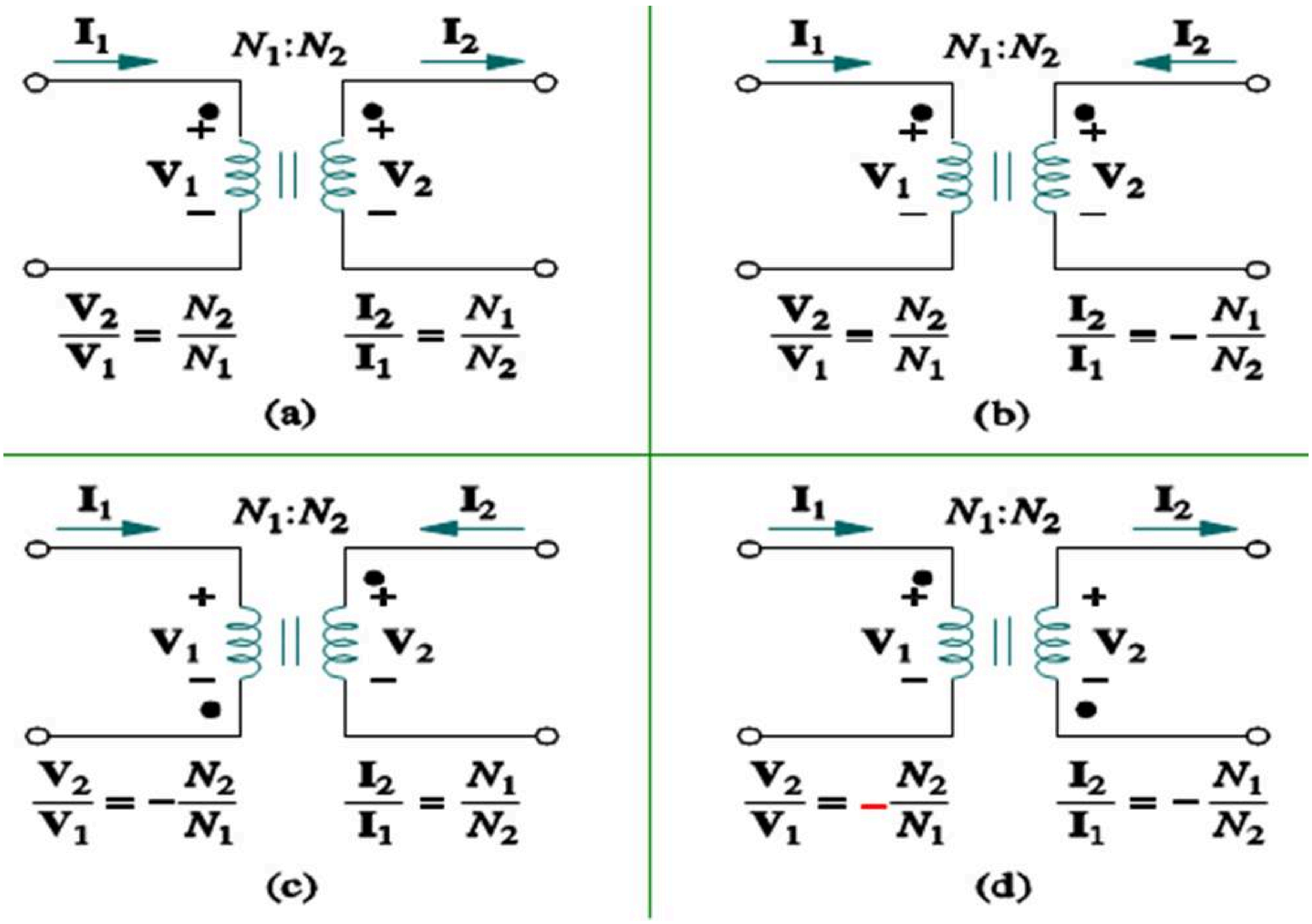


(a) The primary and secondary voltages are in phase when the windings are in the same effective direction around the magnetic path.

(b) The primary and secondary voltages are 180° out of phase when the windings are in the opposite direction.

DIRECTIONS OF WINDINGS

Typical circuits illustrating polarity for voltages and direction of currents of an ideal transformer



STEP-UP TRANSFORMER

•A transformer that has more turns on the secondary than the primary side of transformer will increase the input voltage.

STEP-DOWN TRANSFORMER

•A transformer that has more turns on the primary than the secondary side of the transformer will decrease the input voltage.

