# Northern Technical University
# Technical Institute / Mosul
# Mechanical Techniques Department

# Electrical Technology

## The first stage

## 2020 – 2021

**Suhib Fekry Hamid**

# Chapter One

## Fundamental of Electricity

## Electrical Current:

The continuous flow of free electronic constitutes an electric current. The unit of current is ampere (A) and is measured by Ammeter. It is denoted by the letter "I".

### Ampere:

If one coulomb charge cross over the area of cross section of the conductor per one second then the value of current flows through the conductor is called 'one Ampere'.

### One Coulomb:

$2\pi \times 10^{18}$ Number of electrons is mention as one coulomb.

### Voltage:

To create the current flow in a conductor; the electrical pressure which is used to move the electrons is called voltage. It is denoted by the letter 'V'. The unit of voltage is 'volt' and is measured by voltmeter.

### One Volt:

One volt means the force to move one coulomb of electrons in one second.

### Resistance:

The property of conductor which opposes the flow of current through it is called resistance. It is denoted by the letter 'R'. The unit of resistance is ohms (Ω) and it is measured by Ohm meter.

### Ohm:

When a conductor having 1V potential between the two end points; one ampere current will flowing through the conductor and the resistance value of the conductor is 1 Ohm (Ω).

### Electric Power:

Power is defined as the product of voltage and current. Unit of power is watts and denoted by the letter "P".

$$P = V \times I \qquad watts$$

## The electrical unit:

| Quantity | Symbol | Unit | Abbreviation |
|---|---|---|---|
| Current | I | Ampere | A |
| Voltage | V | volt | V |
| Resistance | R | Ohm | Ω |
| Charge | Q | Coulomb | C |
| Power | P | watt | W |

## Engineering prefix:

| Power of 10 | Prefix | Symbol |
|---|---|---|
| $10^{12}$ | tera | T |
| $10^{9}$ | giga | G |
| $10^{6}$ | mega | M |
| $10^{3}$ | kilo | k |
| $10^{-3}$ | milli | m |
| $10^{-6}$ | micro | $\mu$ |
| $10^{-9}$ | nano | n |
| $10^{-12}$ | pico | p |

**Example-1 Express** the following in engineering prefix:

a) $10 \times 10^4$ volt. b) $0.1 \times 10^{-3}$ watts. C) $250 \times 10^{-7}$ ampere.

Solution:

a) $10 \times 10^4$ Volt $=100 \times 10^3$ V $=100\ k$V.

b) $0.1 \times 10^{-3}$ watts $=0.1 milli$watts $= 0.1$ mW .

c) $250 \times 10^{-7}$ Ampere $= 25 \times 10^{-6}$ A $=25\mu$A.

**Example-2** Convert 0.1MV to kV

Solution:

$$0.1MV = 0.1 \times 10^6\ V = (0.1 \times 10^3) \times 10^3 = 100kV$$

**Homework** : Convert 1800kV to MV

## Law of resistance:

The resistance of a conductor in a circuit depends upon the following states:

- It depends upon the material.
- Directly proportional to the length of the conductor.
- Inversely proportional to the area of the cross-section of the conductor.
- It also depends upon the temperature of the conductor.

Resistance calculation:

$$R = \rho \frac{L}{A}$$

Where:

R is the resistance (ohms)

ρ is specific resistance (resistivity) in (ohm. Meter).

L is length of the conductor (meter).

A is area of the cross section of a conductor (Sq.m).

## Specific resistance:

The resistance that is offered by one cubic cm material is called specific resistance. The following table shows the specific resistance of material:

| Materials | | Specific resistance is ohm - meter |
|---|---|---|
| Gold | - | $2.42 \times 10^{-8}$ |
| Silver | - | $1.63 \times 10^{-8}$ |
| Copper | - | $1.724 \times 10^{-8}$ |
| Aluminium | - | $2.83 \times 10^{-8}$ |
| Rubber | - | $8 \times 10^{7}$ |
| Glass | - | $10 \times 10^{11}$ |

**Example-3:** $1cm^2$ cross section 50m long copper conductor has specific resistance $1.72*10^{-8}$ Ω.cm find the resistance.

Solution:

$$L = 50m = 50 \times 100cm = 5000cm$$

$$A = 1\ cm^2$$

$$specific\ resistance = 1.72 \times 10^{-8} \Omega.cm$$

$$R = \rho \frac{L}{A} = 1.72 \times 10^{-8} \times \frac{5000}{1} = 0.0086\ \Omega$$

### Ohm's Law

A relationship was derived by the scientist Ohm; between the current; voltage and resistance of the circuit. It says;

"At a constant temperature; the current flowing through the circuit is directly proportional to the voltage and inversely proortional to the resistance".

$$\text{Current} = \frac{\text{Voltage}}{\text{Resistance}}$$

$$i.e.\quad I = \frac{V}{R}$$

$$R = \frac{V}{I}$$

$$V = I \times R$$

When the resistance of a circuit is constnt; if the voltage increases the current increases and the voltage degreases the current decreases. If any two of the three values (I; V; R) are known the third value can be easily calculated.

**Example-4**The supply voltage of the circuit is 240V and the resistance value is 12 Ω. Calculate the current flowing through this circuit.

Solution:

Voltage (V) = 240V

Resistance (R) = 12Ω

Current (I) = ?

According to Ohm's law

$$I = \frac{V}{R} = \frac{240}{12} = 20A$$

**Example-5** The supply voltage of the circuit is 230V. if 10A current is flowing through this circuit. Calculate the resistance value of the circuit.

Solution:

Voltage (V) = 230v

Current (I) = 10A

Resistance (R) = ?

According to Ohm's law

$$\mathrm{R} = \frac{\mathrm{V}}{\mathrm{I}} = \frac{230}{10} = 23\Omega$$

**Homework**: Find out the voltage of the circuit when 6A current is flowing through the circuit. Resistance of the circuit is 40Ω.

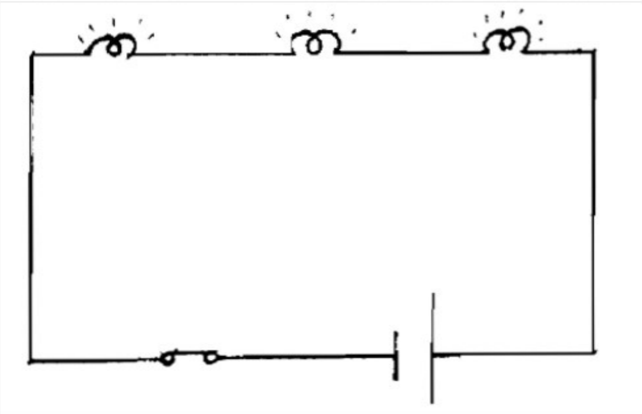
## Electrical Circuits:

The circuit is defined as; the current flows from the supply points through the load to complete path. The type of electrical circuit are:

1) Closed circuit. 2) Open circuit. 3) Short circuit.

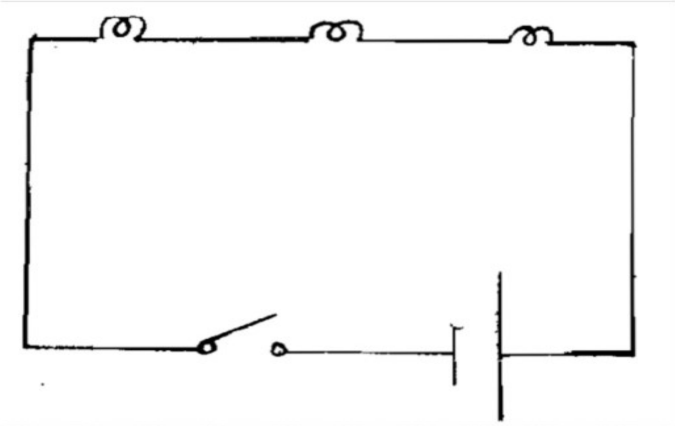
## 1. Closed circuit

When a load is connected between two terminals of an electrical supply in such away; that the current should pass through the load is said to be closed circuit.



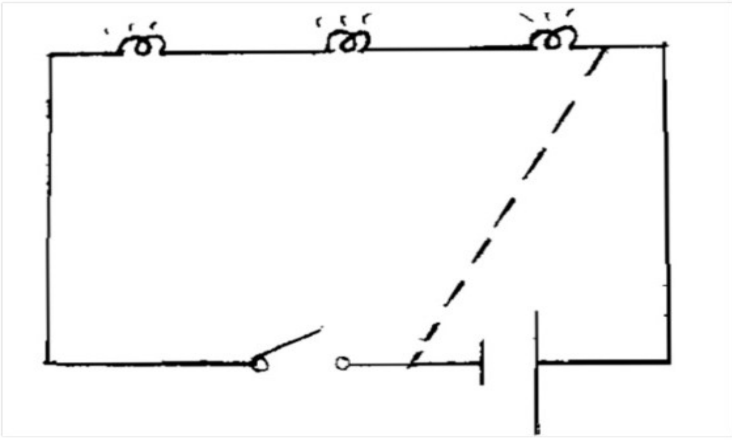
## 2. Open circuit

In a circuit if there is no way to the flow of current due to disconnection of wire or if the switch is off state; then the circuit is said to be open circuit.



### 3. Short Circuit:

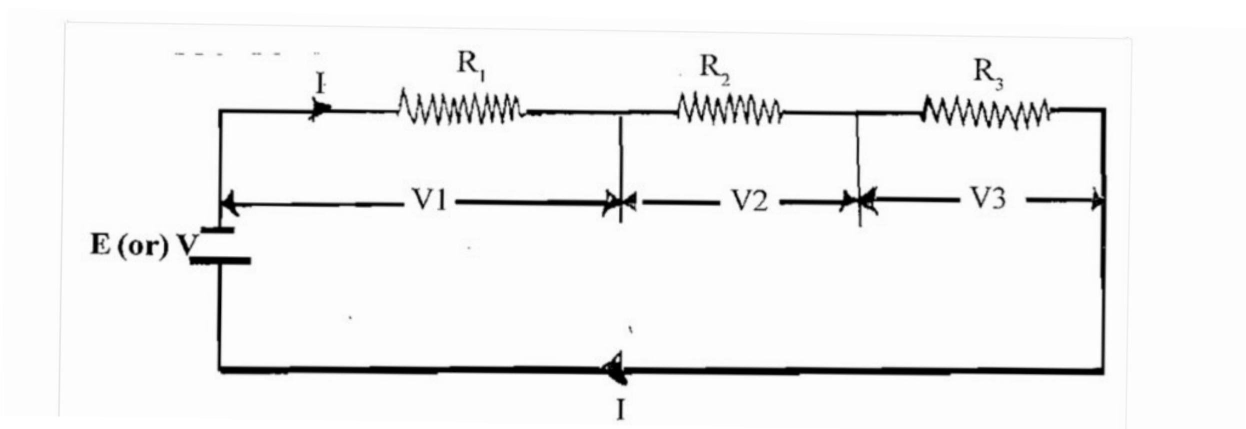
The wires contact each other when there are connected in supply; the short circuit will occurs when two terminals of the supply is connected directly without the load the current flow of the circuit is infinite because it has no resistance.



### Classification of electric circuits

1. Series Circuit.
2. Parallel Circuit.
3. Series Parallel Circuit.
4. Mesh or Network Circuit.

### 1. Series Circuit:



"I" ampere current flows in all three resistors"

Each resistor has a voltage drop across it as given by Ohm's law. Thus

$$V_1 = IR_1;\ V_2 = IR_2;\ V_3 = IR_3$$

The total drop in three resistors put together is:

$$V = V_1 + V_2 + V_3$$

$$= IR_1 + IR_2 + IR_3$$

$$= I(R_1 + R_2 + R_3)$$

$$\frac{V}{I} = R_1 + R_2 + R_3 \left[\frac{V}{I} = R\right]$$

$where\ R = R_1 + R_2 + R_3$

Voltage divider rule:

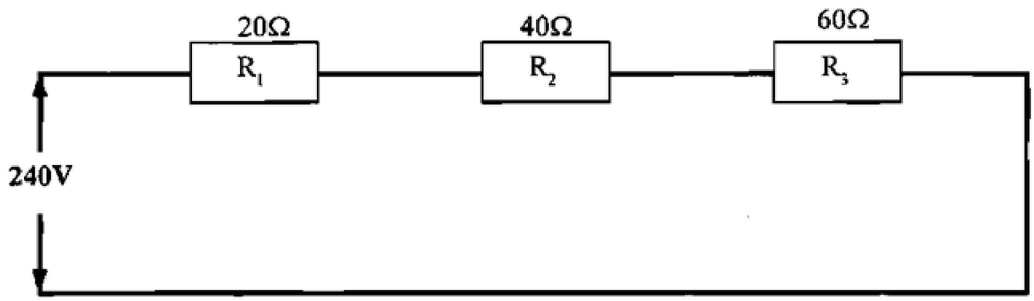
$$V_1 = \mathrm{V} \times \frac{\mathrm{R_1}}{\mathrm{R_1 + R_2 + R_3}}$$

$$V_2 = \mathrm{V} \times \frac{\mathrm{R_2}}{\mathrm{R_1 + R_2 + R_3}}$$

$$V_3 = \mathrm{V} \times \frac{\mathrm{R_3}}{\mathrm{R_1 + R_2 + R_3}}$$

**Example-6**: the 20Ω; 40Ω and 60Ω resistors are connected in series across a 240v supply. Find out the total resistance of the circuit and current that flows through the circuit.

Solution:




$$R_1 = 20\ ;\ R_2 = 40;\ R_3 = 60$$

$$E = 240v$$

$$R_T = ?\ ;\ I = ?$$

According to Ohm's law:

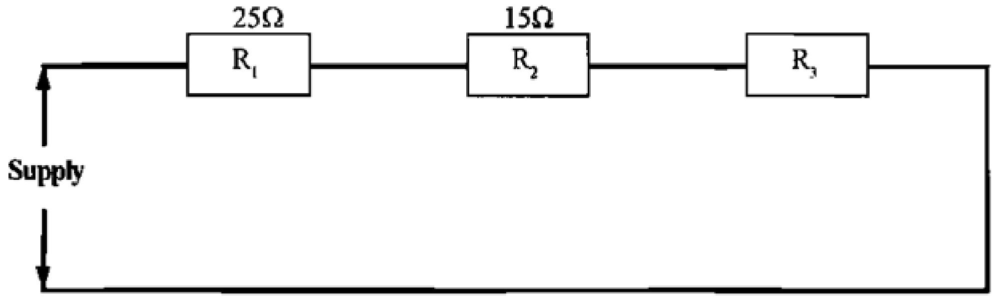
$$I = \frac{V}{R_T}$$

$where\ R_T = R_1 + R_2 + R_3 = 20 + 40 + 60 = 120\Omega$

$$I = \frac{V}{R_T} = \frac{240}{120} = 2A$$

**Example-7:** Three resistors are connected in series. The total resistance ($R_T$) of the circuit is 60Ω. The first two resistors are 25Ω and 15Ω find out the third one.

Solution:

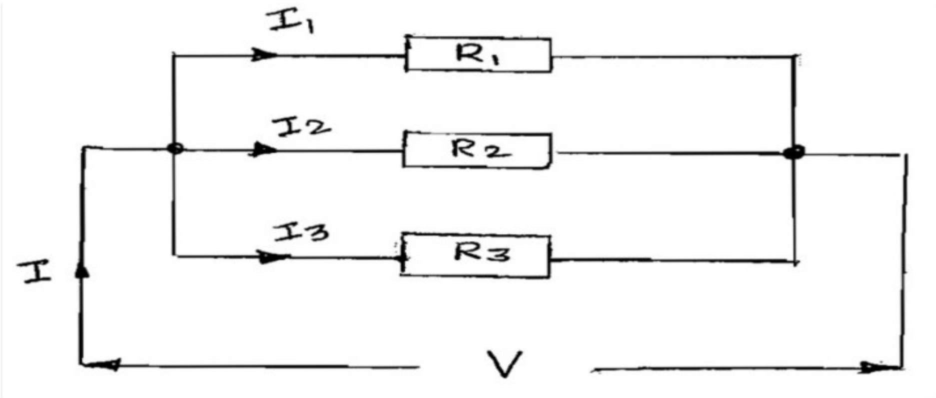



$R_T = R_1 + R_2 + R_3$ $\qquad 60 = 25 + 15 + R_3$

$$R_3 = 60 - 40 = 20\Omega$$

## 2. Resistance in parallel Circuit:

When resistors are connected across one another so that the same voltage is applied between the end points of each; then they are said to be in parallel. The current in each resistor is different and the current I taken from the supply is divided among the resistors.




In parallel circuit total current (I) is equal to some of the current $I_1$; $I_2$ and $I_3$.

$$I = I_1 + I_2 + I_3$$

According to Ohm's law we can find the total resistance ($R_T$) as given below:

$$I = \frac{V}{R_T}$$

$$I_1 = \frac{V}{R_1}$$

$$I_2 = \frac{V}{R_2}$$

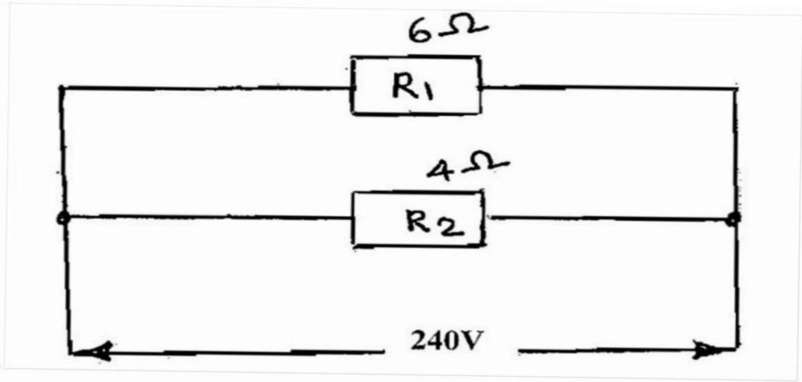
$$I_3 = \frac{V}{R_3}$$

$$R_T = \frac{R_1 R_2 R_3}{R_2 R_3 + R_1 R_3 + R_1 R_2}$$

$$V = V_1 = V_2 = V_3$$

**Example-8**: 6Ω and 4Ω resistors are connected in parallel through 240v supply. Find out the total resistance and current flows in it.

Solution:




$$R_1 = 6\Omega \qquad R_2 = 4\Omega \qquad V = 240v$$

$$R_T = ?$$

In parallel circuit

$$R_T = \frac{R_1 R_2}{R_1 + R_2} = \frac{6 \times 4}{6 + 4} = \frac{24}{10} = 2.4\Omega$$

According to Ohm's law

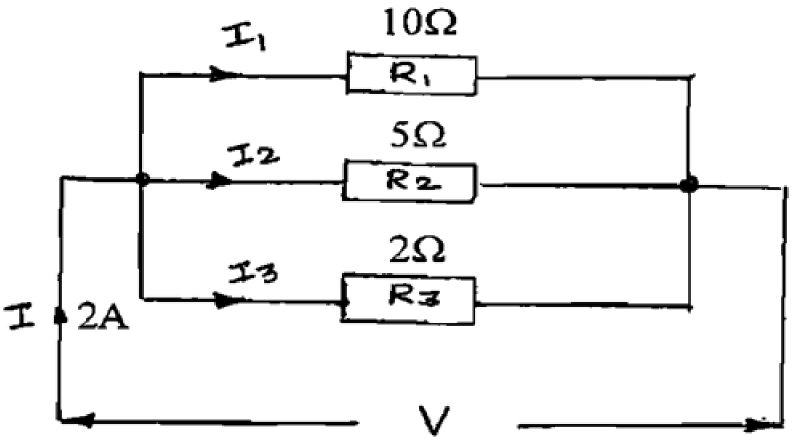
$$I = \frac{V}{R_T} = \frac{240}{2.4} = 100A$$

**Example-9**: Three resistors 10Ω; 5Ω and 2Ω are connected in parallel. The total current flowing in the circuit is 2A. find out the total resistnce and supply voltage of the circuit.

Solution:

$$R_1 = 100\Omega \qquad R_2 = 5\Omega \qquad R_3 = 2\Omega$$

$$R_T = ? \qquad I = 2A \qquad V = ?$$

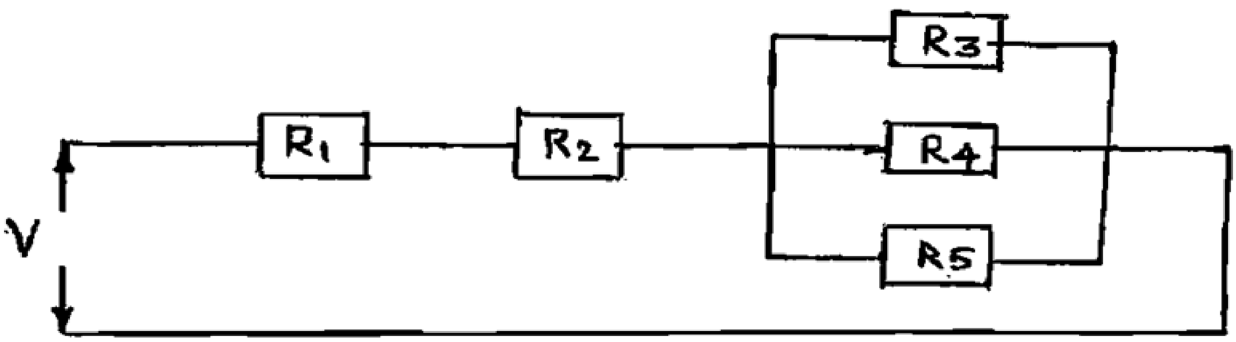



$$R_T = \frac{R_1R_2R_3}{R_2R_3 + R_1R_3 + R_1R_3} = \frac{10 \times 5 \times 2}{(5 \times 2) + (2 \times 10) + (10 \times 5)}$$

$$= \frac{100}{10 + 20 + 50} = \frac{100}{80} = 1.25\Omega$$

$$V = I \times R_T = 2 \times 1.25 = 2.5v$$

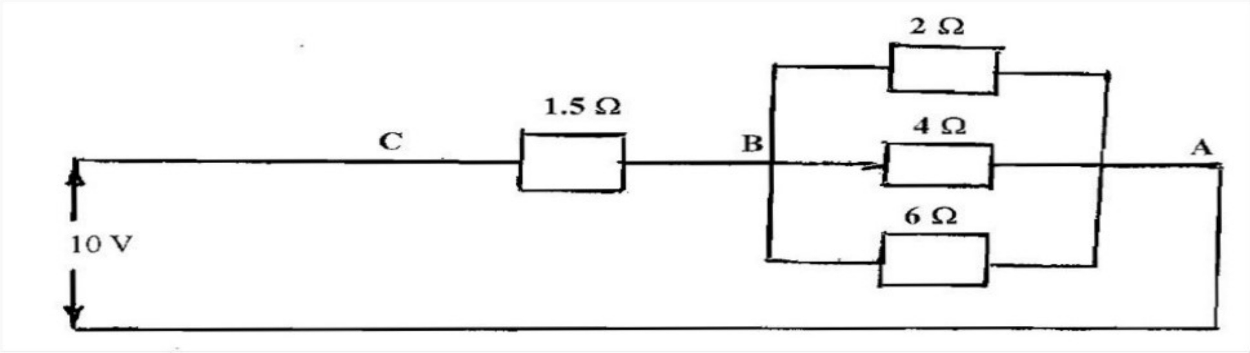
**Resistance in series parallel circuit:** In this circuit one and more resistors connected in series with one more resistors connected in parallel. It is a combination of series and parallel circuit.




Here the total resistance ($R_T$) of the circuit is:

$$R_T = R_1 + R_2 + \frac{R_3 \times R_4 \times R_5}{R_4R_5 + R_5R_3 + R_3R_4}$$

**Example-10**: Three resistors 2Ω; 4Ω and 6Ω are connected in parallel. This parallel combination is connected in series with a resistor of 1.5Ω . Find the current through each resistor when the applied voltage is 10v




Solution:

$$R_P = \frac{R_1R_2R_3}{R_2R_3 + R_1R_3 + R_1R_3} = \frac{2 \times 4 \times 6}{(2 \times 4) + (4 \times 6) + (6 \times 2)}$$

$$= \frac{48}{8 + 24 + 12} = \frac{48}{44} = 1.09\Omega$$

$$R_T = \mathrm{R_P} + \mathrm{R_4} = 1.09 + 1.5 = 2.59\Omega$$

Total current in circuit is:

$$I = \frac{V}{R_T} = \frac{10}{2.59} = 3.86A$$

Voltage drop across AB is:

$$V_{AB} = I \times R_P = 3.89 \times 1.09 = 4.24v$$

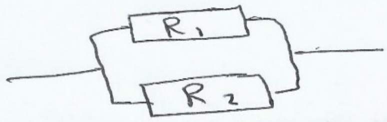
(Voltage is constant in parallel circuit)

Current in 2Ω resistor $= \frac{\mathrm{V_{AB}}}{\mathrm{R_1}} = \frac{4.24}{2} = 2.12\mathrm{A}$

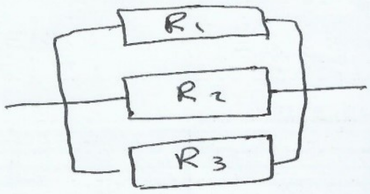
Current in 4Ω resistor $= \frac{\mathrm{V_{AB}}}{\mathrm{R_2}} = \frac{4.24}{4} = 1.06\mathrm{A}$

Current in 6Ω resistor $= \frac{\mathrm{V_{AB}}}{\mathrm{R_3}} = \frac{4.24}{6} = 0.706\mathrm{A}$

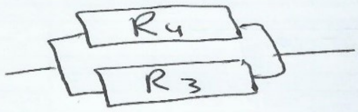
**قوانين الربط التوازي حسب ما تم ذكره في فيديو المراجعة (review)**



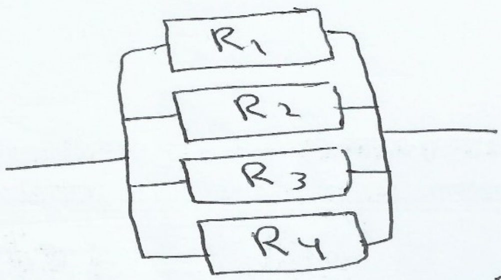

$$R_T = \frac{R_1 R_2}{R_1 + R_2}$$




$$R_4 = \frac{R_1 R_2}{R_1 + R_2}$$




$$R_T = \frac{R_4 R_3}{R_4 + R_3}$$




$$R_5 = \frac{R_1 R_2}{R_1 + R_2} \qquad R_6 = \frac{R_3 R_4}{R_3 + R_4}$$

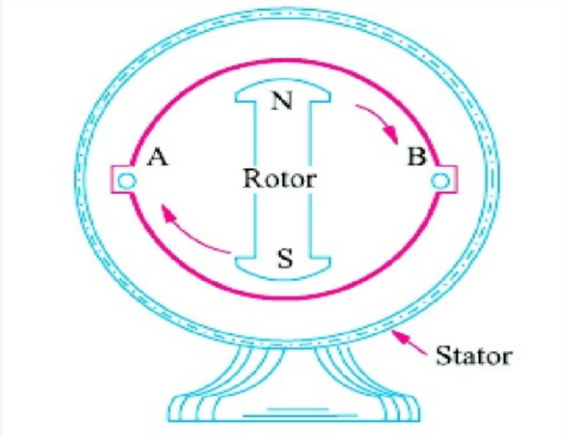
$$R_T = \frac{R_5 R_6}{R_5 + R_6}$$

# Chapter Two

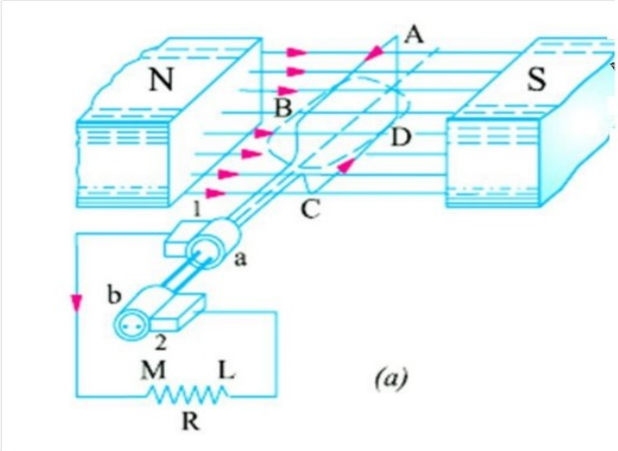
## Alternating Current

## Alternating Current:

Alternating current may be generated by rotating a coil in a magnetic field as shown in figure (a) or by rotating a magnetic field within a stationary coil as shown in figure (b).

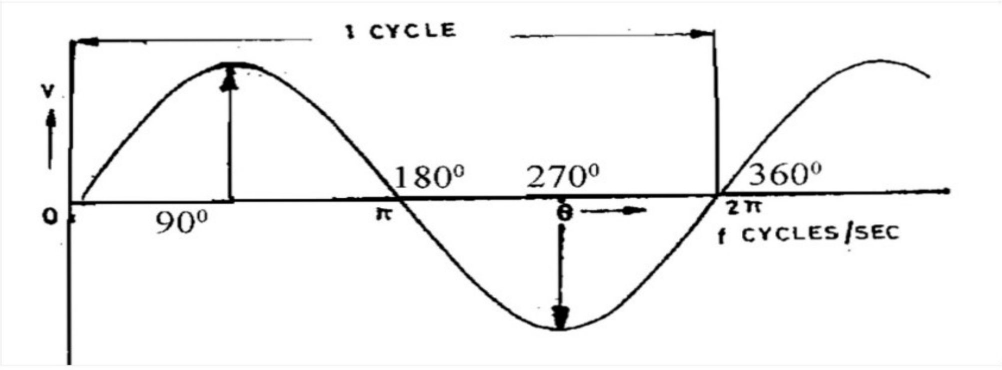



(b)




(a)

Alternating current flows in one direction one time and later its changes its direction of flows. And the magnitude changes at every time. The magnitude depends upon the position of the coil.




### Advantage and disadvantage of AC current:

### Advantage:

- It easy to conduct AC to one place to another place.
- In AC current easy to develop high voltage.
- AC equipment is low cost.
- Possible to convert to DC.
- Easy to step down of setup the voltage by transformer.

- AC motors are cheapest.

Disadvantage:

- Cannot able to store in battery.
- Because of high starting current in AC the voltage drop is occurred.
- The speed of the AC motors is depending up on the frequency.
- According to the induction load; power factor gets low.

If coil rotate in magnetic field or magnetic field rotate inside the coil there is an alternating e. m. f. generate in the coil. The generated emf is proportional to the number of turns of coil, magnetic field strength, and the angle between the coil and magnetic field.

$$e = BLv \sin\theta$$

From this:

$$L = Length\ of\ the\ conductor.$$

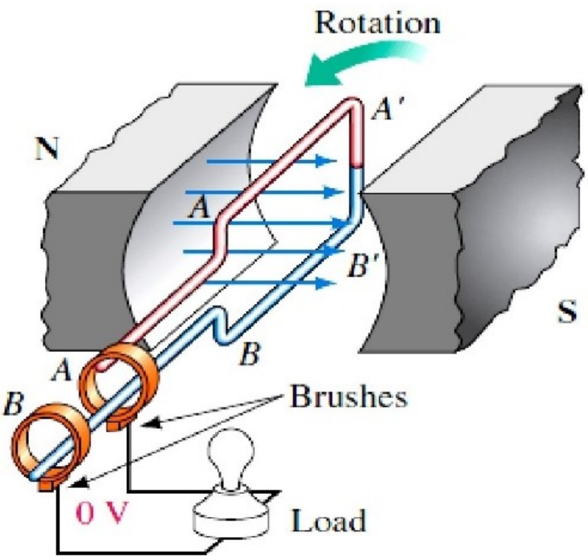
$$v = Velocity\ of\ conductor.$$

$$B = Flux\ density.$$

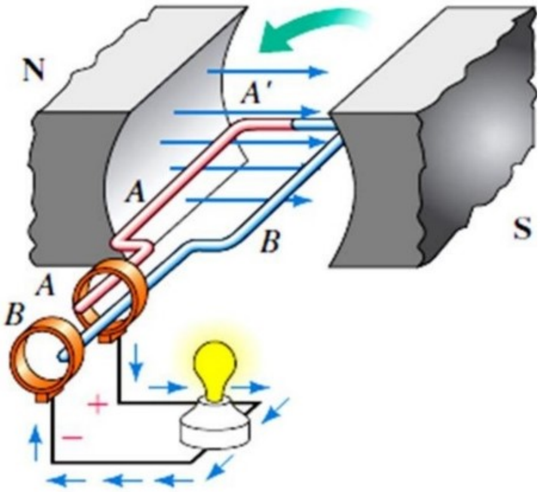
$$\theta = angle\ between\ field\ to\ conductor.$$

$$e = generated\ AC\ emf$$

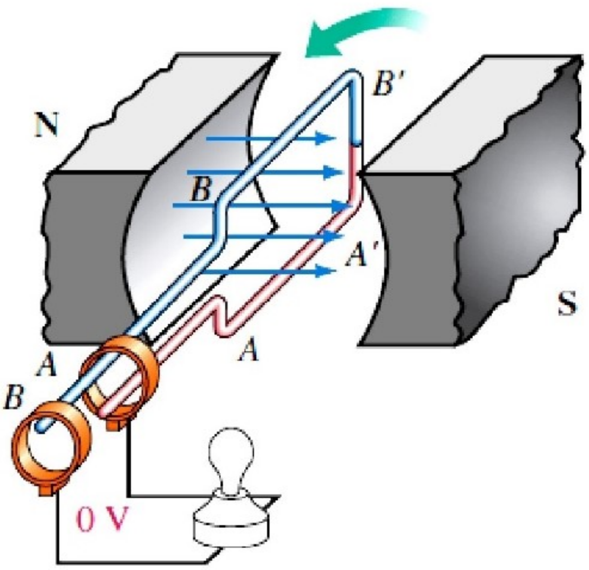
The generated AC emf value is depending upon the sine value of the angle between the magnetic field and conductor.



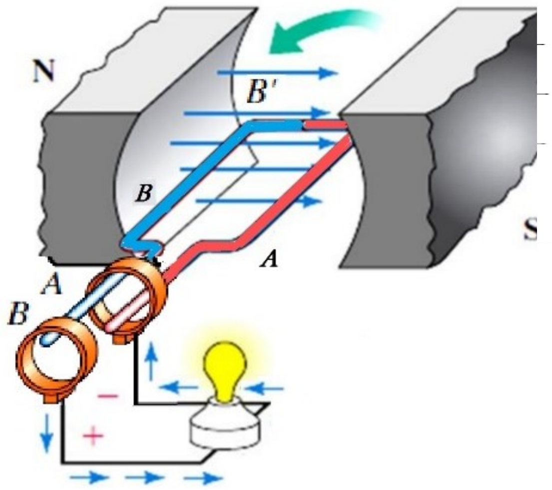

(a) 0° Position: Coil sides move parallel to flux lines. Since no flux is being cut, induced voltage is zero.



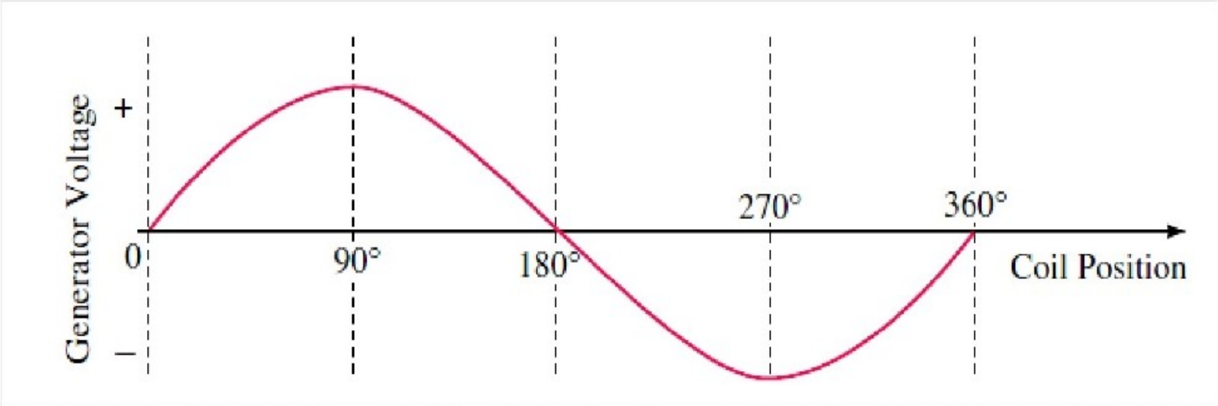

(b) 90° Position: Coil end *A* is positive with respect to *B*. Current direction is out of slip ring *A*.




(c) 180° Position: Coil again cutting no flux. Induced voltage is zero.




(d) 270° Position: Coil end A nega
with respect to B. Current directi
is out of slip ring *B*.




## Cycle:

An alternating current complete set of one positive half cycle and one negative half cycle is called one cycle.

## Time period:

The time taken by an alternating quantity to complete one cycle is called time period. It is denoted by the letter "T".

## Frequency:

The number of cycle per second is called the frequency of the alternating quantity. The unit is hertz (Hz).

## Instantaneous value:

The alternating quantity changes at every time.

$$v = V_{max} \sin \omega t \quad or \quad i = I_{max} \sin \omega t$$

## Maximum value:

The maximum value positive or negative of an alternating quantity is known as its maximum value. Denoted by "$I_{max}$ or $V_{max}$".

## Effective value and RMS value:

The effective value of an alternating current is given by that DC current which when flowing through a given circuit for a given time produces the same heat as produced by the alternating current when flowing through the same circuit for the same time also is called root mean square value RMS. The voltmeter and ammeter are read the effective value only.

$$RMS\ value = \frac{I_{max}}{\sqrt{2}} \quad or \quad \frac{V_{max}}{\sqrt{2}}$$

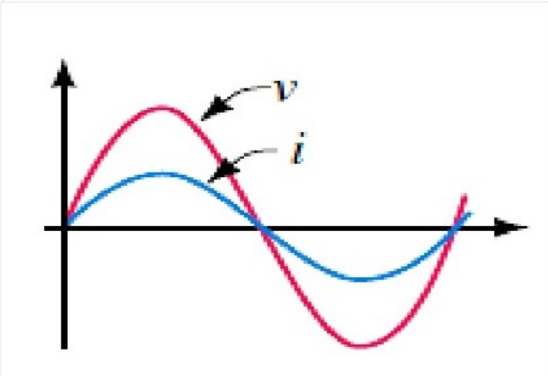
## Average value:

The average value is calculated by the averages of the maximum value of alternating quantity at different instances.

$$Average\ value = \frac{2I_{max}}{\pi} \quad or \quad \frac{2V_{max}}{\pi}$$

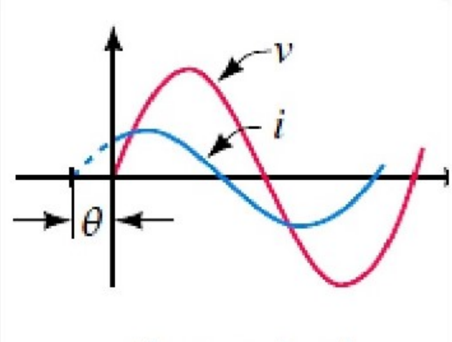
## In phase:

If waveform of two AC quantities (voltage or current) gets the maximum and zero at same time then they are said to be in phase.

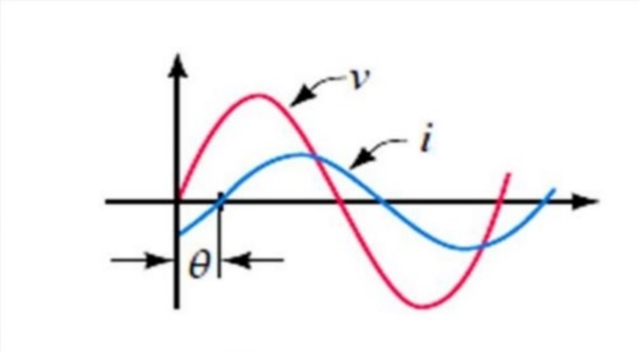


## Out of phase:

If in AC circuit two quantities namely voltage or current waves get the maximum and zero at different value then they are said to be out of phase.



Current leads



Current lags

**بعض القوانين المهمة**

$$i = I_m \, . \, \sin(\omega t) \,,$$
$$v = R.i = R.I_m \sin(\omega t)$$
$$v = V_m . \sin(\omega t)$$
$$V_m = R.I_m$$
$$\omega = 2\pi f,$$

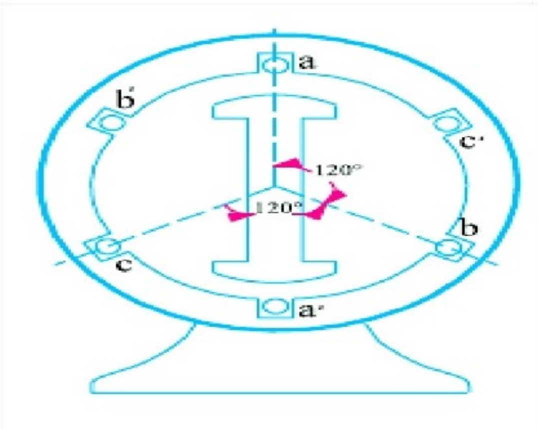
# Chapter Three

## Three Phase System

# Three phase system

## Three phase generator:

Large scale generation of power is achieved by generating three phase e.m.f. using three separate windings insulated from each other. They are placed on the rotor of the alternator. The windings are displaced at angle of 120° with each other as shown in figure (a). When the rotor is rotated e.m.f. will be induced in the three coils (phases).




'a'

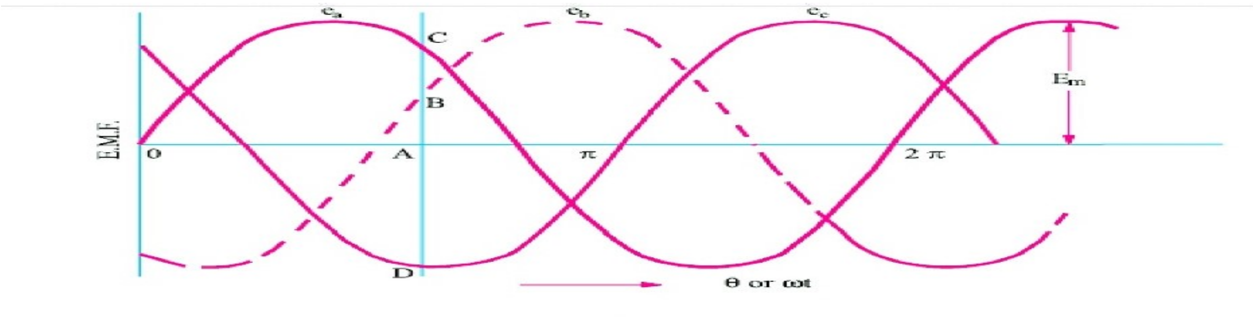
The instantaneous values of the three e.m.f. will be given by curves of figure (b):

$$e_a = E_m \sin \omega t$$

$$e_b = E_m \sin(\omega t - 120^o)$$

$$e_c = E_m \sin(\omega t - 240^o)$$

$$e_a + e_b + e_c = 0$$




b

## Numbering of phase

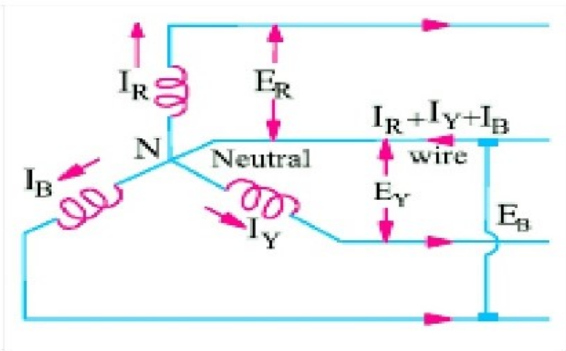
The three phases may be numbered 1; 2; 3 or a; b; c or as is customary they may be given three color. The colors used commercially are red; yellow and blue. In this case the sequence is RYB.

## Interconnection of three phases:

a) Star or Wye (Y) connection.
b) Mesh or Delta (Δ) connection.

## Star or Wye (Y) connection

The three coils are joined together at point N as shown in figure this point is known as star point or neutral point. The three conductors meeting at point N are replaced by a single conductor known as neutral conductor.




The line voltage is equal to:

$$V_L = \sqrt{3}V_{phase}$$

Where $V_L$ is the line voltage and $V_{phase}$ is the phase voltage

Current in phase 1 = $I_R$ ; Current in phase 2 = $I_Y$ ; Current in phase 3 = $I_B$

$$since \;\; I_R = I_Y = I_B = I_{phase}$$

$$the\ line\ current \quad I_L = I_{phase}$$

Total active power is:

$$P = \sqrt{3}.V_L.I_L.\cos\varphi$$

Total reactive power is:

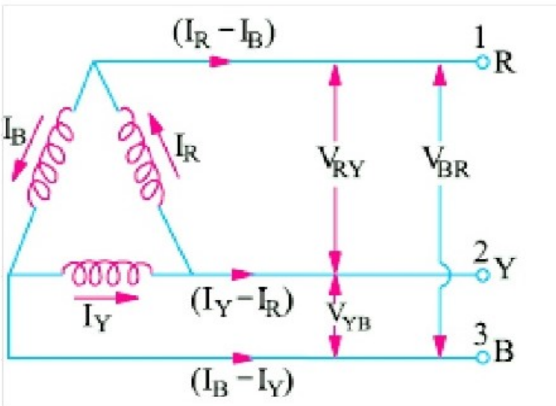
$$Q = \sqrt{3}.V_L.I_L.\sin\varphi$$

Total apparent power is:

$$S = \sqrt{3}.V_L.I_L \quad Obviously \quad S = \sqrt{P^2 + Q^2}$$

## Mesh or Delta connection:

In this form of interconnection the dissimilar ends of the three phase winding are joined together as shown in figure. If the system is balanced then sum of the three voltages round the closed mesh is zero.




The line voltage is equal to:

$$V_L = V_{phase}$$

Where $V_L$ is the line voltage and $V_{phase}$ is the phase voltage

Where $V_L$ is the line voltage and $V_{phase}$ is the phase voltage

$$the\ line\ current \quad I_L = \sqrt{3}.I_{phase}$$

Total active power is:

$$P = \sqrt{3}.V_L.I_L.\cos\varphi$$

Total reactive power is:

$$Q = \sqrt{3}.V_L.I_L.\sin\varphi$$

Total apparent power is:

$$S = \sqrt{3}.V_L.I_L \quad Obviously \quad S = \sqrt{P^2 + Q^2}$$

# Chapter Four

## Electromagnetics

# Electromagnetism

Magnetism plays an important role in electricity. Electrical appliances like Generator; Motor; Measuring instruments and Transformer are based on the electromagnetic principle and also the important components of Television; Radio and Aeroplane are working on the same principle.

## Magnetic Material

Magnetic materials are classified based on the property called permeability as:

1. Dia Magnetic Material.
2. Para Magnetic Material.
3. Ferro Magnetic Material.

## Dia Magnetic Materials

The materials whose permeability is below unity are called Dia magnetic material. Example Lead; Copper; Class and mercury.

## Para Magnetic Material:

The materials whose permeability is above unity are called Para magnetic material. Example Lead; Copper Sulphate; Oxygen and Aluminium.

## Ferro Magnetic Material:

The materials with permeability thousands of times more than that of para magnetic materials. Example Iron; Cobalt; Nickel.

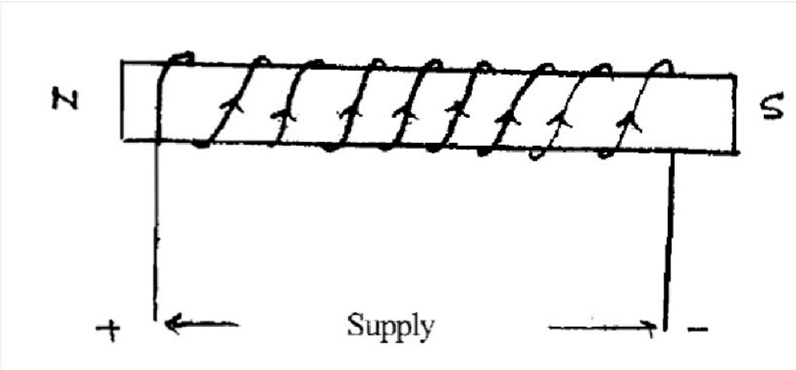
## Permanent Magnet

Permanent magnet means the magnetic materials which will retain the magnetic property at all times permanently. This type of magnets manufactured by aluminum; nickel; Iron; cobalt steel (ALNICO).

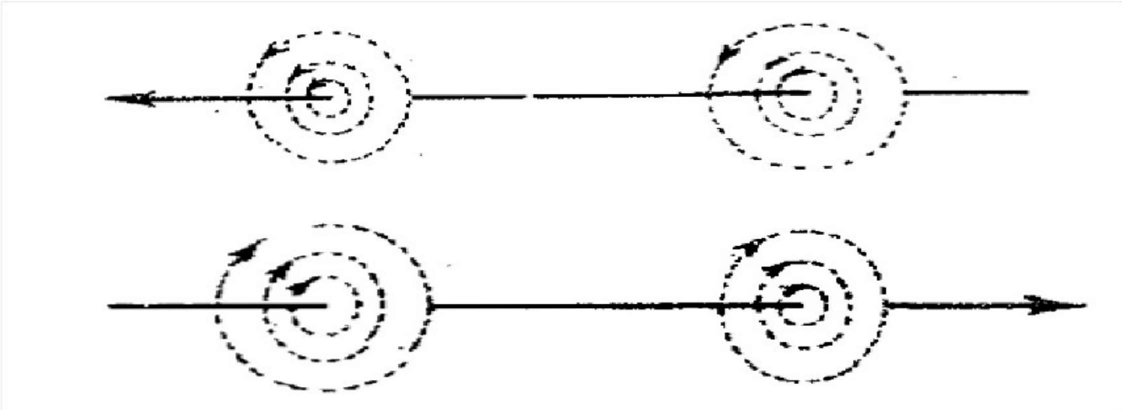
To make a permanent magnet a coil is wound over a magnetic material and DC supply is passed through the coil.

## Electromagnet:

Insulated wire wound on a bobbin in many turns and layers in which current is flowing and a soft iron piece placed in the bobbin is called electromagnet.




### Magnetic Effect by electric current



If current passes through a conductor magnetic field is setup around the conductor. The quantity of the magnetic field is proportional to the current.

Permeability

The permeability of a magnetic material is defined as the ratio of flux created in that material to the flux created in air. Its symbol is μ and

$$\mu = \frac{B}{H}$$

B is the flux density

H is the magnetic force

### Magnetic field

The space around a magnet in which the influence of the magnet can be detected is called the magnetic field.

## Magnetic lines

Magnetic lines of force (flux) are assumed to be continuous loops; the flux lines continuing on through the magnet. They do not at the poles

## Magnetic Flux

The magnetic flux in a magnetic circuit is equal to the total number of lines existing on the cross section of the magnetic core at right angle to the direction of the flux. Its symbol is φ and the SI unit is Weber.

$$\varphi = \frac{N.I}{S} = \frac{N.I.a.\mu_o\mu_r}{l}$$

Where φ totals flux

N number of turns

S reluctance

I current in amperes

$\mu_o$ permeability of free space

$\mu_r$ relative permeability

$l$ $lengh\ of\ the\ magnetic\ path\ in\ m$

a magnetic path across sectional area in $m^2$

## Magnetic field strength

This is also known as field intensity or magnetic intensity and is represented by the letter H. its unit is ampere turns per meter.

$$H = \frac{MMF}{Length\ of\ coil\ in\ meters} = \frac{NI}{l}$$

## Flux density

The total number of lines of force per square meter of the cross-sectional area of the magnetic core is called flux density and is represented by the symbol B. its unit is tesla.

$$B = \frac{\varphi}{A}$$

example-13. calculate flux density at ~~a distance of 5cm form~~ surface of along straight circular conductor (with 1 mm radius) carrying acurrent of 250 A and placed in air.

Solution : $r = 1mm = 10^{-3}$ m

$$B = \frac{\varphi}{A} = \frac{N \cdot I \cdot A \cdot \mu_o \cdot \mu_r}{L \cdot A}$$

$\mu_o = 4\pi * 10^{-7}$ N/m²

$\mu_r = \frac{\mu}{\mu_o}$ ($\mu_r$ for air = 1)

N = 1 (number of turns)

$$B = \frac{I \cdot \mu_o}{L} = \frac{4\pi * 10^{-7} * 250}{2\pi * 10^{-3}}$$

$B = 0.05$ Wb/m²

## Magnetomotive force

The amount of flux density setup in the core is dependent upon five factors: number of turns; material of magnetic core; length of the core and the cross sectional area of the core.

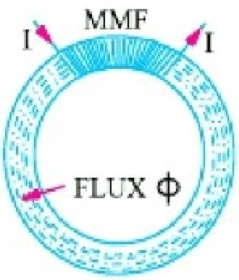
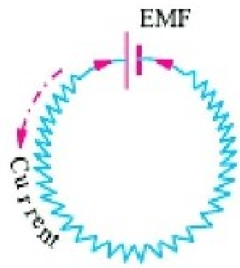
$$MMF = N.I$$

## Magnetic Reluctance

In the magnetic circuit there is something analogues to electrical resistance and is called reluctance. Its symbol is S.

$$S = \frac{l}{\mu_o \mu_r a}$$

# Comparing between magnetic and electric circuit

| Magnetic Circuit | Electric Circuit |
|---|---|
|   Fig. 6.27 |   Fig. 6.28 |
| 1. Flux = $\frac{\text{m.m.f.}}{\text{reluctance}}$ | Current = $\frac{\text{e.m.f.}}{\text{resistance}}$ |
| 2. M.M.F. (ampere-turns) | E.M.F. (volts) |
| 3. Flux $\Phi$ (webers) | Current $I$ (amperes) |
| 4. Flux density $B$ (Wb/m$^2$) | Current density (A/m$^2$) |
| 5. Reluctance $S = \frac{l}{\mu A}\left(= \frac{l}{\mu_0 \mu_r A}\right)$ | resistance $R = \rho \frac{l}{A} = \frac{l}{\rho A}$ |
| Permeance (= 1/reluctance) | Conductance (= 1/resistance) |
| 6. Total m.m.f. = $\Phi S_1 + \Phi S_2 + \Phi S_3 + \ldots$ | Total e.m.f. = $IR_1 + IR_2 + IR_3 + \ldots$ |

## Electromagnetic induction

Electromagnetic induction means the electricity induced by the magnetic field.

