Unit-III

1. What is dynamically induced emf and statistically induced emf?. Write the relation between turns ratio, voltage ratio and current ratios in transformer.

[redacted]

2. Explain Faraday's laws and Lenz's law. What is magnetic hysteresis explain with the help of B-H curve.
3. Write short notes on Auto transformer.
4. Write short notes on Open circuit and Short circuit tests on Transformer. Derive the expression for Efficiency and Voltage regulation of Transformer.
5. Define slip. Mention various applications of three phase induction motor.
6. Explain the construction of three phase Induction motor. Compare squirrel cage and slip ring induction motor.
7. Explain the construction of 1-phase transformer. Explain principle of operation of transformer on no load and ON load.
8. Explain in detail about the ideal transformer and draw its phasor diagram. Draw the exact equivalent circuit of transformer referred to primary.
9. a) Explain how rotating magnetic field is produced in three phase induction motor.
   b) Explain working principle of 3-phase Induction motor.
10. a) Why starter required for 3-phase induction motor and explain any one starting method for 3-phase induction motor with a neat diagram.
    b)Draw and explain Torque- Speed curve for 3-phase Induction motor.

Unit-IV

1)

Q. What is Dynamically and Statically Induced EMF? Write the relation between turns ratio, voltage ratio and current ratio in a transformer.

Electromagnetic Induction:

When a conductor experiences a changing magnetic field, an EMF (electromotive force) is induced in it. This is called **electromagnetic induction,** and it is of two types:

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1. Types of Induced EMF:

A) Dynamically Induced EMF:

- Occurs when the **conductor moves and cuts through magnetic field lines.**
- Used in **generators.**
- EMF is given by:

$$e = B \cdot l \cdot v \cdot \sin\theta$$

B) Statically Induced EMF:

- Occurs when the conductor is **stationary,** but the **magnetic field changes** around it.
- Used in **transformers.**
- EMF is given by:

$$e = -N \cdot \frac{d\phi}{dt}$$

2. Write the Relation Between Turns Ratio, Voltage Ratio, and Current Ratio in a Transformer.

A **transformer** works on the principle of **mutual induction** and is used to step up or step down voltage and current.

Let:

- N_1 = Number of turns in primary coil
- N_2 = Number of turns in secondary coil
- V_1 = Voltage across primary
- V_2 = Voltage across secondary
- I_1 = Current in primary
- I_2 = Current in secondary

Turns Ratio (n):

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

Voltage Ratio:

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

> Secondary voltage **is proportional** to the number of turns.

Current Ratio:

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

> Current is **inversely proportional** to the number of turns.

Summary Table:

Quantity	Formula
Turns Ratio	$\frac{N_2}{N_1}$
Voltage Ratio	$\frac{V_2}{V_1} = \frac{N_2}{N_1}$
Current Ratio	$\frac{I_2}{I_1} = \frac{N_1}{N_2}$

Q2. Explain Faraday's Laws and Lenz's Law. What is Magnetic Hysteresis? Explain with the help of B-H Curve.

1. Faraday's Laws of Electromagnetic Induction

Faraday gave two important laws that explain how EMF is induced in a conductor.

First Law:

- Whenever there is a **change in magnetic flux** linked with a conductor, an **EMF is induced**.
- If the conductor circuit is closed, a **current flows**.

Second Law:

- The **magnitude of induced EMF** is directly proportional to the **rate of change of magnetic flux**.

$$e = -N \cdot \frac{d\phi}{dt}$$

- e: induced EMF
- N: number of turns
- $\frac{d\phi}{dt}$: rate of change of flux
- Negative sign shows direction (Lenz's law)

2. Lenz's Law

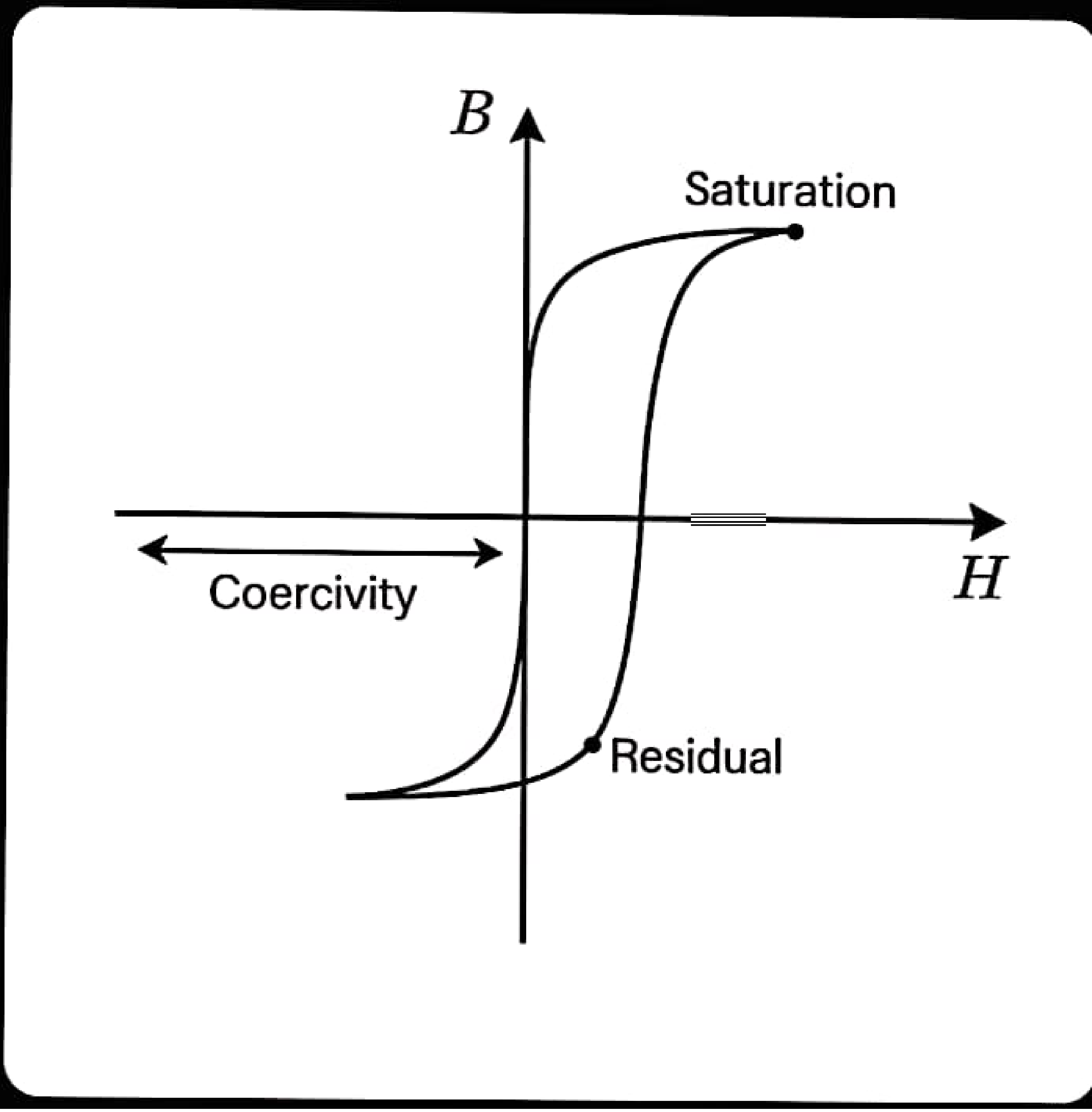
- Lenz's law gives the **direction** of the induced EMF.
- It states:
  The direction of the induced EMF is such that it ***opposes the cause*** *that produces it* (i.e., the change in magnetic flux).
- This is why we have a **negative sign** in Faraday's second law.

3. Magnetic Hysteresis

When a magnetic material like **iron** is magnetized and demagnetized repeatedly, it does not return to its original state immediately. This lagging effect is called **magnetic hysteresis**.

B-H Curve (Hysteresis Loop):

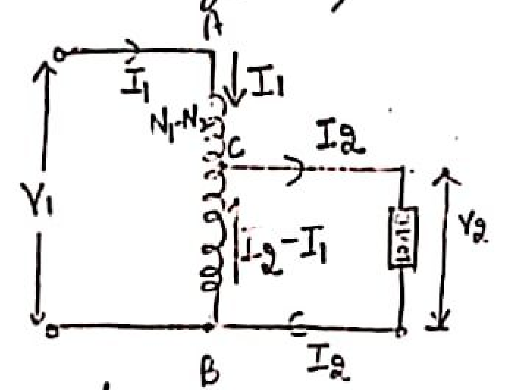
- **B** = Magnetic flux density
- **H** = Magnetizing force
- When you apply and then remove magnetic field **H**, the **B value** does not go back to zero immediately.
- The material retains some magnetism. This is called **retentivity**.
- To make **B = 0**, a reverse **H** is needed. This is called **coercivity**.
- The area inside the B-H loop = **energy loss** due to hysteresis.


B
Saturation
H
Coercivity
Residual

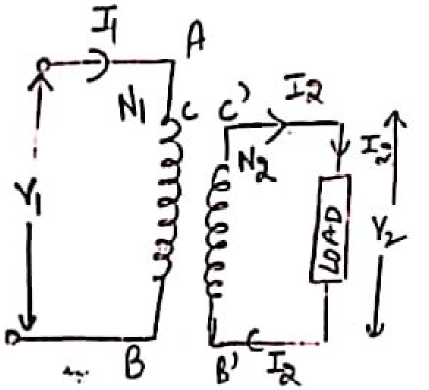
3) Auto transformer (9)

The operating principle and general construction of an auto transformer is same as that of conventional two wdg transformer.

(A transformer which has part of winding common to both primary and secondary circuits is called an auto transformer)



Auto Transformer



Conventional 2 winding transformer

Primary wdg. AC I_1 current flow   Secondary wdg BC (I_2-I_1) flows.

Power delivered to load $= V_2 I_2$

Power in AC winding $= E_{AC} I_1 = (V_1-V_2) I_1$.

Power transformed (BC winding) $= V_2 (I_2-I_1) = V_2 I_2\left(1-\frac{I_1}{I_2}\right)$

$$= V_2 I_2 (1-K)$$

$$\text{Ratio of } \frac{\text{power transformed}}{\text{power delivered}} = \frac{V_2 I_2 (1-K)}{V_2 I_2} = 1-K$$

Power conducted directly = Power delivered − Power transformed

$$= V_2 I_2 - V_2 I_2 (1-K) = K V_2 I_2 \text{ output power}$$

Conductor material required

In an ordinary transformer wt. of conductor

As $N_1 I_1 = N_2 I_2$

$$\propto (N_1 I_1 + N_2 I_2) \propto 2 N_1 I_1$$

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In an auto transformer.

wt. of Cu ∝ wt. of copper in section AB + wt. of Cu in BC Section.

Weight of Cu in Section AB $\propto (N_1 - N_2) I_1$

" " " " section BC $\propto N_2 (I_2 - I_1)$

∴ weight of conductor in A.T $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$

Ratio of weights = $\dfrac{\text{wt. of copper in auto transformer}}{\text{wt. of copper in Two winding transformer}}$

$$= \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_1 I_1} = \frac{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}{2 N_1 I_1}$$

$$= \frac{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}{2 N_1 I_1} = \frac{N_1 I_1 + N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1} = \frac{2 N_1 I_1 - 2 N_2 I_1}{2 N_1 I_1}$$

$$= \frac{2 I_1 (N_1 - N_2)}{2 N_1 I_1} = \left(\frac{N_1}{N_1} - \frac{N_2}{N_1}\right) = (1 - K) \qquad (1-K) = \frac{\text{Wt. auto}}{\text{Wt. 2wdg}}$$

∴ Saving in copper = Wt_{2wdg} − Wt. auto Transformer

$= W_{2wdg} - (1-K) W_{2wdg} = K W_{2wdg}$

Advantages of auto transformer

1. Higher efficiency 2. Smaller size 3. lower cost 4. better voltage regulation.

Disadvantages of autotransformer

1. Due to common connection b/w primary and secondary both side are subject to any stress set up disturbance on either side

2. As voltage ratio of autotransformer increases the common coil is much smaller as compared with entire winding. This means that the economy gained is only a small part of transformer, therefore advantage is minimized

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3) **Q. Explain the construction, working, advantages and disadvantages of an Auto Transformer.**

1. Introduction:

An **autotransformer** is a special type of transformer where **a single winding** acts as both the primary and the secondary winding. It works on the principle of **electromagnetic induction**, just like a regular transformer.

2. Construction:

- It has **only one winding** wound on a laminated iron core.
- A part of this winding is used as the **primary**, and another part as the **secondary**.
- There is an electrical **connection between primary and secondary**, unlike in a normal transformer where the windings are completely separate.
- It may have **taps** to change voltage levels.

3. Working Principle:

- When AC voltage is applied to the primary part, a **changing magnetic field** is produced.
- This induces an **EMF** in the same coil (self-induction) and in the secondary part (mutual induction).
- Power is transferred in **two ways**:
  - **Conductively** (through direct connection of windings)
  - **Inductively** (through magnetic induction)

4. Voltage Relation:

Let:

- V_1: input (primary) voltage
- V_2: output (secondary) voltage
- N_1: primary turns
- N_2: secondary turns

Then,

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

This is the same as a normal transformer.

- Power is transferred in **two ways**:
    - **Conductively** (through direct connection of windings)
    - **Inductively** (through magnetic induction)

---

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

This is the same as a normal transformer.

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5. Advantages of Auto Transformer:

- **Cheaper** (less copper and iron needed)
- **Smaller size and weight**
- **Higher efficiency** (less copper loss)
- **Better voltage regulation**

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6. Disadvantages:

- No **electrical isolation** between primary and secondary (dangerous in some cases)
- Not suitable for **high voltage** applications
- Fault in secondary may directly affect the primary

---

7. Applications:

- Starting induction motors
- As voltage regulators
- Audio systems
- Railway traction systems

Q4) Write short notes on Open Circuit and Short Circuit Tests on Transformer. Derive the expression for Efficiency and Voltage Regulation of Transformer.

1. Open Circuit Test (OC Test):

- **Purpose:** To determine **iron loss** and **no-load parameters**.
- **Procedure:**
  - Conducted on **LV side**, keeping **HV side open**.
  - Instruments: voltmeter, ammeter, wattmeter on LV side.
  - Apply rated voltage using a variac.
- **Readings:**
  Voltage V_0, current I_0, power W_0
- **Results:**
  - **Iron loss =** W_0
  - **Power factor =** $\cos\phi_0 = \frac{W_0}{V_0 I_0}$

2. Short Circuit Test (SC Test):

- **Purpose:** To find **copper loss** and **equivalent impedance**.
- **Procedure:**
  - Conducted on **HV side**, with **LV side short-circuited**.
  - Apply low voltage to get full-load current.
- **Readings:**
  Voltage V_{sc}, current I_{sc}, power W_{sc}
- **Results:**
  - **Copper loss =** W_{sc}
  - **Impedance =** $Z_{eq} = \frac{V_{sc}}{I_{sc}}$

3. Efficiency of Transformer:

$$\eta = \frac{\text{Output}}{\text{Output} + \text{Losses}} = \frac{V_2 I_2 \cos\phi}{V_2 I_2 \cos\phi + P_i + P_c}$$

At **x-load**:

$$\eta = \frac{x V_2 I_2 \cos\phi}{x V_2 I_2 \cos\phi + P_i + x^2 P_c}$$

Where:

- $P_i =$ Iron loss (from OC test)
- $P_c =$ Full-load copper loss (from SC test)

- **Results:**
    - **Iron loss** = W_0
    - **Power factor** = $\cos\phi_0 = \frac{W_0}{V_0 I_0}$

2. Short Circuit Test (SC Test):

- **Purpose:** To find **copper loss** and **equivalent impedance**.
- **Procedure:**
    - Conducted on **HV side**, with **LV side short-circuited**.
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  Voltage V_{sc}, current I_{sc}, power W_{sc}
- **Results:**
    - **Copper loss** = W_{sc}
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At **x-load**:

$$\eta = \frac{x V_2 I_2 \cos\phi}{x V_2 I_2 \cos\phi + P_i + x^2 P_c}$$

Where:

- P_i = Iron loss (from OC test)
- P_c = Full-load copper loss (from SC test)

4. Voltage Regulation:

$$\%\text{Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$$

By formula:

$$\%\text{Regulation} = \frac{I_2(R_{eq}\cos\phi \pm X_{eq}\sin\phi)}{V_2} \times 100$$

- Use "**+**" for lagging and "**–**" for leading power factor.

✅ Conclusion:

OC and SC tests help calculate transformer efficiency, voltage regulation, and losses without actual load. These tests are simple and widely used in practical transformer testing.

Q5. Define Slip. Mention various applications of three-phase induction motor.

Definition of Slip:

In a three-phase induction motor, the rotor does not rotate at the same speed as the rotating magnetic field (synchronous speed). The difference in speed is called slip.

Slip (S) formula:

$$\text{Slip (S)} = \frac{N_s - N}{N_s} \times 100\%$$

Where:

- **Ns** = Synchronous speed (in RPM)
- **N** = Rotor speed (in RPM)

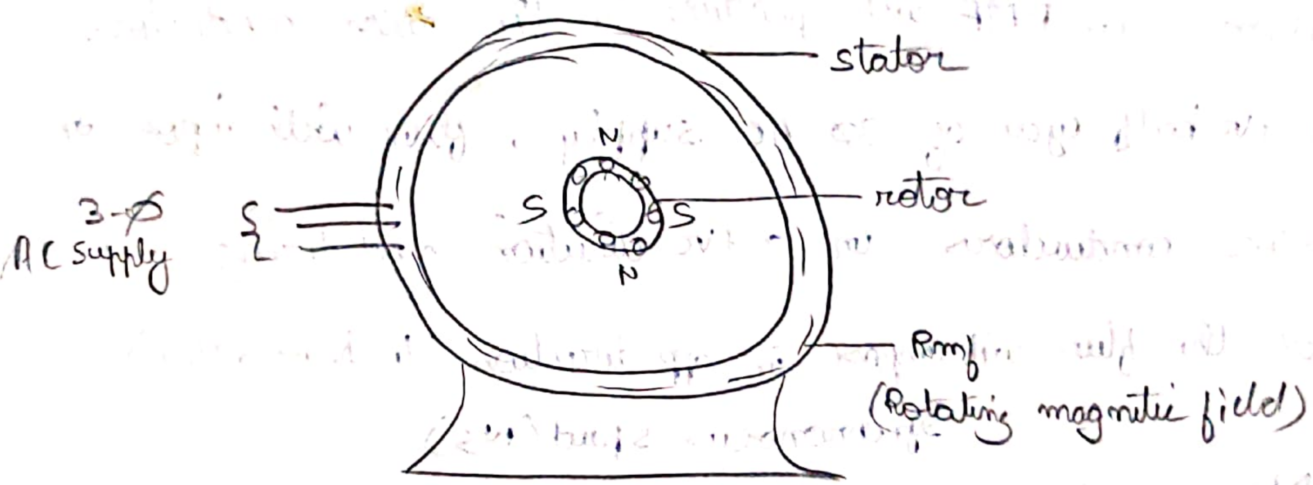
Applications of Three-Phase Induction Motor:

Three-phase induction motors are widely used due to their **simple construction, high efficiency, and low maintenance.**

Major Applications:

1. **Industrial Drives:**
   - Used in lathes, drilling machines, milling machines, and grinders.
2. **Pumps and Compressors:**
   - For water pumping, air compressors, oil pumps, etc.
3. **Fans and Blowers:**
   - Used in ventilation, air handling units, and exhaust systems.
4. **Cranes and Hoists:**
   - Employed in material handling, lifting heavy loads in warehouses.
5. **Elevators and Escalators:**
   - Provide smooth and continuous movement in multi-storey buildings.
6. **HVAC Systems:**
   - Operate compressors and blowers in air conditioning systems.
7. **Textile and Paper Industries:**
   - Run weaving machines, printing presses, and cutting machines.
8. **Agricultural Machinery:**
   - For running electric motors in tube wells, threshers, and sprayers.

4) Explain the construction and working principle of three phase induction motors



A three phase induction ~~motion~~ motor is widely used in industries due to its rugged construction, low cost and self starting capability. It operates on the principle of electromagnetic ~~industrais~~ induction

Construction

Stator

It contains a 3-ϕ winding placed in stator

Its connected to a 3-ϕ AC supply, it produces a rotating magnetic field (RMF)

-> Rotor

· Rotating part placed inside the stator

Two types

· Squirrel cage :- Copper & Alluminium bars shorted by end rings

· Slip Ring : 3-ϕ winding connected to external resistances

Working Principle

The working principle 3Ø Induction Motor, it works on the principle of mutual induction

Whenever a 3Ø AC supply is given to the stator of a 3Ø Induction Motor an alternating flux will link produce in the stator and through air gap the flux will link with the rotor conductors and acc to faraday Law of electromagnetic Induction, an EMF will produce in the rotor conductors

during +ve half cycle of 3Ø AC supply, flux will impose on the rotor conductors in a +ve direction and during -ve half cycle the flux will impose in opp direction (to the main flux)

synchronous speed (N_s)

$N_S = \frac{120f}{P}$

$N_S = \frac{120f}{P}$

N_r - Rotor Speed $= N_S(1-S)$

$N_r = N_S(1-S)$

Slip $(S) = \frac{N_S - N_r}{N_S}$

Slip Speed $= N_S - N_r$

Slip

$N_S = \frac{120f}{P}$

synchronous speed

$N_r = N_S(1-S)$

$N_S = \frac{120f}{P}$

Slip $\frac{N_S - N_r}{N_S}$

Rotor Speed $N_r = N_S(1-S)$

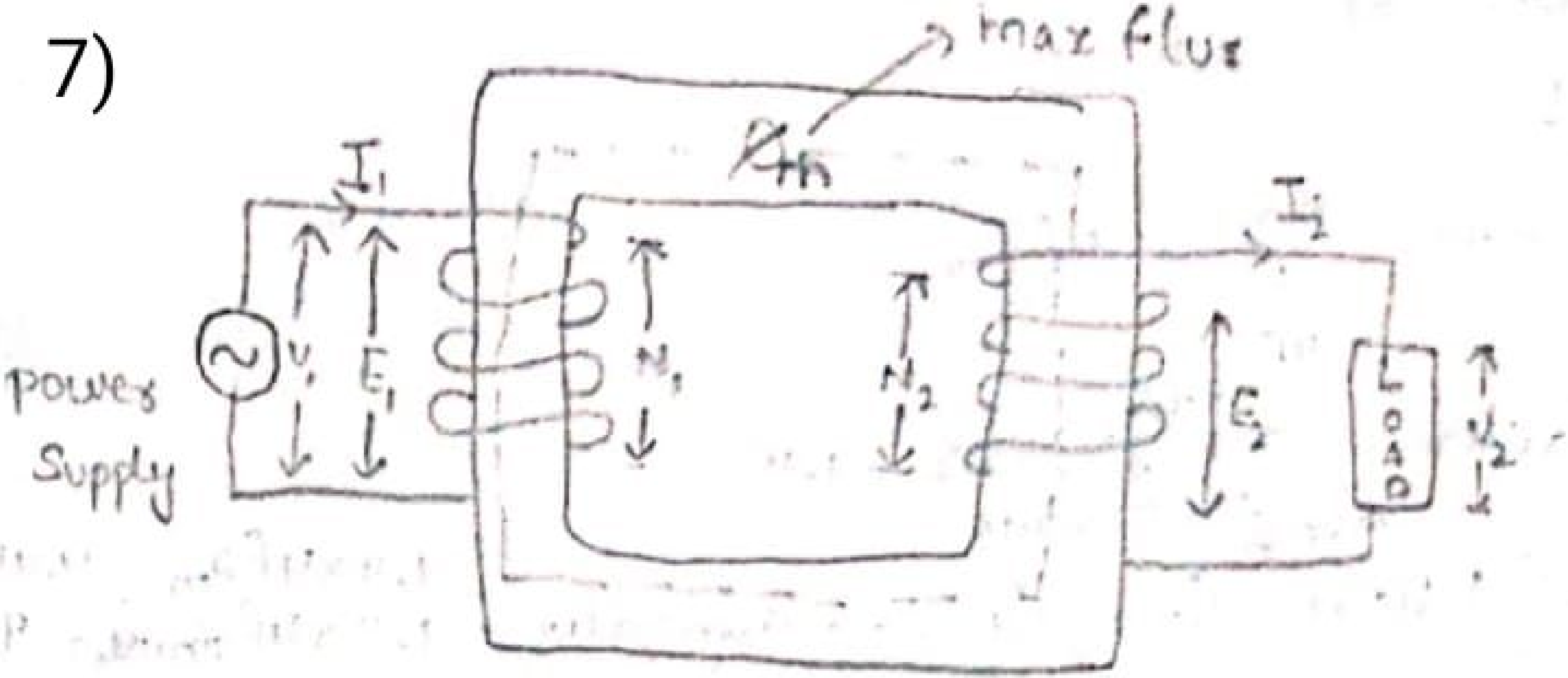
Speed $N_S - N_r$

slip $(S) = \frac{N_S - N_r}{N_S}$

slip speed $= N_S - N_r$

Feature	Squirrel Cage Induction Motor	Slip Ring Induction Motor
Rotor Type	Cylindrical with aluminum/copper bars	Wound rotor with 3-phase windings
Starting Torque	Low to moderate	High (can be controlled using resistors)
External Resistance	Not possible to add	Extra resistance can be added via slip rings
Maintenance	Low (no brushes or slip rings)	High (requires maintenance of brushes and rings)
Cost	Cheaper	More expensive
Efficiency & Robustness	High and very rugged	Slightly less due to added components
Speed Control	Difficult	Easy using rotor resistance
Applications	Fans, pumps, blowers, machines	Cranes, elevators, heavy-duty starters

7)



Transformer:- Transformer is a Static device it works on the principle of mutual Induction. It transfers the electrical energy from one circuit to another circuit without change in frequency.

Q7) Explain the construction of a single-phase transformer. Explain the principle of operation of transformer on no-load and on-load.

---

1. Construction of Single-Phase Transformer:

A single-phase transformer consists of the following main parts:

a) Core:

- Made of **laminated silicon steel** to reduce eddy current losses.
- Provides a path for magnetic flux.

b) Primary Winding:

- Connected to the **AC supply**.
- When AC flows, it produces alternating magnetic flux.

c) Secondary Winding:

- Connected to the **load**.
- Induced EMF due to mutual induction.

d) Insulation:

- Windings are insulated from each other and from the core.

e) Tank & Cooling:

- Transformers are placed in oil-filled tanks for **cooling and insulation**.

3. Transformer on No-Load:

- **Secondary is open**, so no current flows in the secondary.
- Primary draws a small current called **no-load current (I_0)**.
- I_0 has two components:
  - **Magnetizing current (Im)**: produces magnetic flux.
  - **Working current (Iw)**: supplies iron loss.
- Only **core losses (iron loss)** occur in this condition.

---

4. Transformer on Load:

- **Load is connected** on secondary side → current flows in secondary.
- According to **Lenz's Law**, secondary current creates **opposing flux**.
- To maintain the flux, **primary draws more current** from the supply.
- This results in energy transfer from **primary to secondary** via magnetic coupling.
- In this condition, **both copper loss and core loss** occur.

✅ Conclusion:

A single-phase transformer transfers electrical energy from one circuit to another with **constant frequency**, working on the principle of mutual induction. Its operation changes depending on whether it is under **no-load** or **loaded** condition.

Q8) Explain in detail about the Ideal Transformer and draw its Phasor Diagram.

1. Definition of Ideal Transformer:

An **ideal transformer** is a theoretical model of a transformer that assumes **no losses** of any kind. It helps in understanding the **basic working principle** of transformers.

2. Assumptions of an Ideal Transformer:

1. **No winding resistance** (R = 0)
2. **No core losses** (No hysteresis or eddy current loss)
3. **Perfect magnetic coupling** (No leakage flux)
4. **100% efficiency** (Power input = Power output)
5. **All input power is transferred magnetically to the secondary**

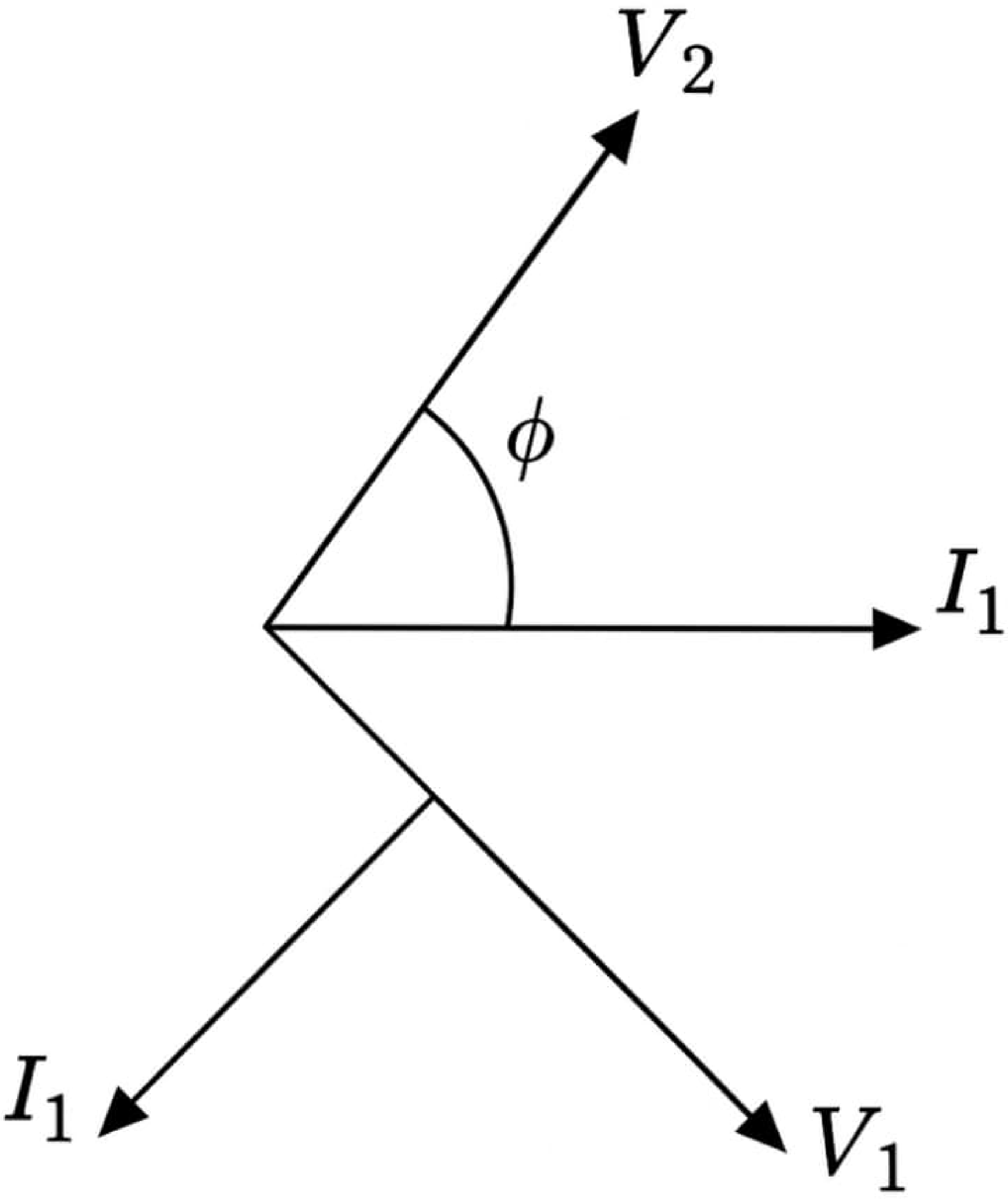
3. Working Principle:

- When **AC voltage** is applied to the **primary winding**, it creates **alternating magnetic flux** in the core.
- This flux links with the **secondary winding**, inducing an EMF by **mutual induction**.
- The ratio of voltages is directly proportional to the turns ratio:

$$\frac{E_1}{E_2} = \frac{N_1}{N_2} \quad \text{or} \quad \frac{V_1}{V_2} = \frac{N_1}{N_2}$$

- Current relationship:

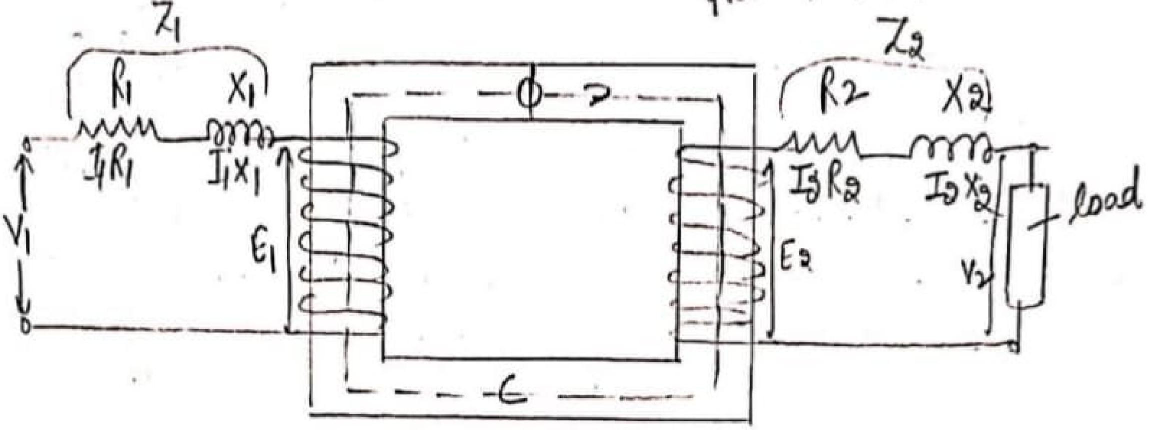
$$\frac{I_2}{I_1} = \frac{N_1}{N_2} \quad \text{or} \quad V_1 I_1 = V_2 I_2$$


V_2
ϕ
I_1
I_1
V_1

Equivalent circuit of Transformer Imp

1 Equivalent resistance and reactance

Actual/practical Transformer



Referred to primary side

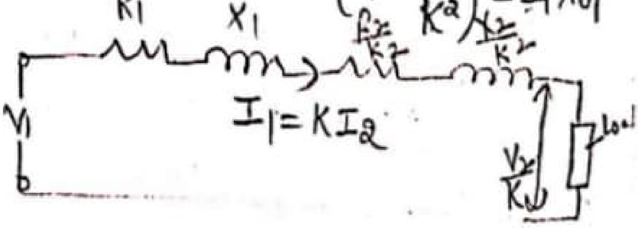
Sec Resistive drop refered to primary

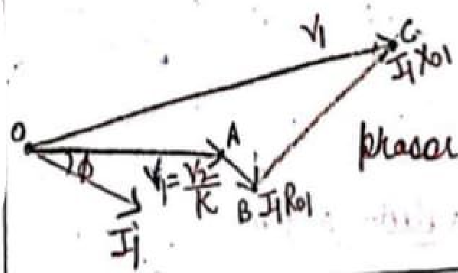
$$\frac{I_2R_2}{K} = \frac{I_1R_2}{K^2}$$

IIly reactive drop $\frac{I_2X_2}{K} = \frac{I_2X_2}{K^2}$

$\therefore$ T. Resistive drop $= I_1\left(R_1 + \frac{R_2}{K^2}\right) = I_1R_{01}$

T. Reactive drop $= I_1\left(X_1 + \frac{X_2}{K^2}\right) = I_1X_{01}$





phasor diagram

$$V_1 = \sqrt{\left(\frac{V_2}{K} + I_1R_{01}\cos\phi + I_1X_{01}\sin\phi\right)^2 + \left(I_1X_{01}\cos\phi + I_1R_{01}\sin\phi\right)^2}$$

Small

Resistive load $= V_1 = \sqrt{\frac{V_2}{K} + I_1R_{01}\cos\phi}$

Capacitive load $V_1 = \sqrt{\frac{V_2}{K} + I_1R_{01}\cos\phi - I_1X_{01}\sin\phi}$

