ELECTRIC MOTORS

3 Phase Induction Motor

A **3-phase induction motor** is a type of **AC motor** widely used in industrial and commercial applications due to its **simplicity, ruggedness, and reliability**.

⚙️ What is a 3-Phase Induction Motor?

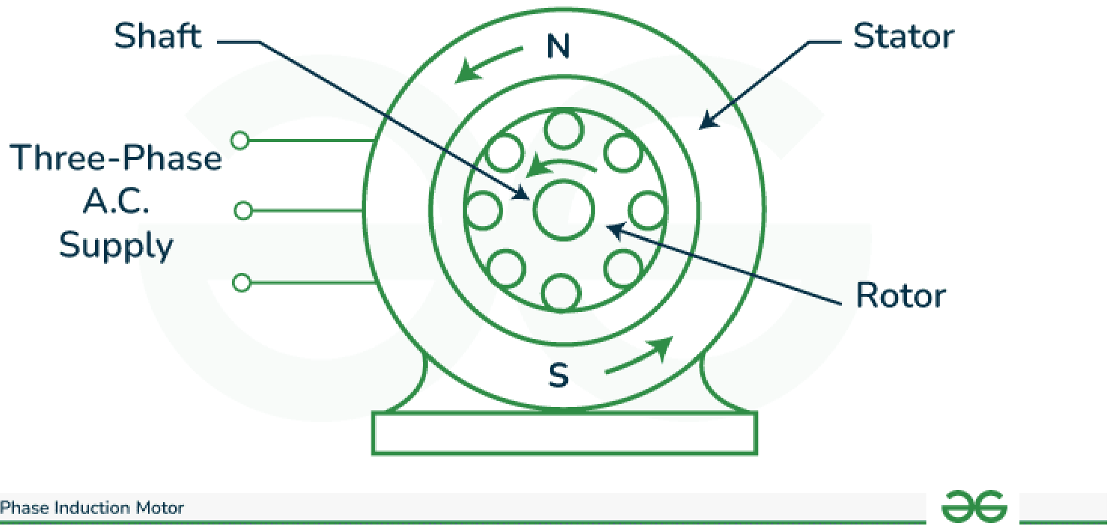
A **3-phase induction motor** is an electric motor that runs on **3-phase alternating current (AC)** and operates on the principle of **electromagnetic induction**, where the rotor current is induced by the rotating magnetic field of the stator.

Working Principle:

Based on **Faraday's Law of Electromagnetic Induction**:

1. The **stator** is supplied with **3-phase AC**, producing a **rotating magnetic field (RMF)**.
2. The **rotating field** cuts through the **rotor conductors**, inducing a current in them.
3. This **induced current** interacts with the magnetic field and **produces torque**, causing the rotor to rotate.

Note: The rotor never reaches synchronous speed; this difference is called **slip**.



Construction:

Part	Description
Stator	Stationary part with 3-phase windings; creates rotating magnetic field.
Rotor	Rotating part (either **squirrel cage** or **wound type**) where current is induced.
Slip Rings (if any)	Used only in wound rotor type.

1. Squirrel Cage Induction Motor

🔧 **Construction:**

- Rotor is made of **conductive bars** (usually aluminum or copper) placed in **slots** and shorted at both ends by **end rings** — forming a **cage-like structure** (like a squirrel cage).

⚡ **Features:**

- No brushes or slip rings
- Simple, rugged, and low-cost
- High efficiency and low maintenance

🛠️ **Applications:**

- Fans, pumps, blowers, lathes, compressors
- Most general-purpose industrial applications

2. Wound Rotor (Slip Ring) Induction Motor

🔧 **Construction:**

- Rotor has a **3-phase winding**, similar to the stator
- Connected to external resistors via **slip rings and brushes**

