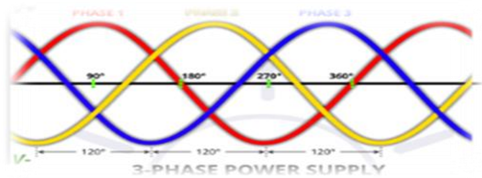
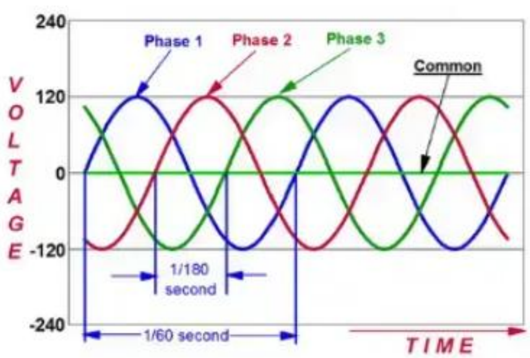
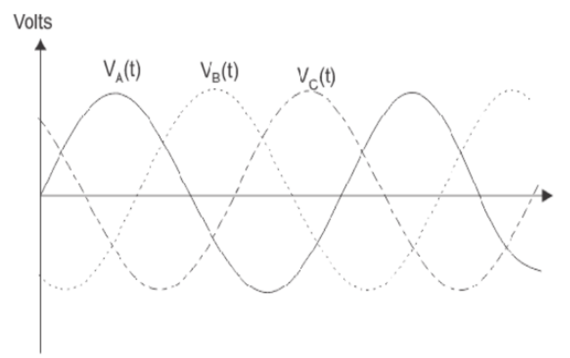
Three Phase System



Introduction:

- There are two types of systems in electric circuits: single-phase and three-phase systems. In a single-phase circuit, current flows through one wire with a return path called the neutral line, allowing minimal power transport. Both the generating and load stations are single-phase in this system, which has been used for a long time.
- In 1882, a new polyphone system was invented, allowing more than one phase for generating, transmitting, and loading power. A **three-phase circuit** is a polyphase system where three phases are sent together from the generator to the load.
- Each phase in a three-phase system has a 120-degree electrical phase difference, dividing the total 360 degrees into three equal parts. This ensures continuous power generation as all three phases work together. The sinusoidal waves for a three-phase system illustrate this division.
- The three phases can be used as single phase each. So if the load is single phase, then one phase can be taken from the **three phase circuit** and the neutral can be used as ground to complete the circuit





Key learnings:

- ***Three Phase Circuit Definition:*** *A three-phase circuit is defined as a system where three electrical phases are used together, each 120 degrees apart, to provide continuous power.*
- ***Star Connection:*** *A star connection includes three phase wires and one neutral wire, ideal for long-distance power transmission due to its ability to handle unbalanced currents.*
- ***Delta Connection:*** *A delta connection uses three wires without a neutral wire and is better suited for short-distance transmission, but it can struggle with unbalanced currents.*
- ***Voltage and Current Differences:*** *In a star connection, the line voltage is √3 times the phase voltage, while in a delta connection, the line voltage is the same as the phase voltage.*
- ***Advantages of Three Phase Circuit:*** *Three-phase circuits are more efficient, use less conductor material, and provide a more stable power supply than single-phase circuits.*

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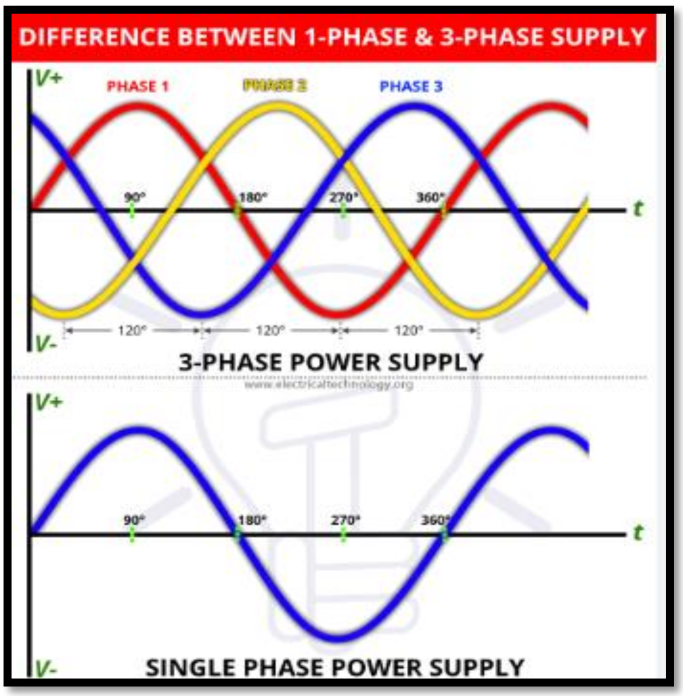
❖ ADVANTAGES OF THREE-PHASE SYSTEM OVER SINGLE PHASE

1. Almost all electric power is generated and distributed in three-phase.
2. When one-phase or two-phase inputs are required, they are taken from the three-phase system rather than generated independently.
3. Even when more than 3 phases are needed, they can be provided by manipulating the available three phases. Example: Aluminum industry, where 48 phases are required for melting purposes.
4. The instantaneous power in a three-phase system can be constant (not pulsating). This results in uniform power transmission and less vibration of three-phase machines.
5. For the same amount of power, the three-phase system is more economical than the single-phase.
6. The amount of wire required for a three-phase system is less than that required for an equivalent single-phase system.



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❖ **<u>Generation of three phase system:</u>** Consider following 3 phase simple loop generator shown infigure 1a. Its generated voltage will be as shown in figure 1b.

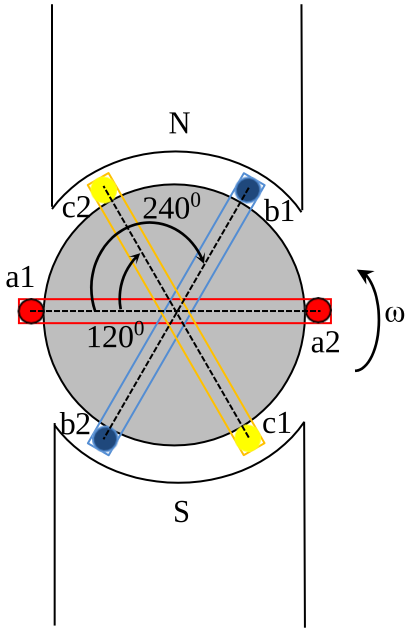

Fig.1a

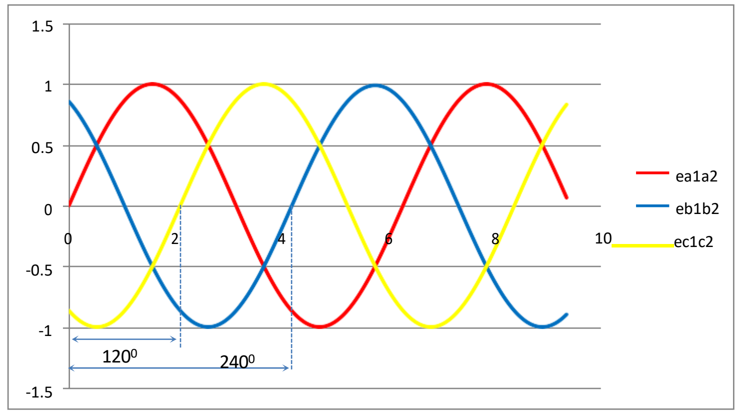

Fig.1b: 3-Phase wave from

$$e_{a1a2} = E_m Sin(\omega t) \qquad \text{-----(1)}$$

$$e_{c1c2} = E_m Sin(\omega t - 120^0) \qquad \text{-----(2)}$$

$$e_{b1b2} = E_m Sin(\omega t - 240^0) \qquad \text{-----(3)}$$

E_{a1a2}, E_{b1b2} & E_{c1c2} are RMS values.

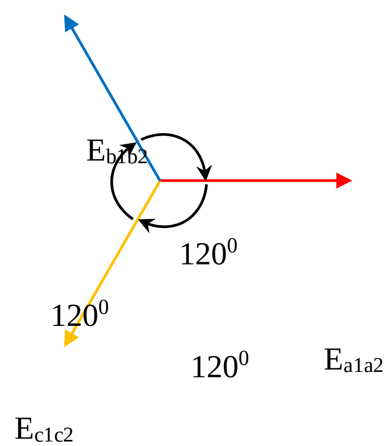

Fig.1c: Phasor Diagram

Phase Sequence: It is the sequence in which current or voltages in different phases attain their maximum values.

Phase sequence may be R-Y-B or R-B-Y as shown bellow

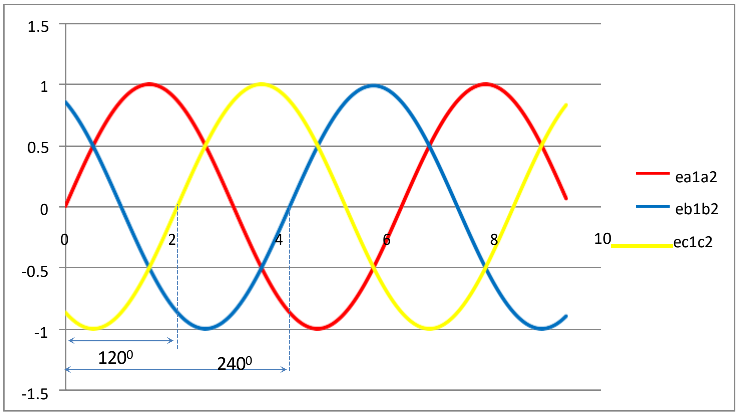

Fig.2a: Phase Sequence R-Y-B

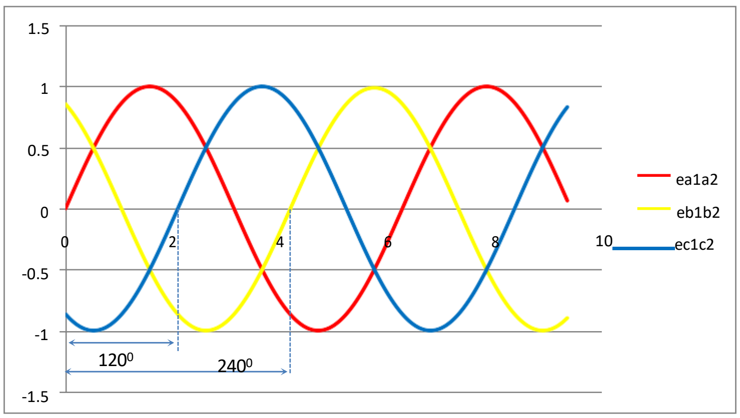

Fig.2b: Phase Sequence R-B-Y

Interconnection of 3-phase system: The six terminals of three phase winding can be connected to form any of the below.

1. Star or WYE (Y) connected 3-ϕ System
2. Mesh or Delta(Δ) connected 3- ϕ System

Star or WYE (Y) connected 3-ϕ System:

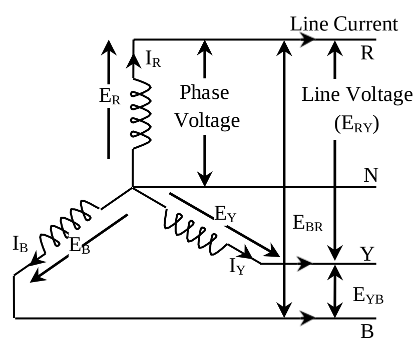

Fig.3a

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E_R, E_Y & E_B are called phase voltages.

I_R, I_Y & I_B are called phase currents.

E_{RY}, E_{YB} & E_{BR} are called line voltages.

From figure it is clear that

$I_R+I_Y+I_B=0$

Line current (I_L) = Phase Current (I_P)

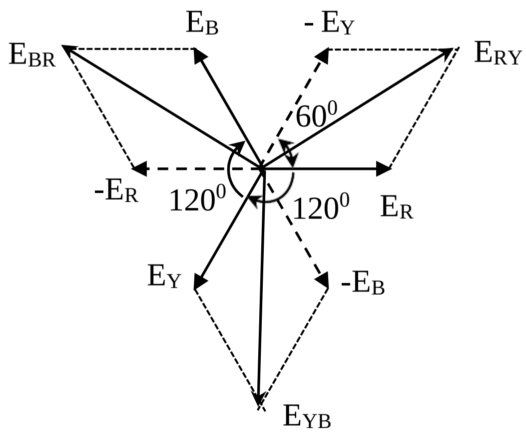

Fig.3b:

Line voltage from above phasor diagram

$$E_{RY} = E_R - E_Y = E_R + (-E_Y)$$

Its magnitude

$$E_{RY} = \sqrt{E_R{}^2 + E_Y{}^2 + 2E_R E_Y \cos 60^0}$$

For balanced 3-phase system

$E_R = E_Y = E_B = E_P$ (Phase Voltage)

So $$E_{RY} = \sqrt{E_P{}^2 + E_P{}^2 + 2E_P E_P \cos 60^0} = \sqrt{E_P{}^2 + E_P{}^2 + 2E_P{}^2 \times \frac{1}{2}}$$

$$E_{RY} = \sqrt{3}E_P$$

Similarly

$$E_{YB} = E_Y + (-E_B) = \sqrt{E_Y{}^2 + E_B{}^2 + 2E_Y E_B \cos 60^0} = \sqrt{3}E_P$$

$$E_{BR} = E_B + (-E_R) = \sqrt{E_B{}^2 + E_R{}^2 + 2E_B E_R \cos 60^0} = \sqrt{3}E_P$$

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Hence for balanced system

$$E_{RY} = E_{YB} = E_{BR} = \sqrt{3}E_P = E_L$$

If ϕ is the angle between phase voltage and phase current then

Active power of 3 phase $= 3\, E_P I_P \cos\phi = 3\, \frac{E_L}{\sqrt{3}} I_L \cos\phi = \sqrt{3} E_L I_L \cos\phi$ W

Reactive power of 3 phase $= 3\, E_P I_P \sin\phi = 3\, \frac{E_L}{\sqrt{3}} I_L \sin\phi = \sqrt{3} E_L I_L \sin\phi$ VAR

Apparent power of 3 phase $= 3\, E_P I_P = 3\, \frac{E_L}{\sqrt{3}} I_L = \sqrt{3} E_L I_L$ VA

❖ Mesh or Delta (Δ) connected 3- ϕ System

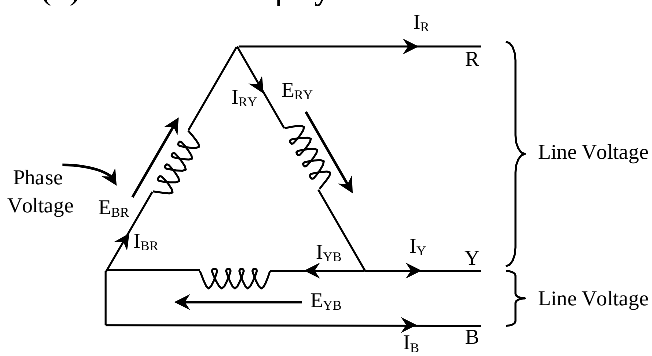

Fig.4a

E_{RY}, E_{YB} & E_{BR} are called phase voltages.

I_{RY}, I_{YB} & I_{BR} are called phase currents.

From figure it is clear that

$$E_{RY}+E_{BR}+E_{BY}=0$$

Line Voltage (E_L) = Phase Voltage (E_P)

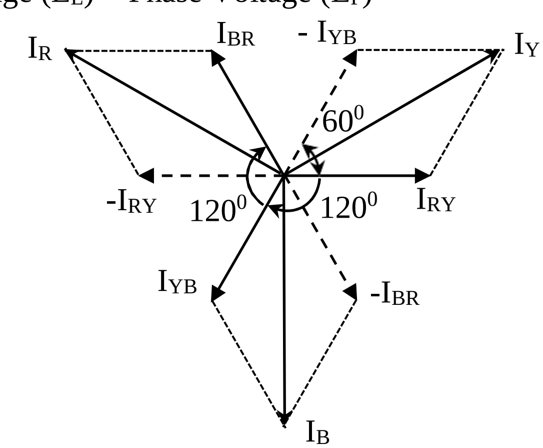

Fig.4b

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Apply KCL at node R

$$I_R = I_{BR} - I_{RY} = I_{BR} + (-I_{RY})$$

Its magnitude from above phasor diagram

$$I_R = \sqrt{I_{BR}{}^2 + I_{RY}{}^2 + 2I_{BR}I_{RY}\cos 60^0}$$

For balanced 3-phase system

$I_{RY} = I_{YB} = I_{BR} = I_P$ (Phase Current)

So $$I_R = \sqrt{I_P{}^2 + I_P{}^2 + 2I_P I_P \cos 60^0} = \sqrt{I_P{}^2 + I_P{}^2 + 2I_P{}^2 \times \frac{1}{2}}$$

$$I_R = \sqrt{3}I_P$$

Similarly

$$I_Y = I_{RY} + (-I_{YB}) = \sqrt{I_p{}^2 + I_P{}^2 + 2I_p I_P \cos 60^0} = \sqrt{3}I_P$$

$$I_Y = I_{YB} + (-I_{BR}) = \sqrt{I_p{}^2 + I_P{}^2 + 2I_p I_P \cos 60^0} = \sqrt{3}I_P$$

Hence for balanced system

$I_R = I_Y = I_B = I_L = \sqrt{3}I_P$

If ϕ is the angle between phase voltage and phase current then

Active power of 3 phase $= 3\, E_P I_P \text{Cos}\,\phi = 3\, E_L \frac{I_L}{\sqrt{3}} \text{Cos}\,\phi = \sqrt{3} E_L I_L \text{ Cos}\,\phi$ W

Reactive power of 3 phase $= 3\, E_P I_P \text{Sin}\,\phi = 3\, E_L \frac{I_L}{\sqrt{3}} \text{Sin}\,\phi = \sqrt{3} E_L I_L \text{ Sin}\,\phi$ VAR

Apparent power of 3 phase $= 3\, E_P I_P = 3\, E_L \frac{I_L}{\sqrt{3}} = \sqrt{3} E_L I_L$ VA

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NOTE:Measurement of power in 3-phase load:

There are three methods

1. One wattmeter method
2. Two wattmeter method
3. Three wattmeter method

1. One wattmeter method :

It is used only for balanced load

Total power consumed by 3-ϕ load

P=3x Power consumed by one phase load

=3x Reading of one wattmeter (W)

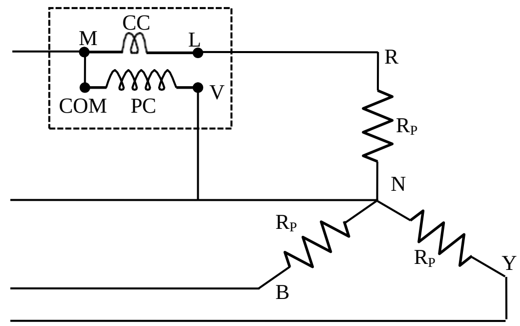


Fig.7a: 3-ϕ Star Connected Balanced Load

Note: if load is delta connected, voltage terminal (V) of PC will be connected to ground.

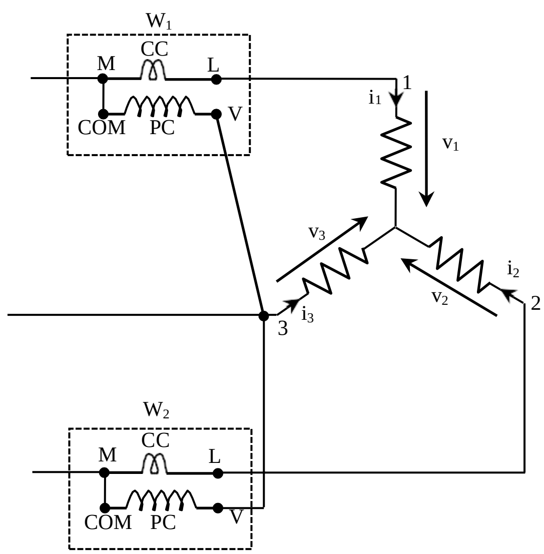
2. Three wattmeter method:

For balanced or unbalanced load total power

$P=W_1+W_2+W_3$

3. <u>Two Wattmeter method:</u>

a. When load is star connected:



The star connected or deltaconnected, total instantaneous power of 3-ϕ load will be the sum of the instantaneous power given by the two wattmeters.Since wattmeter measures active power so total active power of 3-ϕ load will be

$$P= W_1+W_2$$

W_1= Active power measured by wattmeter 1

W_2= Active power measured by wattmeter 2

$$Cos\phi = Cos\tan^{-1}\sqrt{3}\left(\frac{W_1-W_2}{W_1+W_2}\right)$$

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IMPORTANT TERMS:

Star (Y) Connected System	Delta (Δ) Connected System
In star connected system there is common point known as neutral 'n' or star point. It can be earthed.	There is no neutral point in delta connected system
In star connected system we get 3-phase, three wire system and also 3-phase, 4 wire system is taken out.	Only 3-phase, 3 wire system is possible in delta connected system
Line voltage $V_L = \sqrt{3}\, V_{ph}$ or, $V_{ph} = \frac{1}{\sqrt{3}} V_L$	Line voltage = Phase voltage $V_L = V_{ph}$
Line current = Phase current $I_L = I_{ph}$	Line current $I_L = \sqrt{3}\, I_{ph}$ $I_{ph} = \frac{1}{\sqrt{3}} I_L$
Three phase power $= \sqrt{3}\, V_L\, I_{ph} \cos\phi$ $= 3\, V_{ph}\, I_{ph} \cos\phi$	Three phase power $= \sqrt{3}\, V_L\, I_L \cos\phi$ $= 3\, V_{ph}\, I_{ph} \cos\phi$

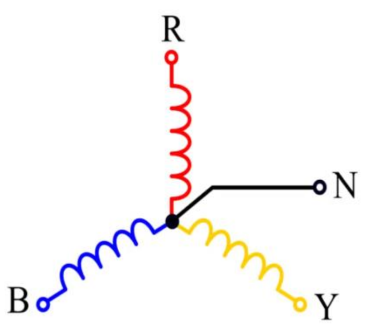


Figure 1 - Star Connection

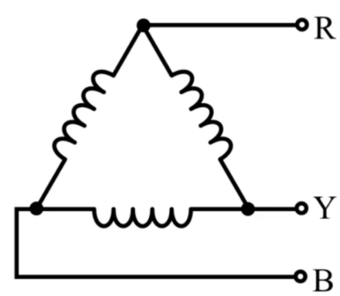
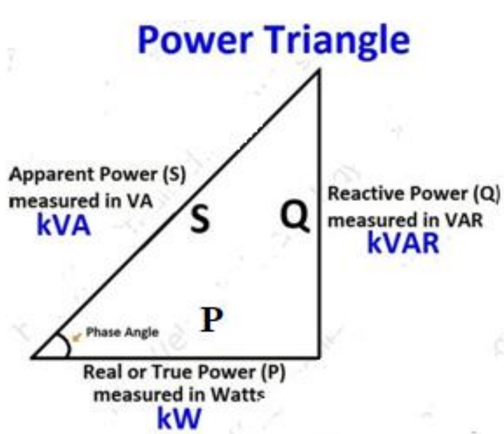


Figure 2 - Delta Connection



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Numerical on Three phase circuits

Case (a): Balanced star connected loads

Example 1. A balanced star connected load of (8+ j6) phase is connected to a 3 phase, 230V, 50c/s supply. Find the line current, power factor, power, reactive volt amperes and total volt amperes.

Solution :

$$\text{Line voltage} = |E_L| = 230 \text{ volts}$$

$$\therefore |E_\phi| = \frac{E_L}{\sqrt{.3}} = \frac{230}{\sqrt{3}} = 133 \text{ volts}$$

$$\text{Load impedance/phase} = Z_\phi = (8 + j6)\ \Omega$$

$$= 10 \angle 36.9^\circ\ \Omega$$

$$\therefore |Z_\phi| = 10\Omega$$

$$\text{and phase angle } \phi = 36.9^\circ \text{ lag}$$

$$I_L = I_\phi = \frac{|E_\phi|}{|Z_\phi|} = \frac{133}{10} = 13.3 \text{ A}$$

$$\text{Power factor} = \cos\phi = \cos 36.9^\circ = 0.8 \text{ lag}$$

$$\left(\text{Also } \cos\phi = \frac{|R_\phi|}{|Z_\phi|} = \frac{8}{10} = 0.8 \right)$$

$$\text{Total volt amperes} = \sqrt{3}\ |E_L|\ |I_L| = |3|\ E_\phi\ |I_\phi|$$

$$= \sqrt{3} \times 230 \times 13.3 = 5298 \text{ VA}$$

$$\text{Power} = \sqrt{3}\ |E_L|\ |I_L| \cos\phi$$

$$= 5298 \times 0.8$$

$$= 4239 \text{ watts}$$

$$\text{Reactive volt-amperes} = \sqrt{3}\ |E_L|\ |I_L| \sin\phi$$

$$= (5298) \times 0.6$$

$$= 3179 \text{ VAR}$$

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2 A balanced star connected load of (3 - j4)2 impedance is connected to 400 V three phase supply. What is the real power consumed?

Solution:

Note: For Star system, unless specified, the given voltage is taken as line voltage.

$$\text{Here } |E_L| = 400 \text{ volts}$$

$$|Z_\phi| = (3 - j4) = 5\angle -53.13^\circ\ \Omega$$

$$\therefore\ |Z_\phi| = 5\Omega \text{ and phase angle } \phi = 53.13^\circ \text{ lead}$$

$$\text{and } |E_\phi| = \frac{|E_L|}{\sqrt{3}} = \frac{400}{\sqrt{3}} = 231 \text{ volts}$$

$$\text{By Ohm's law, } |I_\phi| = \frac{|E_\phi|}{|Z_\phi|} = \frac{231}{5} = 46.2 \text{ A}$$

$$\therefore\ |I_L| = |I_\phi| = 46.2 \text{ A}$$

$$\text{Real power} = \sqrt{3}\ |E_L|\ |I_L| \cos\phi$$

$$= \sqrt{3} \times 400 \times 46.2 \cos 53.13^\circ$$

$$= 19205 \text{ W} = 19.205 \text{ KW}$$

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Case (b): Balanced Delta Connected Load:

Example 3. A symmetrical 3 phase, 400 V system supplies a balanced mesh connected load. The current in each branch circuit is 20A and the phase angle is 40° lag. Find (a) the line current (b) the total power.

Solution: Data: Type of connection = delta

$$|E_L| = |E_\phi| = 400 \text{ volts}$$

$$|I_\phi| = 20 \text{ A}$$

$$\phi = 40° \text{ lag}$$

(a)
$$|I_L| = \sqrt{3}\,|I_\phi|$$
$$= \sqrt{3} \times 20 = 34.64 \text{ A}$$

(b)
$$\text{Total power} = \sqrt{3} \times 400 \times 34.64 \times \cos 40°$$
$$= 18386 \text{ W}$$
$$= 18.386 \text{ KW.}$$

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Example 4. Three impedances each of 10 resistance and 52 inductive reactance are connected in delta to a 400 V, 36 supply. Determine the current in each phase and in each line. Calculate also the total power drawn from the supply and the p.f of the load.

Solution:

$$R_\phi = 10\,\Omega, \quad X_\phi = 5\,\Omega$$

$$|E_L| = |E_\phi| = 400 \text{ volts, since delta connection}$$

$$Z_\phi = 10 + j5 = 11.18\angle 26.6^\circ\,\Omega$$

$$\therefore |Z_\phi| = 11.18\,\Omega, \quad \phi = 26.6^\circ \text{ lag}$$

$$\therefore |I_\phi| = \frac{|E_\phi|}{|Z_\phi|} = \frac{400}{11.18} = 35.8\text{ A}$$

$$|I_L| = \sqrt{3}\,|I_\phi| = \sqrt{3} \times 35.8$$

$$= 62.00\text{ A}$$

$$\text{Power factor} = \cos\phi = \cos 26.6^\circ = 0.89 \text{ lag}$$

$$\left(\text{Also} \quad \cos\phi = \frac{R_\phi}{Z_\phi} = \frac{10}{11.18}\right)$$

$$\text{Total power} = \sqrt{3}\,|E_L|\,|I_L|\cos\phi$$

$$= 3 \times 400 \times 62 \times 0.89$$

$$= 38230\text{ W}$$

$$= 38.23\text{ KW}$$

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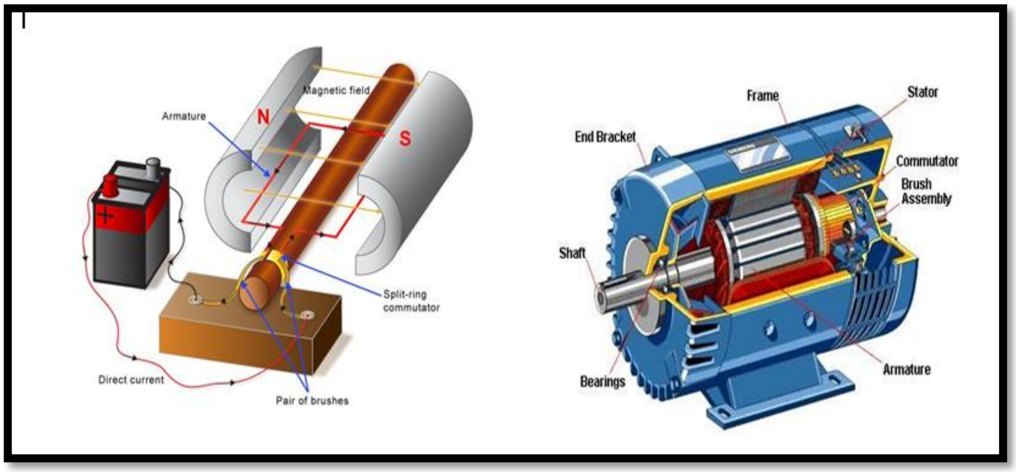
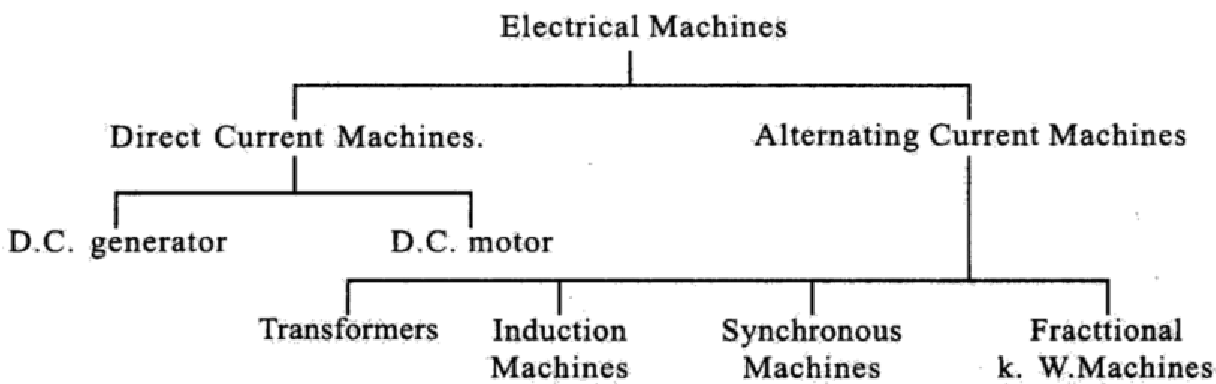
DC Generator



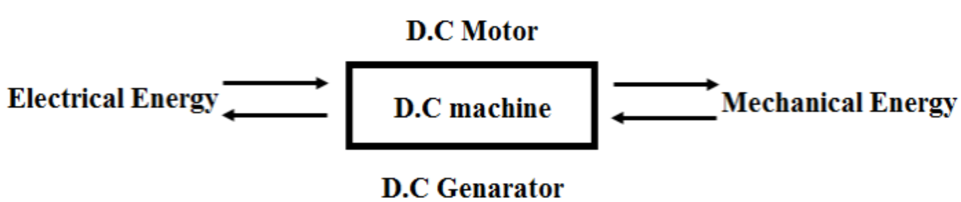


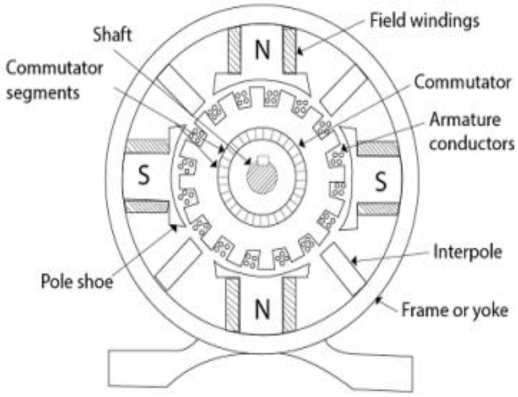
Introduction

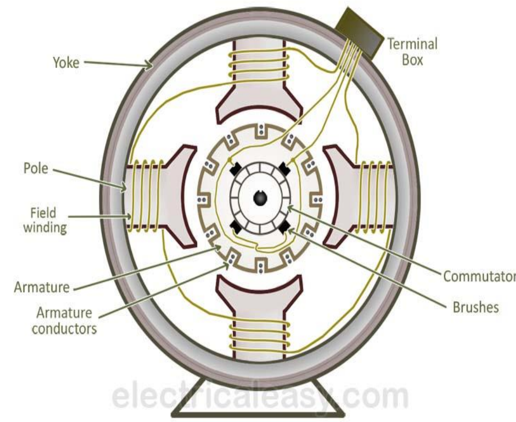
- A DC generator is an electrical machine that converts mechanical energy into electrical energy.

DC machines Introduction

DC machines are broadly classified into two types DC motor and DC generator. DC motor is a device which convert electrical energy into mechanical energy. When a current carrying conductor placed in a magnetic field, it experienced a force. DC generator is a device which converts mechanical (rotational) energy into electrical energy. It works based on the principle of faradays law of electromagnetic induction. Whenever the conductor cuts by the magnetic field emf is induced on it.







Construction Of DC Machine

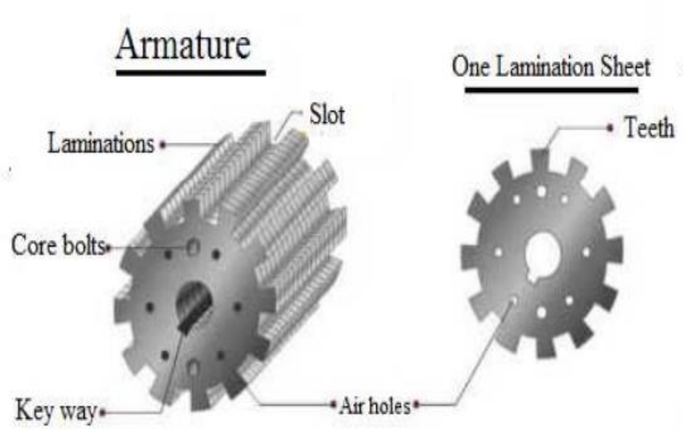
Based on the working principle DC motor & generator, requirement for the both machines are magnetic fields, conductor & mechanical movement. So construction wise both motor & generator are same. Depends upon the types of input (electrical or mechanical) given to the machines it should be differentiated by either motor or generator

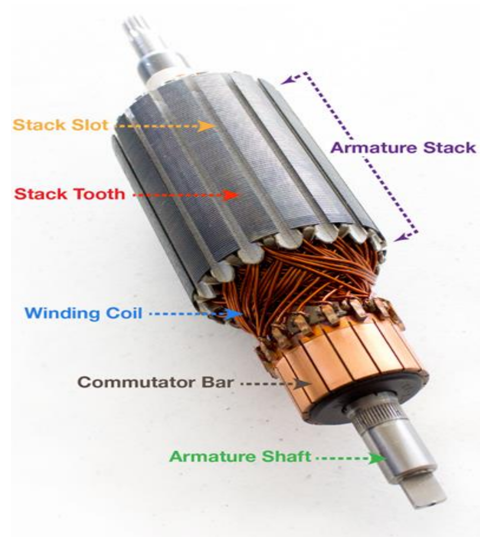
Field winding:

Field windings to be used to produce uniform magnetic flux. The winding are placed in a poles which is located in the yoke. The yoke is a circular outer part of DC machines which is made upon cast iron and projecting even number of poles. It provides space for the field windings. Field windings are like aluminium or copper. Poles shoe are extended and widen because of flux part distribution over to the armature.

Armature Systems:

It is the rotating part of the machine. It consists of two major parts. One is armature core and other is armature winding. A shaft carries cylindrical shaped with slot which is used place the rotating (armature) windings. Usually rotating part of the machines are generally called Rotor. It provides house for the armature conductors and also provides low reluctance to magnetic flux created by the field coils.





Interconnection of armature conductors/coils is called Armature Windings. It is placed over to the periphery of the armature slots. Main function of the armature coil is to generate e.m.f. also carries current in case of D.C motor. Usually copper are preferred to making materials for this windings.

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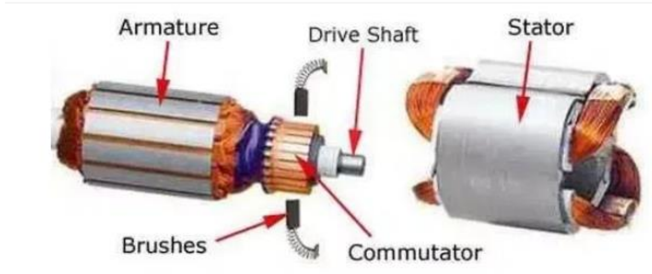
Commutator:

Induced e.m.f in a D.C generator is alternating nature. Rectification is required so commutator are used for this purpose.



It is cylindrical shaped and each commutator segments are made with copper and connected to armature coil with strips. Connections are shown in figure.

Brushes:

It is stationary part & seated over to the commutator. It collects current from commutator and given to stationary external circuit. Usually, it is made with carbon like soft materials. It is in rectangular shape and made to press on the surface of the commutator with help of a spring. For D.C machines two carbon brushes are required.

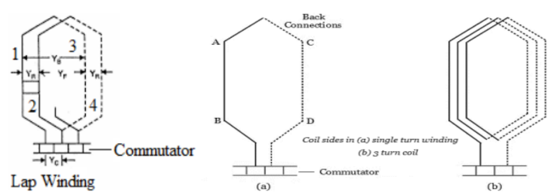
Types of Armature Winding:

More number of conductors arranged in a systematic manner is called windings. Depending upon the conductors connections the armature windings classified as two types,

1. Lap winding
2. Wave winding

Lap winding:

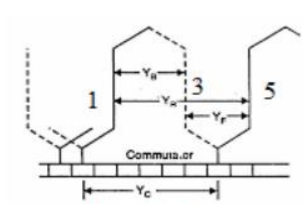
First conductor connected to 3rd conductor for return path and continuation is join or overlap into 2" conductor and move into so on. In this conductor connection are number of poles is number of parallel paths. i,e., A=P number of parallel paths. Figure shows the Lap winding diagram.



Lap Winding

Wave winding:

First conductor is move forwarded shown in figure. The conductor moves ahead like wave. For this connection the total conductors are divided into two parallel paths always i.e., A=2



Wave winding

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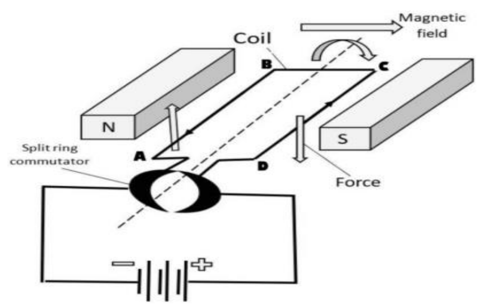
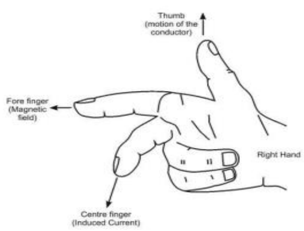
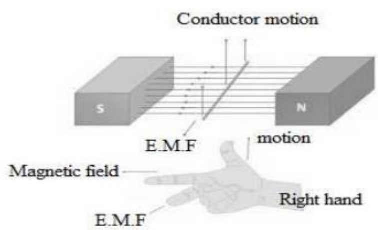
Working Principle of D.C Generator

D.C generator works based on the principle of Faraday’s law of electromagnetic induction.” Whenever the conductor cuts by the magnetic field e.m.f (electro motive force) induced on the conductor. Direction of the induced e.m.f can be determined using Fleming’s right-hand rule.







Fleming’s Right Hand Rule:

Stretch the thumb, index finger and middle finger of right hand perpendicular to each other. If index finger points out the direction of the magnetic field and thumb represents the direction of the motion conductor means than middle finger gives the direction of the induced e.m.f. In this way we can identify the direction of induced e.m.f using Fleming’s right-hand rule.

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E.M.F Equation of dc generator

Let

P = Number of poles in the filed systems

Φ = flux per pole (webers)

N = Speed of the armature(revolution per minute –rpm)

Z = Total number of conductors

= Number conductors X slot per conductor

A = parallel paths For Lap winding, A=P ;Wave winding A=2

$$induced e.m.f \propto \frac{d\varphi}{dt} - - - - - 1$$

$$d\varphi = PX\varphi - - - - - 2$$

$$dt = \frac{60}{N} - - - - - 3$$

$$induced e.m.f per conductor e = 1\,X\frac{d\varphi}{dt} = \frac{PX\varphi}{\frac{60}{N}}$$

According to faraday's law, the rate of change of conductor's cuts by the magnet filed e.m.f induced on the conductor

$$e = \frac{P\varphi N}{60} X \frac{Z}{A} = \frac{\varphi ZNP}{60A} volts - - - - - - 4$$

For total conductors per parallel path

$$E_{induced} = \frac{\varphi ZN}{60} volts - - - - - - - 5$$

$$E_{induced} = \frac{\varphi ZNP}{120} volts - - - - - - - 6$$

Equation-4 general equation of a D.C. generator.

For Lap wound machine, A = P….., **Equation-5**

For wave wound machine, A = 2,….. **Equation-6**

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Solved Example Problems of DC Machines (generator)

1. Calculate the emf generated by a 6 pole DC generator having 480 conductors and driven at a speed of 1200 rpm. The flux per pole is 0.012 Wb. Assume the generator to be (a) Lap wound, (b) Wave wound.

Solution:

$$E_g = \frac{\phi ZN}{60} \times \frac{P}{A} \text{ Volts.}$$

(a) For a lap wound machine,

$$A = P = 6$$

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 6} = 115.2 \text{ volts.}$$

$$E_g = 115.2 \text{ V.}$$

(b) For a wave wound machine,

$$E_g = \frac{0.012 \times 480 \times 1200 \times 6}{60 \times 2}$$

$$= 345.6 \text{ Volts}$$

$$\boxed{E_g = 345.6 \text{ Volts.}}$$

2. A wave connected armature winding has 19 slots with 54 conductors per slot. If the flux per pole is 0.025 Wb and number of poles is 8, find the speed at which the generator should be run to give 513 V. Also find the speed if the armature is lap connected.

Solution:

P = 8

φ = 0.025 Wb

Z = 19 × 54 = 1026

A = 2 (for wave)

Eg = 513 Volts

$$E_g = \frac{P\phi ZN}{60A} \text{ (or) } N = \frac{60 E_g A}{\phi ZP}$$

$$N = \frac{60 \times 513 \times 2}{0.025 \times 1026 \times 8} \quad \text{(For lap wound } A = P = 8)$$

$$\boxed{N = 1200 \text{ rpm.}}$$

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3. The armature of a 4-pole, 600 rpm, lap wound generator has 100 slots. If each coil has 4 turns, calculate the flux per pole required to generate an emf of 300 V.

Solution:

No. of poles = 4; Speed 600 rpm,

No. of slots = 100; E_g = 300 V

No. of conductors Z = 100 × 4 × 2=8

Lap wound generator, A = P = 4

$$\text{Generated emf } E_g = \frac{P\phi ZN}{60A}$$

$$\therefore \text{ Flux/Pole } \phi = \frac{E_g \times 60A}{PZN}$$

$$= \frac{300\times60\times4}{4\times800\times600}$$

$$\boxed{\phi = 37.5 \text{ mWb.}}$$

4. A 6-pole, lap wound armature rotated at 350 rpm is required to generate 300 V. The useful flux per poles is 0.05 Wb. If the armature has 120 slots; calculate the no. of conductors per slot.

Solution:

Given data:

No. of Poles, P = 6, Speed N = 350 rpm, E_g = 300 V, Flux / Pole = 0.05 Wb

No. of Slots = 120. For lap wound generator, A = P = 6.

To find:

No. of conductors / slot.

Solution:

$$\text{Generated Emf } E_g = \frac{P\phi ZN}{60A}$$

$$\text{No. of conductors } Z = \frac{E_g \times 60A}{P\phi N}$$

$$= \frac{300\times60\times4}{4\times0.05\times350}$$

$$\boxed{Z = 1029.}$$

No. of conductors / slot = 1029/120 = 8.575

Conductors / Slot = 9

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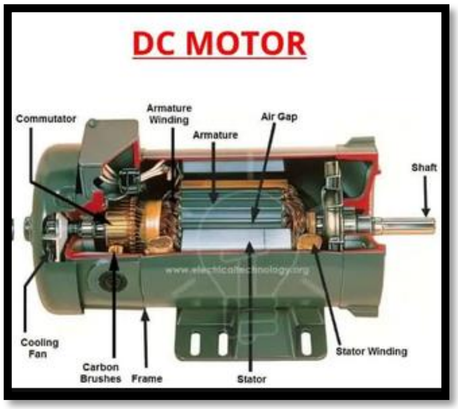
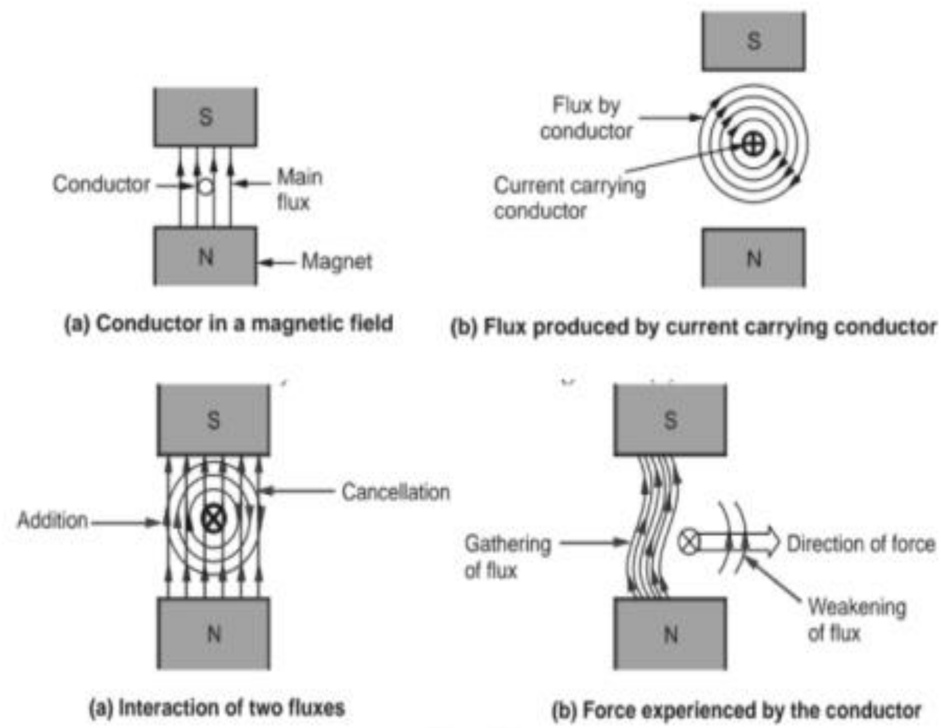
DC Motor:



- A DC motor is an electrical machine that converts electrical energy into mechanical energy.
- **Principle of Operation of a D.C Motor**

The principle of operation of d.c motor can be stated in a single statement as "when a current carrying conductor is placed in a magnetic field; it experiences a mechanical force". In de motor, field winding produces a required magnetic field while armature conductors play a role of a current carrying conductors and hence armature conductors experience a force. As conductors are placed in the slots which are on the periphery, the individual force experienced by the conductors acts as a twisting or turning force on the armature which is called a torque.



(a) Conductor in a magnetic field
(b) Flux produced by current carrying conductor
(a) Interaction of two fluxes
(b) Force experienced by the conductor

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❖ **TORQUE EQUATION**: Torque is turning or twisting force about an axis torque is measured by the product of force and the radius at which the force acts. Consider a wheel of radius 'r' metres acted on by a circumferential force 'F' Newton as shown in fig 3.31.

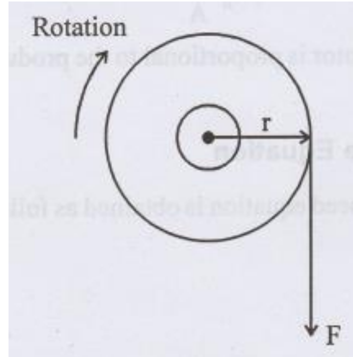

Figure 3.31

The angular velocity of the wheel is

$\omega = 2\pi N / 60$

Torque, $T = F \times r$

Work done per revolution = F × distance moved

$= F \times 2\pi r$

Power developed, P = Work done / Time = F × 2πr / time for 1 rev

$$= \frac{F \times 2\pi r}{60/N}$$

$$P = (F \times r)\left(\frac{2\pi N}{60}\right)$$

$P = T\omega$

T = Torque in N-m,

ω = Angular speed r/sec

Power in armature = Armature torque × ω

$$E_b I_a = T_a \times \frac{2\pi N}{60}$$

$$E_b = \frac{\phi ZNP}{60A}$$

$$\frac{\phi ZNP}{60A} I_a = T_a \frac{2\pi N}{60}$$

$$T_a = 0.159\, \phi\, I_a \frac{PZ}{A}$$

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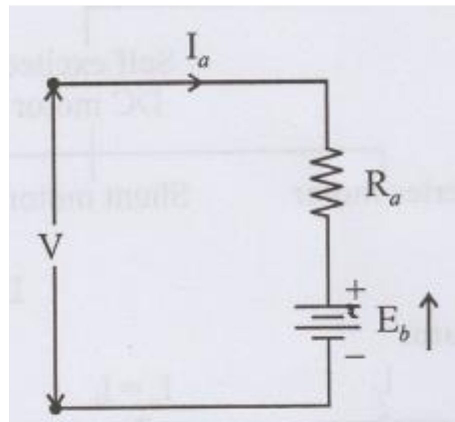
❖ **Back Emf and its Significance in DC Motor**

In a DC motor when the armature rotates, the conductors cut the lines of force of magnet field, so that an emf is induced in the armature. This induced emf acts in opposition to the current in the machine and the applied voltage so this emf is called back emf or counter emf. According to lenz's law, the direction of the back emf opposes the supply voltage the back emf is calculated from the equation of induced emf in the generator.

$$E_b = \frac{P\Phi ZN}{60A}$$

Where



ϕ - flux/pole in wb

P - Number of poles

Z - Total number of conductors in the armature

N - Speed in rpm

A - No of parallel paths

The equivalent circuit of a motor is shown in fig . Here, the armature circuit is equivalent to a source of emf E_b, in series with a resistance R_a and a DC supply is applied across, series connection of R_a and E_b. The voltage equation is $V = E_b + I_a R_a$

From the above voltage equation

Armature current $I_a = V – E_b / R_a$

Where V - Applied voltage , E_b - Back emf,I_a - Armature current, R_a - Armature resistance

V - E_b - Net voltage in the armature circuit

(i) If the motor speed is high, back emf E_b is large and armature current is small.

(ii) If the motor speed is low, back emf E_b will be less and armature current is more.

The significance of Back EMF: The presence of back emf makes the d.c. motor a self-regulating machine i.e., it makes the motor to draw as much armature current as is just sufficient to develop the torque required by the load.

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APPLICATIONS OF DC MOTOR

Type of Motor	Characteristics	Applications
Shunt	Speed is fairly constant and medium starting torque.	1. Blowers and fans 2. Centrifugal and reciprocating pumps 3. Lathe machines 4. Machine tools 5. Milling machines 6. Drilling machines
Series	High starting torque. No load condition is dangerous. Variable speed.	1. Cranes 2. Hoists, Elevators 3. Trolleys 4. Conveyors 5. Electric locomotives
Cumulative compound	High starting torque. No load condition is allowed.	1. Rolling mills 2. Punches 3. Shears 4. Heavy planers 5. Elevators
Differential compound	Speed increases as load increases.	Not suitable for any practical applications

Numericals on Torque Equation of DC Motor

1.A 4 pole DC motor has a wave wound armature with 594 conductors. The armature current is 40 A and flux per pole is 7.5 mwb. Calculate the torque developed by the motor.

Given :P = 4, Z = 594, Ia = 40 A, ϕ = 7.5 mwb

For wave wound A = 2

Torque developed

$$T_a = 0.159\ \phi\ \frac{I_a PZ}{A}$$

$$= 0.159 \times 7.5 \times 10^{-3} \times \frac{40 \times 4 \times 594}{2}$$

$$T_a = 56.66 \text{ N-m}$$

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2.A 4 pole DC motor takes an armature current of 50 A. The armature has 480 lap connected conductors. The flux per pole is 20 mWb. Calculate the gross torque developed by the motor.

Solution:

No. of poles P = 4

Armature current I_a = 50 A

No. of conductors Z = 480

$\varphi = 20 \times 10^{-3}$

Lap connection A = P = 4.

$$T_a = 0.159\,\phi\,I_a\,\frac{PZ}{A}$$

$$= 0.159 \times 20 \times 10^{-3} \times \frac{50 \times 4 \times 480}{4}$$

$$\boxed{T_a = 76.32 \text{ N-m.}}$$

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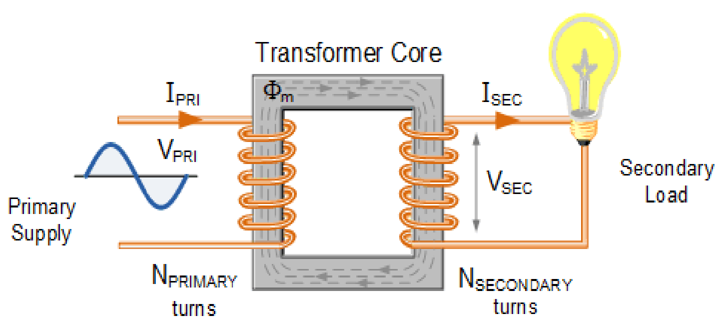
Transformer

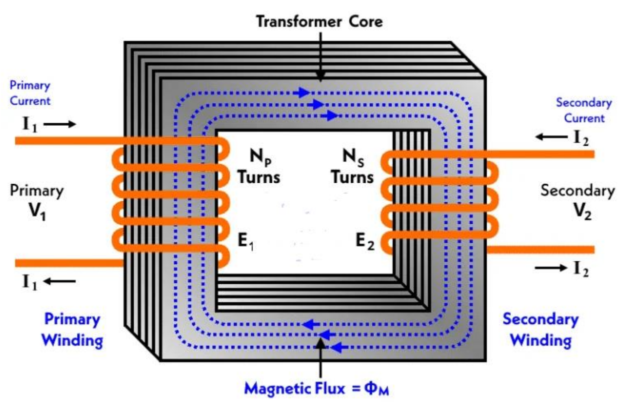
- The transformer is a static device that transfers electrical energy from one electrical circuit to another electrical circuit at constant frequency..

Introduction:

- The transformer is a device that transfers electrical energy from one electrical circuit to another electrical circuit at constant frequency . The two circuits may be operating at different voltage levels but always work at the same frequency. Basically transformer is an electro-magnetic energy conversion deviceIt is commonly used in electrical power system and distribution systems. It can change the magnitude of alternating voltage or current from one value to another. This useful property of transformer is mainly responsible for the widespread use of alternating currents rather than direct currents i.e., electric power is generated, transmitted and distributed in the form of alternating current.
- Transformers have no moving parts, rugged and durable in construction, thus requiring very little attention. They also have a very high efficiency as high as 99%.

<u>Construction & Principle of Working:</u>





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Construction & Principle of Working: The principle of mutual induction states that when two coils are inductively coupled and if current in one coil is changed uniformly then an e.m.f. gets induced in the other coil. This e.m.f. can drive a current, when a closed path is provided to it. The transformer works on the same principle. In its elementary form, it consists of two inductive coils which are electrically separated but linked through a common magnetic circuit. The two coils have high mutual inductance. The basic transformer is shown in the Fig. 6.1.1.

• One of the two coils is connected to a source of alternating voltage. This coil in which electrical energy is fed with the help of source is called primary winding (P). The other winding is connected to load. The electrical energy transformed to this winding is drawn out to the load.

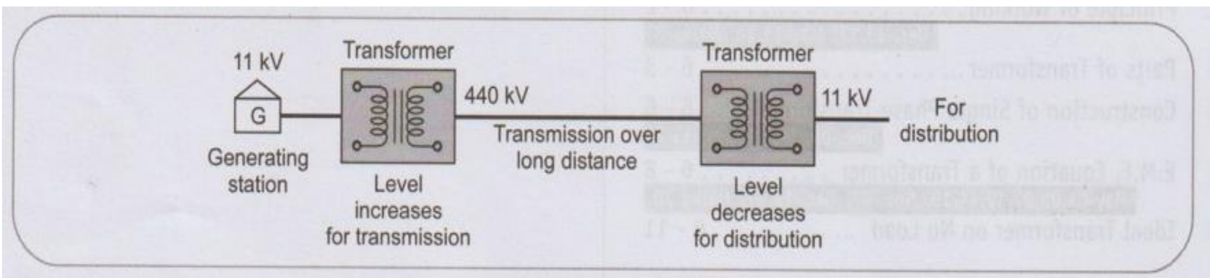

Fig. 6.1.1 Use of transformers in transmission system

This winding is called secondary winding (S). The primary winding has N_1 number of turns while the secondary winding has N_2 number of turns. Symbolically the transformer is indicated as shown in the Fig. 6.2.1.

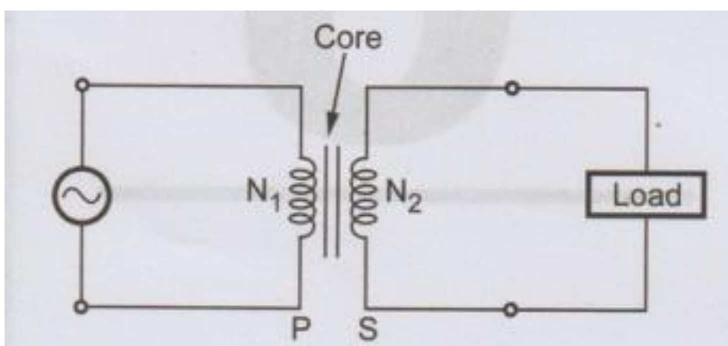

Fig. 6.2.1 Symbolic representation

• When primary winding is excited by an alternating voltage, it circulates an alternating current. This current produces an alternating flux (ϕ) which completes its path through common magnetic core as shown dotted in the Fig. 6.2.2. Thus an alternating, flux links with the secondary winding. As the flux is alternating, according to Faraday's law of an electromagnetic induction, mutually induced e.m.f. gets developed in the secondary winding. If now load is connected to the secondary winding, this e.m.f. drives a current through it.

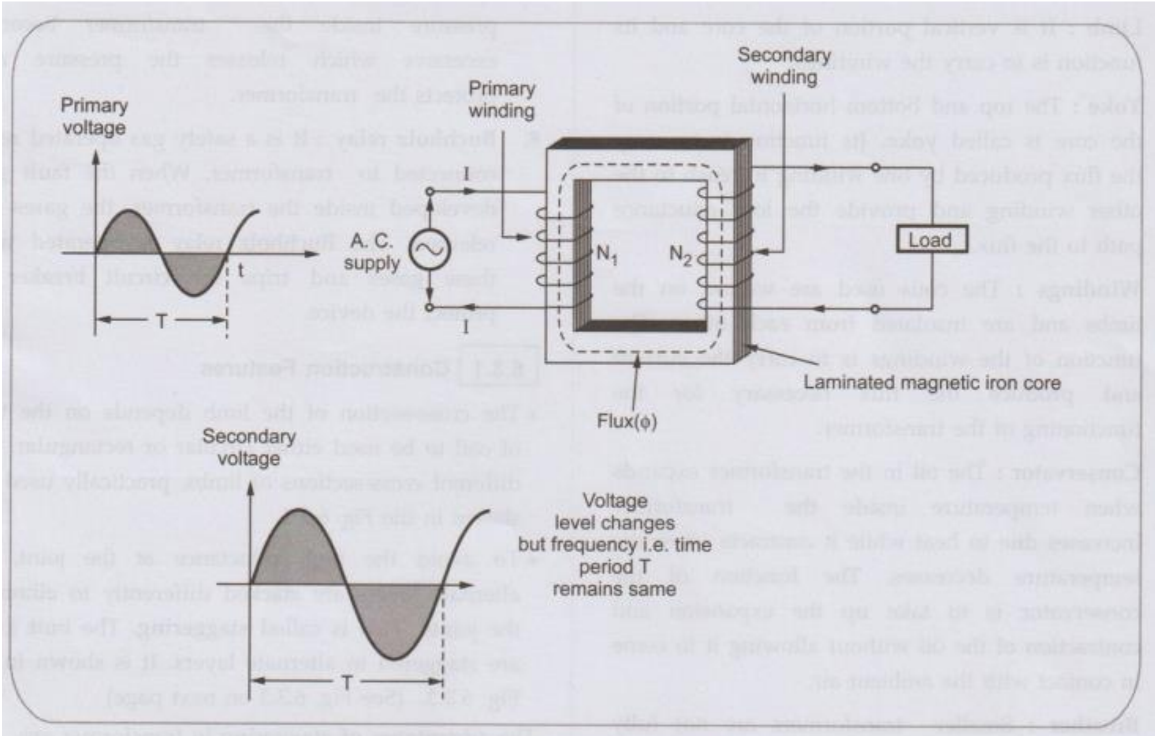

Fig. 6.2.2 Basic transformer

- Thus though there is no electrical contact between the two windings, an electrical energy gets transferred from primary to the secondary.

Main Parts of the Transformer

The various parts of transformer are,

1. Core: It is made up of high grade silicon steel laminations. Its function is to carry the flux, providing low reluctance to it. Generally 'L' es shaped or 'I' shaped laminations are used as shown in the Fig. 6.2.2

2. Limb : It is vertical portion of the core and its function is to carry the windings.

3. Yoke : The top and bottom horizontal portion of the core is called yoke. Its function is to carry the flux produced by one winding to reach to the other winding and provide the low reluctance path to the flux.

4. Windings: The coils used are wound on the limbs and are insulated from each other. The function of the windings is to carry the current and produce the flux necessary for the functioning of the transformer.

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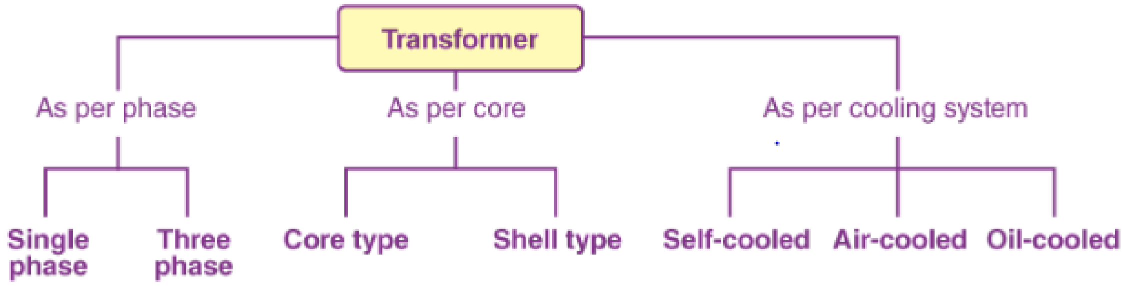
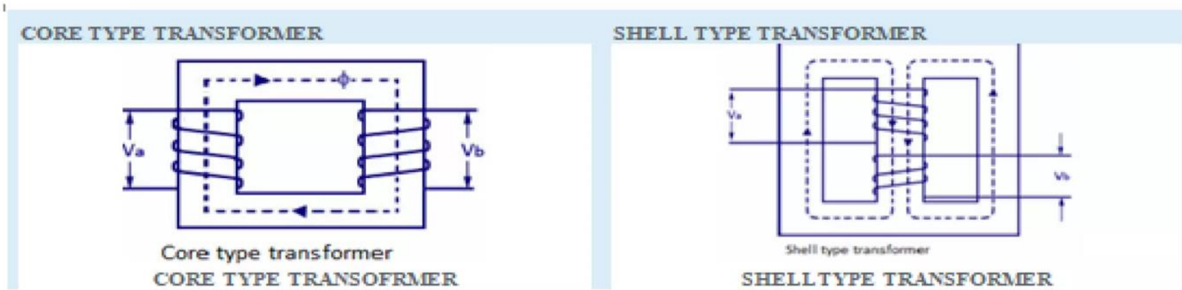
Classification of transformer:

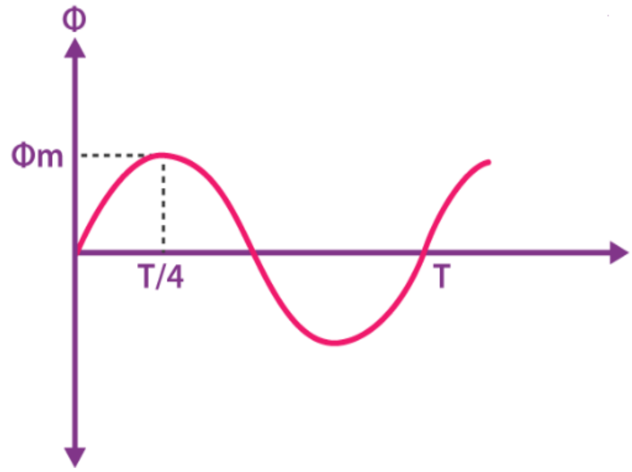


Comparison of core and shell type Tranformer



1. In core type transformer winding is placed on **two core limb**	**1.** In shell type transformer winding is placed on **mid arm of the core.**
2. It has only one magnetic circuit or magnetic flux path.	**2.** It has two magnetic circuit or magnetic flux path
3. Core type transformer are used for lower voltage level applications	**3.** Shell type transformers are used for higher voltage level applications.
4. Core type transformer has more leakage flux hence more losses therefore less efficiency.	**4.** Shell type transformer has less leakage flux hence less losses therefore better efficiency.
5. It has less mechanical protection to coil.	**6.** It has better mechanical protection to coil.
6. Transformer losses (copper losses, iron losses) are more than shell type transformer.	**6.** Transformer losses (copper losses, iron losses) are less than core type transformer.
7. Maintenance & repairing of this type transformer is simple than shell type transformer.	**7.** Maintenance & repairing of this type transformer is complex than core type transformer.
8. Core type transformer has **two limbs.**	**8.** Shell type transformer has **three limb.**
9. cylindrical type winding are used.	**9.** Sandwich type winding are used.
10. Natural cooling is provided since more surface is exposed to atmosphere.	**10.** Natural cooling is less effective as compare to shell type transformer.

❖ EMF Equation of Transformer



N_1 – Number of turns in the primary

N_2 – Number of turns in the secondary

Φ_m – Maximum flux in the weber (Wb)

T – Time period. It is the time taken for 1 cycle.

The flux formed is a sinusoidal wave. It rises to a maximum value of Φ_m and decreases to a negative maximum of Φ_m. So, flux reaches a maximum in one-quarter of a cycle. The time taken is equal to T/4.

Average rate of change of flux = $\Phi_m/(T/4) = 4f\Phi_m$

Where, f = frequency

$T = 1/f$

Induced EMF per turn = Rate of change of flux per turn

Form factor = RMS value / average value

RMS value = 1.11 $(4f\Phi_m) = 4.44\, f\Phi_m$ [form factor of a sine wave is 1.11]

RMS value of EMF induced in winding = RMS value of EMF per turn x No. of turns

❖ **Primary Winding** RMS value of induced EMF = $\mathbf{E_1 = 4.44\, f\Phi m * N_1}$

❖ **Secondary Winding** RMS value of induced EMF = $\mathbf{E_2 = 4.44\, f\Phi m * N_2}$

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44f\,\Phi m$$

This is the EMF equation of the transformer.

For an ideal transformer at no load condition,

E_1 = Supply voltage on the primary winding

E_2 = Terminal voltage (theoretical or calculated) on the secondary winding

Voltage Transformation Ratio

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = k$$

K is called the voltage transformation ratio, which is a constant.

Case 1:If $N_2 > N_1$, K>1, it is called a step-up transformer.

Case 2: If $N_2 < N_1$, K<1, it is called a step-down transformer.

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❖ Applications of Transformers

- Transformers are used in a variety of applications, including power generation, transmission and distribution, lighting, audio systems, and electronic equipment Power generation: Transformers are used in power plants to increase the voltage of the electricity generated by the plant before it is sent to the grid.
- Transmission and distribution: Transformers are used in the transmission and distribution of electricity to increase or decrease the voltage of electricity as it is sent from power plants to homes and businesses.
- Lighting: Transformers are used in lighting systems to decrease the voltage of electricity before it is sent to light bulbs.
- Audio systems: Transformers are used in audio systems to increase or decrease the voltage of electricity before it is sent to speakers.
- Electronic equipment: Transformers are used in a variety of electronic devices, including computers, TVs, radios, and cell phones.
- Transformers are a vital part of the electrical grid and are used in a variety of applications to ensure that electricity is delivered safely and efficiently.

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<u>**Solved Example Problems of Transformer**</u>

Example 1.The maximum flux density in the core of a 250/300 V, 50 Hz single phase transformer is 1.2 Wb/m2. If the emf per turn is 8 volt, determine (i) Primary and Secondary turns, (ii) Area of the core.

Solution:

(i) E1 = N1 × emf induced/turn

E1 = 250/8 = 32; N2 = 3000/8 = 375.

(ii) We may use

E2 = 4.44 *ƒ*N2 Bm A

$$3000 = 4.44 \times 50 \times 375 \times 1.2 \times A$$

$$A = \frac{3000}{4.44 \times 50 \times 375 \times 1.2}$$

$$A = 0.03\ m^2.$$

Example 2.A single phase transformer has 400 primary and 1000 secondary turns. The net cross sectional area of the core is 60 cm2. If the primary winding be connected to a 50 Hz supply at 520 V. Calculate (i) the peak value of flux density in the core, (ii) the voltage induced in the secondary winding.

Solution:

Transformation Ratio: $K = N_2/N_1 = 1000/400 = 2.5$:

(i) $E_2/E_1 = K \qquad \therefore\ E_2 = E_1 K = 520 \times 2.5 = 1300$ V

$E_2 = 1300$ V.

(ii) $E_1 = 4.44 f N_1 B_m A$

$$520 = 4.44 \times 50 \times 400 \times B_m \times (60 \times 10^{-4})$$

$$B_m = \frac{520}{4.44 \times 50 \times 400 \times 60 \times 10^{-4}}$$

$B_m = 0.976$ Wb/m^2.

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