PARAMETERS IN TRANSFORMER

Voltage Ratio: = $\frac{V_1}{V_2}$

Turns Ratio: = $\frac{N_1}{N_2}$

Current Ratio: = $\frac{I_2}{I_1}$

Transformer Ratio

$$\frac{N_1}{N_2} = \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

Efficiency:

$$\eta = \frac{P_{out}}{P_{in}}$$

EXERCISE:

A transformer has 800 turns on the primary and a turns ratio of 0.25. How many turns are on the secondary?

Solution

$n = N_s / N_p$

$N_s = N_p \times n = 800 \times 0.25 =$ **200 turns**

POWER LOSSES

A practical transformer differs from the ideal transformer in many respects.
The practical transformer has:-

•**Iron or core losses** - eddy current and hysterisis losses

•**copper losses** - in the resistance of the windings

I**ron or core losses**

• The magnitude of these losses is quite small. This losses due to eddy current and hysteresis loss in it.

Copper losses

•Is the energy loss in the windings when the transformer is loaded.

Total copper loss, **Pc = Ip2Rp + Is2Rs**

Hysteresis

•The alternating flux causes changes in the alignment of the molecules in the magnetic cores.

•The change is energy consuming and heat is produced within the core.

•The energy loss is referred to as hysteresis loss, the degree of loss being dependent on the material used .

EFFICIENCY OF TRANSFORMER

efficiency of a transformer can be defined as the output power divided by the input power.
That is efficiency = output / input . Transformers are the most highly efficient electrical devices.
Most of the transformers have full load efficiency between 95% to 98.5% .

As a transformer being highly efficient, output and input are having nearly same value, and hence it is impractical to measure the efficiency of transformer by using output / input.

A better method to find efficiency of a transformer is using,
efficiency = **(input - losses) / input** = **1 - (losses / input).**

$$\text{efficiency} = \frac{\text{output (in watts)}}{\text{input (in watts)}}$$

TRANSFORMER APPLICATIONS IN INDUSTRY

Transformer applications in industry
Reference: OneMonroe

CHALLENGES IN TRANSFORMER APPLICATIONS

Scan me to understand the challenges in transformer applications

EXERCISE 1

A doorbell requires 0.4 A at 6V. It is connected via a transformer whose primary coil contains 2000 turns to a 120V AC line. Calculate:-

(a) NS

(b) IP

SOLUTION:

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{6}{120} = \frac{N_s}{200}$$

$$N_s = 10 \text{ turns}$$

$$\frac{N_s}{N_p} = \frac{I_p}{I_s} = \frac{10}{200} = \frac{I_p}{0.4}$$

$$I_p = 0.02A$$

EXERCISE 2

The transformer in Figure 1 has a turns ratio of 3. What is the voltage across the secondary winding?

