CHAPTER 14

ELECTROMAGNETIC INDUCTION

1. Flux Linkages = $N\phi$

2. $\mathcal{E} = -N \frac{\Delta\phi}{\Delta t}$ → Faraday's Law

3. Motional emf:

$$\mathcal{E} = vBl \sin\theta$$

4. Self-Inductance:

$$\mathcal{E} = L \frac{\Delta I}{\Delta t}$$

$$L = \frac{\mathcal{E}}{\Delta I/\Delta t}$$

L is ratio b.w induced emf and rate of change of current

$$L = \frac{N\phi}{I}$$

For a solenoid:

$$L = \mu_0 n^2 l A$$

where $n = \frac{N}{l}$

5. Emf due to mutual induction:

$$\varepsilon = N_B\left(\frac{\Delta\Phi_m}{\Delta t}\right)$$

N_B: no. of turns of coil B

$\Delta\Phi/\Delta t$: Rate of change of mutual flux

$$\varepsilon = M\frac{\Delta I}{\Delta t}$$

Mutual Inductance:

$$M = \frac{N\Phi}{I}$$

6. emf produced in AC Generator:

$$\varepsilon = NAB(\omega\sin\omega t)$$

$$\varepsilon = \varepsilon_{max}\sin\omega t$$

$$\varepsilon = \varepsilon_{max}\sin(2\pi f)t$$

7. For Transformer:

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

$$\frac{V_s}{V_p} = \frac{I_p}{I_s}$$

8. Current in motor:

$$I = \frac{(V - \varepsilon)}{R}$$

ε : Back emf

9. Efficiency of motor:

$$\eta = \frac{\text{Work done by Motor}}{\text{Energy Consumed by Motor}} \times 100\,\%$$

$$\eta = \frac{\text{Back emf}}{\text{Applied emf}} \times 100$$

* $\varepsilon = N\omega AB$ or $\varepsilon = NAB\omega$
(For Generator)

* ELECTROMAGNETIC INDUCTION

→ When the magnetic flux linking a conductor changes, an emf is induced in the conductor. This phenomenon is known as electromagnetic induction

→ The basic requirement for electromagnetic induction is the change in flux linking the conductor (or coil)

* FARADAY'S LAW OF ELECTROMAGNETIC INDUCTION

$$\varepsilon = N\frac{\Delta\phi}{\Delta t}$$

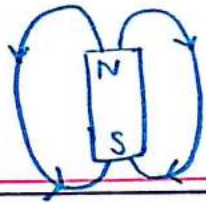
For MCQ: The time rate of change of flux has the same dimention as that of potential difference

* LENZ'S LAW

→ The induced emf always opposes the change in flux. The direction of induced emf is given by Lenz's law.

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

→ The induced current will flow in such a direction so as to oppose the cause that produces it.



* The lines of magnetic field from a bar magnet form closed lines. By convention, the field ~~line~~ direction is taken to be outward from the north pole and in to the south pole of the magnet.

→ Lenz's law is a consequence of law of conservation of energy.

The mechanical energy in overcoming the opposition is converted into electrical energy which appears in the coil

* SEISMOMETER

Types:

1. Inertial :

   Based on Newton's First Law

2. Electromagnetic :

   Based on electromagnetic induction

INDUCED EMF

→ Whenever a conductor is placed in a varying magnetic field, emf is induced in the conductor and this emf is called induced emf

1. STATICALLY INDUCED EMF

→ Conductor : stationary
→ Magnetic Field : Moving
→ Example : Transformer

2. DYNAMICALLY INDUCED EMF

→ Conductor : Moving
→ Magnetic Field : Stationary
→ Example : DC Generator

MOTIONAL EMF

→ Motional emf is voltage generated across the length of a conductor that is moving through a magnetic field
→ Dynamically induced emf

* $\varepsilon = vBl \sin\theta$

* SELF INDUCED EMF

→ example of statically induced emf
→ The phenomena in which emf induces in a coil due to its own variable magnetic field
→ The property of a coil that opposes any change in the amount of current flowing through it is called self-inductance or inductance.
(A coil is called an inductor)

→ The inductor is made by forming a coil of wire around a core.
The core may be:
1. Soft iron
2. Air

SELF- INDUCTANCE

→ If a steady current (DC) is flowing in a circuit, there will be no inductance.
→ When AC is flowing in the same circuit, the current is constantly changing and hence the circuit exhibits inductance.
→ The electrical property that resists either increase or decrease in current is known as inductance.
→ The purpose of inductor is to oppose any change in the magnitude of current in the circuit.

