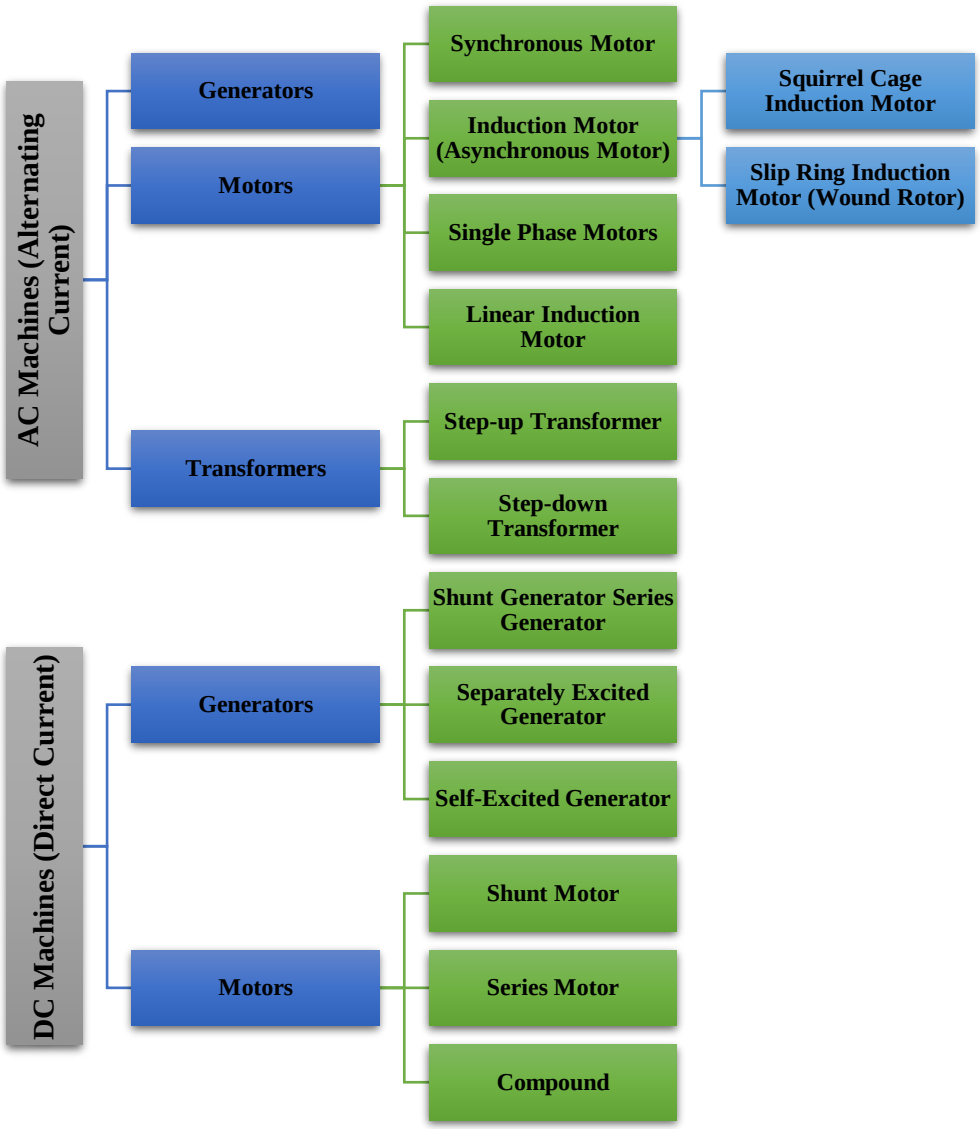
1. Introduction

Electrical machines are electromechanical energy conversion devices. They operate on the principle of **electromagnetic induction**, as formulated by Faraday. Depending on their operation mode:



2. Fundamental Principle

Michael Faraday was a self-taught scientist who approached physics through careful experimentation rather than mathematical theory. His intuitive understanding of nature led to discoveries that would later be expressed in the mathematical framework.

3. The Mathematical Statement of Faraday's Law

The induced electromotive force (EMF) in a conductor moving in a magnetic field is given by Faraday's law as shown figure 1:

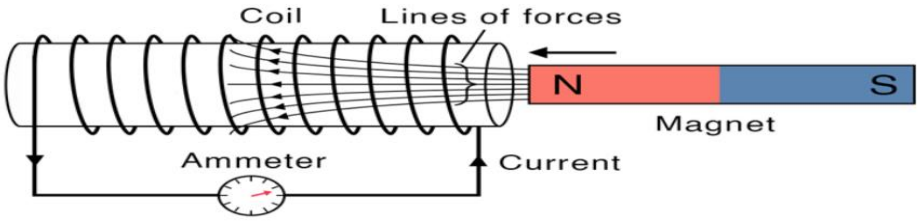


Figure 1. Faraday's low

$$\mathbf{EMF = -Nd\Phi/dt}$$

where:

- **EMF** is the electromotive force, measured in volts. Despite its name, EMF is not actually a force but rather the voltage induced in a circuit.
- **N the number of turns**
- **Φ** (phi) represents magnetic flux, which we can think of as the "amount" of magnetic field passing through a surface.
- **dΦ/dt** is the rate of change of magnetic flux with respect to time.

- The negative sign embodies Lenz's Law, which we'll discuss shortly.

The magnetic flux itself is defined as:

$$\Phi = B \times A \times \cos(\theta)$$

Where B is the magnetic field strength, A is the area of the loop, and θ is the angle between the magnetic field and the normal to the surface.

Ex.: A bar magnet moves through a 100-turn coil with cross-sectional area of 0.01 m^2, magnetic field change: $\Delta B = 0.5$ T to 0 T and time taken: $\Delta t = 0.2$ seconds

Solution:

- Initial flux: $\Phi_1 = B_1 \times A = 0.5 \times 0.01 = 0.005$ Wb
- Final flux: $\Phi_2 = B_2 \times A = 0 \times 0.01 = 0$ Wb
- Change in flux: $\Delta\Phi = \Phi_2 - \Phi_1 = -0.005$ Wb
- **Induced EMF = $-N \times (\Delta\Phi/\Delta t) = -100 \times (-0.005/0.2) = 2.5$ V**

4. Main Constructional Parts of Electrical Machines

Electrical machines consist of main parts as shown figure 2.:

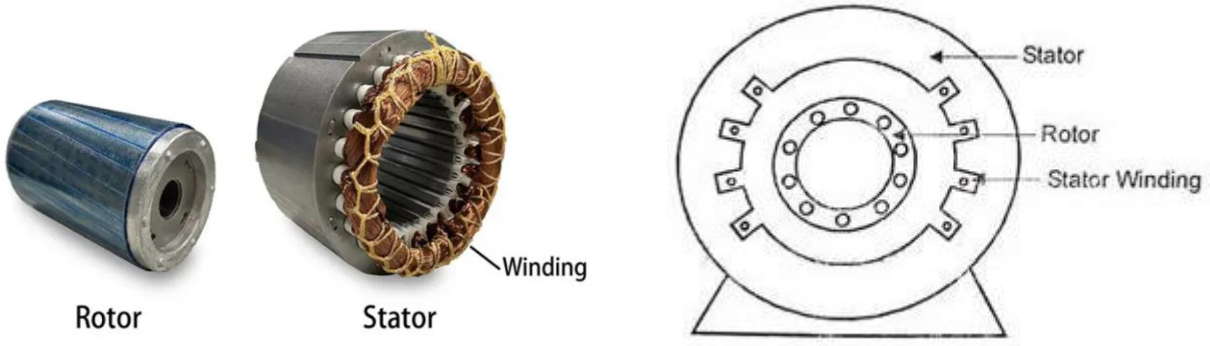


Figure 2. The main parts of electrical machines

1. **Stator (Stationary part):**
   - Provides support and protection.
   - Contains slots for windings.
   - Made of laminated silicon steel to reduce eddy current losses.
2. **Rotor (Rotating part):**
   - Mounted on the shaft with bearings.
   - Contains conductors or windings.
3. **Air Gap (g):**
   - Small clearance between stator and rotor.
   - Determines magnetic coupling and reluctance:

The fundamental equation for magnetic reluctance in an air gap:

$$R = L / (\mu_0 \times A)$$

Where:

- R = magnetic reluctance ($A^{-1} \cdot Wb^{-1}$)
- L = air gap length (m)
- μ_0 = permeability of free space = $4\pi \times 10^{-7}$ H/m
- A = cross-sectional area (m^2)

Magnetic Field in Air Gap

$$H = B / \mu_0$$

$$B = \mu_0 \times H$$

Where:

- H = magnetic field intensity (A/m)
- B = magnetic flux density (T)

Ex.: find Air Gap Reluctance of motor with, air gap length 0.8 mm, rotor diameter: D = 150 mm, and air gap area: A = 0.0942 m^2

Solution:

$$R_{gap} = L/(\mu_0 \times A)$$

$$R_{gap} = (0.8 \times 10^{-3})/(4\pi \times 10^{-7} \times 0.0942)$$

$$R_{gap} = 6.76 \times 10^6 \text{ A·t/Wb}$$

5. Auxiliary Components

- **Windings:**

  Copper or aluminum conductors.
- **Commutator (DC Machines):**

  Converts alternating induced EMF into direct current.
- **Slip Rings (AC Machines):**

  Provide external connections to rotor windings.
- **Bearings:**

  Support the shaft for smooth rotation.
- **Cooling System:**

  Fans or ducts for heat dissipation.

6. Energy Conversion Equation

The electromagnetic torque (Te) developed in a machine is expressed as:

$$T_e = P_{gap} / \omega_m$$

Where:

$Pgap$ = air-gap power (W),

ω_m = mechanical angular speed (rad/s).

Air-gap power is related to the interaction between flux and current:

$$P_{gap} = 3 \times E \times I \times \cos\varphi$$

Where E = induced EMF, I = current, and ϕ = power factor angle.

7. Materials Used

- **Core:** Laminated silicon steel (minimizes eddy currents).
- **Windings:** High-conductivity copper.
- **Frame:** Cast iron or mild steel.
- **Insulation:** Mica, epoxy resin, or varnish (for high thermal stability).