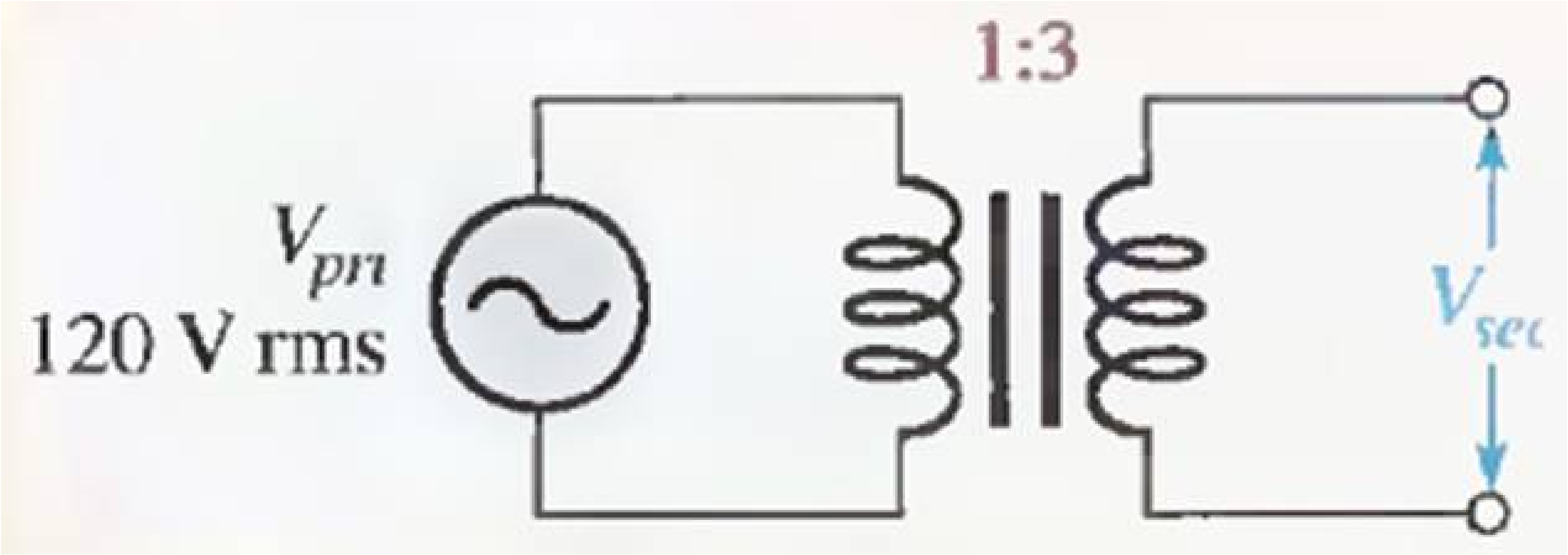


Figure 1

The transformer in Figure 2 has a turns ratio of 0.2. What is the secondary voltage?

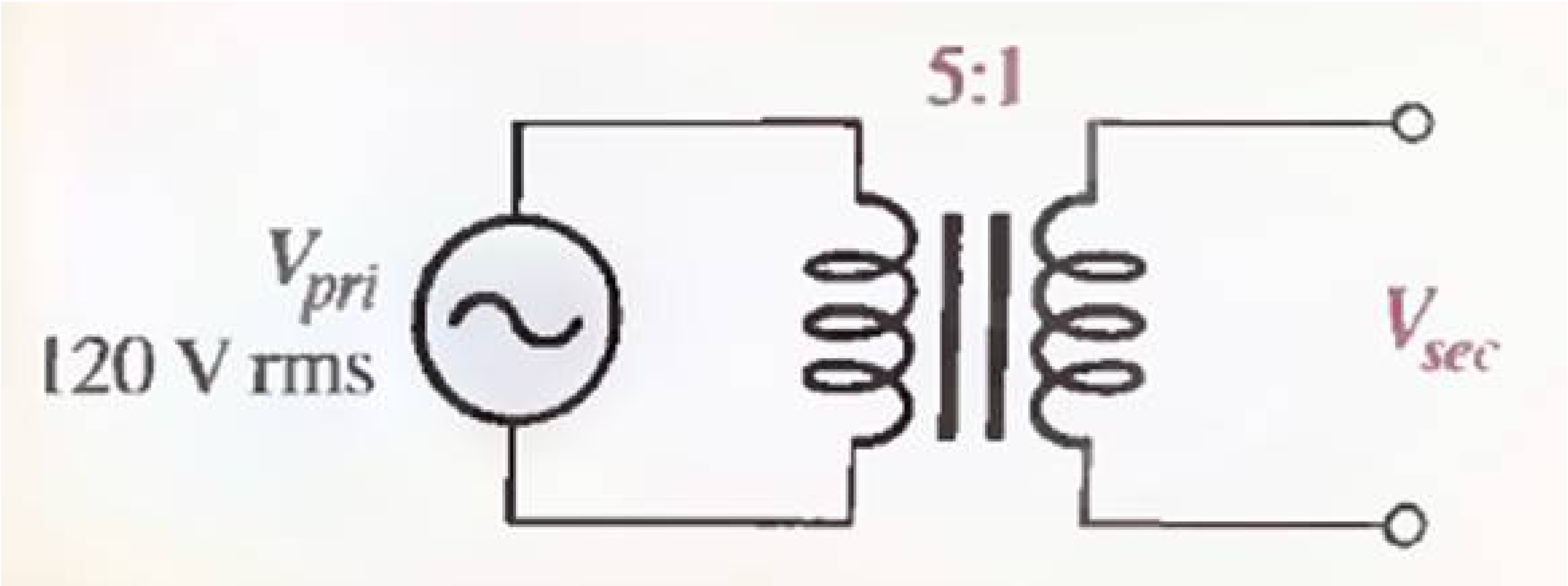
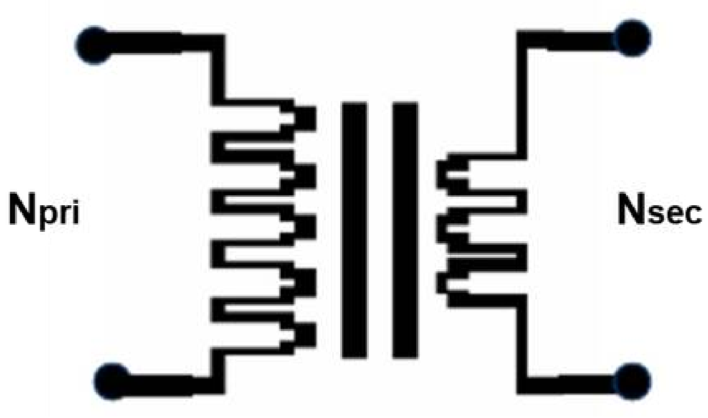