## Faraday's laws of Electromagnetic induction

There are two laws of Faraday's laws of electromagnetic induction. They are:

1) First Law. 2) Second law.

## First law

Whenever a conductor cuts the magnetic flux lines an emf is induced in the conductor.

## Second law

The magnitude of the induced emf is equal to the rate of change of flux-linkage.

## Induced electromotive force

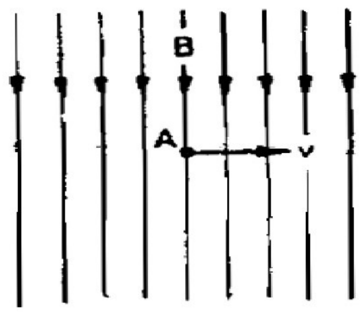
Induced electromotive force is of two types: they are

i) Dynamically induced emf.
ii) Statically induced emf.

## Dynamically induced emf

Dynamically induced emf means an emf induced in a conductor when the conductor moves across a magnetic field. The figure shows when a conductor "A" with the length "L" moves across a "B" wb/m$^2$ flux density with "v" velocity. Then the dynamically induced emf is induced in the conductor. This induced emf is utilised in the generator.

$$emf = B.l.v$$

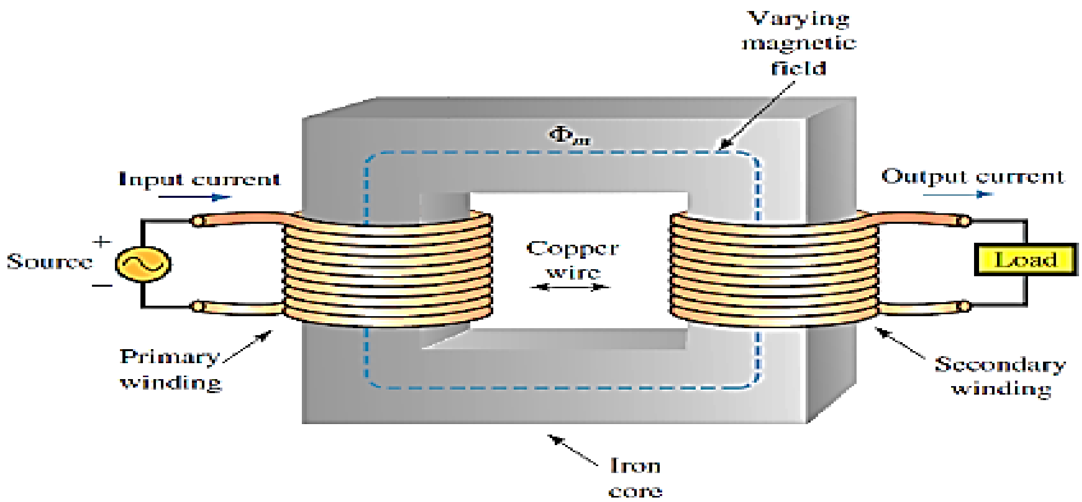


# Chapter Five

## The Transformer and AC Machines

# The transformer

A transformer is a magnetically **coupled circuit,** i.e., a circuit in which the magnetic field produced by time-varying current inone circuits induces voltage in another. To illustrate, a basic iron-core transformer is shown in Figure. It consists of two coils wound on a common core. Alternating current in one winding establishes a flux which links the other winding and induces voltage in it. Power thus flows from one circuit to the other via the medium of the magnetic field, with no electrical connection between the two sides. The winding to which we supply power is called the **primary,** while the winding from which we take power is called the **secondary.** Power can flow either direction, as either winding can be used as the primary or the secondary.




## Faraday's Law

All transformer operation is described by Faraday's law. Faraday's law (in SI units) states that the voltage induced in a circuit by a changing magnetic field is equal to the rate at which the flux linking the circuit is changing. When Faraday's law is applied to iron-core and air-core transformers, however, the results that emerge are quite different: Iron-core transformers are found to be characterized by their turn's ratios, while air-core transformers are characterized by self- and mutual inductances.

**Voltage Ratio**

Now apply Faraday's law. Since the flux linkage equals $N\Phi$ and since $N$ is constant, the induced voltage is equal to $N$ times the rate of change of $\Phi$, i.e., $e = Nd\Phi/dt$. Thus, for the primary,

$$e_p = N_p \frac{d\Phi_m}{dt}$$

while for the secondary

$$e_s = N_s \frac{d\Phi_m}{dt}$$

Dividing Equation 24–1 by Equation 24–2 and cancelling $d\Phi_m/dt$ yields

$$\frac{e_p}{e_s} = \frac{N_p}{N_s}$$

The ratio of primary voltage to secondary voltage is equal to the ratio of primary turns to secondary turns. This ratio is called the **transformation ratio** (or **turns ratio**) and is given the symbol a.

$$a = N_p/N_s$$

## Step-Up and Step-Down Transformers

A **step-up** transformer is one in which the secondary voltage is higher than the primary voltage, while a **step-down** transformer is one in which the secondary voltage is lower. Since $a = Ep/Es$, a step-up transformer has $a<1$, while for a step-down transformer, $a > 1$. If $a = 1$, the transformer's turns ratio is **unity** and the secondary voltage is equal to the primary voltage.

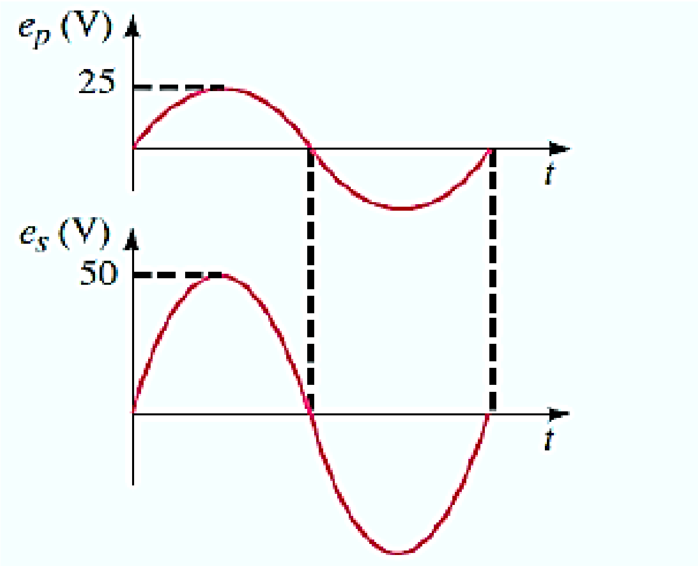
**EXAMPLE-14**Suppose the transformer has 500 turns on its primary and 1000 turns on its secondary.a. Determine its turn's ratio. Is it step-up or step-down?b. If its primary voltage is $e_p$=25 sin w*t*V, what is its secondary voltage?c. Sketch the waveforms.

**Solution**

a. The turns ratio is $a = N_p/N_s$= 500/1000 =0.5. This is a step-up transformer.

b. $e_s = e_p/a$ = (25 sin w*t*)/0.5 = 50 sin w*t*V.

c. Primary and secondary voltages are in phase as noted earlier.




H.WIf the transformers have 600 turns on their primary and 120 turns on their secondary, and $E_p$= 120 V, what is $E_s$

# AC Machines

## Classification of AC Rotating Machines

•**Synchronous Machines:**

•**Synchronous Generators:** A primary source of electrical energy.

•**Synchronous Motors:** Used as motors as well as power factor compensators (synchronous condensers).

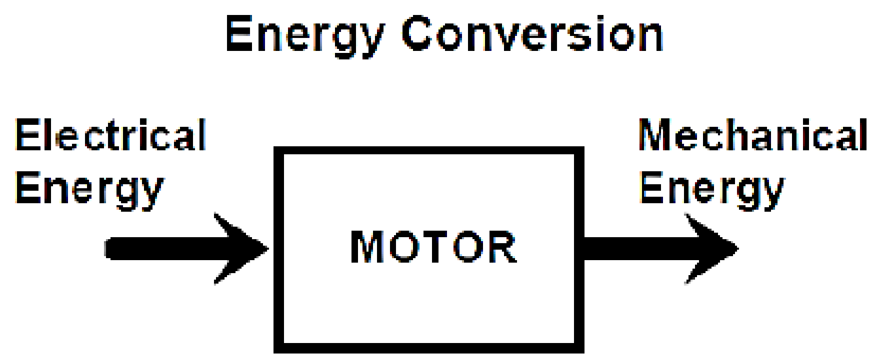
•**Asynchronous (Induction) Machines:**

•**Induction Motors:** Most widely used electrical motors in both domestic and industrial applications.

•**Induction Generators:** Due to lack of a separate field excitation, these machines are rarely used as generators.

## Energy Conversion

- Generators convert mechanical energy to electric energy.
- Motors convert electric energy to mechanical energy.




The construction of motors and generators are similar.
Every generator can operate as a motor and vice versa.

**Practical Motor Applications:**

1. Refrigerators.
2. Washing machines.
3. Clocks.
4. Drills.
5. Pumps.

Advantages
– Low Initial Cost - $/Hp
– Simple & Efficient Operation
– Compact Size – cubic inches/Hp
– Long Life – 30,000 to 50,000 hours
– Low Noise
– No Exhaust Emissions
– Withstand high temporary overloads
– Automatic/Remote Start & Control

• Disadvantages
– Portability
– Speed Control
– No Demand Charge

## Induction motors

The induction motor is the most commonly used AC motor in industrial applications because of its simplicity, rugged construction, and relatively low manufacturing costs. The reason that the induction motor has these characteristics is because the rotor is a self-contained unit, with no external connections. This type of motor derives its name from the fact that AC currents are induced into the rotor by a rotating magnetic field.

# Three-phase Induction Motor

The three-phase induction motor the most commonly used type of motor in industrial applications. In particular, the squirrel-cage design is the most widely used electric motor in industrial applications.

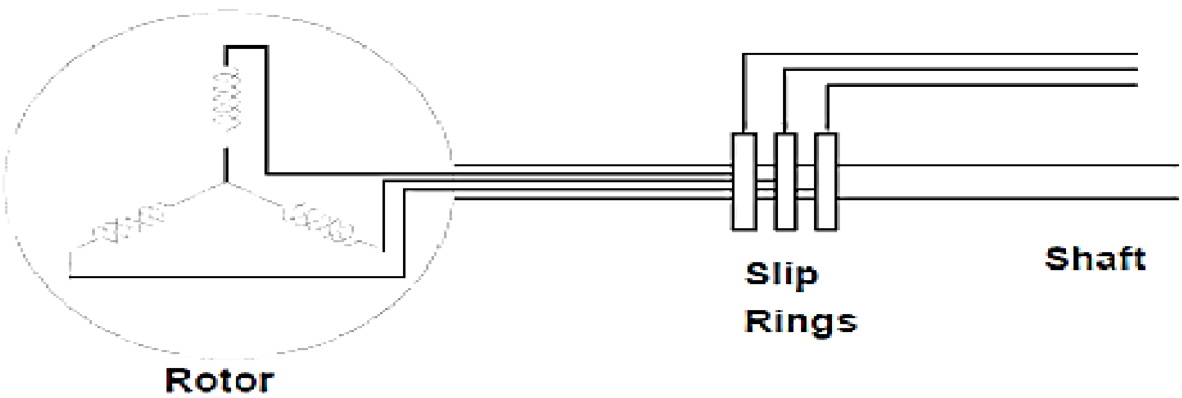
**Construction:** The main body of the Induction Motor comprises of two major parts:

**A. Stator:** Stator is made up of number of stampings in which different slots are cut to receive 3 phase winding circuit which is connected to 3 phase AC supply. The three phase windings are arranged in such a manner in the slots that they produce a *rotating magnetic field* after AC supply is given to them. The windings are wound for a definite number of poles depending upon the speed requirement.

**B. Rotor:** Rotor consists of cylindrical laminated core with parallel slots that carry conductor bars.

## Two types of Rotor:

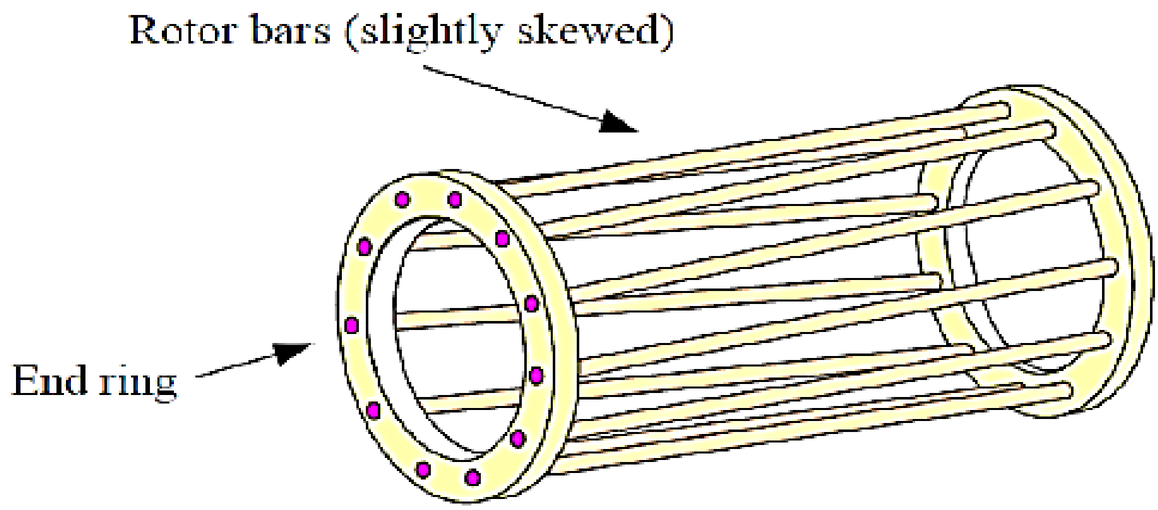
**1. Wound Rotor/slip ring:** The terminals of the rotor windings are connected to insulated slip rings mounted on the rotor shaft. Carbon brushes bearing on these rings make the rotor terminals available to the circuitry external to the motor. The rotor winding is usually short circuited through external resistances that can be varied.




Wound rotor slip rings and connections

## 2. Squirrel Cage:

A squirrel cage rotor has a winding consisting of conducting bars (of copper or aluminum) short-circuited at each end by conducting end rings.




**Working Principle:**

When balanced 3-phase AC voltages are applied to the stator terminal, stator currents flow through the stator circuits. These currents produce a rotating *mmf*that can be represented as a *rotating magnetic field*. This rotating magnetic field induces voltages in the rotor windings, by Faraday's law. These induced voltages, in turn, cause balanced currents to flow in the short-circuited rotor. These rotor currents then produce a rotor *mmf*, which can also be represented as a *rotating magnetic field*. The interaction of these two rotating magnetic fields produces an electromagnetic torque *Te*, which is used to turn mechanical load *Tm*. At steady state.

**The following sequence of events takes place:**

- A voltage E = BLv is induced in each conductor while it is being cut by the flux (Faraday's Law)
- The induced voltage produces currents which circulate in a loop around the conductors (through the bars).
- Since the current-carrying conductors lie in a magnetic field, they experience a mechanical force (Lorentz force).
- The force always acts in a direction to drag the conductor along with the magnetic field.

## Switchgear

The apparatus used for switching; controlling and protecting the electrical circuits and equipment is known as switchgear. The switchgear equipment is essentially concerned with switching and interrupting currents either under normal or abnormal operating conditions.

Switchgear Equipment:

1. Switches: A switch is a device which is used to open or close an electrical circuit in a convenient way. It can be used under full load or no load conditions but it cannot interrupt the fault currents. When the contacts of a switch are opened an arc is produced in the air between the contacts. This is particularly true for circuits of high voltage and large current capacity.
2. Fuse: A fuse is a short piece of wire or thin strip which melts when excessive current flows through it for sufficient time. It is inserted in series with the circuit to be protected. Under normal operating conditions the fuse element it at a temperature below its melting point. Therefore it carries the normal load current without overheating. However when a short circuit or overload occurs the current through the fuse element increases beyond its rated capacity. This raises the temperature and the fuse element melts.

3. Circuit breakers:

A circuit breaker works as a switching device as well as a current interrupting device. It does this by performing the following two functions:

1. Switching operating during normal working of operation and maintenance.
2. Switching operation during abnormal conditions that may arise such as over current; short circuit etc.

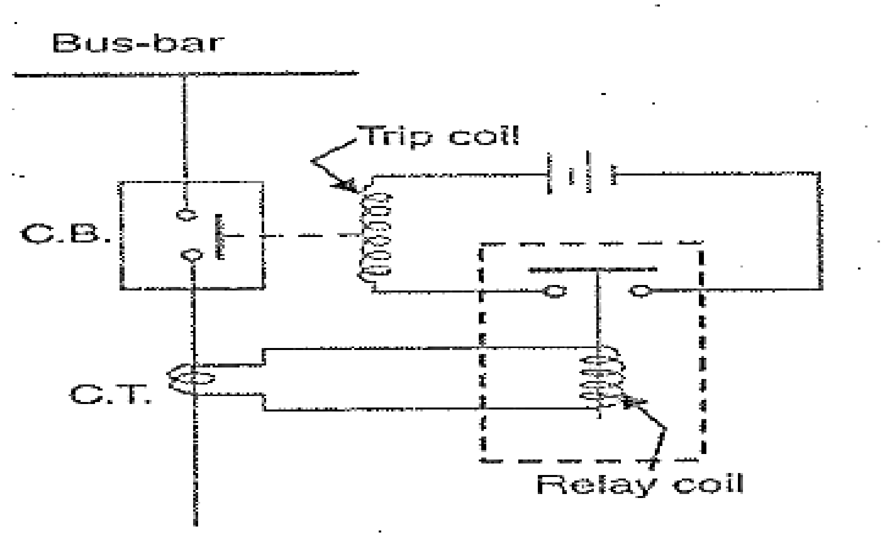



Figure shows the circuit breaker

When any high voltage circuit is interrupted there is a tendency towards an arc formation between the two separating contacts. Therefore the major aim in a circuit breaker design is to quench the arc rapidly enough to keep the contacts in normal state by one of the following methods;

1. High resistance interruption: in this method arc resistance is increased. This method is generally used in DC circuit breakers and low medium voltage AC circuit breakers.
2. In this method: the arc is interrupted at a current zero instance. At that instance. The air between the separating contacts is anodized by introducing fresh air sf6 gas or for an AC are interruptions.

# References


1. Electrical Technology by – Theraga.
2. Electrical Technology by – Hughes.
3. Electrical Technology by – Erick.