HOW INDUCTANCE WORK

* When current is increased:
  Self induced emf is opposite to applied voltage

* When current is decreased:
  Self induced emf is same as applied voltage

FACTORS AFFECTING INDUCTANCE

$$L = \mu_0 n^2 l A$$
$$n = N/L$$

1. Shape and Number of turns (N) $L \propto N^2$
2. Diameter of coil
3. Coil length
4. Type of material used in core i-e Relative permeability of material surrounding the coil (μ_0)
5. Rate of change of flux linking the coil ($\Delta\phi/\Delta t$)

Anything that affects magnetic field also affects inductance of coil.

* Doubling the length of coil while keeping the same number of turns halves the value of inductance

$$L \propto \frac{1}{l}$$

* SERIES COMBINATION OF INDUCTORS

$$L_e = L_1 + L_2 + L_3$$

* PARALLEL COMBINATION OF INDUCTORS

$$\frac{1}{L_e} = \frac{1}{L_1} + \frac{1}{L_2}$$

* ENERGY STORED IN AN INDUCTOR

$$E = \frac{1}{2} L I^2$$

* INDUCED EMF

$$\varepsilon = -N \frac{\Delta \phi}{\Delta t}$$

Induced current:

$$I = \frac{\varepsilon}{R} = \frac{N}{R} \frac{\Delta \phi}{\Delta t}$$

→ Magnitude of induced emf cannot be affected by resistance of the coil
(Because emf is not affected by resistance)

→ When north pole of a magnet moves towards a stationary loop, an induced current I flows in the anti clockwise sense in the loop

→ When north pole of the magnet is moved away from the loop, the current I flows in the clockwise sense in the loop.

* MUTUAL INDUCTANCE

The property of two neighbouring coils to induce voltage in one coil due to the change of current in the other is called mutual inductance.

* EDDY CURRENTS

→ The current which induces in a metal block due to a changing magnetic flux is called eddy current

→ Eddy currents are currents induced in metals moving in a magnetic field or metals that are exposed to a changing magnetic field

→ Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field.

→ The magnitude of the current in a given loop is proportional to the strength of the magnetic field, the area of the loop, and the rate of change of flux, and inversely proportional to the resistivity of the material.

→ An eddy current creates a magnetic field that opposes the change in the magnetic field that created it.

→ Eddy currents produce heat.
(The current flowing through the resistance of the conductor also dissipates energy as heat in the material)

→ Eddy currents are a cause of energy loss in AC inductors, transformers, electric motors and generators.

→ To reduce eddy currents, the solid cylinder could be replaced with a stack of 'coins' with insulation between one another. The insulation between the coins' increases resistance and reduces eddy current, thus reducing friction or heating

AC GENERATOR

* Main Parts:
  1. Pole pieces (U-shaped magnet) with concave poles
  2. Armature (Assembly of coil on iron cylinder)
  3. slip rings (as connector)
  4. Carbon brush (external supply)

$$V = V_0 \sin 2\pi ft$$
$$I = I_0 \sin 2\pi ft$$

→ The direction of induced emf and current changes every half cycle.

→ The domestic electricity supply has a frequency of 50 Hz, which means that the generator makes 50 revolutions each second.

DC GENERATOR

→ In DC Generator, split rings or commutators are used in place of slip rings.

→ DC Generator produce one-directional pulsating DC, not pure DC

→ For pure DC many coils are wound around cylindrical core.

BACK MOTOR EFFECT IN GENERATOR

→ The back motor effect is the counter torque which opposes the rotational motion of the coils in a generator when the generator is under load.

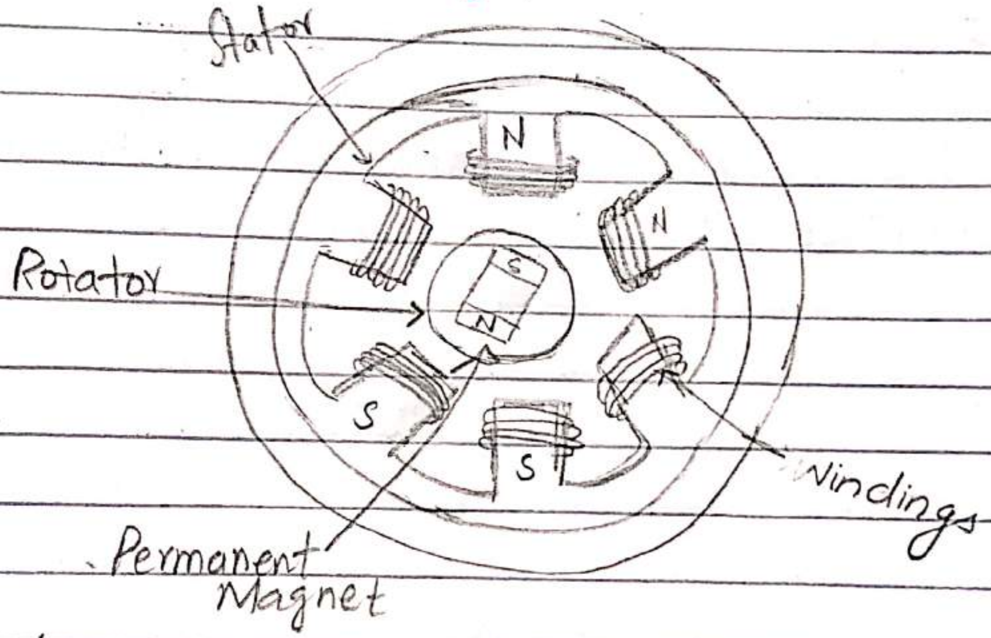
→ The back motor effect depends upon the load connected to the generator