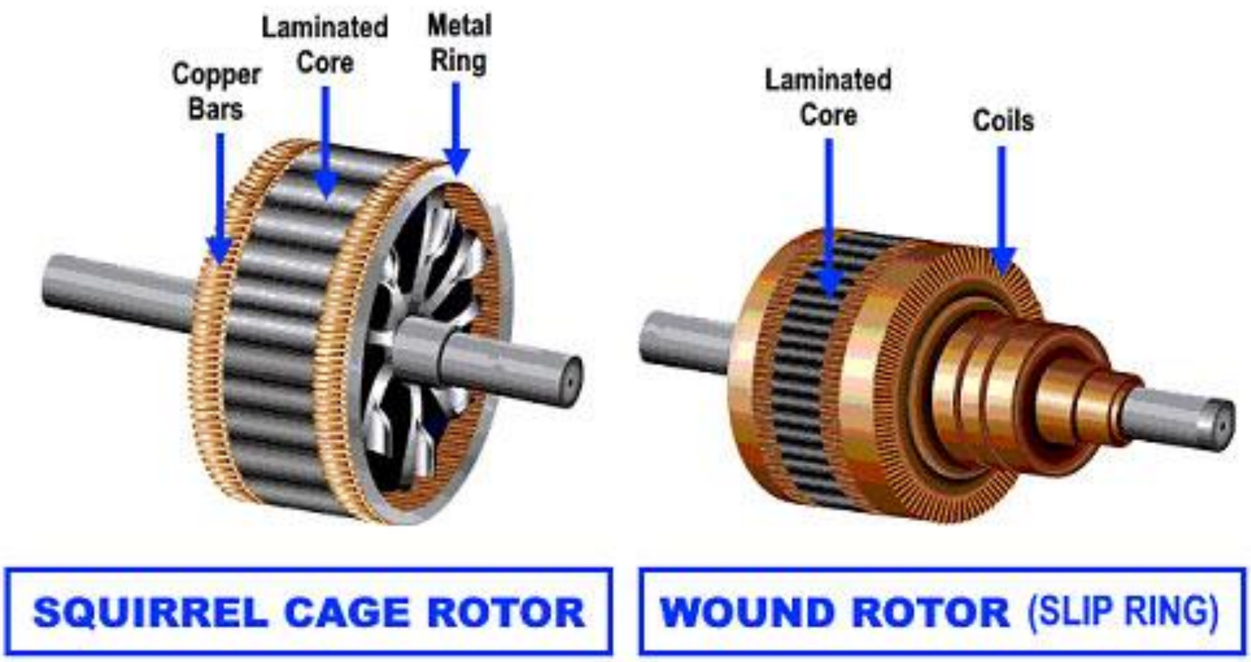
⚡ **Features:**

- Allows **external resistance control**, so better **torque control** at startup
- Higher maintenance due to brushes/slip rings

🛠️ **Applications:**

- Cranes, elevators, conveyors
- Applications requiring **high starting torque** or **variable speed**

Feature	Squirrel Cage Motor	Wound Rotor Motor
Rotor Type	Short-circuited bars	3-phase winding with slip rings
Speed Control	Difficult	Easy with external resistors
Starting Torque	Moderate	High
Maintenance	Low	High (due to brushes/slip rings)
Cost	Low	High
Applications	General-purpose loads	Heavy-duty loads requiring control



⚙️ Principle of Operation of a 3-Phase Induction Motor

A **3-phase induction motor** works on the principle of **electromagnetic induction**, specifically **Faraday's Law** and **Lorentz Force**. It is called an "induction" motor because **current is induced in the rotor** without any physical connection to a power supply.

1. Three-Phase Supply to Stator

- When a **3-phase AC supply** is given to the stator winding, it produces a **rotating magnetic field (RMF)**.
- This magnetic field **rotates at synchronous speed**:

$$Ns = 120 \times \frac{f}{p}$$

Where:

  - Ns = synchronous speed (RPM)
  - F = supply frequency (Hz)
  - P = number of poles

2. Induced EMF in Rotor

- The **rotating magnetic field** cuts the **stationary rotor conductors**.
- By **Faraday's Law**, this induces an **electromotive force (EMF)** in the rotor.

3. Current in Rotor & Torque Production

- Since the rotor circuit is closed (squirrel cage or wound), **induced EMF causes current to flow**.
- The **interaction between rotor current and stator magnetic field** produces a **Lorentz force** (Fleming's Left Hand Rule).
- This force creates a **torque**, causing the **rotor to rotate**.