Figure 2

EXERCISE 3

A transformer has 500 primary turns and 3000 secondary turns. If the primary voltage Is 240V, determine the secondary voltage, Assuming an ideal transformer.



SOLUTION

Given: $N_p=500, N_s=3000$

$V_p=240V$, $V_s=?$

$V_p/V_s=N_p/N_s$

$V_s=V_p \times N_s/N_p$

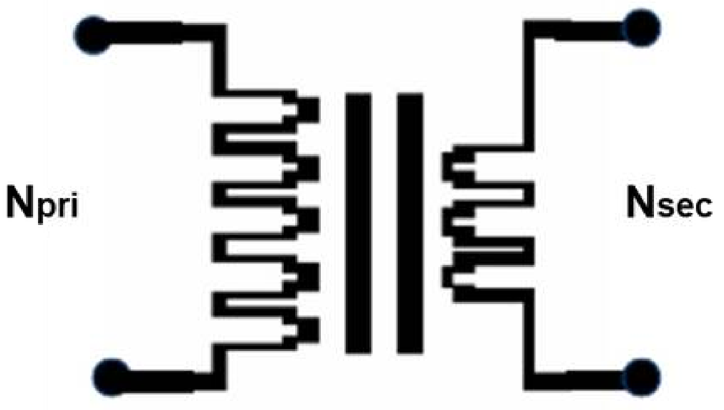
$=240 \times (3000/500)$

$=240 \times 6$

$=$**1440V**

EXERCISE 4

An ideal transformer has a turns ratio of 8:1 and the primary current is 3A when it is supplied at 240V. Calculate the secondary voltage and current.



SOLUTION

Given: N=8:1, Ip=2A, Vp=240V

N=8/1=Vp/Vs

Vs=Vp/8

=240/8

=**30V**

VsIs=VpIp

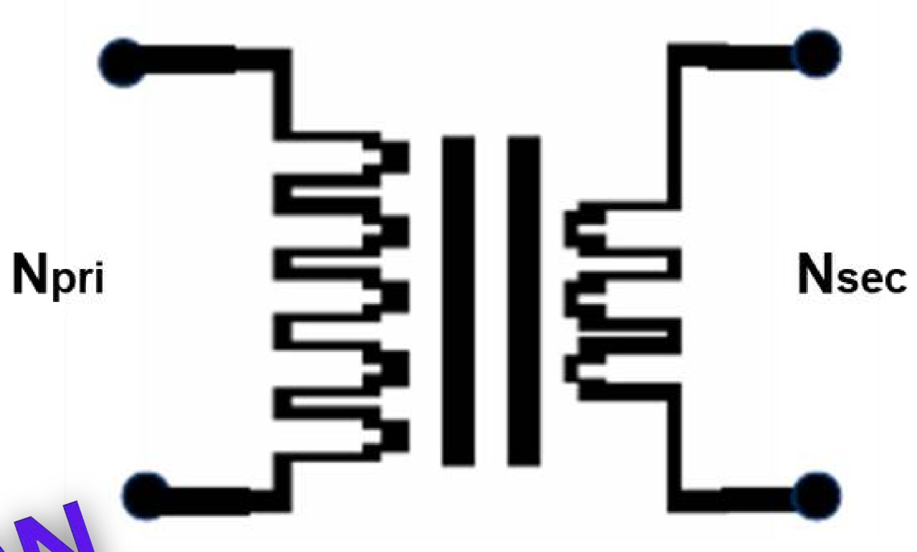
Is=(VpIp)/Vs

=(240X3)/10

=**24A**

EXERCISE 5

An ideal transformer, connected to a 240V mains, supplies a 12V, 150W lamp. Calculate the transformer turns ratio and the Current taken from the supply.



SOLUTION

Given: P=150W, Vs=12V, Vp=240V

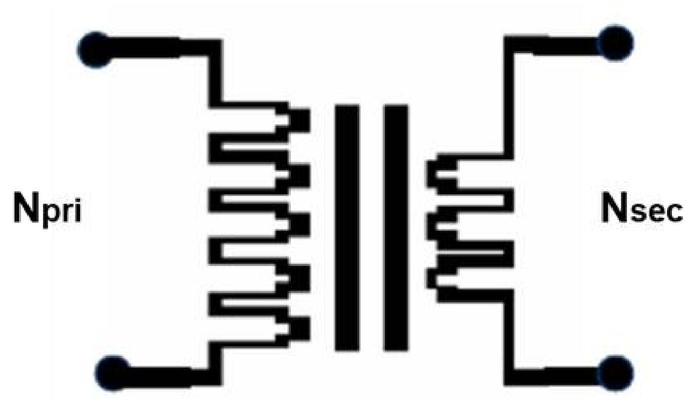
P=IsVs
Is=P/Vs
= 150/12
=12.5A

Turns, N= Vp/Vs
=240/12
=20

:- Ip = (Vs X Is)/Vp
=(12 X 12.5)/240
=**0.625V**

EXERCISE 6

A 12Ω resistor is connected across the secondary winding of an ideal transformer whose secondary voltage is 120V. Determine The primary voltage if the supply current is 4A.



SOLUTION

Given: $R = 12\Omega$, $V_s = 120V$, $I_p = 4A$

$I_s = V_s/R$

$= 120V/12\Omega$

$= 12A$

turns, $N = I_s/I_p$

$= 12/4$

$= 3$

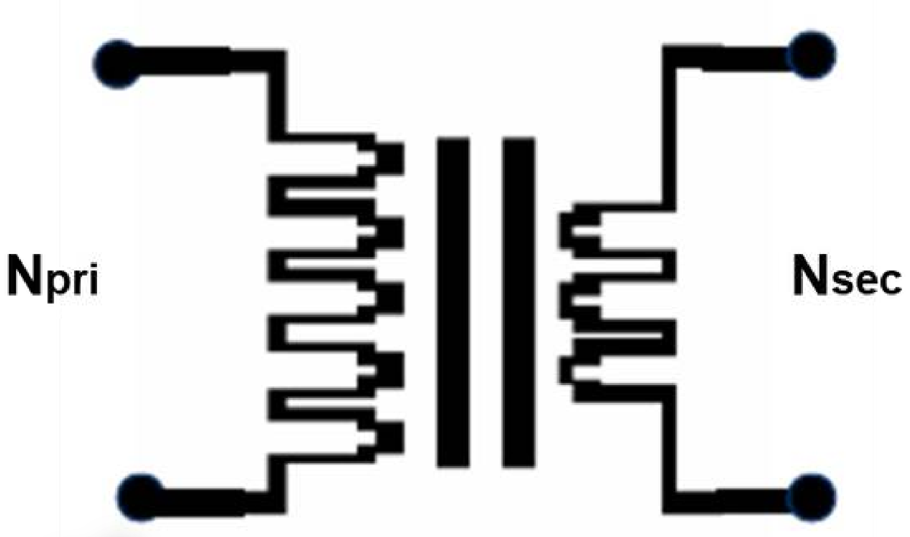
:- $V_p = (N_p/N_s) \times V_s$

$= 3 \times 120$

$=$ **360V**

EXERCISE 7

A 15Ω resistor is connected across the secondary winding of an ideal transformer whose secondary voltage is 240V. Determine The primary voltage if the supply current is 8A.



SOLUTION

Given: R= 15Ω , Vs = 240V, Ip = 8A

Is= Vs/R
= 240V/15Ω
=16A

turns, N= Is/Ip
=16/8
=2

:- Vp = (Np/Ns) X Vs
=2 X 240
=**480V**

EXERCICES 8

(a) Illustrate the parts of an ideal transformer

(b) A 50 kVA, single-phase transformer has 500 turns on the primary and 100 turns on the secondary. The primary is connected to 2500V, 50Hz supply. Calculate the following :

i) The secondary voltage on open circuit

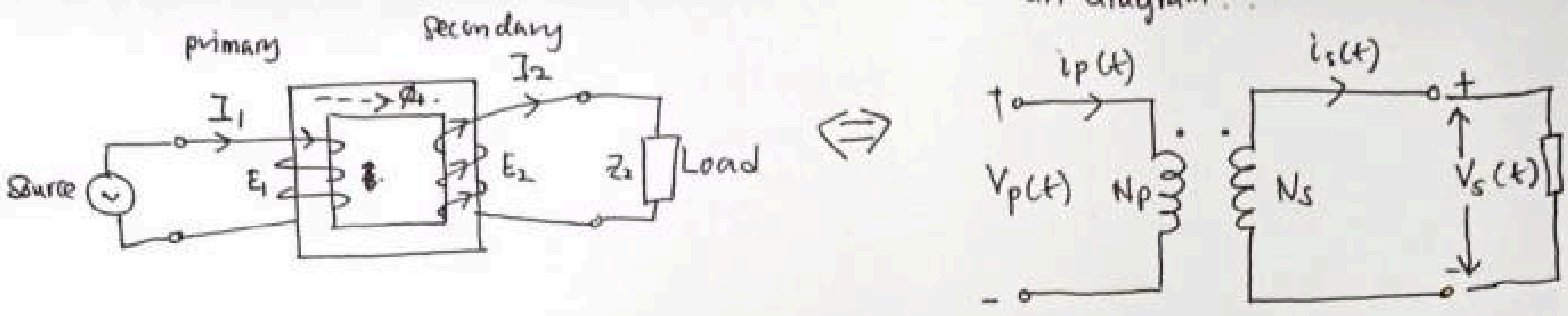
ii) The current flowing through the windings on full load, Ip and Is

iii) The maximum value of flux

SOLUTION

a) The parts of an ideal transformer

circuit diagram :



b)

given :-

power rating ; $S = 50kVA = 50000VA$

primary voltage, $V_p = 2500V$

frequency, $f = 50Hz$

primary turns, $N_p = 500$

secondary turns, $N_s = 100$

* The formula ;-

$$\frac{N_p}{N_s} = \frac{V_p}{V_s}$$

Rearrange :-

$$V_s = V_p \times \frac{N_s}{N_p}$$

Calculate :-

* $V_s = V_p \times \frac{N_s}{N_p}$

$= 2500 \times \frac{100}{500}$

$= 500V$ #

→ primary current, $I_p = \frac{S}{V_p}$

$= \frac{50k}{2500}$

$= 20A$ #

→ secondary current, $I_s = \frac{S}{V_s}$

$= \frac{50k}{500}$

$= 100A$ #

* The maximum flux is related to the primary voltage by the transformer Emf equation :-

$$E_p = 4.44 f N_p \phi_{max}$$

→ maximum flux, $\phi_{max} = \frac{V_p}{4.44 f N_p}$

$= \frac{2500}{(4.44)(50)(500)}$

$= 0.0225\ Wb$ #

EXERCICES 9

A single phase ideal transformer contains 3000 circumferences at primary coil and 800 circumferences at secondary coil. Primary coil is connected to 240VAC, 50Hz supply. Calculate:

i) Secondary voltage

ii) Current on secondary coil if the current on primary coil is 5A.

iii) Transformer power on primary and secondary coils

SOLUTION

Given:-

$N_p = 3000$

$N_s = 800$

$V_p = 240\ VAC$

$f = 50\ Hz$

$I_p = 5A$

formula:-

$\Rightarrow \frac{N_p}{N_s} = \frac{V_p}{V_s}$

$V_s = V_p \times \frac{N_s}{N_p}$

$\Rightarrow V_p I_p = V_s I_s$

Calculations:-

i. Secondary voltage, $V_s = V_p \times \frac{N_s}{N_p}$

$= 240 \times \frac{800}{3000}$

$= 64\ V$

ii. Secondary current, $I_s = \frac{V_p I_p}{V_s}$

$= \frac{(240)(5)}{64}$

$= 18.75A$

iii) Transformer power on ~~power~~ primary and secondary coils:-

$P_{pri} = I_p V_p$

$= (5)(240)$

$= 1200\ Watt$

$P_{sec} = I_s V_s$

$= (18.75)(64)$

$= 1200\ Watt$

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ELECTRICAL
TRANSFORMER

Understanding Transformers:
A Student Reference

Transformers are critical components in electrical systems, facilitating the efficient transmission and distribution of electricity. As technology evolves, so too do the demands placed on these devices, making it imperative for aspiring engineers to grasp their underlying principles and operational nuances.
This book aims to equip you with the tools and understanding necessary to navigate the complexities of electrical transformers either for the student embarking on your journey in electrical engineering or a professional seeking to refresh their knowledge.