→ The device in the circuit that consumes electrical energy is known as "load"

AC MOTOR

→ Read Topic in Book Pg 166

→ also known as induction motor bcz it is based on electromagnetic induction
→ Two Parts:
1. Stator : stationary part
2. Rotor : Rotating part



→ Stator : A group of electromagnets arraunged around cylinder with poles facing towards stator poles.
→ Rotor : located inside the stator and is mounted on the motor's shaft:
The rotor consists of coils wound on a laminated iron armature mounted on an axle.

→ The rotor coils are not connected to the external powe supply, and an induction motor has neither commutato nor brushes.

→ An induction motor is so named bcz eddy currents are induced in the rotor coils by the rotating magnetic field of the stator.

BACK EMF IN MOTORS

→ Any rotating coil will have an induced emf. In motors this is called back emf since it opposes the emf input to the motor

→ The magnitude of the back emf increases with the speed of motor

→ V and ε are in opposite polarity

$$V = \varepsilon + IR$$

→ If motor is overloaded, the back emf decreases and allows the motor to draw more current.

→ If motor is overloaded beyond the limits, the current could be so high that it may burn the motor.

→ To protect the motor at low speeds a resistor in series is switched in to the circuit to protect the coils from burning out.

TRANSFORMERS

→ A device used to transform electrical power from one voltage and current level to another.
→ makes use of AC current

→ Three main parts:
1. Two coils of wire (primary and secondary)
3. Laminated iron core connecting both wires

→ Primary coil is connected to input electrical supply (AC)

→ Principle of transformer:
1. Electromagnetism (electric current can produce a magnetic field)
2. Electromagnetic induction

→ The amount of energy cannot be stepped up or down

Step-Up Transformer:

$V_s > V_p$

$N_s > N_p$

$R_s < R_p$

$I_s < I_p$

Step - Down Transformer:

$N_p > N_s$

$V_p > V_s$

$I_s > I_p$

For Transformer:

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

$$\frac{V_s}{V_p} = \frac{I_p}{I_s}$$

* If a high voltage is required a step-up transformer is used, whereas if a high current is required a step-down transformer is used

EFFICIENCY OF TRANSFORMER

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} \times 100$$

* The long distance transmission of electrical energy is done at high potential and low current

* In Pakistan the frequency of AC is 50 Hz. The number of times the voltage reverse its direction will be : 100

* ENERGY LOSSES IN TRANSFORMERS

Energy loss in transformers occurs due to:

1. Flux Leakage
(not all the flux due to the primary passes through the secondary due to poor design of the core or the air gaps in the core)

2. Eddy Currents
3. Resistance of the windings
4. Hysteresis

* REDUCING ENERGY LOSSES

→ Flux Leakage can be reduced by winding the primary and Secondary coils one over the other.
→ In high current, low voltage windings, resistance of the windings can be minimised by using thick wire.
→ To reduce eddy currents, transformer windings are made of laminated iron, that is, many thin sheets of iron pressed together but separated by thin insulating layers.
→ Magnetic material which has a low hysteresis loss should be used.

→ The electricity first goes to a transformer at the power plant that boosts the voltage upto 400,000 volts.

→ When electricity travels long distances it is better to have it high voltages.

→ The long thick cables of transmission lines are made of copper or aluminium bcz they have a low resistance.

→ The voltage is eventually reduced to 220 volts for larger appliances and 110V for lights, TVs and other small appliances.

MCQ 2016: As a loop of wire with a resistance of 10 Ω moves in a non-uniform magnetic field, it loses K.E at a uniform rate of 4mJ/s the induced current in the loop is :

a) zero (b) 2mA (c) 2.8mA (d) 20mA ✓

Sol:-

$$P = \frac{\Delta K.E}{\Delta t} = \frac{4mJ}{s} = 4mW$$

$$P = 4 \times 10^{-3} W$$

$$P = I^2 R$$

$$I^2 = \frac{P}{R}$$

$$= \frac{4 \times 10^{-3}}{10}$$

$$= 4 \times 10^{-4}$$

$$I = \sqrt{4 \times 10^{-4}}$$

$$= 0.02A$$

$$I = 20mA$$