4. Slip: Rotor Always Lags Behind RMF

- The rotor **never catches up** with the RMF speed, because if it did, there would be **no relative motion → no induced EMF → no torque**.
- The difference between **synchronous speed (Ns)** and **actual rotor speed (Nr)** is called **slip (S)**:

$$S = \frac{(Ns - Nr)}{Ns} \times 100\%$$

In Summary:

1. 3-phase AC supply creates rotating magnetic field (RMF) in stator
2. RMF cuts rotor conductors, inducing EMF (Faraday's Law)
3. Induced EMF causes rotor current
4. Rotor current + RMF = Torque (Lorentz Force)
5. Rotor starts rotating, always slower than stator field (slip)

1. Effect of Slip on Rotor Frequency (fr)

$$fr = S \times fs$$

2. Effect of Slip on Rotor Impedance (Zr)

Rotor impedance is:

$$Zr = \sqrt{R_r^2 + (S\,X_r)^2}$$

⚙️ Induction Motor vs DC Motor:

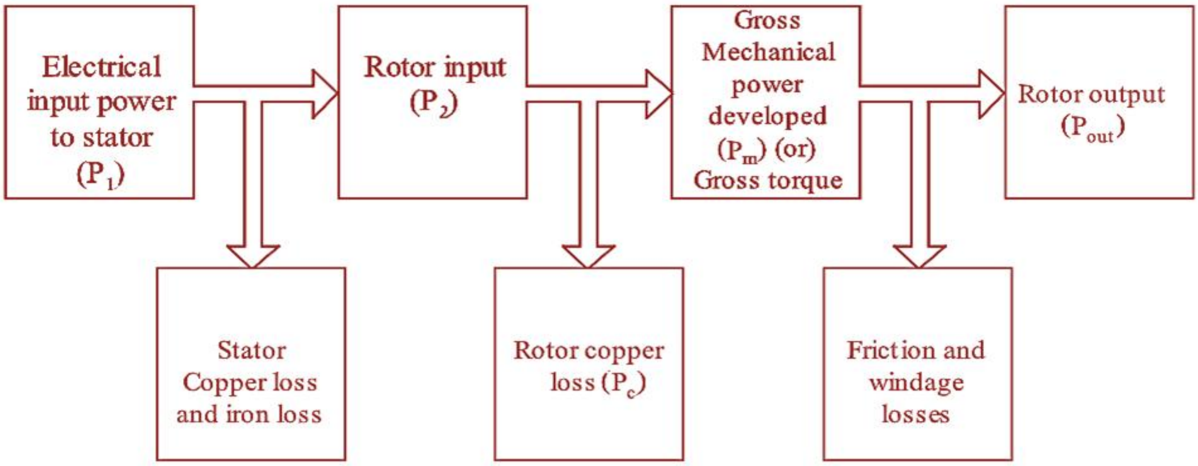
Parameter	Induction Motor (AC)	DC Motor
Definition	An AC motor in which current is **induced** in the rotor	A motor that runs on **direct current** power supply
Types	- Squirrel Cage - Slip Ring (Wound Rotor) - Single/3-Phase	- Series - Shunt - Compound
Current Input	**AC (Alternating Current)**	**DC (Direct Current)**
Commutator & Brushes	❌ **Not required** (brushless)	✅ **Required** (for commutation)
Supply Phases	- Single-phase - **3-phase (common)**	Single-phase only
Starting Mechanism	Self-starting (3-phase), needs starter for heavy loads	May need starter (series motors are self-starting)
Maintenance	✅ **Low** (no brushes/commutator)	❌ **High** (due to brushes and commutator wear)
Speed Control	❌ Difficult & complex	✅ Easy with voltage/resistance methods
Efficiency	✅ High (especially 3-phase)	Slightly lower due to brush/commutator losses
Torque Characteristics	- Moderate starting torque - High running torque (3-phase)	- Series: High starting torque - Shunt: Constant speed
Cost	✅ Lower (simple construction)	❌ Higher (more components)
Size & Weight	Generally **more compact**	Bulkier due to more components
Common Applications	- Industry: pumps, compressors, conveyors, fans - Appliances	- Electric vehicles, cranes, lifts, trains, small tools