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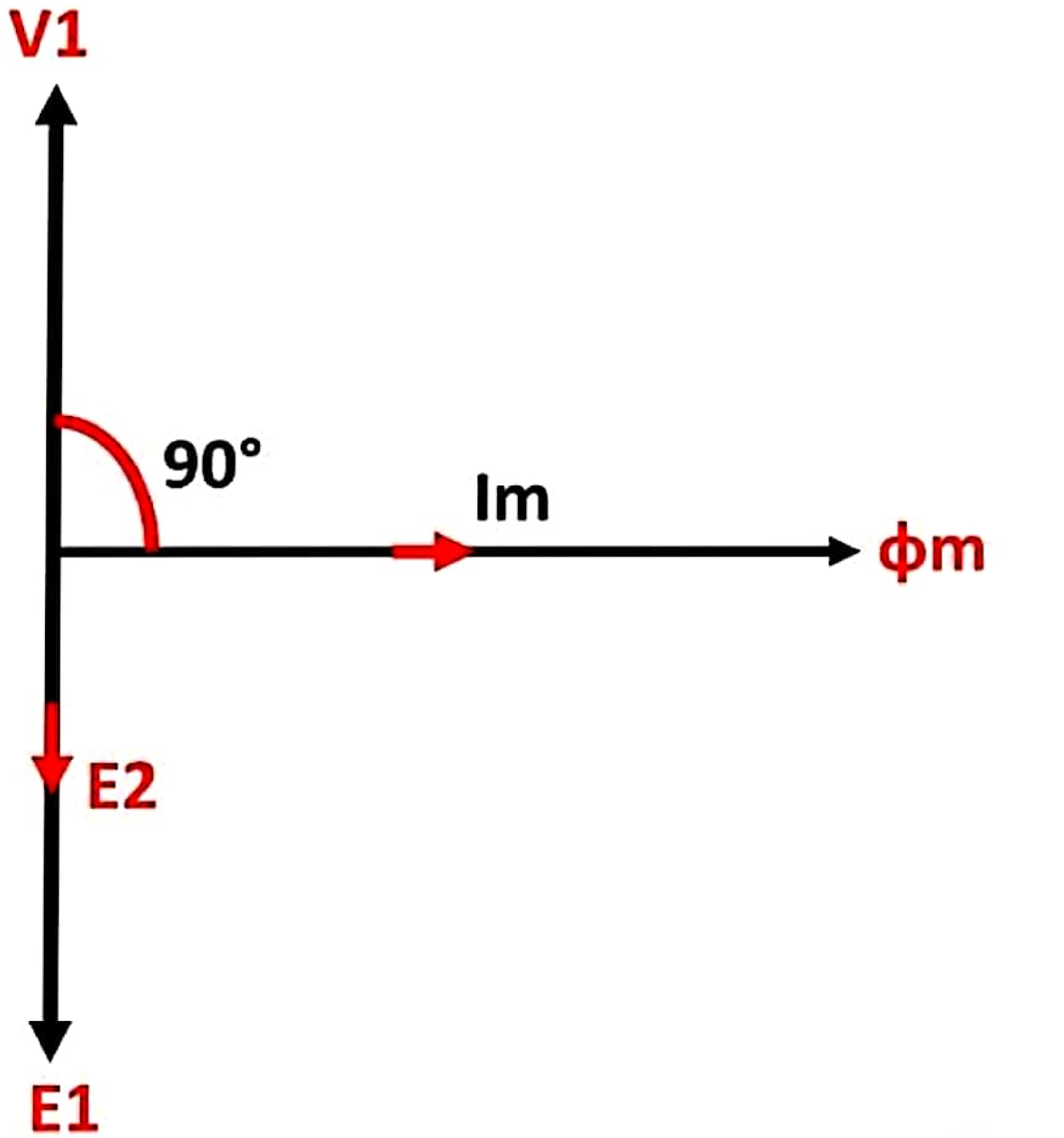
4. Phasor Diagram of Ideal Transformer:

Case: When transformer is under load with lagging power factor (inductive load):



Phasor Diagram of an Ideal Transformer

Q9)

a) How Rotating Magnetic Field is Produced in a Three-Phase Induction Motor?

- When a **three-phase AC supply** is given to the **stator winding**, three alternating currents are produced, each 120° apart in phase.
- Each phase winding produces an **alternating magnetic field**.
- These three magnetic fields **combine vectorially** to produce a **single rotating magnetic field (RMF)**.
- This RMF rotates in the air gap of the motor at **synchronous speed (Ns)**:

$$N_s = \frac{120 \times f}{P}$$

Where:
f = frequency (Hz),
P = number of poles

b) Working Principle of Three-Phase Induction Motor:

- Based on **Faraday's Law** and **Lorentz Force Principle**.
- The **rotating magnetic field (RMF)** cuts the **stationary rotor conductors**, inducing an **EMF** due to electromagnetic induction.
- Since the rotor forms a closed circuit, **current flows** in the rotor.
- According to **Lenz's Law,** the rotor tries to oppose the cause (relative motion), so it **starts rotating** in the direction of the RMF.
- The rotor always rotates **slightly slower than synchronous speed** → hence the name "induction motor".

Q10)

a) Why Starter is Required for a 3-Phase Induction Motor? Explain One Starting Method with Diagram.

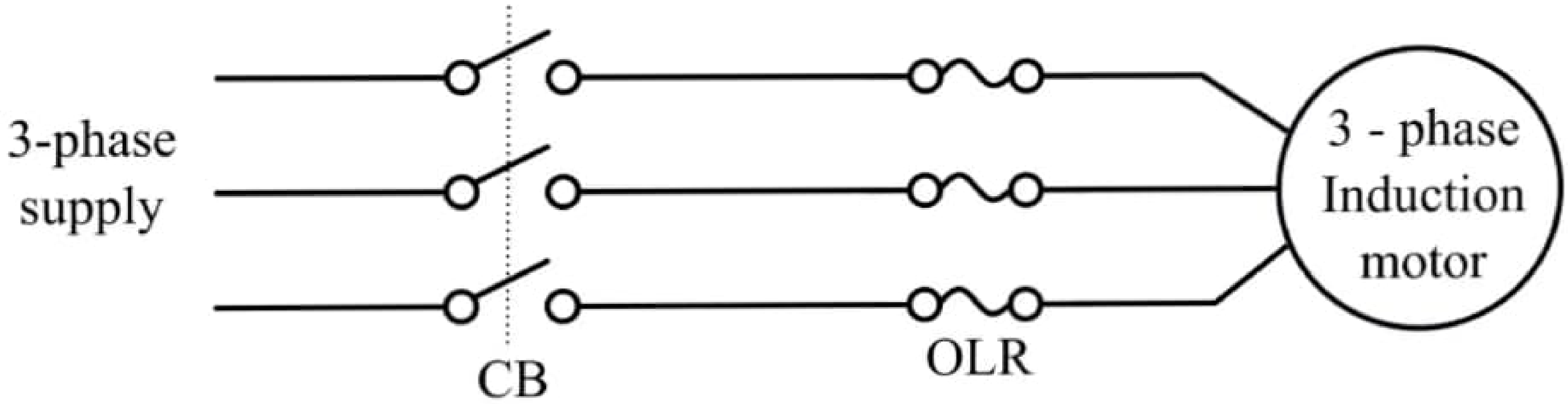
- At starting, the rotor is stationary, so the **slip = 1**.
- The motor draws **5 to 7 times** the rated current due to low rotor impedance at standstill.
- This **high starting current** can:
  - Damage windings
  - Cause voltage drops
  - Trip circuit breakers

➡ Hence, **a starter is required** to limit the starting current.

Direct-On-Line (DOL) Starter (Simple Starting Method):

- It connects the motor directly to the full line voltage.
- Suitable for **small motors (below 5 HP)**.
- Includes overload and short-circuit protection.

Diagram:



Direct On-Line (D.O.L.) Starter

b) Torque-Speed Characteristic of a 3-Phase Induction Motor:

- **Torque (T)** vs **Speed (N)** curve shows:
  - **Starting torque:** High
  - **Maximum torque (Breakdown torque):** At certain slip before full load
  - **Full-load torque:** Lower than max torque
  - **Torque drops** as speed approaches synchronous speed

Key Points on the Curve:

- Torque is **zero** at synchronous speed
- At start (0 speed), slip = 1 and torque is high
- Used to understand motor behavior under load

✅ Conclusion:

- The RMF is essential for torque production.
- A starter protects the motor from high inrush current.
- The torque-speed curve helps analyze performance and load-handling capacity of the induction motor.

causing the motor to develop more torque.

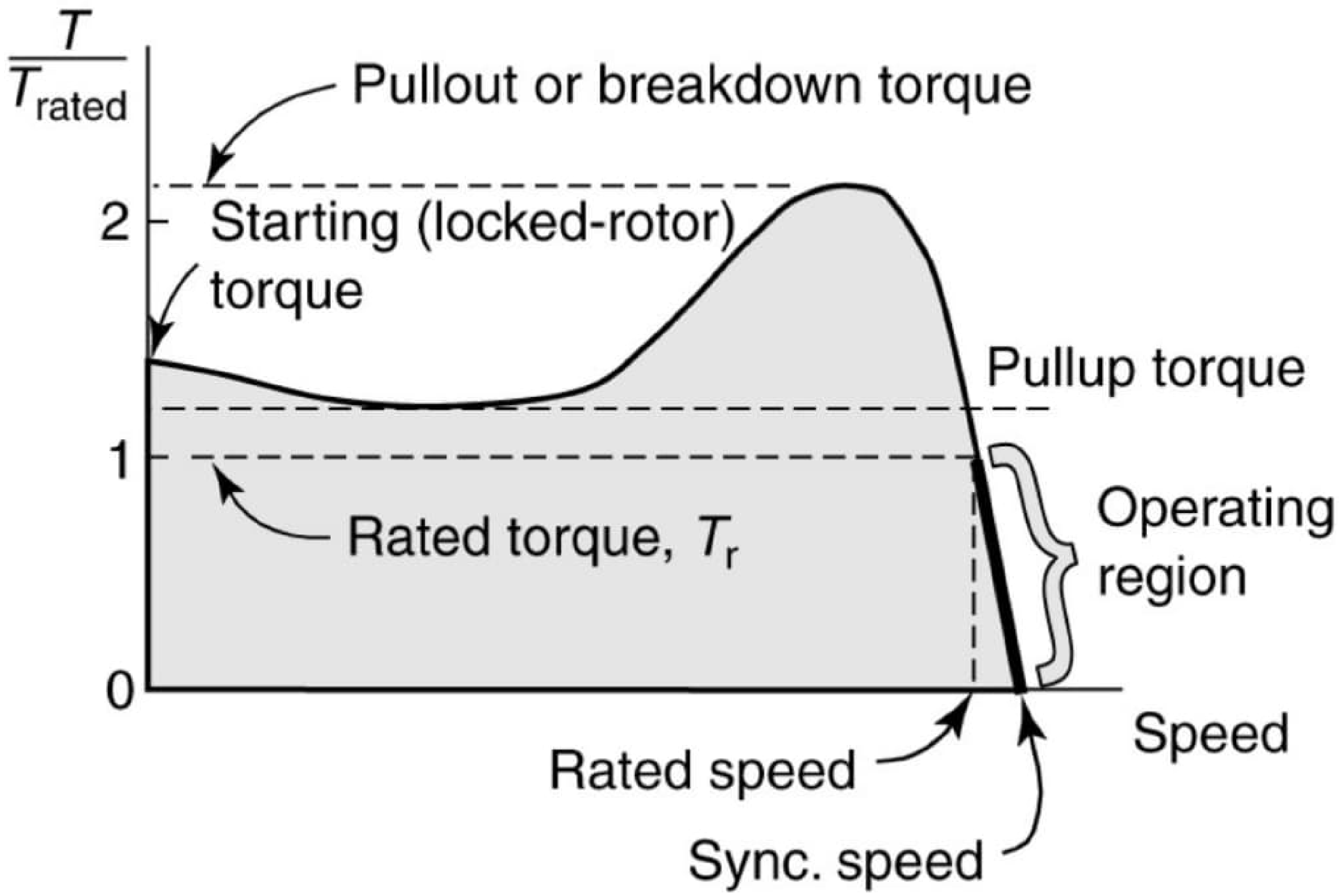


Figure 5. Induction motor torque-speed characteristic.