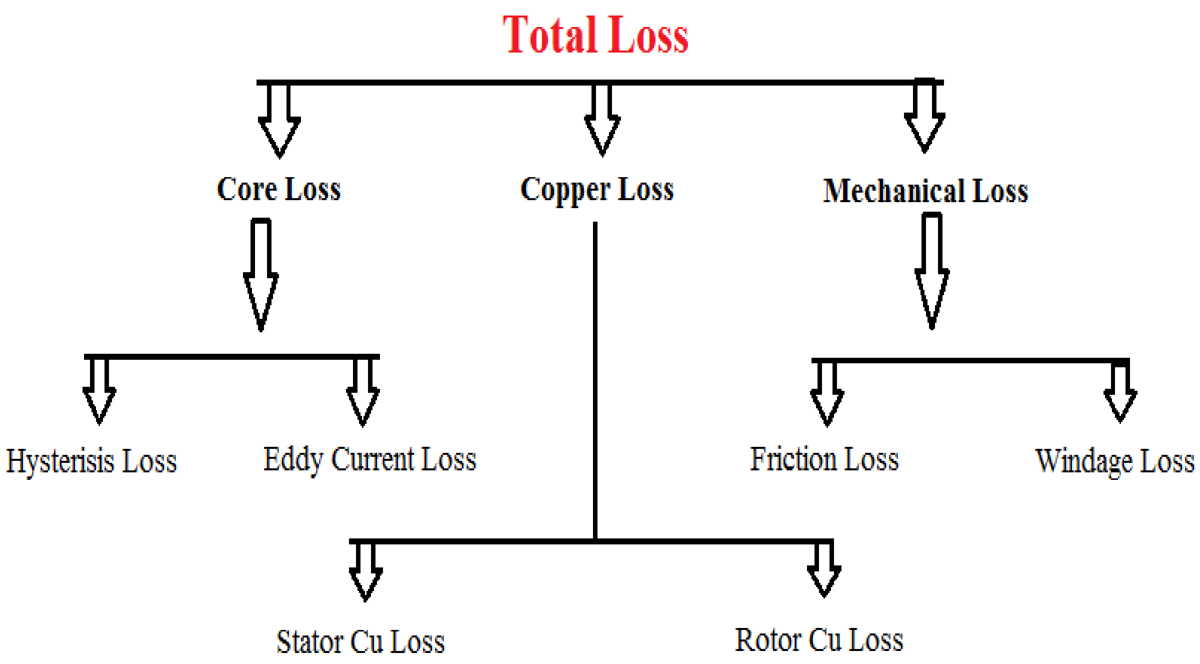
Parameter	Induction Motor (AC)	DC Motor
Speed Dependence	Depends on **frequency and slip**	Depends on **applied voltage**
Power Factor	**Lagging** (due to inductance)	**Unity** (ideal)
Starting Current	**High inrush current** at startup	Can be high, especially in series motors

📝 **Summary:**

- **Induction Motor** = Best for **industrial, rugged, continuous-duty applications**
- **DC Motor** = Best for **applications needing fine speed control or high torque**, like **electric vehicles and robotics**

Power Stages in Motor:





📃 Types of Losses in a Motor

1. Copper Losses (I²R Losses)

- **Where:** In stator and rotor windings
- **Cause:** Due to resistance in the conductors
- **Formula:**
  - DC Motor: $Pcu = I^{2R}$ (Armature & field)
  - AC Motor: $Pcu = I^{2R}$ (Stator & rotor)

📌 **Depends on current** — increases with load.

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2. Iron or Core Losses (Magnetic Losses)

- **Where:** In the stator and rotor cores (laminated iron)
- **Two types:**
  - **Hysteresis Loss**: Due to magnetization reversal
  - **Eddy Current Loss**: Due to circulating currents in the core

📌 **Depends on frequency and voltage**; reduced by laminating the core.

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3. Mechanical Losses

- **Due to:** Friction in bearings and air resistance (windage)
- **Nature:** Almost constant, independent of load

📌 Increases slightly with speed.

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4. Stray Load Losses

- **Miscellaneous losses** due to leakage flux, harmonics, etc.
- Very small and hard to measure precisely

📌 Typically 0.5–1% of the input power.

🔻 **Total Motor Losses:**

$$Total\ Loss = Copper\ Losses + Iron\ Losses + Mechanical\ Losses + Stray\ Losses$$

⚡ **Efficiency of a Motor:**

$$Efficiency(\%) = \frac{Input\ Power}{Output\ Power} \times 100$$

Where:

$$Input\ Power = Output\ Power + Total\ Losses$$

Torque Slip Characteristics: