3 Set

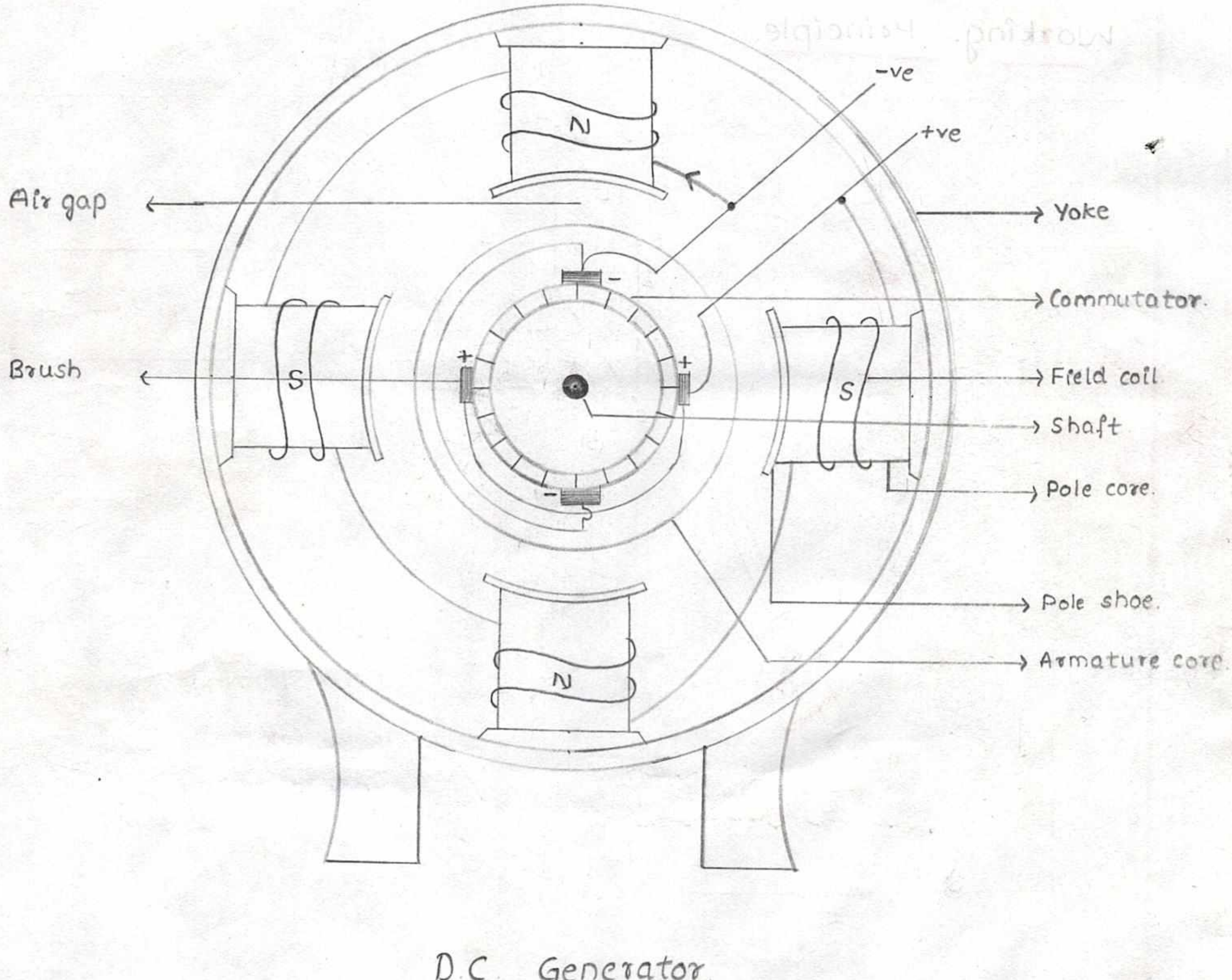
DC Machines

D.C machines.

Two types : 1. D.C Generators.
2. D.C Motor.

D.C Generator.

Constructional features.



D.C Generator.

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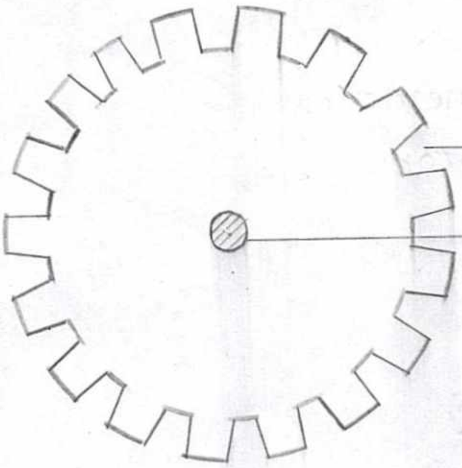
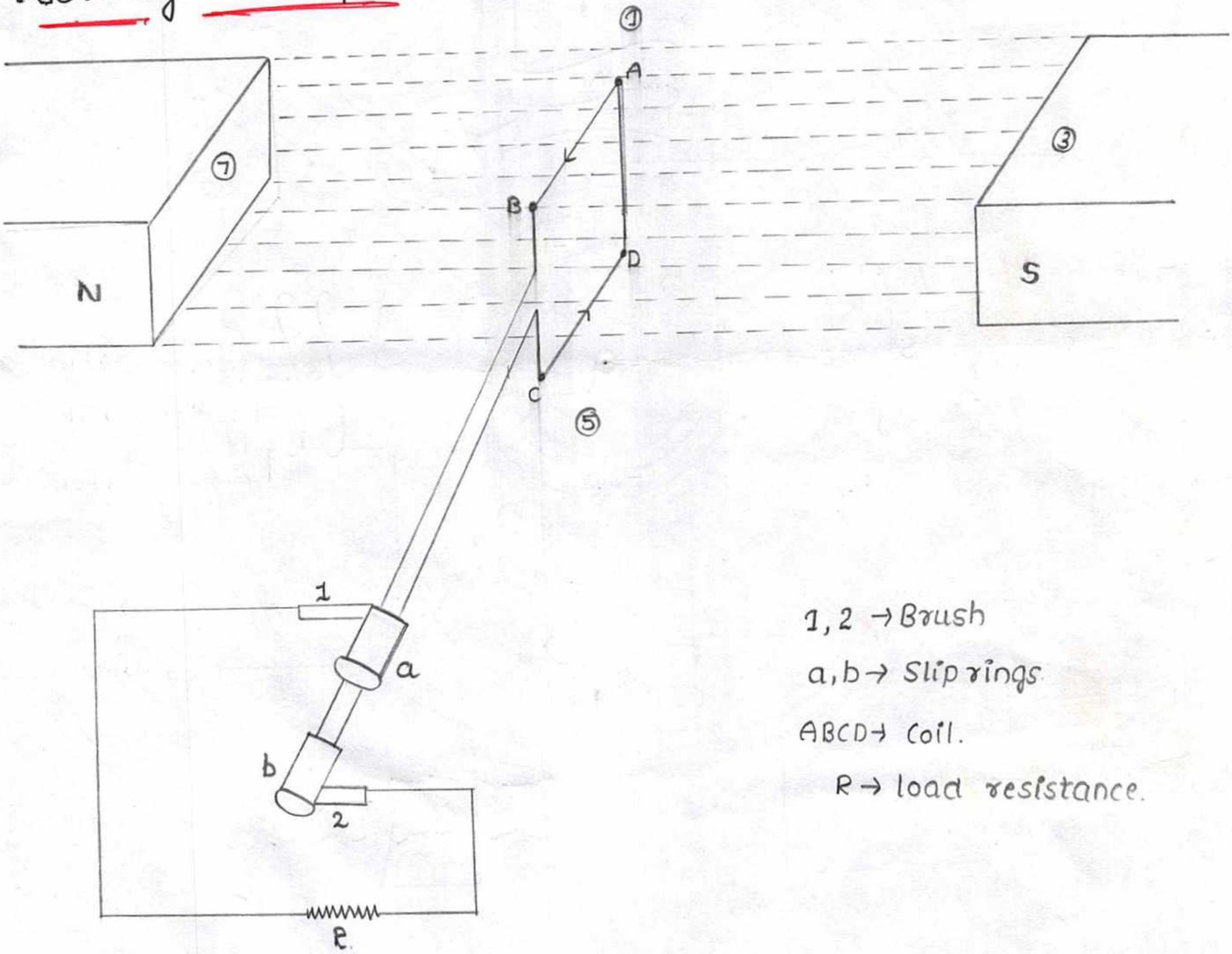
3 set

Armature stamping.



Working Principle.



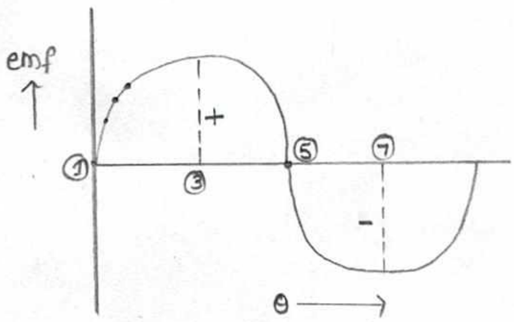
1, 2 → Brush

a, b → Slip rings

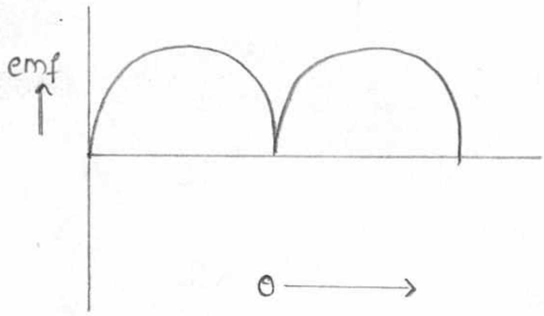
ABCD → Coil.

R → load resistance.

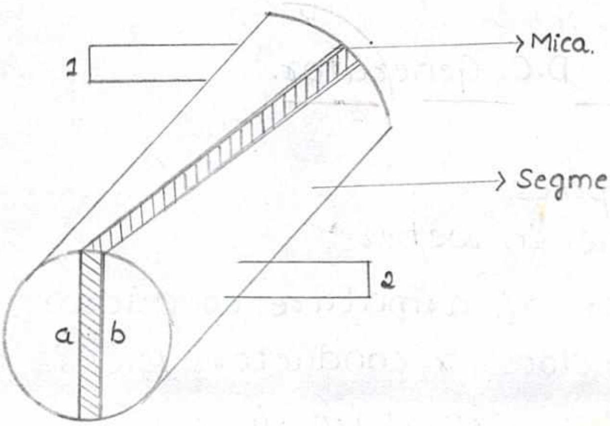
AC wave form.

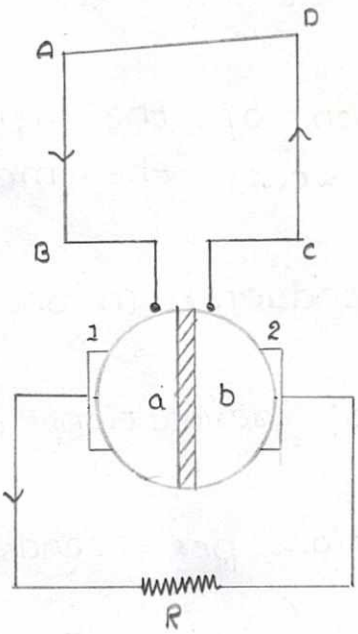


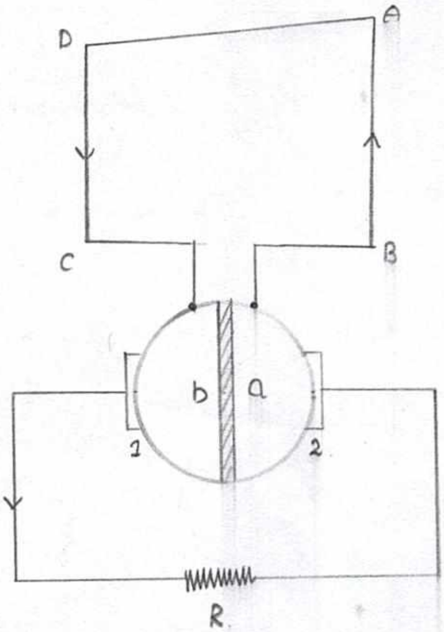
DC wave form.



Split ring commutator.







EMF equation of D.C. Generator.

Let,

P = Number of poles.

ϕ = Flux per pole in webers.

Z = Total number of armature conductors.

= Number of slots x conductors /slot.

N = Speed of the armature in rpm.

A = Number of parallel parts.

A = P for LAP winding.

A = 2 for wave winding.

During one revolution of the armature in a 'p' pole generator each conductor cuts the magnetic flux 'p' times.

∴ Flux cut by one conductor in one revolution = $P\phi$ wb.

Since the number of revolutions of the armature is "N" rpm.

∴ Number of revolutions per seconds = $\frac{N}{60}$

∴ Flux cut by each conductor per second =

Flux cut by each conductor per revolution x Number of revolution /second.

$= P\phi \times \frac{N}{60} = \frac{P\phi N}{60}$ volts

The number of conductors / parallel path = Z/A.

∴ Total emf generated,

E_g = average emf induced per conductor × Number of conductor / parallel path.

$$= \frac{P\phi N}{60} \times \frac{Z}{A}$$

$$= \frac{P\phi NZ}{60A} \text{ volts.}$$

For LAP wound machine,

the number of parallel paths = Number of poles.

i.e $A = P$.

$$\therefore E_g = \frac{P\phi NZ}{60A}$$

$$\boxed{E_g = \frac{\phi NZ}{60} \text{ volts.}}$$

For wave wound machines,

the number of parallel path = Number of poles.

i.e $A = 2$.

$$\therefore E_g = \frac{P\phi NZ}{120} \text{ volts.}$$

For a perticular machine P.A, Z are constant.

$$\therefore \boxed{E_g \propto \phi N}$$

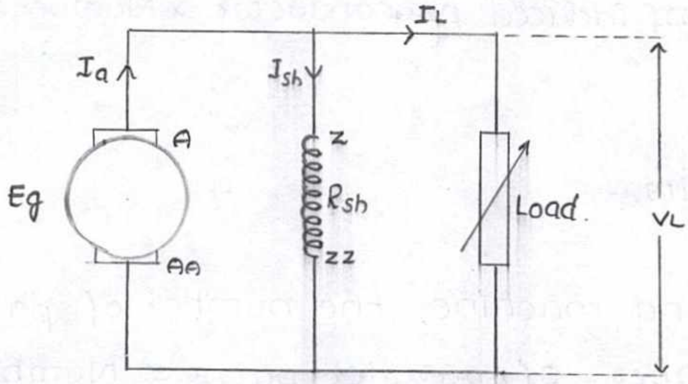
Classification of DC: Generaters

(2) Self exicted D.C generators.

(1) Self exicted D.C generators are those in which field coils are excited by the D.C voltage generated by the generator itself. These generators are further classified into following types.

Depending upon the way of connection of field winding with the armature winding.

a) Shunt Wound Generator.



Z, ZZ → Field winding

A, AA → Armature winding.

Ra → Armature winding resistance in ohms.

Rsh → Shunt field winding resistance in ohms.

Ia → Armature current in ampheres

Ish → Shunt field current in ampheres.

I_L → Load current in ampheres.

V_L → Load voltage or terminal voltage.

In shunt wound generator, the field winding is connected in parallel with armature winding (induced emf). The generated emf equation is given by,

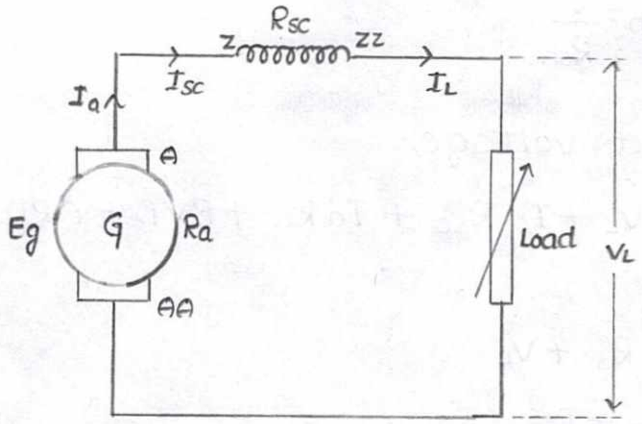
$$E_g = V_L + I_a R_a + BVD + ARD$$

where,
BVD → Brush voltage drop
ARD → Armature reaction drop.
$I_a \rightarrow I_L + I_{sh}$.
$I_{sh} \rightarrow \frac{V_L}{R_{sh}}$.

Output power $(P_L) = I_L \times V_L$ (power consumed by load)

Power generated $(P) = E_g \times I_a$

b) Series Wound Generator.



$I_{sc} \rightarrow$ Series field winding current.

$R_{sc} \rightarrow$ Series field winding resistance.

In this type field winding is connected in series with armature winding.

Here $I_a = I_{sc} = I_L$.

Generated emf, $E_g = V_L + I_{sc} R_{sc} + I_a R_a + BVD + ARD$.

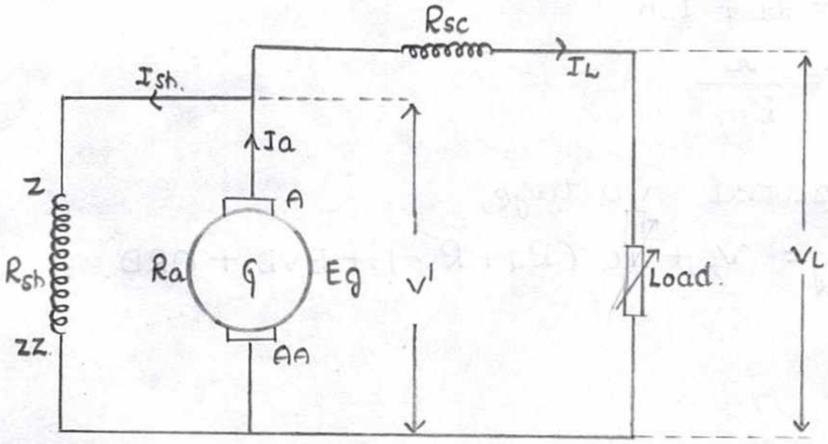
$\therefore E_g = V_L + I_a R_{sc} + I_a R_a + BVD + ARD$. $[\because I_{sc} = I_a]$.

$$\therefore \boxed{E_g = V_L + I_a(R_{sc} + R_a) + BVD + ARD}$$

Compound Generator.

It consists of both series and shunt winding, it can be either short shunt or long shunt.

a) Short shunt compound generator.



V' = voltage across shunt field winding.

$$I_{sh} = \frac{V'}{R_{sh}}.$$

The generated voltage,

$$E_g = V_L + I_{sc} R_{sc} + I_a R_a + BVD + ARD.$$

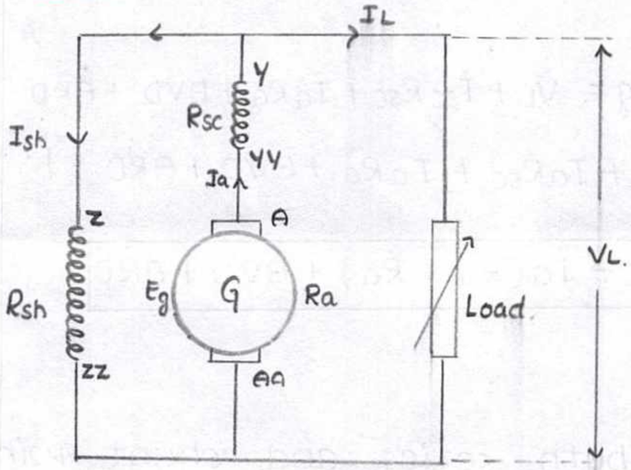
where,

$$V' = I_{sc} R_{sc} + V_L$$

$$I_a = I_{sh} + I_{sc}$$

$$I_{sc} = I_L.$$

b) Long shunt compound generator.



Here,

$$I_a = I_{sc}$$

$$I_a = I_L + I_{sh}$$

$$I_{sh} = \frac{V_L}{R_{sh}}$$

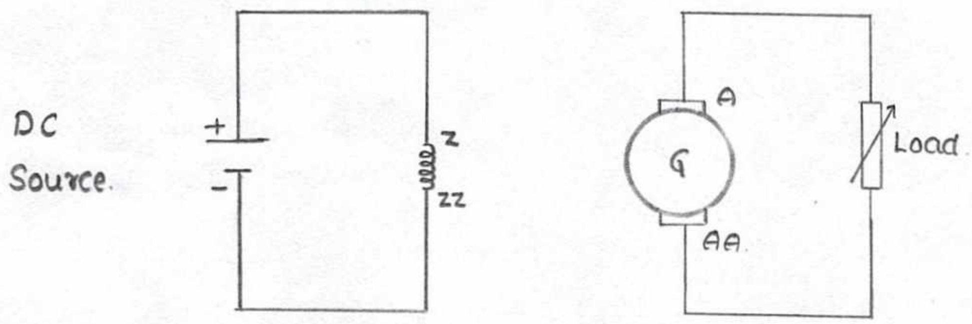
The generated voltage,

$$E_g = V_L + I_a (R_a + R_{sc}) + BVD + ARD.$$

Classification of D.C. generator.

D.C. generators are classified mainly into 2 types depending upon the way of excitation.

2. Seperately excited D.C. generators.



Z, ZZ → Field winding.

A, AA → Armature winding.

Seperately excited D.C generators are those in which field coils are excited from a seperate D.C source.

DC Generator Constructional features

·DC Generator is a DC Machine which converts mechanical energy into electrical energy. It works on the principle of Faraday's laws of Electromagnetic Induction.

D.C generator/machine/motar consists of the following parts:

1. Magnetic field system: (Stationary part) :-

The main object of the field system is to create an uniform magnetic field within which an armature rotates. Electromagnets are preffered in comparison with the permanent magnets.

The magnetic field system consists of the following parts:

(a) YOKE :- It acts as the frame of the magnetic machine & carries the flux produced by the poles. It is cylindrical in shape. In small machines the cast iron is used for Yoke. But, in large machine, fabricated steel Yoke is used.

(b) POLE CORE :- It is circular in shape. It is used to carry the field coils through which exciting current flows. Silicon steel is used as a material for the pole core.

(c) POLE SHOE :- It gives support to the field coils and spread out the flux in the air gap. The pole cores are laminated one and another are bolted to the yoke. In some machines the yoke & the pole core are madeup with single casting and the laminated pole shoes are attached to the pole cores.

(d) MAGNETISING COIL or FIELD COIL :-

It provides the no. of ampere turns of excitation required to give the proper flux through the armature to induce the desired voltage.

Generator Construction and Features

DC Generator: A DC Machine makes constant [illegible] energy into electrical energy [illegible] works on the principle of Faraday's laws of Electromagnetic Induction.

[illegible] generator / [illegible] consists of the following parts:

1. Magnetic field system (stationary part):

The main object of the field system is to create [illegible] magnetic field which [illegible] [illegible] rotating [illegible] are [illegible] [illegible] with the [illegible]

The magnetic field system consists of the following items:

(a) Yoke: It refers to the frame of the magnetic machine [illegible] carries the flux produced by the poles. It is cylindrical in shape. In small machines the cast iron is used as yoke. But in large machines fabricated steel yoke is used.

[illegible]: [illegible]

field coils through which exciting current flows. [illegible] [illegible] used as a material for the pole core.

(c) POLE SHOE: It gives support to the field coils and spread out the flux in the air gap. The pole core [illegible] [illegible] one and [illegible] bolted to the yoke. [illegible] machines the [illegible] of the pole core are [illegible] and the [illegible] poles are [illegible] to the pole cores.

(d) MAGNETISING COIL OR FIELD [illegible]:

It provides the no of ampere turns of excitation required to give the proper flux through the armature to induce [illegible] desired voltage.

2. Armature :- It is the rotating part of a DC machine. It is circular in shape and laminated one and another. It consists of no. of slots on its external surface. The armature windings are placed in those slots & the current will be induced in those coils when the armature rotates in a magnetic field.

It is made up of silicon steel stampings & each stamping is separated from its neighbouring one by a thin layer of paper or varnish as an insulation. These are placed one above the other, the thickness of the stamping is about 0.06 mm.

COMMUTATOR :- It collects the current from the armature conductors. It acts as a rectifier i.e., it converts the alternating into uni-directional current. It is circular in shape, it is made up of high Conducting hard Copper. It has many segments & these are insulated from each other by a thin layer of Mica.

BRUSHES :- The function of the brushes is the Collection of the Current from the commutator & Supply it to the external load circuit. The brushes are manufactured with high degree of hardness & these are housed in the brush holders. It is in the shape of the rectangular block. The brushes are classified as Carbon, graphite, Carbon-graphite etc.

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It is made up of silicon steel stampings [illegible] [illegible] [illegible] is separated from the neighbouring one by a thin layer of paper or varnish as an insulation. These are placed one above the other. The thickness of the stampings is about 0.05 mm.

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DC Generator

Working Principle of DC Generator :-

DC Generator is a machine which converts mechanical energy into electorical energy. This energy conversion is based on the principle of production of dynamically induced emf ie., according to Faraday's law(s)

It states that "whenever a conductor cuts the magnetic flux, dynamically induced emf will be produced in it. This emf will cause ~~in~~ a current to flow in the conductor, if the conductor circuit is closed.

Let us consider a single turn rectangular coil ABCD rotating in magnetic field which is as shown in fig 1. The two ends of the coil are connected to the sliprings a and b which are insulated from each other and from the shaft. Carbon brushes are pressed against the sliprings.

Imagine a coil is rotating in clockwise direction. When the plane of the coil is at right angles to the flux i.e., when it is in position 1, the flux linked with the coil is maximum but the rate of change of flux linkage is ~~maximum~~ minimum. Hence there is ~~max.~~ no induced emf in the coil. As the coil continues to rotate, the rate of change of flux linkages increases till it reaches the position no.(3) At this position the plane of the coil is parallel to the flux lines. Therefore the flux linked with the coil is ~~zero~~ minimum but the rate of change of flux is ~~zero~~ maximum. ~~Therefore no emf will be induced in the coil~~.

DC Generator

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Imagine a coil is rotating in clockwise direction. When the plane of the coil is at right angles to the flux i.e. when it is in position 1, the flux linked with the coil is maximum but the rate of change of flux linkage is minimum. Hence there is zero induced emf in the coil. As the coil continues to rotate, the rate of change of flux linkages increases till it reaches the position no. (3). At this position the plane of the coil is parallel to the flux lines. Therefore the flux linked with the coil is zero but the rate of change of flux is maximum. ~~Hence maximum emf will be~~ induced in the coil.

In the next part of the revolution ie., from 90° to 180° the flux linked with the coil gradually increases but rate of change of flux decreases. Hence the induced emf decreases gradually upto the position no. 5 of the coil and it reduces to zero.

In the next part of revolution ie., from 180° to 360° the variation of emf is similar to that of the first half revolution But it is found that the direction of the induced current is reversed. From this we conclude that the current which we obtain from a generator reverses its direction after every half revolutions. The current which undergoes the reversal in its direction is known as alternating current.

For making the flow of current unidirectional, the slip rings are replaced by split rings (commutator). These are cylindrical in shape and is cut into two segments which are insulated from each other by a thin layer of Mica. And this concept can be explained by refering to fig(4)

WORKING OF SPLIT RINGS :-

These are morementary parts with armature which helps in coversion of AC to DC.

There will be two segments in split rings. In the consecutive revolving of armature the segments also changes so that the direction of current in external load circuit will be same all though the direction of current in armature changes.

So, split rings / Commutator rectifies alternating current into direct current.

In the next part of the revolution i.e. from 90° the lines linked with the coil gradually increase but rate of change of flux decreases. Hence the induced emf decreases gradually w.r.t. the position 90° of the coil and it reduces to zero.

In the next part of a rotation i.e. from 180° to 360° the variation of emf is similar to that of the first half revolution. But it is found that the direction of the induced current is reversed. From this we conclude that the current which we obtain from a generator reverses its direction after every half revolution. The current which undergoes reversal in its direction is known as alternating current.

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DC Generator.

1. DC shunt generator supplies a load of 7·5 kW at 200 volts. Calculate the induced emf, if the armature resistance 0·6 Ω and field resistance 80 Ω.

Given,

$P_L = 7.5\ kW$

$V_L = 200$ volts.

$E_g = ?$

$R_a = 0.6\ \Omega$

$R_{sh} = 80\ \Omega$

Solution:-

$$E_g = V_L + I_a R_a + BVD + ARD.$$

where,

$$I_a = I_L + I_{sh}$$

$$I_{sh} = \frac{V_L}{R_{sh}} = \frac{200}{80} = 2.5A$$

$$I_L = \frac{P_L}{V_L} = \frac{7.5 \times 10^3}{200} = 37.5A.$$

$\therefore I_a = 40A.$

$\therefore E_g = 200 + (40 \times 0.6) + 0 + 0$

$E_g = 224$ volts

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2. A long shunt compound generator delivers a load current of 50 A at 500 volts. and it has armature, series and shunt field resistances of 0.5 Ω, 0.03 Ω and 250 Ω respectively. Calculate the generated emf and Ia. Allow 1V / brush as contact drop.

Given,

$I_L = 50\ A$

$V_L = 500\ v$

$R_a = 0.5\ \Omega$

$R_{sc} = 0.03\ \Omega$

$R_{sh} = 250\ \Omega$

$E_g = ?$

$I_a = ?$

$BVD = 2V.$

Solution:-

$I_a = I_L + I_{sh}$

$I_{sh} = \frac{V_L}{R_{sh}} = \frac{500}{250} = 2\ A$

$I_L = \frac{P_L}{V_L} = \frac{25000}{500} = 50\ A.$

where, $P_L = V_L \times I_L$

$= 500 \times 50 = 25000$

$\therefore I_a = 50 + 2 = 52\ A.$

$E_g = V_L + I_a(R_a + R_{sc}) + BVD + ARD$

$= 500 + 52(0.5 + 0.03) + 2 + 0$

$\boxed{E_g = 529.56\ \text{volts}}$

3. A 110 volts compound generator having armature, shunt, series winding resistance of 0.6 Ω, 25 Ω, 0.04 Ω respectively. The load consists of 200 lamps, each rated at 55w, 110 volts. Find the generated emf and the armature current, when the machine is connected as short shunt generator.

Given,

$V_L = 110\,V$

$P_L = 55 \times 200 = 11000$ watts.

$R_a = 0.6\,\Omega$

$R_{sh} = 25\,\Omega$

$R_{sc} = 0.04\,\Omega$

$E_g = ?$

$I_a = ?$

Solution:-

$E_g = V_L + I_{sc}R_{sc} + I_aR_a + BVD + ARD$

where,

$I_a = I_L + I_{sh}$

$I_L = \frac{P_L}{V_L} = \frac{11000}{110} = 100A$

$I_{sh} = \frac{V'}{R_{sh}} = \frac{V_L + I_{sc}R_{sc}}{R_{sh}} = \frac{110 + (100 \times 0.04)}{25} = 4.56\,A.$

$\therefore I_a = 100 + 4.56 = 104.56\,A.$

$\therefore E_g = 110 + (100 \times 0.04) + (104.56 \times 0.6) + 0 + 0$

$E_g = 176.736$ volts

4. A shunt generator has no load induced emf of 150V and when it is loaded terminal voltage decreases to 140 volts. Find I_L, load resistance and $R_a = 0.2\Omega$ and $R_{sh} = 100\Omega$.

Given,

$R_a = 0.2\Omega$

$R_{sh} = 100\Omega$

$E_g = 150V$

$V_L = 140V$

$I_L = ?$

$R_L = ?$

Solution:-

$$E_g = V_L + I_aR_a + BVD + ARD$$

$$150 = 140 + I_a(0.2) + 0 + 0$$

$$\boxed{I_a = 50A}$$

$$I_{sh} = \frac{V_L}{R_{sh}} = \frac{140}{100} = 1.4\ A.$$

$$I_a = I_L + I_{sh}$$

$$50 = I_L + 1.4$$

$$\boxed{I_L = 48.6A}$$

$$R_L = \frac{V_L}{I_L}$$

$$= \frac{140}{48.6}$$

$$\boxed{R_L = 2.88\Omega}$$

5. A 4 pole DC shunt generator with lap connected armature has a field and armature resistance of 50Ω and 0.1Ω. If the generator supplies 60, 110V, 40 watts lamps. Calculate the total armature current, current in each armature conductor and the generated emf. Take 1V/brush as contact drop.

Given,

DC shunt generator.

$P = 4$

$A = P$ (lap wound)

$R_{sh} = 50\Omega$

$R_a = 0.1\Omega$

$P_L = 60 \times 40 = 2400$ watts.

$V_L = 110V$

$I_a = ?$

$BVD = 1V/brush = 2V$.

$E_g = ?$

Solution:-

$$E_g = V_L + I_a R_a + BVD + ARD.$$

$$I_a = I_L + I_{sh}$$

$$I_{sh} = \frac{V_L}{R_{sh}} = \frac{110}{50} = 2.2\,A$$

$$I_L = \frac{P_L}{V_L} = \frac{2400}{110} = 21.81\,A.$$

$$\therefore I_a = 24\,A.$$

$$E_g = 110 + (24 \times 0.1) + 2 + 0$$

$$\boxed{E_g = 114.4 \text{ volts}}$$

Current in each armature current

$$= \frac{I_a}{A}$$

$$= \frac{24}{4}$$

$$\boxed{= 6\,A}$$

6. Calculate the emf generated by a 4 pole, wave wound armature having 45 slots, with 18 conductors per slots, when driven at a speed of 1200 rpm, flux per pole is 0.16 milliwb.

Given,

$P=4$

Number of slots = 45.

Number of conductors per slot = 18.

$N=1200$

$\phi = 0.16 \times 10^{-3}$

$A=2$.

∴ Total number of conductors = $Z = 45 \times 18 = 810$.

Solution:-

$$E_g = \frac{P\phi N Z}{60A}$$

$$= \frac{4 \times 0.16 \times 10^{-3} \times 1200 \times 810}{60 \times 2}$$

$$E_g = 5.184 \text{ volts}$$

7. An 8 pole lap connected armature of DC machine has 960 conductors and flux per pole is 40 milliwb. The armature rotates with a speed of 400rpm. Calculate the generated emf, if the same machine is wave connected, at what speed it must be driven to generate a voltage of 400v.

Given,

$P=8$

$A=P$

$Z=960$

$\phi=40\times10^{-3}$ wb.

$N=400$ rpm.

$E_g=?$

Solution:-

$$E_g=\frac{P\phi NZ}{60A}$$

$$=\frac{8\times40\times10^{-3}\times400\times960}{60\times8}$$

$$\boxed{E_g=256} \text{ volts.}$$

If $A=2$,

$N=?$

$E_g=400$

$$E_g=\frac{P\phi NZ}{60A}$$

$$400=\frac{8\times40\times10^{-3}\times N\times960}{60\times2}$$

$$\boxed{N=156.25 \text{ rpm}}$$

8. A DC generator develops an emf of 200 volts, when driven at a speed of 1000 rpm with flux/pole of 0.02 wb. If the emf is increased to 210 volts, at 1100 rpm, what should be the value of flux/pole under new circumstances.

Given,

$E_{g_1} = 200\,V$

$N = 1000\,rpm$

$\phi_1 = 0.02\,wb$

$E_{g_2} = 210\,V$

$N_2 = 1100\,rpm$

$\phi_2 = ?$

Solution:-

We know that,

$$E_g = \frac{P\phi NZ}{60A}$$

For a perticular machine, P, A, Z are constant.

$$E_g \propto \phi N$$

$$E_{g_1} \propto \phi_1 N_1$$

$$E_{g_2} \propto \phi_2 N_2$$

$$\frac{E_{g_1}}{E_{g_2}} = \frac{\phi_1 N_1}{\phi_2 N_2}$$

$$\frac{200}{210} = \frac{0.02 \times 1000}{\phi_2 \times 1100}$$

$$\boxed{\phi_2 = 0.019\,wb}$$

9. An armature of 4 pole DC generator is required to generate a emf of 520 volts, when revolving at a speed of 660 rpm. Calculate the magnetic flux per pole, if the armature has 144 slots with 2 coils sides/slot and each coil consists of 3 turns, the armature is wave wound.

Given,

$P=4$

$E_g=520$ volts.

$N=660$ rpm.

$\phi=?$

No. of slots $=144$.

Number of coilside/slot $=2$

Number of turns/coil $=3$.

$A=2$ (wave wound).

Solution:-

We know that,

$$E_g=\frac{P\phi NZ}{60A}$$

Total number of armature conductors = Number of slots x Number of coilside/slot x Number of turns/coil.

$= 864$.

$$520=\frac{4\times\phi\times660\times864}{60\times2}$$

$$\boxed{\phi=0.0273\ Wb}$$

10. An armature of 4 pole DC generator is required to generate a voltage of 800 volts, when revolving at a speed of 480 rpm. Calculate the flux/pole, if the armature has 128 slots with 2 coil sides /slot, each coil consists of 4 turn, wave connected.

Given,

$P=4$

$E_g = 800$ volts.

$N = 480$ rpm.

$\phi = ?$

Slots = 128.

Number of coilsides/slot = 2.

turn = 4

$A = 2$.

Solution:-

$$Z = 128 \times 2 \times 4$$
$$= 1024.$$

$$E_g = \frac{P\phi NZ}{60A}$$

$$800 = \frac{4 \times \phi \times 480 \times 1024}{60 \times 2}$$

$$\boxed{\phi = 0.048 \text{ wb}}$$

11. A 4 pole DC generator runs at a speed of 750 rpm and generate voltage of 240 V. The armature is wave wound, it has 792 conductors, if the total flux from each pole is 0.0145 wb. Calculate the leakage co-efficient.

Given,

$P = 4$

$N = 750$ rpm.

$E_g = 240$ volts.

$A = 2$ (wave wound).

$Z = 792$.

Total flux from each pole $= 0.0145$ wb.

leakage co-efficient $= \lambda = ?$

Solution:-

$$E_g = \frac{P \phi N Z}{60A}$$

$$240 = \frac{4 \times \phi \times 750 \times 792}{60 \times 2}$$

$$\phi = 0.01212 \text{ wb.}$$

$$\lambda = \frac{\text{Total flux/pole}}{\text{Working flux/pole}}$$

$$= \frac{0.0145}{0.01212}$$

$$\boxed{\lambda = 1.19}$$

12. The armature of 8 pole, lap connected generator develops an emf of 500 volts. It has 800 conductors, runs at a speed of 1500 rpm. Find the useful flux/pole, if the number of turns in each field coil is 1200, what is the average value of emf induced in each coil, when the field coil is opened, the flux dies away in 0.05 seconds.

Given,

$P = 8$

$A = P$ (lap wound)

$E_g = 500$ volts.

$Z = 800$

$N = 1500$ rpm.

$\phi = ?$

Number of turns in each field coil, "N" = 1200.

Average emf induced, $e = ?$

$t = 0.05$ sec.

Solution :-

$$E_g = \frac{P \phi N Z}{60A}$$

$$500 = \frac{8 \times \phi \times 1500 \times 800}{60 \times 8}$$

$$\boxed{\phi = 0.025 \text{ wb}}$$

Average emf induced in field coil, $e = N \cdot \frac{d\phi}{dt}$

$$= 1200 \times \frac{0.025}{0.05}$$

$$\boxed{e = 600 \text{ volts}}$$

13. A 4pole, lap wound D.C generator has a useful flux of 70 megalines. It has 220 turns in the armature and rotates with a speed of 800 rpm. Calculate the value of generated voltage.

Given,

$P=4$

$A=2$

$\phi=70$ megalines.

$T=220$

$Z=2T$

$N=800$ rpm.

Solution:-

1 megaline = 10 mwb.

70 megaline $=70\times10\times10^{-3}$

$$E_g=\frac{P\phi NZ}{60A}$$

$$=\frac{4\times70\times10\times10^{-3}\times800\times2\times220}{60\times4}$$

$$\boxed{E_g=4106.66 \text{ volts}}$$

14. A DC Shunt generator develops an emf of 220 volts, when driven at a speed of 1000 rpm, with a flux per pole of 0.015 wb. If the speed is increased to 1100 rpm and at the same time armature reaction weakens the flux by 5%. Then what is the induced emf.

DC Motor

1. A 220 volts DC shunt motor has a armature resistance of 0.8Ω and field resistance of 200Ω. Determine the back emf, when it gives an output of 7.46 kW at 85% of efficiency.

Given,

DC shunt motor

$V = 220V.$

$R_a = 0.8\Omega$

$R_{sh} = 200\Omega$

$E_b = ?$

Output power = 7.46 kW.

$\eta = 85\%.$

Solution:-

For shunt motor, $E_b = V - I_aR_a - BVD - ARD$

$$\boxed{E_b = 188.9\ V}$$

where,

$I_a = I - I_{sh}$

$I_{sh} = V/R_{sh} = \frac{220}{200} = \boxed{1.1\ A}$

$\therefore$ ~~Ia = ...~~

$$\eta = \frac{\text{output power}}{\text{input power}}$$

$$\text{Input power} = \frac{7.46 \times 10^3}{0.85}$$

$= 8.77\ kW.$

Input power = VI

$$I = \frac{P}{V} = \frac{8.77 \times 10^3}{220}$$

$= 39.89\ A$

$\therefore I_a = 39.89 - 1.1$

$\boxed{I_a = 38.79}\ A$

$\therefore E_b = 220 - 38.79(0.8)$

$\boxed{E_b = 188.9\ V}$

2. A 220 V DC shunt motor has an armature resistance of 0.5 Ω, if the full load armature current is 20 A. Find the induced emf.

Given,

$V = 220V$

$R_a = 0.5\Omega$

$I_a = 20A$

$E_b = ?$

Solution:-

$$E_b = V - I_a R_a - BVD - ARD$$

$$= 220 - (0.5 \times 20)$$

$$\boxed{E_b = 210V}$$

3. A 230 volt DC shunt motor has an armature resistance of 0.5 Ω and a field resistance of 150 Ω. It rotates at a speed of 1000 rpm. It takes no load current of 5 A on application of load, speed decreases to 900 rpm. Find the armature current and the torque developed.

Given,

$V = 230V$

$R_a = 0.5\Omega$

$R_{sh} = 115\Omega$

$N_0 = 1000\,rpm.$

$I_0 = 5A$ (No load current).

$N = 900\,rpm.$

$I_a = ?$

$T_a = ?$

Solution:-

Case 1:- At no load,

$$E_{b_0} = V - I_a R_a - BVD - ARD$$

where,

$$I_a = I_0 - I_{sh} = 5 - 2 = 3A.$$

$$I_{sh} = V/R_{sh} = 230/115 = 2A.$$

$$I_a = 5A.$$

$\therefore E_{b0} = 230 - (3 \times 0.5)$

$E_{b0} = 228.5$ volts.

$E_b = \frac{P \phi N Z}{60 A}$

For a perticular machine, $E_b \propto \phi N$

$E_b \propto N$.

$N_0 = 1000$ rpm

Case 2 :- At full load,

$N_1 = 900$ rpm.

$E_{b1} = ?$

we know that,

$E_b \propto N$.

$\therefore E_{b0} \propto N_0$

$E_{b1} \propto N_1$

$\frac{E_{b0}}{E_{b1}} = \frac{N_0}{N_1}$

$E_{b1} = 205.65$ volts

$E_{b1} = V - I_a R_a - BVD - ARD$.

$205.65 = 230 - I_a(0.5)$

$I_a = 48.7A$

$T_a = ?$

we know that,

$T_a = (0.159) \phi I_a Z \, P/A$

output power $= E_b \cdot I_a$

$= 205.65 \times 48.7$

$= 10015.155$ watts.

we know that,

output power $= \frac{2 \pi N T}{60}$

$T = \frac{60 \times \text{output power}}{2 \pi N}$.

$T = 106.6409$

4. Determine the value of armature torque established by the armature of a 4 pole DC motor having 774 armature conductors, 2 parallel paths with a flux of 40 miliwb, when it is drawing a load current of 50 A.

Given,

$T_a = ?$

$P = 4$

$Z = 774$

$\phi = 40$ miliwb.

$I_a = 50$ A.

Solution:-

$$T_a = 0.159 \phi I_a Z \cdot P/A.$$

$$T_a = 0.159 \times 40 \times 10^{-3} \times 50 \times 774 \times 4/2.$$

$$\boxed{T_a = 492.264}$$

D.C. Motor.

A D.C Motor is a D.C machine which converts electrical energy into mechanical energy.

This action is based on the principle that when a current carrying conductor placed in a magnetic field, it will experiences a force.

The magnitude of the force is given by,

$$F = BIL \text{ newtons.}$$

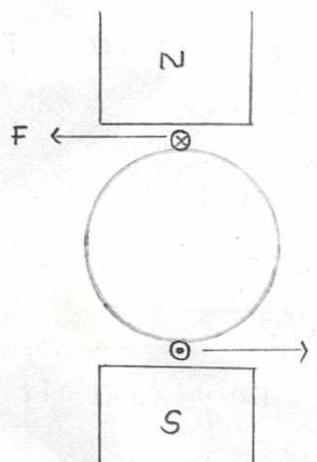
Where,

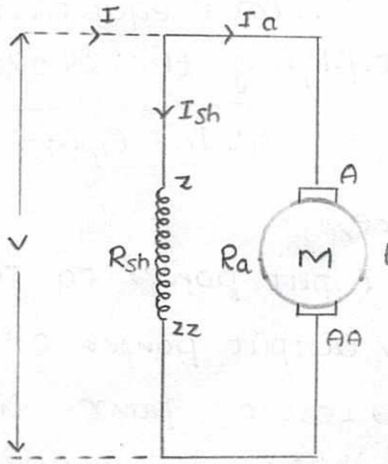
- $B \rightarrow$ Flux density in wb/m^2.
- $I \rightarrow$ Current carried by the conductor in ampheres.
- $L \rightarrow$ Length of the conductors in meters.

The direction of the force is determined by Flemming's left hand rule.

It states that, If the three figures of the left hand. i.e fore figer, middle and thumb finger are stretched, such that they are mutually perpendicular to each other.

- → The fore finger indicates the direction of flux.
- → The middle figer indicates the direction of the current.
- → The thumb finger indicates the direction and motion of the conductor.





$V \rightarrow$ applied voltage.

$E_b \rightarrow$ Back emf.

$I \rightarrow$ Input current.

$A, AA \rightarrow$ Armature winding.

$Z, ZZ \rightarrow$ Field winding.

$I_a \rightarrow$ Armature current.

$R_a \rightarrow$ Armature resistance.

$I_{sh} \rightarrow$ Shunt field winding current.

$R_{sh} \rightarrow$ Shunt field winding resistance.

Consider a two pole machine with two conductors. The direction of the current in the conductor is as indicated in the diagram. The direction of the force is indicated.

When a D.C voltage is applied to the terminals of the motor, current flows through the armature winding and force will be exerted and it is run in one direction.

When the motor is at rest the voltage $\boxed{V = I_a R_a}$. But when the armature starts rotating the armature conductors cuts the magnetic lines of force and hence the emf will be induced in the armature conductor of a D.C. motor. [According to Faraday's law].

The nature of the induced emf is such that it opposes the applied voltage. Hence the emf induced in the armature conductor of a D.C motor is called as back emf (E_b). The relation between the induced emf and the applied voltage is given by $\boxed{V = E_b + I_a R_a}$. This equation is called as motor equation.

Multiplying the above equation by armature current I_a. we get,

$$\boxed{V I_a = E_b I_a + I_a^2 R_a}$$

where,

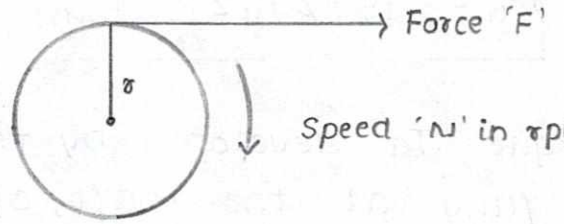
$V I_a \rightarrow$ Input power to the armature in watts.

$E_b I_a \rightarrow$ Output power of the motor in watts.

$I_a^2 R_a \rightarrow$ Loss of power in the armature winding and it is known as copperloss.

The output power of the motor is also known as Gross power. The back emf E_b is directly proportional to the speed. Whenever the load on the motor increases speed slightly decreases and hence back emf decreases.

Torque equation.



r = Radius in meters.

It is defined as the action of force acting on a body, which tends to rotate it.

It is the product of the force "F" and the radius "r" at which this force acting.

$$\therefore T_a = F \times r.$$

Let,

- T_a be the armature torque in Nm.
- F be the Force in N.
- r be the radius of armature in meter.
- N be the speed of armature in rpm.

Workdone by the force in one revolution, W = Force x Distance.

$$W = F \times 2\pi r \text{ Joules.}$$

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

But we know that,

$$T_a = F \times r.$$

$$\therefore \text{Workdone / second} = \frac{T_a 2\pi N}{60} \rightarrow (1)$$

power developed by the armature, $E_a I_a \rightarrow (2)$

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

But we know that,

$$E_b = \frac{P\phi NZ}{60A}$$

Substituting the value of Eb in above eqⁿ③, we get,

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

$$\therefore T_a = \frac{P\phi Z I_a}{2\pi A}$$

$$\therefore \boxed{T_a = 0.159\, \phi I_a Z \frac{P}{A} \ Nm}$$

The torque Ta developed by the armature will not be available fully at the shaft, of the motor because some power will be utilized in supplying friction and windage losses.

The difference between the armature torque Ta and loss of torque due to friction is known as shaft torque.

$$\therefore T_{sh} = T_a - T_{loss}$$

$$\boxed{T_{sh} = 0.159\, \phi I_a Z \frac{P}{A} - \frac{60}{2\pi N} \times \text{Friction and windage losses.}}$$

$P = T\omega$

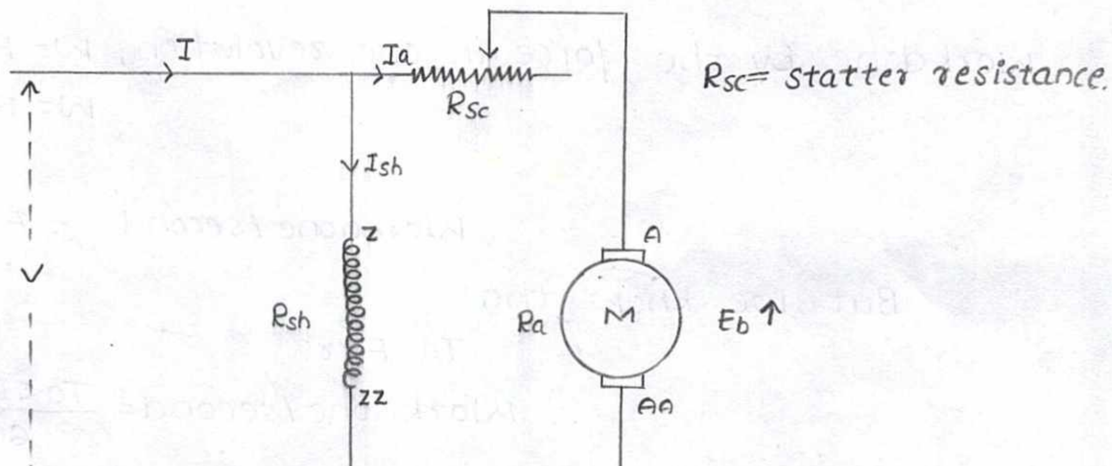
$T = P/\omega$

$T = P / \frac{2\pi N}{60}$

$\therefore T = \frac{60P}{2\pi N}$

$= \frac{60}{2\pi N}$ Friction and windage loss.

Starter:



Starter is a device which consists of a resistance connected in series with the armature winding during the starting of D.C motor. It is gradually decreased, when the motor gains its speed.

Neccessity of Starter for a D.C. Motor.

We know that,

$$V = E_b + I_a R_a$$

The current drawn by the motor will be,

$$I_a = \frac{V - E_b}{R_a}$$

Where,

V is applied voltage.
E_b is back emf
R_a is armature winding resistance
I_a is armature current.

When the motor is at rest, there is no back emf. Hence, $E_b = 0$.
∴ The current drawn by the armature winding $I_a = \frac{V}{R_a}$

If the full voltage is applied across the stationary armature, then it will drawn very large current. Because armature winding resistance is very small.
[If $V = 230\,v$, $R_a = 1\,\Omega$, ∴ $I_a = 230\,A$]

This current is very high as compare to the rated current of the motor. This current results in burning of winding cause damage to the commutator and the brushes.

∴ To avoid this, an extra resistance is connected in series with the armature winding during the starting condition of the motor [5-10 sec].

$$I_a = \frac{V}{R_a + R_{sc}}$$

Which results in limits the starting current to a safe value. The starting resistance is gradually removed as the motor gains its speed. and it develops back emf. and therefore current decreases.

Types of D.C Motors.

D.C Motors are classified depending upon the way in which the field windings are connected to the armature. These are classified into 3 types.

1. D.C shunt motor
2. D.C series motor.
3. D.C compound motor.

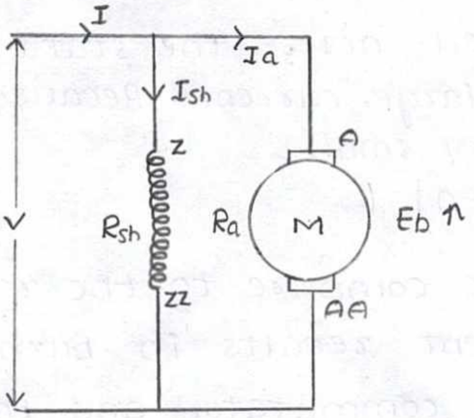
D.C compound motor classified into 2 types.

i) Cumulatévely compounded D.C Motor.

ii) Differentialy compounded D.C Motor.

which are may be connected either as long or short shunt.

1. D.C. shunt motor.



A, AA → Armature winding.
Z, ZZ → Field winding.
I → Input current
Ish → Shunt field current.
Ia → Armature current.
V → Supplied voltage.
Ra → Armature resistance.
Rsh → Shunt field resistance.
Eb → Back emf.

In this type of motor the field winding is connected in parallel with armature winding.

The back emf E_b induced in the armature winding is given by

$$E_b = V - I_a R_a - BVD - ARD$$

where,

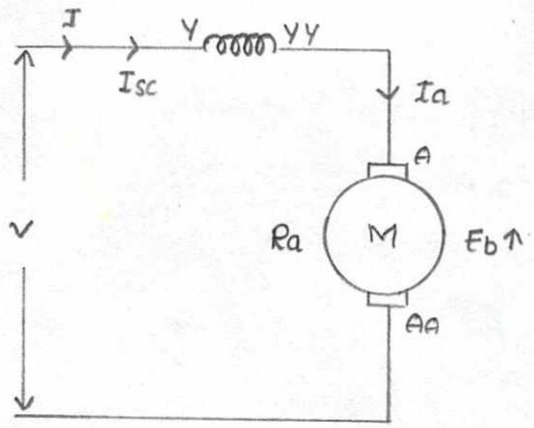
$$I_a = I - I_{sh}$$

$$I_{sh} = \frac{V}{R_{sh}}$$

$P = VI$ input power

$P = E_g I_a$ Output power.

2. D.C. series motor.



Y, YY → Series field winding.

I_{sc} → Series field current.

R_{sc} → Series field Resistance.

In this type field winding is connected in series with the armature winding.

The series field winding carries the armature current and hence it should have a very small resistance. So that voltage drop across it is very small. Hence it is made up of few thick copper turns.

The back emf induced in the armature winding is given by,

$$E_b = V - I_{sc} R_{sc} - I_a R_a - BVD - ARD.$$

$$\because I_a = I_{sc}.$$

$$\therefore E_b = V - I_a (R_a + R_{sc}) - BVD - ARD.$$

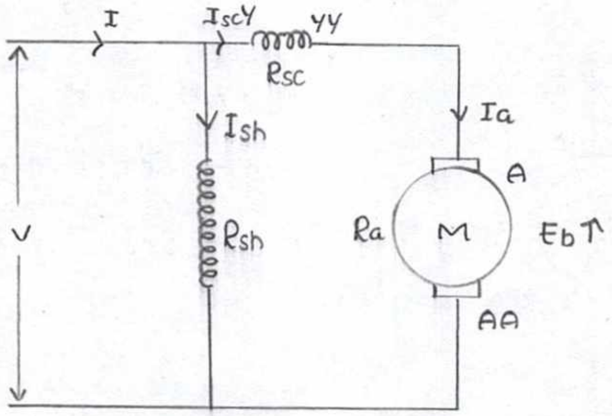
D.C compound motor.

It contains both shunt field and series field winding. If the fluxes, ϕ_{sh} produced by the shunt field winding and ϕ_{sc} produced by the series field winding are in the same direction, they are aditive and such a motor is called as cumulatively compounded.

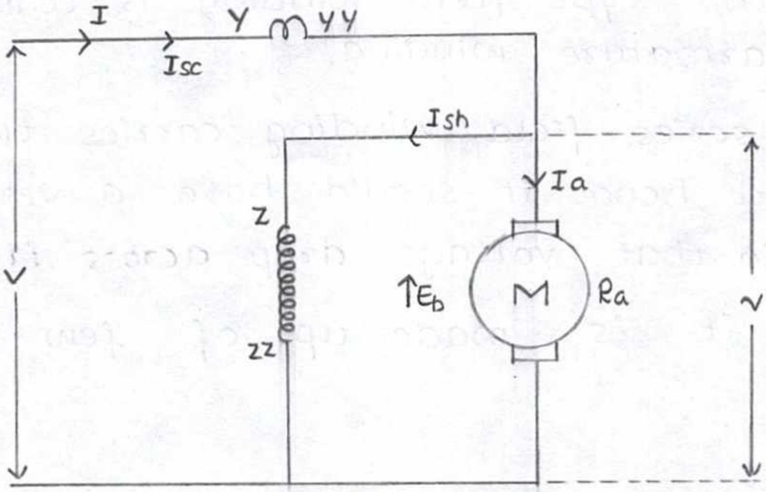
If the 2 fluxes opposes each other then the motor is said to be differentialy compounded.

Depending upon the way in which the 2 field windings are connected the compound motor either long or short shunt.

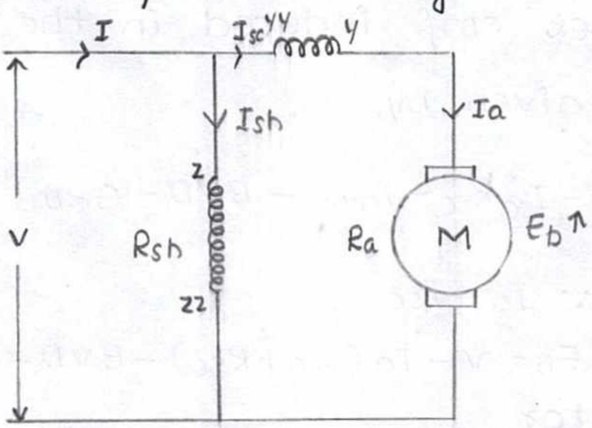
a) Cumulatively compounded long shunt DC motor.



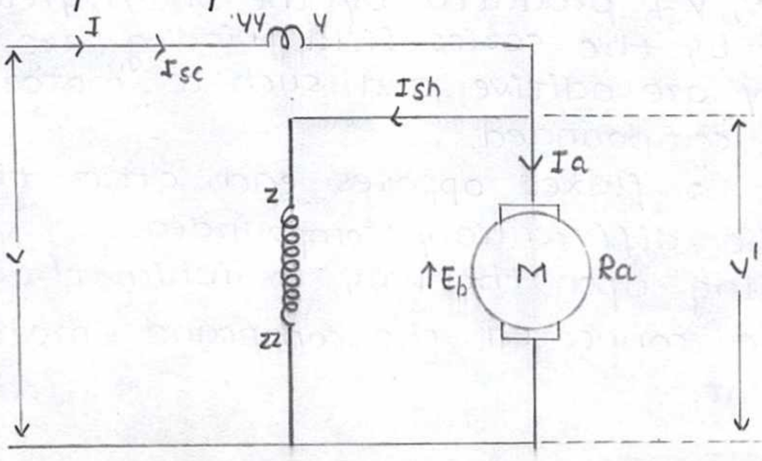
b) Cumulatively compounded short shunt D.C. motor.



a) Differentialy compounded long shunt D.C motor.



b) Differentialy compounded short shunt D.C motor.



For cumulatively or differentialy compounded long shunt D.C motor, the back emf is given by,

$$E_b = V - I_{sc}R_{sc} - I_aR_a - BVD - ARD.$$

Here, $I_a = I_{sh}$ $\quad I_a = I - I_{sh}$

$$\therefore E_b = V - I_a(R_a + R_{sc}) - BVD - ARD.$$ $\quad I_{sh} = \frac{V}{R_{sh}}$

For cumulatively or differentialy compounded short shunt D.C motor, the back emf is given by,

$$E_b = V - I_{sc}R_{sc} - I_aR_a - BVD - ARD.$$

Here, $V - I_{se}R_{sc} = V'$ $\quad I_a = I - I_{sh}$

$$\therefore E_b = V' - I_aR_a - BVD - ARD.$$ $\quad I_{sh} = \frac{V'}{R_{sh}}$

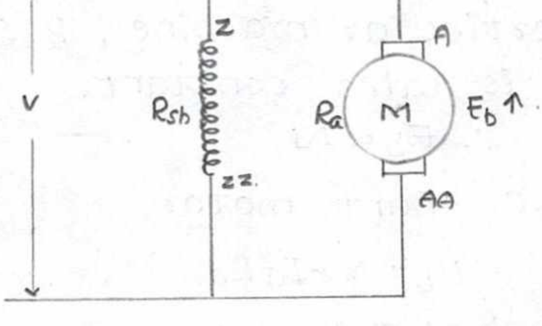
Characteristics of D.C Motor.

The characteristics of a D.C motor are studied by keeping the applied voltage constant.

The following are the 3 important characteristics of D.C motor.

1. Torque v/s Armature current (T_a v/s I_a) characteristic is also known as electrical characteristics.
2. Speed v/s Armature current (N v/s I_a) characteristics.
3. Speed v/s Torque characteristics (N v/s T_a). It is also known as mechanical characteristics.

Characteristics of shunt motor.



1. T_a v/s I_a characteristics.

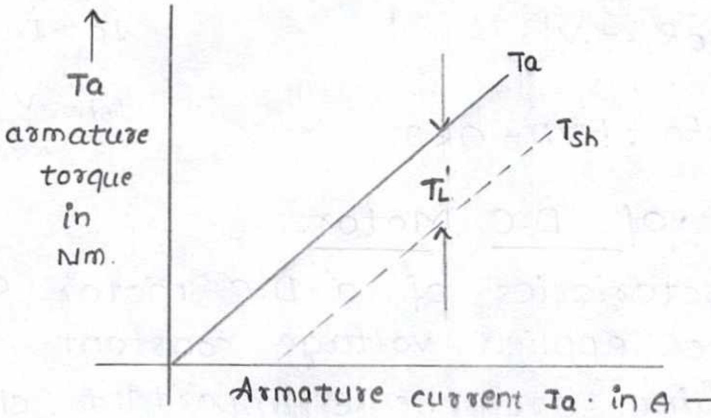
In a D.C. shunt motor, the field current I_{sh} is constant because the applied voltage is constant. and hence the flux produced is also constant.

We know that,

$$T_a = 0.159\, \phi\, I_a\, Z \frac{P}{A} \text{ Nm.}$$

For particular machine, P, A, Z are constant. and ϕ is also constant.

$$\therefore T_a \propto I_a.$$



Hence Torque v/s I_a characteristics is a straight line passing through the origin, the shaft torque T_{sh} always less than armature torque T_a.

From the above characteristics, it is observed that D.C. shunt motor has medium starting torque. Hence it is not suitable where very large loads are required to be started.

2. N v/s I_a characteristics.

We know that the back emf,

$$E_b = \frac{P\phi NZ}{60A}$$

For a perticular machine, P, A, Z are constant. and hence ϕ is also constant.

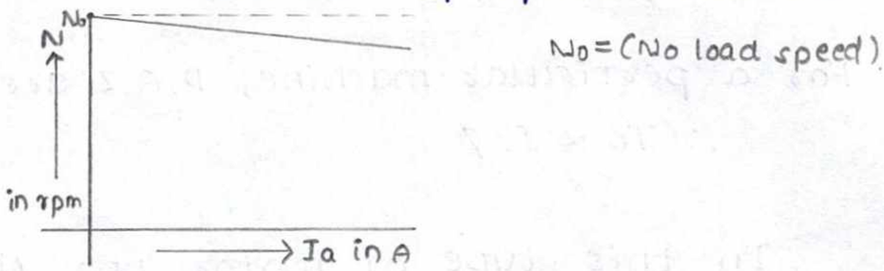
$$\therefore E_b \propto N$$

For a D.C shunt motor,

$$E_b = V - I_a R_a$$

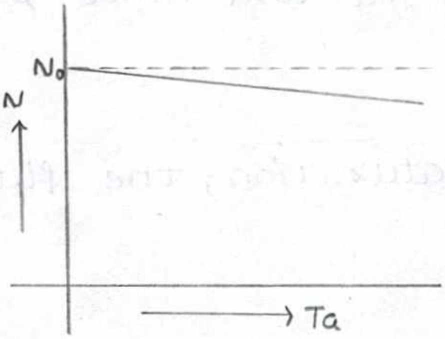
$$\therefore V - I_a R_a \propto N$$

As Ia increases, the speed N decreases, but I_aR_a drop is very small as compared to the applied voltage. Hence the decrease of speed also less.



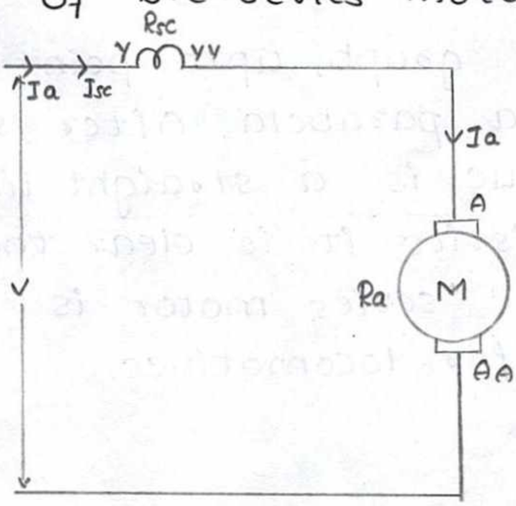
From the above characteristics it is clear that change of speed of a D.C shunt motor is very small. Hence a D.C shunt motor may be considered as almost a constant speed motor.

N v/s Ta.



From the above two characteristics, we know that Ia v/s Ta and $V-I_a \propto N$ and hence, speed v/s Torque characteristics is similar to speed v/s armature current characteristics.

Characteristics of D.C series motor.



Torque v/s armature current.

We know that armature torque, $T_a = 0.159 \phi I_a Z \frac{P}{A}$.

For a perticular machine, P, A, Z are constant.

$\therefore T_a \propto I_a \phi$

In this type of motor the flux ϕ depends upon the amount of current flowing through series field winding (I_{sc}).

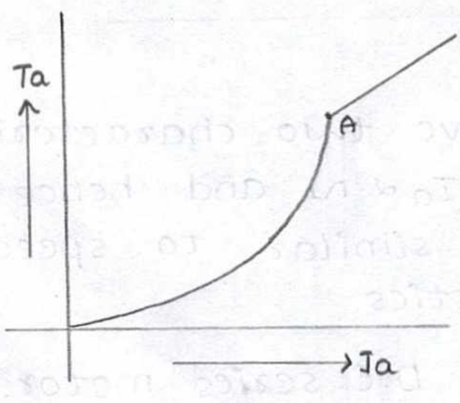
$\therefore \phi \propto I_{sc}$

But here, $I_{sc} = I_a$ and hence $\phi \propto I_a$.

$\therefore T_a \propto I_a^2$

But after saturation, the flux remains constant.

$\therefore T_a \propto I_a$.



From the graph, upto point A, $T_a \propto I_a^2$. Hence the curve is a parabola. After saturation $T_a \propto I_a$. Hence the torque is a straight line. From the above characteristics, it is clear that the starting torque of a D.C series motor is very high. Hence it is suitable for locomotives.

Speed v/s armature current characteristics.

We know that, $E_b = \frac{P\phi NZ}{60A}$.

For a perticular machine, P, A, Z are constant.

$\therefore E_b \propto \phi N$ or $N \propto \frac{E_b}{\phi}$.

But for a series motor, $E_b = V - (I_a)(R_a + R_{sc})$.

$$\therefore N \propto \frac{V - I_a(R_a + R_{sc})}{\phi}$$

From the above equation it is clear that as load on the motor increases, there are 2 factors which influence the speed.

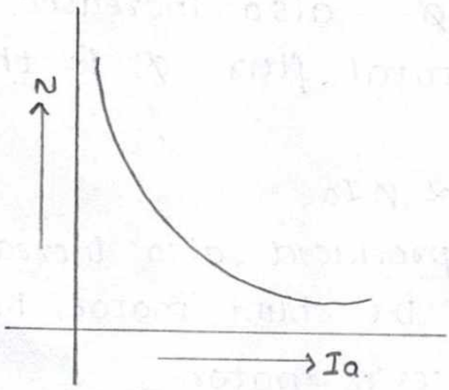
a) As $I_a(R_a + R_{sc})$ increases, speed decreases.

b) As the flux, ϕ increases, due to which speed is decreases.

But it has been observed that the decrease of speed is due to first factor is negligibly small as compared to the decrease of speed 2nd factor. Hence, $N \propto \frac{1}{\phi}$

But $\phi \propto I_a$.

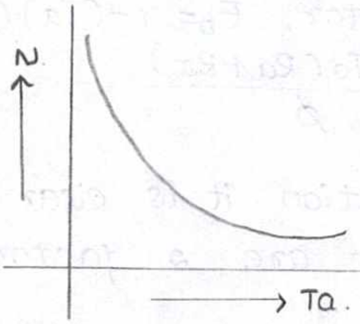
$$\therefore N \propto \frac{1}{I_a}.$$



From the above characteristics, we observed that as load (I_a) increases, the speed decreases, over a wide range. Hence, D.C. series motor is considered as variable speed motor.

At low load, I_a is very small. and hence speed is dangerously high. Hence, if a D.C series motor is started without anyload, the speed is very high and it may run out of the foundation. Hence D.C series motor should never be started without load.

Speed v/s Torque.



From the above characteristics in the D.C series motor, it is clear that speed v/s Torque characteristics is similar to speed v/s armature current characteristics.

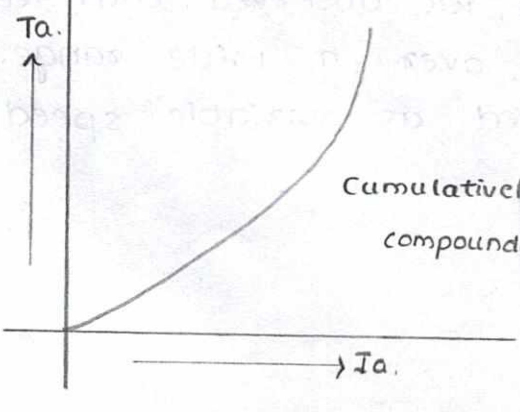
Characteristics of D.C compound motor.

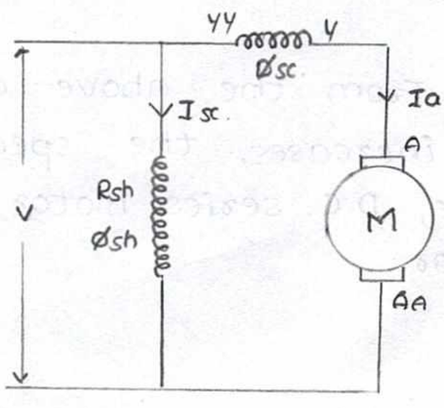
Torque v/s armature current characteristics.

In case of cumulatevely compounded D.C motor, as load increases armature current I_a also increases as I_a increases, the flux ϕ_{sc} also increases. But flux ϕ_{sh} remains constant. The total flux ϕ is the sum of ϕ_{sc} and ϕ_{sh}.

Hence $T_a \propto \phi I_a$.

Hence torque produced also increases, but at a faster rate than in case of D.C shunt motor, but at a lesser rate than in case of D.C series motor.

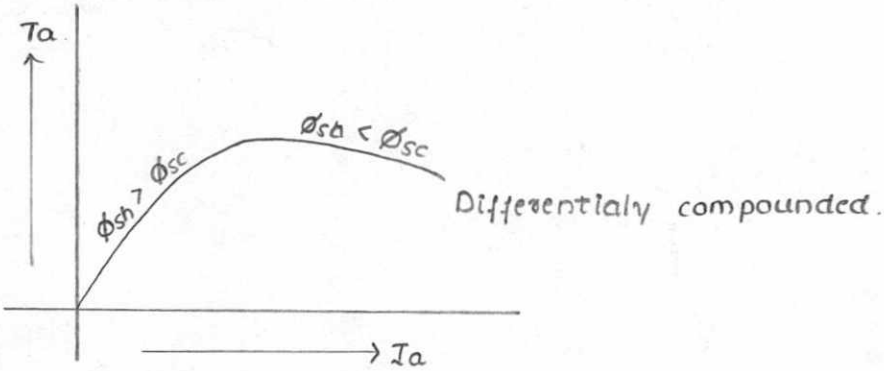




In case of differentialy compounded D.C motor as I_a increases, the flux ϕ_{sc} also increases. The flux ϕ_{sh} is constant. But here ϕ_{sc} opposes ϕ_{sh} and hence, the resultant flux ϕ,

$$\phi = \phi_{sh} - \phi_{sc}.$$

As we know that $T_a \propto \phi I_a$. Increase of I_a increases the torque. But decrease of ϕ, decrease the torque T_a.



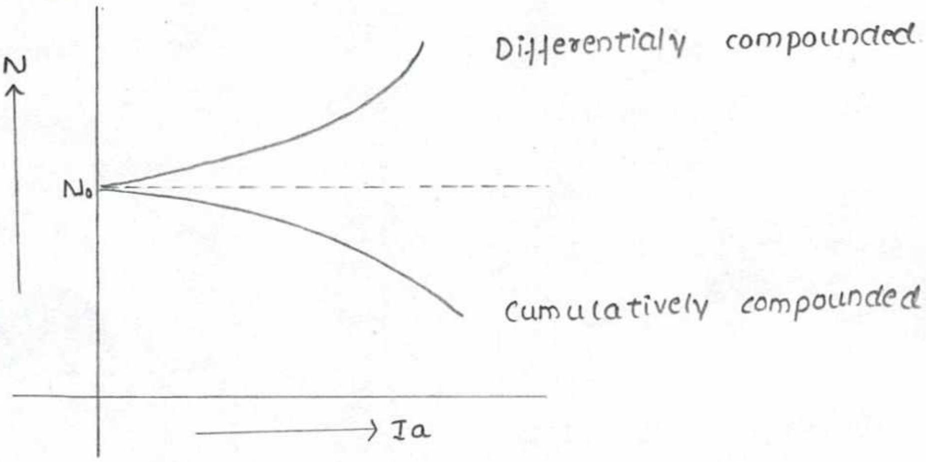
N v/s Ia characteristics.

We know that, $N \propto \frac{E_b}{\phi}$ $\because \left[E_b = \frac{P\phi NZ}{60A}\right]$

But,

$$E_b = V - I_a(R_a + R_{sc}).$$

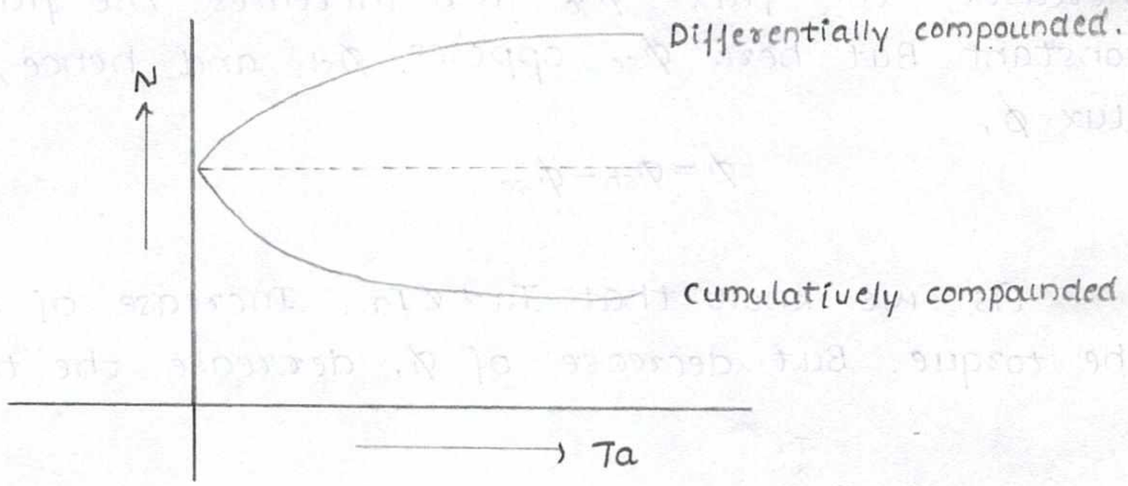
$$N \propto \frac{V - I_a(R_a + R_{sc})}{\phi}.$$



For a cumulatively compounded motor as I_a increases the resultant flux ϕ also increases. Hence speed decreases. Here the decrease of speed is faster than D.C. shunt motor and slower than D.C series motor.

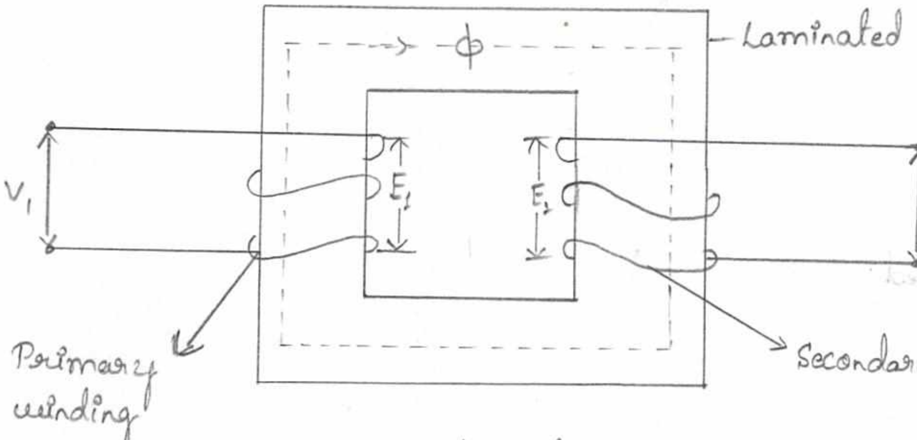
In case of differentialy compounded motor as I_a increases, the flux ϕ decreases due to which speed increases.

N v/s Ta Characteristics.



TRANSFORMERS

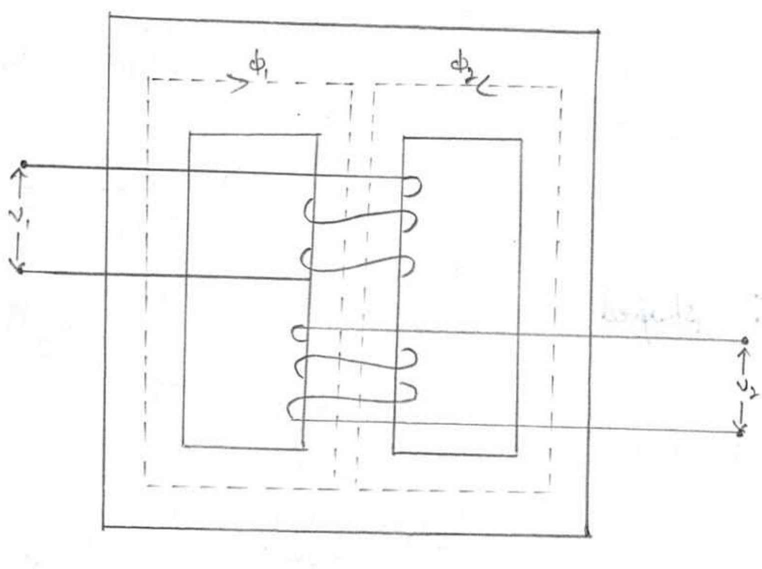
Core type transformer



$V_1 \rightarrow$ Supply voltage
$V_2 \rightarrow$ load voltage

$\phi \rightarrow$ flux
$E_1 \rightarrow$ self induced emf
$E_2 \rightarrow$ mutually induced emf

Shell type transformer



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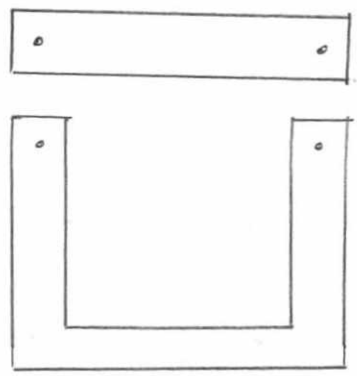
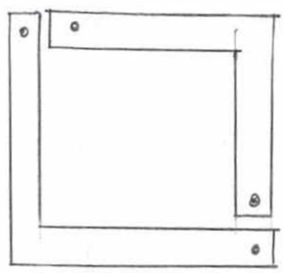
Types of Stampings

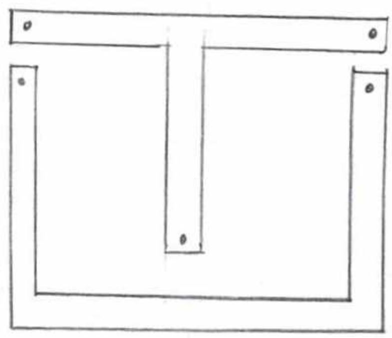
(1) U and I shaped



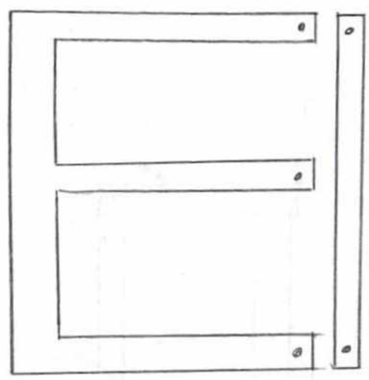
(2) L shaped



(3) U and T shaped



(4) E and I shaped



Transformer is a static device which transfer power from one circuit to another with out change in frequency.

It consists of silicon steel core and two windings are placed on it. These two windings are magnetically linked with each other and they are not electrically connected. These two windings are insulated from each other and from the core.

The winding connected to the supply mains is called as primary winding and the winding connected to the load is secondary winding. The two windings an usually wound one above the other.

Transformer consists of suitable container for the assembled core and the winding and this contains is called as transformer tank. This tank is filled with oil and it acts as an insulating media. And it is also used for coding purpose. Suitable bushings are empolyed in order to bring out the terminals of primary and secondary winding. The temperature guage and oil level guage are used for the measurement of temperature of hot oil and the oil level.

The transformer is also provided with conservated tank in order to keep the main tank with full of oil. A gas operated relay (Buchholtz) to protect the transformer from the fast.

Various types of stampings are employed in the construction of transformer core. The stampings are placed one above the other with insulation between them. i.e., it is coated with a thin layer of varnish. The thickness of the lamination varies from 0.35 mm to 0.5 mm. The joints of the laminated core are staggered to avoid continuous gap which causes an increase in the magnetising current. If it is not properly staggered, then it will have less mechanical strength and it will cause a humming noise during the operation.

Depending upon the construction of the transformer classified core and shell type.

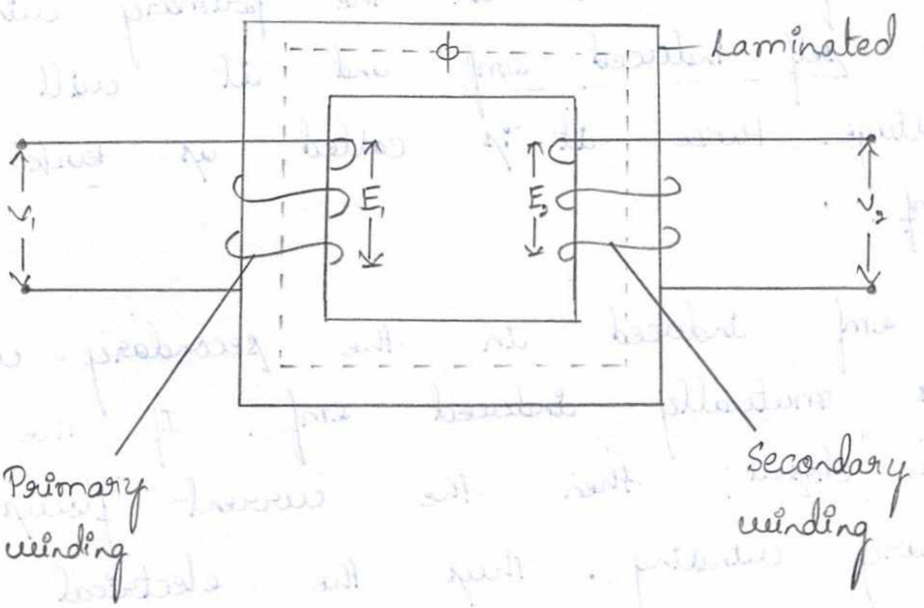
In core type the winding surrounds considerable part of the core, where as in shell type core surrounds the portion of the winding.

Depending upon the purpose of operation, it is classified as, <u>step up</u> and <u>step down</u> transformer

Working principle :-

Transformer is a static device which transfer power from one circuit to another without change in frequency.

Core type transformer diagram



It can raise the voltage or lower voltage but with corresponding decrease or increase of current. The physical basis of transformer is by mutual induction between the two circuits linked by a common magnetic flux. The two windings are electrically separated but they are magnetically linked through a path of low reluctance. The two coils posses high mutual inductance.

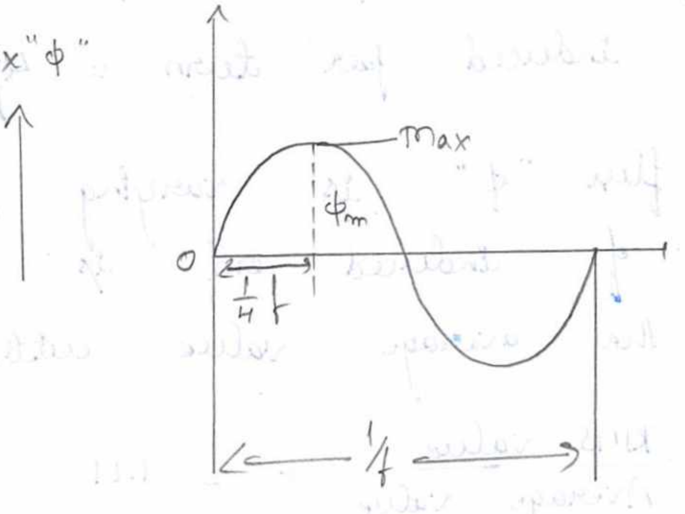
If one winding is connected to a source of AC voltage, an alternating flux will be set up in the core and most of which is linked with other winding. This flux is circulating through the core and there by it produces an emf both in primary and secondary winding. (according to Faraday's emf).

The emf induced in the primary winding 'E_1' is called as self induced emf and it will opposes the applied voltage. Hence it is called as back emf or counter emf.

The emf induced in the secondary winding E_2 is called as mutually induced emf. If the secondary circuit is closed, then the current flows through the secondary winding. Thus the electrical energy will be transferred from primary to secondary. The magnitude of the emf induced in each winding is mainly depends upon the no of turns in each winding.

In an ideal transformer $V_1 = E_1$ and $V_2 = E_2$ and hence $V_1 I_1 = V_2 I_2$.

EMF equation of transformer :



Let N_1 be the no. of turns in primary winding.
N_2 be the no. of turns in secondary winding.
ϕ_m maximum value of flux in webers in core.
Max of Flux density $B_m = \frac{\phi_m}{A}$

$$\therefore \boxed{\phi_m = B_m A}$$

A be the area of core in m^2.
B_m be the maximum value of flux density wb/m^2
f be the frequency of AC input in Hertz.

From the figure, it is clear that the flux φ varies from its "0" value to a maximum value in one quarter of a cycle.

i.e., in $\frac{1}{4f}$ Sec.

$\therefore$ Average rate of change of flux $= \frac{d\phi}{dt} = \frac{\phi_m}{1/4f} = 4f\phi_m$

Now rate of change of flux per turn means the emf induced in volts.

$\therefore$ Average emf induced per turn $= 4f\phi_m$ volts.

Since the flux "ϕ" is varying sinusoidaly, the RMS value of induced emf is obtained by multiplying the average value with form factor.

$$\text{Form factor} = \frac{\text{RMS value}}{\text{Average value}} = 1.11$$

$\therefore$ RMS value of induced emf / turn $= 4f\phi_m \times 1.11$

$= 4.44 f\phi_m$ volts.

The RMS value of induced emf in the primary winding E_1 = RMS value of emf induced emf / turn $\times$ no of turns in the primary winding.

$$\boxed{E_1 = 4.44 f \phi_m N_1 \text{ volts}} \qquad \boxed{E_1 = 4.44 f B_m A N_1} \text{ volts}$$

lly $\boxed{E_2 = 4.44 f \phi_m N_2 \text{ volts}}$

$\therefore \boxed{E_2 = 4.44 f B_m A N_2 \text{ volts}} \qquad \because \boxed{\phi_m = B_m A}$

In an ideal transformer $E_1 = V_1$ and $E_2 = V_2$

$$\therefore \boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{V_2}{V_1} = k}$$

where k is called as transformation ratio.

If $N_2 > N_1$ then $K > 1$
Then it is called as stepup transformer.

If $N_2 < N_1$ then $K < 1$
then it is called as stepdown transformer.

Also we know that in an ideal transformer input power is equal to output power.

$$V_1 I_1 = V_2 I_2$$

$$\boxed{\frac{V_2}{V_1} = \frac{I_1}{I_2}}$$

Transformer losses :-

It is a static device hence there is no mechanical losses. The losses that occurring in a transformer are
(1) Iron loss / core loss.
(2) Copper loss.

Iron loss / Core loss :- (W_i)

This loss occur in the core of the transformer. the iron losses are of two types, eddy current loss and hysteresis loss.

a) Eddy current loss : (W_e) - This loss will occur due to the flow of eddy current in the laminations of the core. This current will be induced in the laminations due to the alternating flux. This will cause power loss in the core and it heats up the core.

The eddy current loss is given by.

$$W_e = K B_m^2 f^2 t^2 V \text{ watts}$$

where k is constant whose value depends upon quality of the magnetic material used.

Bm is max. value of flux density in wb/m².

f is the supply frequency in Hz.

t is the thickness of the lamination in mtr.

v is the volume of the core in m³.

In order to keep the value of eddy current as small as possible, the core must be made up of thin laminations and they must be insulated from each other. The iron loss of transformer is constant at all loading conditions including no load.

(b) Hysteresis loss: (W_h) - This loss will occur in the core of the transformer due to the cycles of magnatisation and it is given by

$$W_h = K B_m^{1.6} f V \text{ watts}$$

Hence,

the iron loss $W_i = W_e + W_h$

Copper loss :- (W_c)

This loss is mainly depends upon the resistance of primary and secondary winding and it is always proportional to the square of the current and it is a variable one.

Total copper loss = copper loss in primary winding + copper loss in secondary winding

$$= I_1^2 R_1 + I_2^2 R_2$$

where I_1 & R_1 are the primary current and resistance of the winding.

I_2 & R_2 are the secondary current and secondary winding resistance.

Hence total loss in a transformer $\boxed{W = W_i + W_c}$

Efficiency of a transformer :-

The efficiency of a transformer at any load in power factor is defined as the ratio of output power in the secondary winding to the input power in primary winding.

$$\eta = \frac{\text{output power in watts}}{\text{Input power in watts}}$$

$$= \frac{\text{I/p - losses}}{\text{I/p power}}$$

$$= \frac{\text{Input power - [Iron loss + copper loss]}}{\text{Input power.}}$$

Input power = $V_1 I_1 \cos\phi_1$

V_1 is primary voltage.

I_1 is primary current.

$\cos\phi_1$ is power factor of primary winding.

Output power = $V_2 I_2 \cos\phi_2$

V_2 is secondary voltage.

I_2 is secondary current.

$\cos\phi_2$ is power factor of secondary winding.

Maximum efficiency of a transformer will occur only when Iron loss is equal to copper loss.

Iron loss = Copper loss

i.e., $\boxed{w_i = x^2 w_c}$

where x is the loading condition.

$x = 1$ for full load.

$x = 1/2$ for half full load.

$x = 1/4$ for 25% of full load.

w_i = Iron loss. (constant)

w_c = full load copper loss.

The efficiency of the transformer can also be calculated as follows

$$\% \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + w_i + x^2 w_c} \times 100$$

(or)

$$\% \eta = \frac{x \, KVA \cos\phi}{x \, KVA \cos\phi + w_i + x^2 w_c} \times 100$$

$\cos\phi = \frac{KW}{KVA}$

NOTE: In a transformer iron loss is mainly depends upon the voltage "V" and copper loss is mainly depends upon the current "I". Hence transformer rating is in VA / KVA / MVA.

Condition for maximum efficiency of a transformer

We know that efficiency, $\eta = \frac{\text{output power in watts}}{\text{Input power in watts}}$

Input power $= V_1 I_1 \cos\phi_1$

where V_1 is primary voltage.

I_1 is primary current.

$\cos\phi_1$ is primary power factor.

$$\eta = \frac{\text{Input power} - \text{losses}}{\text{Input power}}$$

$$\eta = \frac{\text{Input power} - [\text{Iron loss} + \text{copper loss}]}{\text{Input power}}$$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - w_i - I_1^2 R_{01}}{V_1 I_1 \cos\phi_1}$$

$$\eta = 1 - \frac{w_i}{V_1 I_1 \cos\phi_1} - \frac{I_1 R_{01}}{V_1 \cos\phi_1}$$

The efficiency is maximum only when differentiating the above equation with respect to I_1 and equating it to zero.

$$\therefore \frac{d\eta}{dI_1} = 0$$

$$\frac{d\eta}{dI_1} = 0 + \frac{w_i}{V_1 I_1^2 \cos\phi_1} - \frac{R_{01}}{V_1 \cos\phi_1} = 0$$

$$\frac{R_{01}}{V_1 \cos\phi_1} = \frac{w_i}{V_1 I_1^2 \cos\phi_1}$$

$$\therefore \boxed{w_i = I_1^2 R_{01}}$$

Hence iron loss = copper loss.

The copper losses of a transformer can also be written as equal to $I_2^2 R_{02}$.

$\therefore$ For maximum efficiency, $w_i = I_2^2 R_{02}$

$$\therefore \boxed{I_2 = \sqrt{\frac{w_i}{R_{02}}}}$$

I_2 is the load current for which the efficiency of a transformer maximum.

Voltage regulation of a transformer

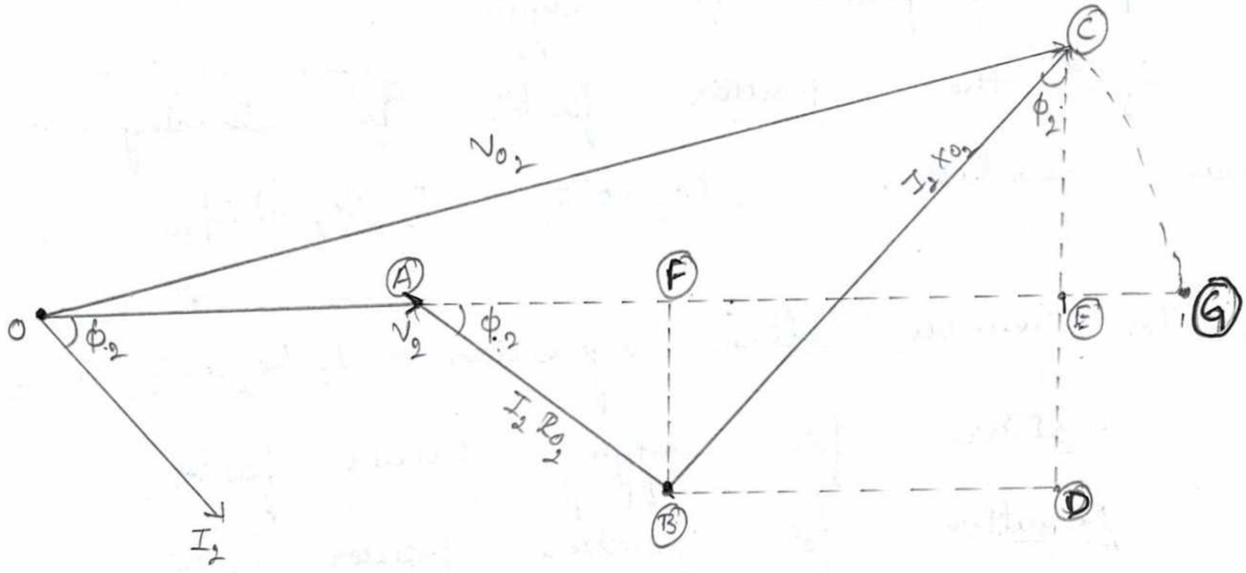
The voltage regulation of a transformer is defined as (at any load & power factor) change in the secondary terminal voltage from no load to full load, keeping the primary voltage constant.

$\therefore$ voltage regulation $= V_{02} - V_2$

where V_{02} is no load secondary terminal voltage.

V_2 is full load secondary terminal voltage.

$$\% \text{ voltage regulation} = \frac{V_{02} - V_2}{V_{02}} \times 100$$



$V_2 \rightarrow$ Full load voltage.

$I_2 \rightarrow$ Full load current which lags V_2 by an angle ϕ_2.

$\cos\phi_2 \rightarrow$ Power factor of the load.

$I_2 R_{o_2} \rightarrow$ Equivalent resistance drop reffer to Secondary.

$I_2 X_{o_2} \rightarrow$ Equivalent reactance drop reffer to Secondary.

Vector $\vec{OA}$ represents V_2, $\vec{AB}$ represents $I_2 R_{o_2}$ and $\vec{BC}$ represents $I_2 X_{o_2}$. The vector sum of these vectors is $\vec{OC}$ which represents no load terminal voltage V_{o_2}. An arc is drawn from C to G.

$$\text{Voltage regulation} = V_{o_2} - V_2$$
$$= OC - OA$$
$$= OG - OA$$
$$\simeq OE - OA$$
$$= AE$$
$$= AF + FE$$
$$\text{Voltage regulation} = AF + BD$$
$$= I_2 R_{o_2} \cos\phi_2 + I_2 X_{o_2} \sin\phi_2$$

The above equation gives the regulation, when the power factor is lagging.

If the power factor is leading,

voltage regulation $= I_2 R_{o_2} \cos\phi_2 - I_2 X_{o_2} \sin\phi_2$

$\therefore$ In general, voltage regulation $= I_2 R_{o_2} \cos\phi_2 \pm I_2 X_{o_2} \sin\phi_2$

Positive for lagging power factor.

Negative for leading power factor.

$$\therefore \quad \% \text{ voltage Regulation} = \frac{I_2 R_{o_2} \cos\phi_2 \pm I_2 X_{o_2} \sin\phi_2}{V_{o_2}} \times 100$$

$$\frac{I_2 R_{o_2}}{V_{o_2}} \times 100 \longrightarrow \% \text{ Resistive drop.}$$

$$\frac{I_2 X_{o_2}}{V_{o_2}} \times 100 \longrightarrow \% \text{ Reactance drop.}$$

Explain the difference between core type and shell type transformer.

core type	shell type.
*) the windings surrounded a considerable part of the core.	*) the core surrounded a considerable part of windings.
*) The coils may be rectangular or circular in shape.	*) The core is rectangular in shape.
*) The core is always laminated to reduce eddy current losses.	*) It is laminated to reduced eddy current losses.
*) core type transformers are used to handle low and medium voltage windings.	*) Shell type transformer are used for handling very high voltages.
*) the primary & secondary windings are connected on separate limbs but in actual construction the 2 windings are interleaved to reduce the leakage flux.	*) the primary winding and secondary winding are wound on the central limb.

Problems:-

1. A single phase core type 6600/230 volts, 50 Hz transformer has a core area of 400 cm^2 and the maximum flux density is 1.18 $wb\,m^{-2}$. Calculate the no. of turns on primary and secondary winding.

Given Data:-

Transformer

$E_1 = 6600$ V

$E_2 = 230$ V

$f = 50$ Hz

$A = 400\ cm^2 = 400 \times 10^{-4}\ m^2$

$B_m = 1.18\ wb\,m^{-2}$

$N_1 = ?$

$N_2 = ?$

Soln: WKT,

$$E_1 = 4.44 f B_m A N_1$$

$$6600 = 4.44 \times 50 \times 1.18 \times 400 \times 10^{-4} \times N_1$$

$$N_1 = \frac{6600}{104784 \times 10^{-4}}$$

$$N_1 = 0.0629 \times 10^4$$

$$\boxed{N_1 = 629.86}$$

$$\boxed{N_1 \simeq 630}$$

$$E_2 = 4.44 f B_m A N_2$$

$$230 = 4.44 \times 50 \times 1.18 \times 400 \times 10^{-4} \times N_2$$

$$N_2 = \frac{230}{104784 \times 10^{-4}}$$

$$N_2 = 0.00219 \times 10^4$$

$$\boxed{N_2 = 21.949}$$

$$\boxed{N_2 \simeq 22}$$

2. The maximum flux density in the core of 230/3000 V, 50 Hz single phase transformer is 1.2 wbm^{-2}. If the induced emf per turn is 8V, find the no of primary and secondary turns and the cross sectional area of the core.

Given data:

$E_1 = 230V$.

$E_2 = 3000V$.

$f = 50 Hz$.

$B_m = 1.2 \, wbm^{-2}$.

Emf induced per turn = 8 V.

$N_1 = ?$

$N_2 = ?$

$A = ?$

Soln:- Emf induced per turn = 8 V

$$N_1 = \frac{E_1}{8} = \frac{230}{8} = 28.75$$

$$\boxed{N_1 \simeq 29}$$

$$N_2 = \frac{E_2}{8} = \frac{3000}{8}$$

$$\boxed{N_2 = 375}$$

$$E_1 = 4.44 f B_m A N_1$$

$$230 = 4.44 \times 50 \times 1.2 \times A \times 28.75$$

$$230 = 7659 \times A$$

$$A = \frac{230}{7659}$$

$$\boxed{A = 0.03 \, m^2}$$

3. A 20 KVA transformer has 200 turns on primary and 40 turns on secondary. Primary is connected to 1000 V, 50 Hz supply. Determine secondary voltage, current flowing through the two windings on full load and the maximum value of flux.

Given data:

20 KVA transformer.

$N_1 = 200$

$N_2 = 40$

$E_1 = 1000 V$

$f = 50 Hz$.

$E_2 = ?$

$I_1 = ?$

$I_2 = ?$

$\phi_m = ?$

Soln WKT,

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

$$\frac{E_2}{1000} = \frac{40}{200}$$

$$E_2 = \frac{1000 \times 4}{20}$$

$$\boxed{E_2 = 200 V}$$

Rated primary current $I_1 = \frac{\text{Transformer rating}}{\text{Primary voltage}}$

$$= \frac{20 kVA}{1000 V}$$

$$= \frac{20 \times 10^3 VA}{1000 V}$$

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

$$\boxed{I_1 = 20 A}$$

$$I_2 = \frac{\text{transformer rating}}{\text{Secondary voltage}}$$

$$= \frac{20\ KVA}{200}$$

$$= \frac{20 \times 10^3}{200} A$$

$$\boxed{I_2 = 100\ A}$$

$$E_1 = 4.44\ f\ \phi_m\ N_1$$

$$1000 = 4.44 \times 50 \times \phi_m \times 200$$

$$\phi_m = \frac{1000}{44400}$$

$$\boxed{\phi_m = 0.022\ wb}$$

4. A 25 KVA single phase transformer as 250 turns on primary and 40 turns on secondary. Primary is connected to 1000V, 50 Hz. Determine primary and secondary current, secondary emf, max value of flux and load impedence on secondary & primary winding.

Given data:

$N_1 = 250$ — $I_2 = ?$

$N_2 = 400$ — $E_2 = ?$

$E_1 = 1000V$ — $\phi_m = ?$

$f = 50 Hz$ — $Z_1 = ?$

$I_1 = ?$ — $Z_2 = ?$

Soln: Load Impedence, $Z = \frac{V}{I}$

primary, $Z_1 = \frac{V_1}{I_1}$

Secondary, $Z_2 = \frac{V_2}{I_2}$

WKT, $\frac{E_2}{E_1} = \frac{N_2}{N_1}$

$$\frac{E_2}{1000} = \frac{40}{250}$$

$$E_2 = \frac{4 \times 1000}{25}$$

$$\boxed{E_2 = 160\ V}$$

$$I_1 = \frac{\text{transformer rating}}{\text{primary voltage}} = \frac{25\ KVA}{1000V} = \frac{25 \times 10^3\ VA}{1000\ V} = 25A$$

$$\boxed{I_1 = 25A}$$

$$I_2 = \frac{\text{transformer rating}}{\text{secondary voltage}} = \frac{25KVA}{160\ V} = \frac{25 \times 10^3\ VA}{160\ V} = 156.25\ A$$

$$\boxed{I_2 = 156.25A}$$

$$E_1 = 4.44\ f \phi_m N_1$$

$$1000 = 4.44 \times 50 \times \phi_m \times 250$$

$$1000 = 55500 \times \phi_m$$

$$\phi_m = \frac{1000}{55500}$$

$$\boxed{\phi_m = 0.0180\ wb}$$

$$Z_1 = \frac{V_1}{I_1}$$

$$= \frac{1000}{25}$$

$$\boxed{Z_1 = 40}$$

$$Z_2 = \frac{V_2}{I_2}$$

$$= \frac{160}{156.25}$$

$$\boxed{Z_2 = 1.024}$$

5. A single phase transformer with 10 : 1 turns ratio and rated at 50 kVA, 2400/240 V is used to step down the voltage of a distribution system. The low tension voltage to be kept constant at 240 V. Find the value of load impedence on low tension side, so that transformer is loaded fully. Also calculate the value of flux, if the low tension side as 23 turns.

Given datas:

10 : 1 turns ratio transformer.

50 KVA.

$E_1 = 2400$ V.

$E_2 = 240$ V.

$Z_2 = ?$

$\phi_m = ?$

$N_2 = 23$

Soln

$$Z_2 = \frac{V_2}{I_2}$$

$$I_2 = \frac{\text{Transformer rating}}{\text{Secondary voltage}} = \frac{50 \times 10^3}{240}$$

$$\boxed{I_2 = 208.3 \text{ A}}$$

$$Z_2 = \frac{V_2}{I_2} = \frac{240}{208.3}$$

$$\boxed{Z_2 = 1.15 \ \Omega}$$

$$E_2 = 4.44 f \phi_m N_2$$

$$240 = 4.44 \times 50 \times \phi_m \times 23.$$

$$240 = 5106 \times \phi_m$$

$$\phi_m = \frac{240}{5106}$$

$$\boxed{\phi_m = 0.047 \text{ wb}}$$

6. A single phase 50 Hz, core type, transformer has a square core of 20 cm side. The max flux density is 1 wbm^{-2}. calculate the no of turns per limb on high and low voltage side for a voltage ratio of 3000/220 V.

Given datas.

$f = 50$ Hz

Square core of 20 cm side.

$\therefore A = 20 \times 20$ cm^2.

$B_m = 1$ wbm^{-2}.

No of turns / limb on HV and LV side

$E_1 = 3000$ V

$E_2 = 220$V

Soln:- WKT,

$$E_1 = 4.44 f B_m A N_1$$

$$3000 = 4.44 \times 50 \times 1 \times 400 \times 10^{-4} \times N_1$$

$$3000 = 88800 \times 10^{-4} N_1$$

$$N_1 = \frac{3000}{88800 \times 10^{-4}}$$

$$N_1 = 0.0337 \times 10^4$$

$$\boxed{N_1 = 337.83}$$

$$E_2 = 4.44 f B_m A N_2$$

$$220 = 4.44 \times 50 \times 1 \times 400 \times 10^{-4} \times N_2$$

$$220 = 88800 \times N_2 \times 10^{-4}$$

$$N_2 = \frac{220}{88800 \times 10^{-4}}$$

$$N_2 = 0.00247 \times 10^4$$

$$\boxed{N_2 = 24.77}$$

Usually in a transformer half of the primary turns and half of the secondary turns are wound on each limb and they are equally shared.

$\therefore$ No of turns / limb on HV side $= \frac{N_1}{2} = \frac{337.83}{2} = 168.69 \simeq 169$

No of turns / limb on LV side $= \frac{N_2}{2} = \frac{24.77}{2} = 12.38 \simeq 12$

7. A single phase 50 Hz, core type transformer has a rectangular core of $20 \times 15\ cm^2$. The max available flux density is $1.04\ wbm^{-2}$. Find the no of turns on HV & LV side. For a voltage ratio of 3300/230 V. Assume the net iron length to be 0.9 times the gross iron length. Also calculate the emf / turn on HV and LV side.

Given data:

$f = 50\ Hz$

$A = 20 \times 15\ cm^2 = 300 \times 10^{-2} m^2$

$B_m = 1.04\ wbm^{-2}$

$N_1 = ?$

$N_2 = ?$

$E_1 = 3300\ V$

$E_2 = 230\ V$

Assume net iron length = 0.9 × Gross iron length

emf / turn = ?

Soln

Assume net iron length = 0.9 × Gross iron length.

$= 0.9 \times 20$

$= 18\ cm$

Area of the core $A = 18 \times 15\ cm^2$

$$\boxed{A = 270\ cm^2}$$

WKT, $E_1 = 4.44 f B_m A N_1$

$$3300 = 4.44 \times 50 \times 1.04 \times 270 \times 10^{-4} \times N_1$$

$$3300 = 62337.6 \times N_1 \times 10^{-4}$$

$$N_1 = \frac{3300}{62337.6 \times 10^{-4}}$$

$$N_1 = 0.0529 \times 10^4$$

$$\boxed{N_1 = 529.3}$$

$$E_2 = 4.44 f B_m A N_2$$

$$230 = 4.44 \times 50 \times 1.04 \times 270 \times 10^{-4} \times N_2$$

$$230 = 62337.6 \times 10^{-4} \times N_2$$

$$N_2 = \frac{230}{62337.6 \times 10^{-4}}$$

$$N_2 = 0.0036 \times 10^{-4}$$

$$\boxed{N_2 = 36.89}$$

Emf / turn on primary $= \frac{E_1}{N_1}$

$$= \frac{3300}{529.3}$$

$$= \boxed{6.23V}$$

Emf / turn on secondary $= \frac{E_2}{N_2}$

$$= \frac{230}{36.89}$$

$$= \boxed{6.23V}$$

8. A 10 KVA, 400/200 V, 50 Hz single phase transformer has a full load efficiency of 96 % at 0.8 power factor lagging. Determine the iron loss. What would be the efficiency at half of the full load and at unity power factor? The full load copper loss is 200 watts.

Given data:

10 KVA transformer.

$E_1 = 400V$

$E_2 = 200V$

$f = 50 Hz$

Full load $\eta = 96\%$ at $\cos\phi = 0.8$ at $x = 1$

$w_i = ?$

$\eta = ?$ when $x = 1/2$ and when $\cos\phi = 1$.

Full load copper loss $w_c = 200$ watts.

Soln: WKT,

$$\eta = \frac{x \, KVA \cos\phi}{x \, KVA \cos\phi + w_i + x^2 w_c}$$

$$0.96 = \frac{(1) 10 \times 10^3 \times 0.8}{1 \times 10 \times 10^3 \times 0.8 + w_i + (1)^2 (200)}$$

$$0.96 = \frac{8 \times 10^3}{8 \times 10^3 + w_i + 200}$$

$$0.96 = \frac{8000}{8000 + w_i + 200} = \frac{8000}{8200 + w_i}$$

$$7680 + 0.96 w_i + 192 = 8000$$

$$w_i = \frac{128}{0.96} = \boxed{133.33 \text{ watts}}$$

$$\eta = \frac{x\,KVA\,\cos\phi}{x\,KVA\,\cos\phi + w_i + x^2 w_c}$$

$$\eta = \frac{(1/2)\,(10\times10^3)\,(1)}{(1/2)\,(10\times10^3)\,(1) + 133.3 + (1/2)^2\,(200)}$$

$$\eta = \frac{5\times10^3}{5\times10^3 + 133.3 + 0.25\times200}$$

$$\eta = \frac{5000}{5000 + 133.3 + 50}$$

$$\eta = \frac{5000}{5183.3}$$

$$\eta = 0.9646$$

$$\boxed{\%\,\eta = 96.46\,\%}$$

9. A 10 KVA, 400/200 volts single phase transformer as a max efficiency of 98 % at 90 % of full load and at 0.8 power factor. Find the efficiency at full load and at 0.6 power factor.

Given data:

10 KVA transformer

$E_1 = 400V$

$E_2 = 200V$

$\eta_{max} = 98\,\%$ when $x = 0.9$ and $\cos\phi = 0.8$

$\eta = ?$ when $x = 1$ and $\cos\phi = 0.6$

Soln WKT,
$$\eta = \frac{x\,KVA\,\cos\phi}{x\,KVA\,\cos\phi + w_i + x^2 w_c}$$

$$0.98 = \frac{(0.9)\,(10\times10^3)\,0.8}{(0.9)\,(10\times10^3)\,(0.8) + w_i + (0.9)^2 w_c}$$

$\therefore$ $w_i + (0.9)^2 w_c = 146.93$ watts

WKT, η_{max} will occur in a transformer only when iron loss = copper loss.

i.e., $w_i = x^2 w_c$

$\therefore$ $w_i = (0.9)^2 w_c = \frac{146.93}{2}$

$\therefore$ $\boxed{w_i = 73.46 \text{ watts}}$

At 90% of full load copper loss

$w_c = 73.46$ watts.

i.e., $(0.9)^2 w_c = 73.46$

$$w_c = \frac{73.46}{(0.9)^2} = \frac{73.46}{0.81}$$

Full load $\boxed{w_c = 90.69 \text{ watts}}$

$$\eta = \frac{x\,kVA\,\cos\phi}{x\,kVA\,\cos\phi + w_i + x^2 w_c}$$

$$= \frac{1 \times (10 \times 10^3) \times 0.6}{1 \times 10 \times 10^3 \times 0.6 + 73.46 + 1^2(90.69)}$$

$$= \frac{6000}{10{,}000 \times 0.6 + 73.46 + 90.69}$$

$$= \frac{6000}{6000 + 73.46 + 90.69}$$

$$= \frac{6000}{6164.15}$$

$\eta = 0.9734$

$\boxed{\% \eta = 97.34 \%}$

10. A 20 KVA, 220/110V single phase transformer takes 800 watts on no load with full load voltages impressed. On short circuit, with full load current it takes 1200 watts. Find the max efficiency with purely resistive load.

Given data:

20 KVA transformer

$E_1 = 220V$

$E_2 = 110V$

It takes 800 watts on no load.

$\therefore$ $w_i = 800$ watts.

Full load copper loss

$w_c = 1200$ watts.

$\eta_{max} = ?$ when $\cos\phi = 1$ ($\because$ resistive load).

Soln:- WKT, max efficiency will occur in a transformer only when iron loss = copper loss.

i.e., $w_i = x^2 w_c$

$800 = x^2 (1200)$

$\therefore x^2 = \frac{800}{1200}$

$x^2 = 0.66$

$\boxed{x = 0.81}$

$$\eta_{max} = \frac{x \, KVA \, \cos\phi}{x \, KVA \, \cos\phi + w_i + x^2 w_c}$$

$$\eta_{max} = \frac{(0.81)(20\times10^3)(1)}{(0.81)(20\times10^3)(1) + 800 + (0.81)^2 + (1200)}$$

$$\eta_{max} = \frac{0.81 \times 20,000}{0.81 \times 20,000 + 800 + 0.6561 \times 1200}$$

$$= \frac{16200}{17787.32}$$

$$= 0.91$$

$$\boxed{\% \eta = 91\%}$$

11. A single phase transformer working at 0.8 power factor has an efficiency of 94% at both (3/4)th full load and full load of 600 KW. Determine the efficiency at half full load.

Given data:

$\cos\phi = 0.8$

$\eta = 94\%$ at $x = \frac{3}{4}$ of full load. and full load of 600 kW.

$\eta = ?$ when $x = \frac{1}{2}$.

Soln: Case 1:. At full load of 600 kW.

$O/P = 600$ kW

$\eta = 94\%$

$I/P = ?$

WKT $\eta = \frac{O/P}{I/P}$

$I/P = \frac{O/P}{\eta}$

$I/P = \frac{600 \text{ kW}}{0.94}$

$\boxed{I/P = 638.29 \text{ kW}}$

Total losses = I/p − o/p

$= 638.29 - 600$

$\therefore$ $w_i + x^2 w_c = 38.29$ kW.

$\therefore$ $w_i + (1)^2 w_c = 38.29$ —— ①

Case 2: At $\frac{3}{4}$ full load

$o/p = \frac{3}{4} \times 600$

$o/p = 450$ kW

$\eta = 94\%$

$\therefore$ $I/p = \frac{o/p}{\eta} = \frac{450}{0.94} = 478.72$ kW.

Total losses = I/p − o/p

$= 478.72 - 450$

$\therefore$ $w_i + x^2 w_c = 28.72$ kW

$\therefore$ $w_i + (3/4)^2 w_c = 28.72$ —— ②

solving equation ① & ②

$w_i + 1^2 w_c = 38.29$

$w_i + (3/4)^2 w_c = 28.72$

$0.4375 w_c = 9.57$

$\therefore$ $w_c = 21.87$ kW

$w_i + 1^2 w_c = 38.29$

$w_i + 1^2 (21.87) = 38.29$

$w_i + 21.87 = 38.29$

$w_i = 38.29 - 21.87$

$w_i = 16.42$ kW

η at $\frac{1}{2}$ full load

$$\eta = \frac{x\,kVA\ \cos\phi}{x\,kVA\ \cos\phi + w_i + x^2 w_c}$$

WKT, $kVA\ \cos\phi = kW$

$$\eta = \frac{x\,kW}{x\,kW + w_i + x^2 w_c}$$

$$\eta = \frac{(\frac{1}{2})\,600}{\frac{1}{2}\times 600 + 16.47 + (\frac{1}{2})^2 (21.87)}$$

$$\eta = \frac{300}{300 + 16.47 + 0.25(21.87)}$$

$$\eta = \frac{300}{321.8875}$$

$$\eta = 0.932$$

$$\boxed{\%\eta = 93.2\%}$$

12. A 50 kVA, 3000/300 V single phase transformer has an iron loss and full load copper loss of 400 W and 600 W respectively. calculate the efficiency at half full load and at 0.9 power factor. Also calculate the load at which efficiency is maximum.

Given data:

50 kVA transformer

$E_1 = 3000V$

$E_2 = 300V$

$w_i = 400W$

$w_c = 600W$

$\cos\phi = 0.9$ at $x = \frac{1}{2}$ & $\eta = ?$

$$\eta = \frac{x\,kVA\ \cos\phi}{x\,kVA\ \cos\phi + w_i + x^2 w_c}$$

$$= \frac{\frac{1}{2} \times (50\times10^{+3})\ 0.9}{\frac{1}{2} \times (50\times10^{+3}) \times 0.9 + 400 + (\frac{1}{2})^2 \times 600}$$

$$= \frac{22500}{22500 + 400 + 0.25 \times 600}$$

$$= \frac{22500}{23050}$$

$$= 0.976$$

$$\boxed{\%\ \eta = 97.6\ \%}$$

Load for max efficiency = Full load kVA $\times \sqrt{\frac{\text{Iron loss}}{\text{Full load cu loss}}}$

$$\eta_{max} = 50\sqrt{\frac{400}{600}}$$

$$\eta_{max} = 50\sqrt{0.666}$$

Load for max η = 40.8 kVA

Three phase induction Motor.

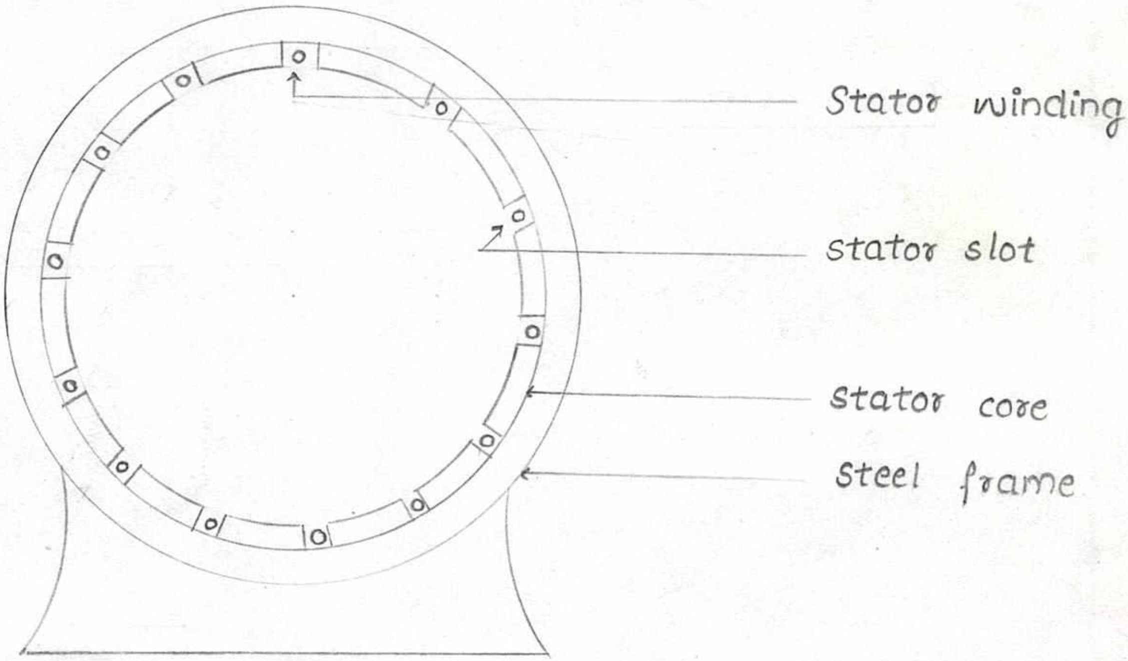
Three phase induction motor is an AC motor and it is extensively used because of the following advantages.

→ Its construction is simple.
→ Its rugged (strong) and almost unbreakable.
→ Its cost is low and it is highly releable.
→ Its efficiency is high.
→ It works with good power factor at rated load.
→ Its maintainence cost is less.
→ It is a self starting machine.

[Its starting torque is low when load is increases its speed decreases. This is the disadvantage].

Constructional features.

Stator



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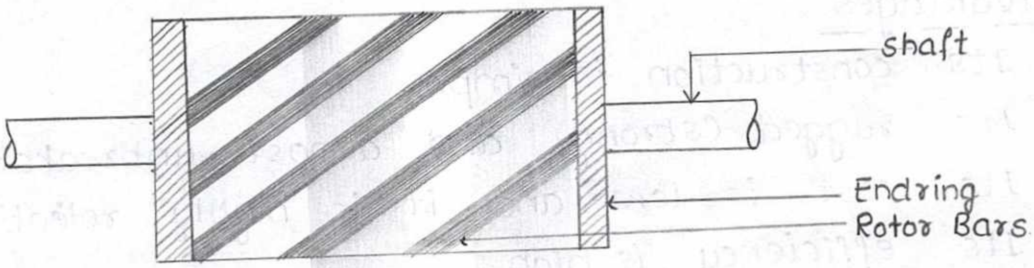
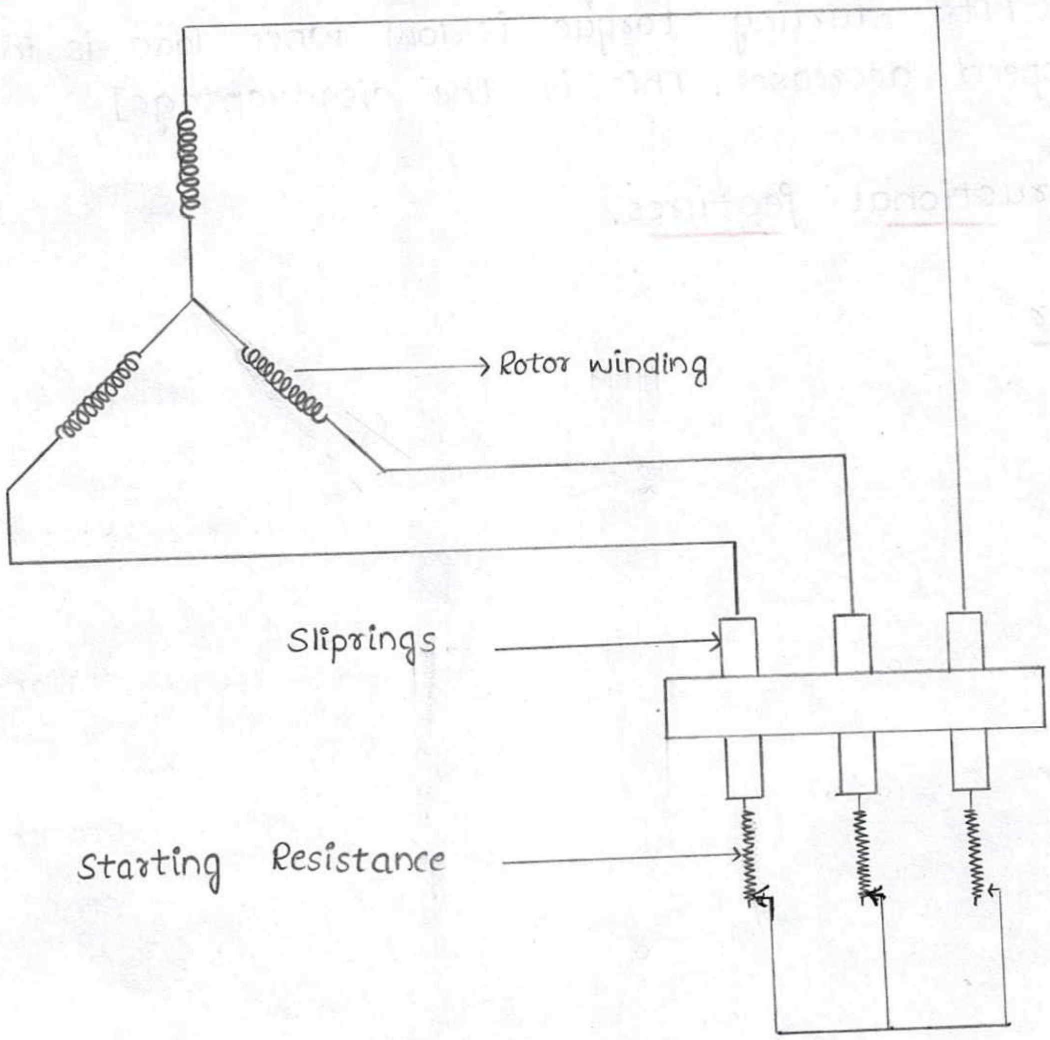
Rotor.

a) Squirel cage Rotor.



b) Phase wound Rotor. / Slip ring Rotor



Three-phase induction motor mainly consists of 2 parts. Stator and Rotor.

Stator.

It is the stationary part of an induction motor. It consists of steel frame, which encloses a hallow cylindrical core madeup of thin laminations of silicon steel to reduce the eddy current losses. It consists of number of slots on its inner surface and these slots are uniform and parallel to each other. The 3-phase stator windings are placed in each slots which are insulated from each other and from the core. These conductors are of a balanced 3-phase star connected winding or delta connected winding.

These windings are wound for different number of poles depending upon the requirement of the speed.

Rotor.

a) Squirrel cage rotor.

It is the rotating part of an induction motor. It consists of cylindrical laminated core with parallel slots for carrying rotor conductors. Copper or Aluminium bars are used as rotor conductors. Rotor bars are welded by using cu endrings. Thus these bars are short circuit at both the ends. ∴ It is not possible to add an extra resistance in series with rotor conductors.

The rotor slots are slightly skewed, which helps in 2 ways.

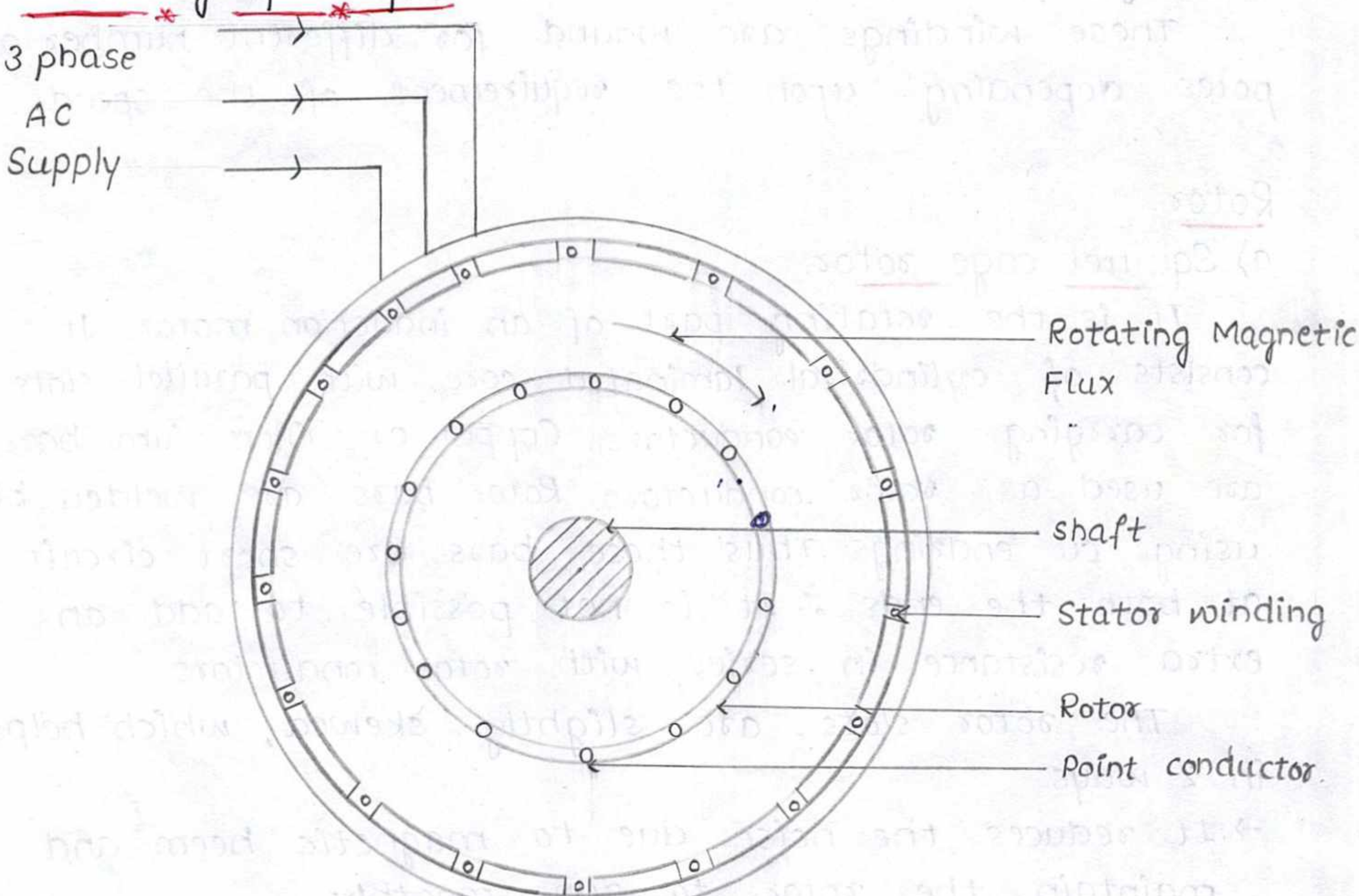
→ It reduces the noise due to magnetic heem and maintain the rotor to run smoothly.

→ It reduces the locking tendency between stator and rotor.

b) Phase wound rotor or Slipring rotor.

It is laminated, cylindrical core having uniform slots on its external surface. The 3-phase winding which is star connected is placed in those slots. The ends of the star connected windings are brought out and connected to 3 insulated sliprings. Here there is a provision of insurting a resistance in series with rotor circuit. This helps to increase the starting torque of an induction motor. As the motor gains its speed, the resistance is gradually cut off and rotor windings are short circuited through sliprings.

"Working principle."



When a 3 phase AC supply is given to the stator winding of an induction motor, it produces a rotating field of a constant magnetic flux. This magnetic flux rotating at a constant speed and this speed is called as Synchronus speed "N_s". and it is given by, $N_S = \frac{120f}{P}$
where, 'f' is supply frequency
'P' be the number of poles.

The rotating magnetic field sweeps across the rotor conductors, which are stationary. Therefore due to relative speed between the rotating flux and the stationary conductors, an emf will be induced in the rotor winding. [According to Faraday's law.]

And hence current flows through rotor conductors. The direction of the induced current is such that it opposes the flux, that produces the emf. Therefore to decrease the relative motion, the rotor starts rotating in the same direction as that of the rotating flux. But it always runs less than Synchronaus speed. and the actual speed of the rotor is represented by 'N'.

Since the actual speed of the rotor of an induction motor is always less than synchronous speed, the induction motor is called as Asynchronous Motor.

The difference between the synchronous speed N_s of magnetic flux and the actual speed N of the rotor is called as slip speed.

Slip.(S).

It is defined as the ratio of Slip speed to the synchronous speed.

$\therefore$ Fractional slip $s = \frac{N_s - N}{N_s}$

$$\% S = \frac{N_s - N}{N_s} \times 100$$

Frequency of Rotor current.

Let,

P be the number of poles.

f be the frequency of AC supply.

S be the fractional slip.

f' be the frequency of induced current in rotor.

N_s be the synchronous speed of stator flux.

N be the speed of the rotor in rpm.

When the rotor is at rest, the frequency of rotor current is equal to supply frequency. But when motor is rotating, the frequency of the current induced in the rotor conductors is proportional to the slip speed.

i.e $N_s - N = \frac{120 f'}{P} \rightarrow (1)$.

But we know that,

$$N_s = \frac{120 f}{P} \rightarrow (2)$$

Deviding eq^n (1) by eq^n (2),

$$\frac{N_s - N}{N_s} = \frac{120 f'}{P} \times \frac{P}{120 f}$$

$$\frac{N_s - N}{N_s} = \frac{f'}{f}$$

But we know that,

$$\frac{N_s - N}{N_s} = S$$

$$\therefore S = \frac{f'}{f}$$

$$\therefore \boxed{f' = S \cdot f}$$

When motor is at rest,

we know that, $f' = Sf$

$$f' = \frac{N_s - 0}{N_s} f \qquad [\because N = 0].$$

$$\therefore \boxed{f' = f}$$

Squirrel cage induction motor.

Advantages.

→ It is simple in construction, rugged and can withstand rough handling.

→ Maintanance cost is less.

→ It has better efficiency and power factor.

→ Simple star-delta startor is sufficient to start the motor.

Disadvantages.

→ It has low starting torque.

→ The powerfactor of starting is low.

→ The starting current is high and it has no smooth running.

→ It is not possible to add extraresistance in the rotor circuit.

Phase wound induction motor.

Advantages.

→ It has external resistance in the rotor circuit, which can be used as a startor.

→ It has higher starting torque and lower starting current.

→ External resistance can be used to control the speed and also to improve the powerfactor. The motor is smooth running.

→ It can be built of very high capacity.

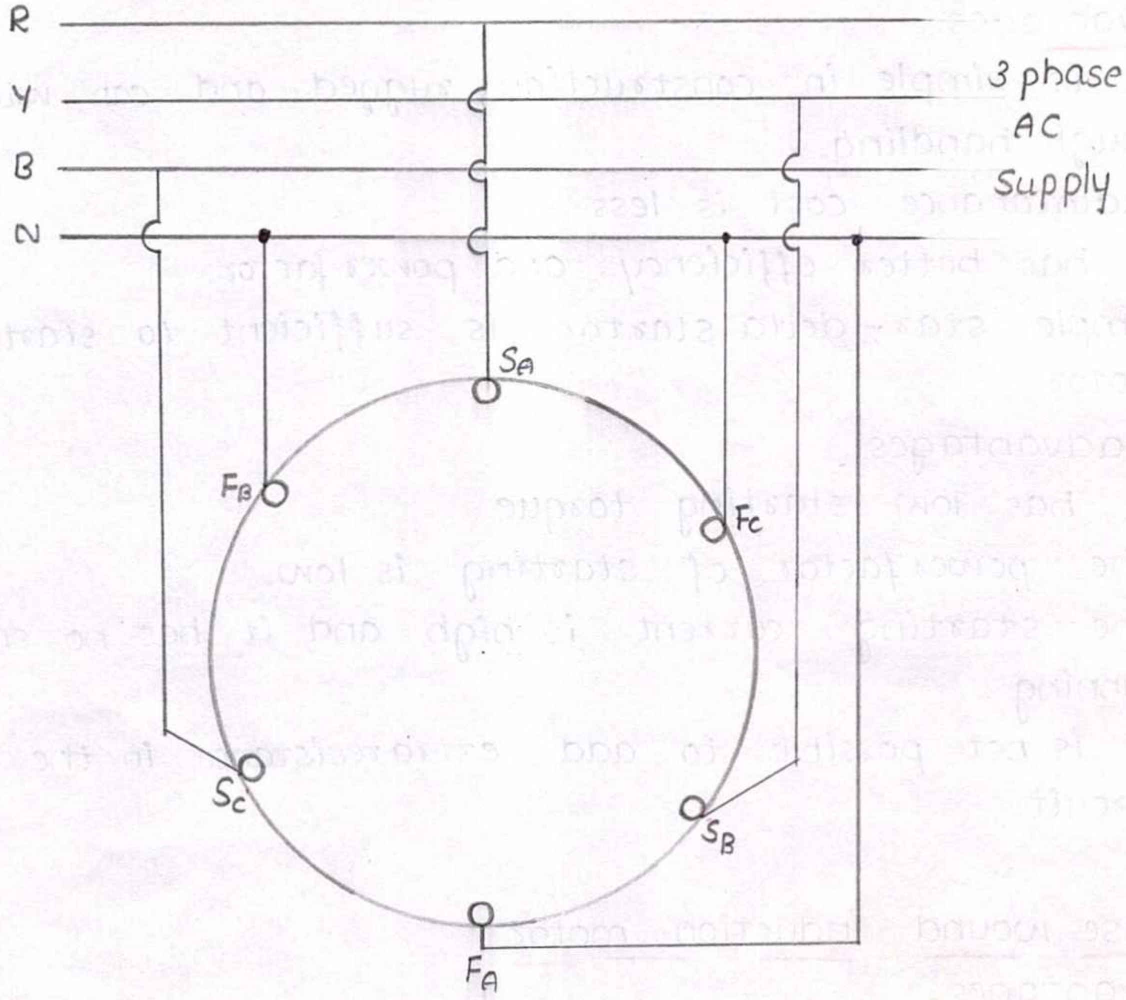
Disadvantages.

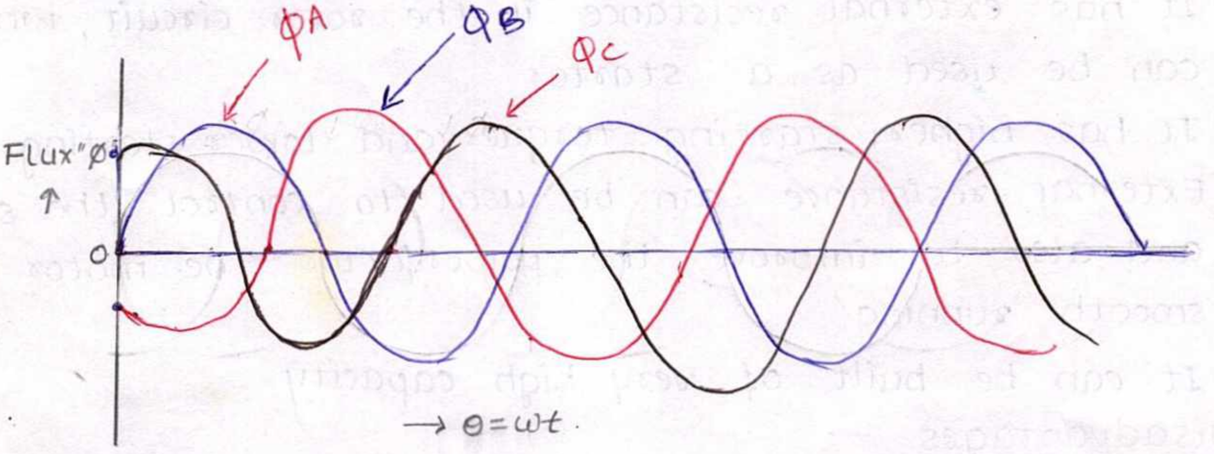
→ The size of the slipring induction motor of the same capacity is more than that of squirrel cage induction motor.

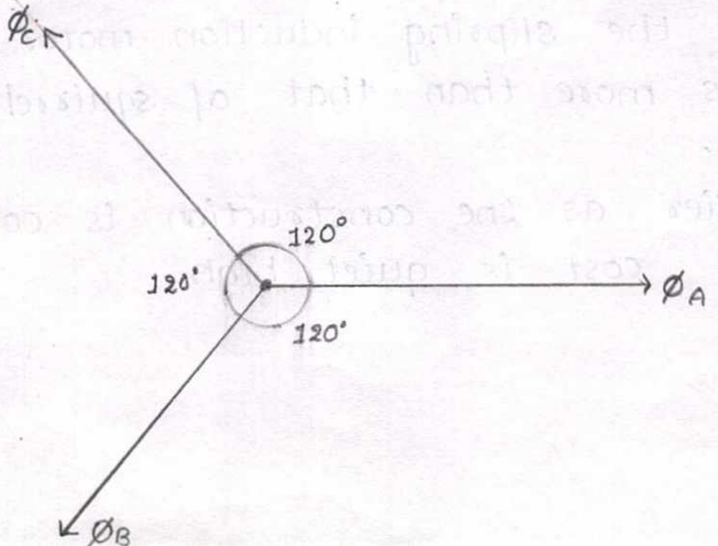
→ It is costlier as the construction is complecated.

→ Maintanance cost is quiet high.

Concept of Rotating Magnetic Field.







We know that,

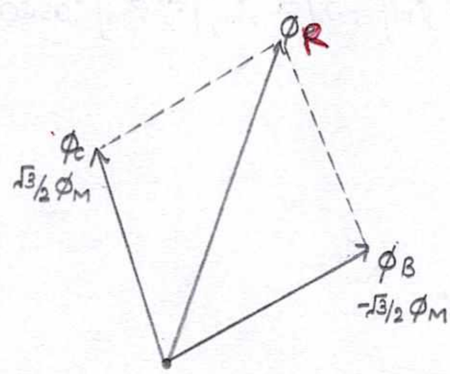
$$\phi_A = \phi_m \sin\theta$$

$$\phi_B = \phi_m \sin(\theta - 120^\circ)$$

$$\phi_C = \phi_M \sin(\theta - 240^\circ)$$

case 1 :- when $\theta = 0$,

$\phi_A = 0$. $\phi_B = -\sqrt{3}/2\,\phi_M$ $\phi_C = \sqrt{3}/2\,\phi_M$



$$\phi_R = \sqrt{\phi_B^2 + \phi_C^2 + 2\phi_B\phi_C\cos\theta}$$

$$= \sqrt{0.74 + 0.74 + (-1.499)\,0.5}$$

$$= 1.48\,\phi_M$$

$$\boxed{\phi_R = 1.5\,\phi_M}$$

case 2 :- When $\theta = 60$,

$$\phi_A = \phi_M \sin 60^\circ$$

$$\boxed{\phi_A = \sqrt{3}/2\,\phi_M}$$

$$\phi_B = \phi_M \sin(60^\circ - 120^\circ)$$

$$\phi_B = \phi_M \sin(-60^\circ)$$

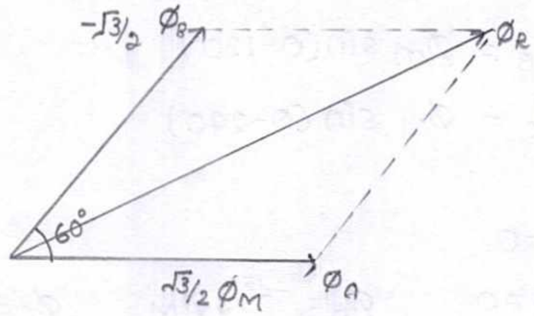
$$\boxed{\phi_B = -\sqrt{3}/2\,\phi_M}$$

$$\phi_C = \phi_M \sin(60^\circ - 240^\circ)$$

$$\phi_C = \phi_M \sin(-180^\circ)$$

$$\boxed{\phi_C = 0.}$$

$$\phi_R = \sqrt{\phi_A^2 + \phi_B^2 + 2\phi_A\phi_B \cos\theta}$$



$$\phi_R = \sqrt{\left[\frac{\sqrt{3}}{2}\phi_m\right]^2 + \left[\frac{\sqrt{3}}{2}\phi_m\right]^2 + 2\left[\frac{\sqrt{3}}{2}\phi_M\right]\left[\frac{\sqrt{3}}{2}\phi_M\right]\cos 60°}$$

$$\boxed{\phi_R = 1.5\phi_M}$$

case 3 :- When $\theta = 120°$,

$\phi_A = \phi_M \sin 120°$

$\boxed{\phi_A = \sqrt{3}/2\,\phi_M}$

$\phi_B = \phi_M \sin(\theta - 120°)$

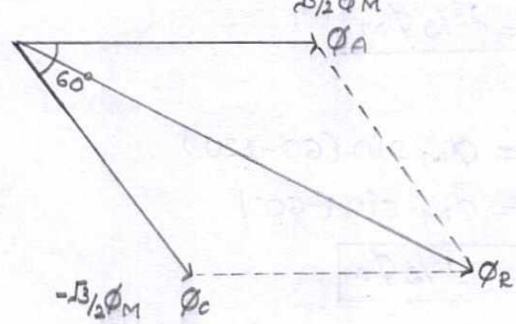
$\phi_B = \phi_M \sin(120° - 120°)$

$\boxed{\phi_B = 0}$

$\phi_C = \phi_M \sin(120° - 240°)$

$\phi_C = \phi_M \sin(-120°)$

$\boxed{\phi_C = -\sqrt{3}/2\,\phi_M}$



$$\phi_R = \sqrt{\phi_A^2 + \phi_B^2 + 2\phi_A\phi_B \cos\theta}$$

$$\phi_R = \sqrt{\left[\frac{\sqrt{3}}{2}\phi_M\right]^2 + \left[\frac{\sqrt{3}}{2}\phi_M\right]^2 + 2\left[\frac{\sqrt{3}}{2}\phi_M\right]\left[\frac{\sqrt{3}}{2}\phi_M\right]\cos 60°}$$

$$\boxed{\phi_R = 1.5\phi_M}$$

case 4 :- When $\theta = 180°$,

$\phi_A = \phi_M \sin 180°$

$\boxed{\phi_A = 0}$

$\phi_B = \phi_M \sin(180° - 120°)$

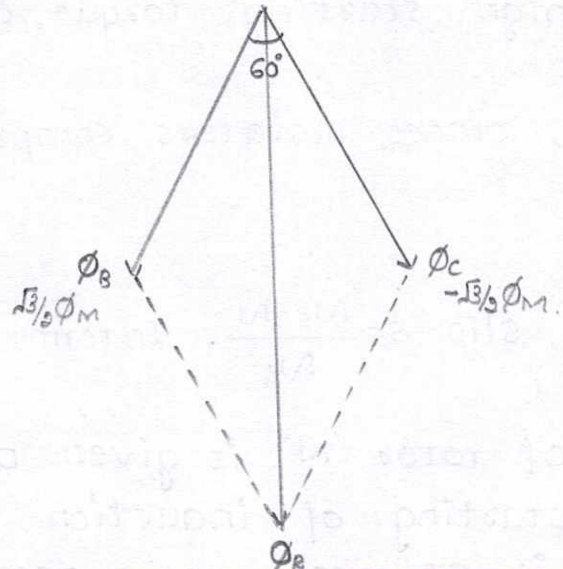
$\phi_B = \phi_M \sin 60°$

$\boxed{\phi_B = \sqrt{3}/2\, \phi_M}$

$\phi_C = \phi_M \sin(180° - 240°)$

$\phi_C = \phi_M \sin(-60°)$

$\boxed{\phi_C = -\sqrt{3}/2\, \phi_M}$



$$\phi_R = \sqrt{\phi_B^2 + \phi_C^2 + 2\phi_B\phi_C \cos\theta}$$

$$\phi_R = \sqrt{\left[\frac{\sqrt{3}}{2}\phi_M\right]^2 + \left[\frac{\sqrt{3}}{2}\phi_M\right]^2 - 2\left[\frac{\sqrt{3}}{2}\phi_M\right]\left[\frac{\sqrt{3}}{2}\phi_M\right]\cos 60°}$$

$\boxed{\phi_R = 1.5\phi_M}$

From the above discussion, we conclude that as θ varies, the resultant flux also rotates with the same angular velocity and which is having a constant magnitude of $1.5\phi_M$.

Applications of Squirrel cage induction motor.

→ Squirrel cage induction motor is widely used in almost all industrial applications.

→ It is used, where moderate starting torque is required with normal starting current.

→ It is used in fans, blowers, centrifugal pumps etc.

→ It is also used where high torque and low current is required.

→ It is used in convayers, compressors, creshors, grinders, printing machines, drilling machines etc.

Applications of phase wound induction motor.

→ It is used where high starting torque and low starting current is required.

→ It is used in lifts, cranes, elevators, compressors etc.

Significance of slip.

We know that, slip $s = \frac{N_s - N}{N_s}$. Interms of speed, the actual speed of rotor 'N' is given by $N = N_s(1-s)$.

During the starting of induction motor. i.e when the motor is at rest, the speed N is zero.

∴ The slip $s = 1$.

This is the maximum value of slip.

As we know that at any instant N_s is not equal to N ($N_s \neq N$)

Hence s is not equal to zero. ($s \neq 0$). Which is possible in induction motor. So, slip of an induction motor can not be zero at any circumstances.

Practically motor operates in the slip range of point 0.01 to 0.05 (1% to 5%). The slip corresponding to full load speed of an induction motor is called as full load slip.

Neccesity of startor for an induction motor.

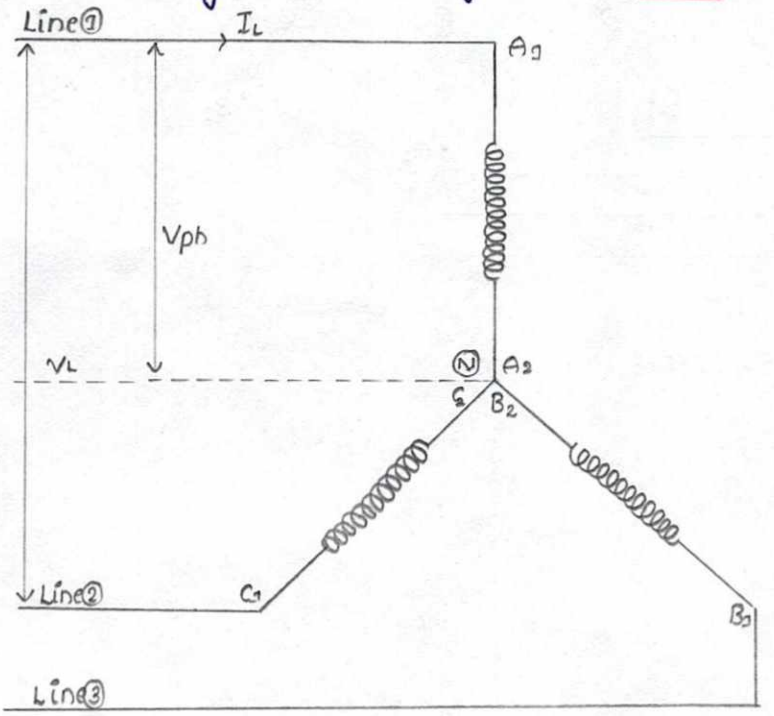
3-phase induction motor is a self starting machine. But at the time of starting, it draws huge current about 5-7 times the full load current and produces only about 1.5 - 2.5 times the full load torque, when it is directly connected to 3-phase AC supply. This large initial inrush current is due to the absence of back emf. This large current causes an effect on the operation of the motor. Hence stator is required. In case of phase wound induction motor resistance can be added in the rotor circuit. But it is not possible in case of Squirrel cage induction motor.

∴ Different method of starting Squirrel cage induction motor are,

1. By using Primary resistors.
2. By using Auto transformer.
3. By using star-delta stator.

Star - delta stator.

During starting condition.



I_L = Line current
N = Neutral
V_L = Line voltage
V_{ph} = Phase voltage
I_{ph} = Phase current

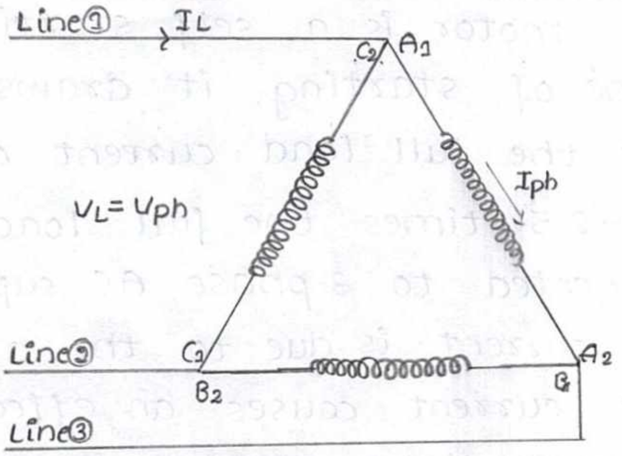
In star connection,

$$V_{ph} = \frac{V_L}{\sqrt{3}}$$

and

$$I_L = I_{ph}$$

During running condition.



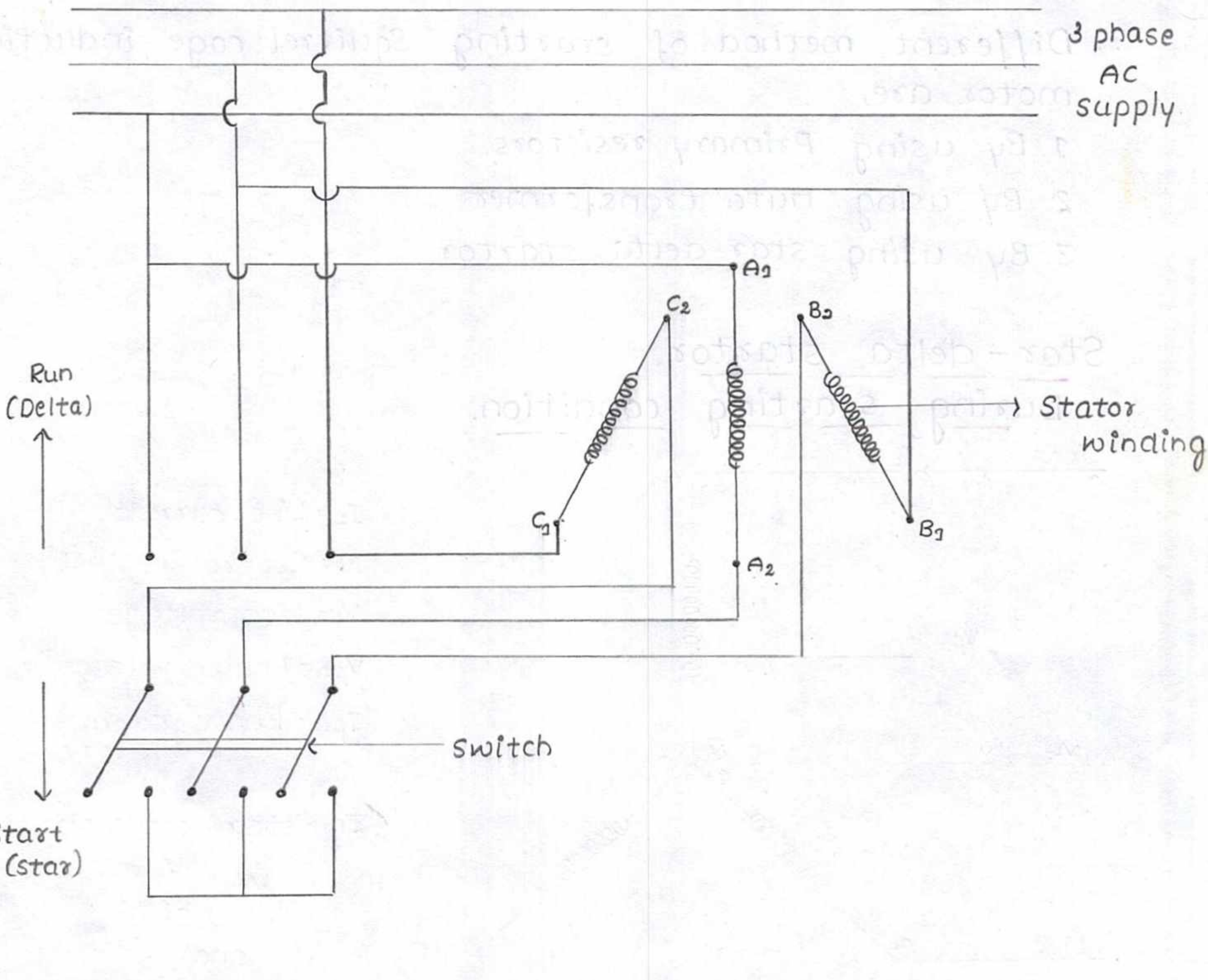
In delta connected winding

$$I_{ph} = \frac{I_L}{\sqrt{3}}$$

and

$$V_L = V_{ph}$$

Star-delta starter.



Star-delta startor is used in a 3-phase induction motor. The above diagram represents the wiring arrangement of star-delta startor. Its operation is very simple and in this method the motor is started with its winding connected in star and thus the voltage applied across each phase will be $\frac{V_L}{\sqrt{3}}$, where V_L is line voltage.

When once the motor gains its speed, the stator winding connections are changed from star to delta by using the switch. ∴ At this time the rated voltage will be applied across the winding. The ratio of line current at the time of motor starting will be equal to 1/3.

From the figure its observed that, motor is started by putting the switch on the start side and when it attains the speed, the switch is changed to run side. This method of starting is cheeper one and hence it is used.

1. A 3 phase, 4 pole, 50 Hz induction motor runs at 1440 rpm. Find the slip speed, Fractional slip, frequency of rotor current, percentage slip and how many altration will the rotor voltage makes per minute.

Given,

3phase induction motor.

$P = 4$

$f = 50\ Hz$

$N = 1440\ rpm$.

$N_s - N = ?$

$\frac{N_s - N}{N_s} = s = ?$

$f' = ?$

$\%\ s = ?$

$$N_s = \frac{120 f}{P}$$

$$\therefore N_s = \boxed{1500\ rpm}$$

Slip speed $= N_s - N = 1500 - 1440$

$= \boxed{60\ rpm}$

Fractional slip $= \frac{N_s - N}{N_s} = \boxed{0.04}$

$\%$ slip $= 0.04 \times 100 = \boxed{4}$

Frequency of the rotor current $= f' = s \cdot f$

$= 0.04 \times 50$

$= \boxed{2\ Hz}$

$2 \times 60 = 120$.

$\therefore$ 120 altration will the rotor voltage makes per minute.

2. A 12 pole, 3 phase alternator is driven at a speed of 500 rpm, supplies power to an 8 pole, 3phase induction motor. If slip of motor at full Load is 3%, Calculate the full load speed of the motor.

Alternator data.
$P = 12$ pole
$N_s = 500$ rpm.

Induction motor data.
$P = 8$ pole
$S = 3\%$
$N = ?$

Solution.

From the alternator data,

$$N_s = \frac{120f}{P}$$

$$f = \frac{500 \times 12}{120} = 50 \text{ Hz.}$$

From induction motor data,

$$S = \frac{N_s - N}{N_s}$$

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{8} = 750 \text{ rpm.}$$

$$\therefore 0.03 = \frac{750 - N}{N_s}$$

$$\boxed{N = 727.5 \text{ rpm.}}$$

3. A 6 pole induction motor running from 50 Hz supply has an emf in the rotor of frequency 2.5 Hz. Determine the value of slip and speed of motor.

Given,
$P = 6$ pole
$f = 50$ Hz
$f' = 2.5$ Hz.
$S = ?$
$N = ?$

Solution.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{6} = \boxed{1000 \text{ rpm.}}$$

$$f' = S \cdot f$$

$$\therefore S = \frac{f'}{f} = \frac{2.5}{50} = 0.05$$

$$S = \frac{N_S - N}{N_S}$$

$$N = S \cdot N_S - N_S$$

$$= 0.05 \times 1000 - 1000$$

$$\boxed{N = 950\ rmp}$$

4. A 3 phase induction motor is wound for 4 pole. and it is supplied from 60 Hz supply. Find synchronous speed, speed of rotor when slip 4%, rotor current frequency when rotor runs at 1200 rpm.

Given,

$P = 4$

$f = 60\ Hz$

$N_S = ?$

$N = ?$ when $S = 4\%$

$f' = ?$ when $N = 1200$.

Solution:

$$N_S = \frac{120f}{P} = \frac{120 \times 60}{4} = \boxed{1800\ rpm}$$

$$S = \frac{N_S - N}{N_S}$$

$$0.04 = \frac{1800 - N}{1800}$$

$$\boxed{N = 1728\ rpm}$$

$$f' = S \cdot f$$

$$= \frac{N_S - N}{N_S} \cdot f$$

$$= \frac{1800 - 1200}{1800} \times 60$$

$$= 0.33 \times 60$$

$$\boxed{f' = 19.98}\ Hz.$$

5. A 4 pole induction motor operates from 50 Hz supply. Find speed at which magnetic field of stator is rotating, speed of the rotor, when slip is 0.04, frequency of rotor current which slip is 0.03 and frequency of rotor current at stand still.

Given,

$P = 4$

$f = 50$ Hz.

$N_s = ?$

$N = ?$ when $s = 0.04$

$f' = ?$ when $s = 0.03$

$f' = ?$ when $N = 0$.

Solution:

$$N_s = \frac{120f}{P} = \boxed{1500\ rpm}$$

$$s = \frac{N_s - N}{N_s}$$

$$0.04 = \frac{1500 - N}{1500}$$

$$\boxed{N = 1440\ rpm}$$

$$f' = f \cdot s = 50 \times 0.03 = \boxed{1.5\ Hz}$$

$$f' = s \cdot f = \frac{N_s - N}{N_s} \times 50 = \boxed{50\ Hz}$$

6. The stator of 3 phase induction motor has 3 slots/pole/phase If the supply frequency is 50 Hz, find the number of stator poles, total number of slots in the stator, also calculate the stator flux.

Given,

Number of slots/pole/phase = 3.

$f = 50$ Hz

$P = ?$

Total number of slots = ?

$N_s = ?$

Solution:

we know that, $P = 2n$

$n \rightarrow$ number of slots/pole/phase

$$P = 2 \times 3$$

$$\boxed{P = 6}$$

$$N_s = \frac{120f}{P}$$

$$= \frac{120 \times 50}{6} = \boxed{1000\,rpm}$$

∴ Total number of slots = 3 × 6 × 3

$$= \boxed{54}$$

7. A 4 pole 50 Hz induction motor has a slip of 1% at no load. When it is loaded, slip is 2.5%. Find the change in speed from no load to full load.

Given,

P = 4

f = 50 Hz

S = 1% at no load

S = 2.5% at full load

change in speed = ?

At no load,

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500\,rpm.$$

$$S = \frac{N_s - N_o}{N_s}$$

$$0.01 = \frac{1500 - N_o}{1500}$$

$$\boxed{N_o = 1485\,rpm.}$$

At full load,

$$0.025 = \frac{1500 - N_1}{1500}$$

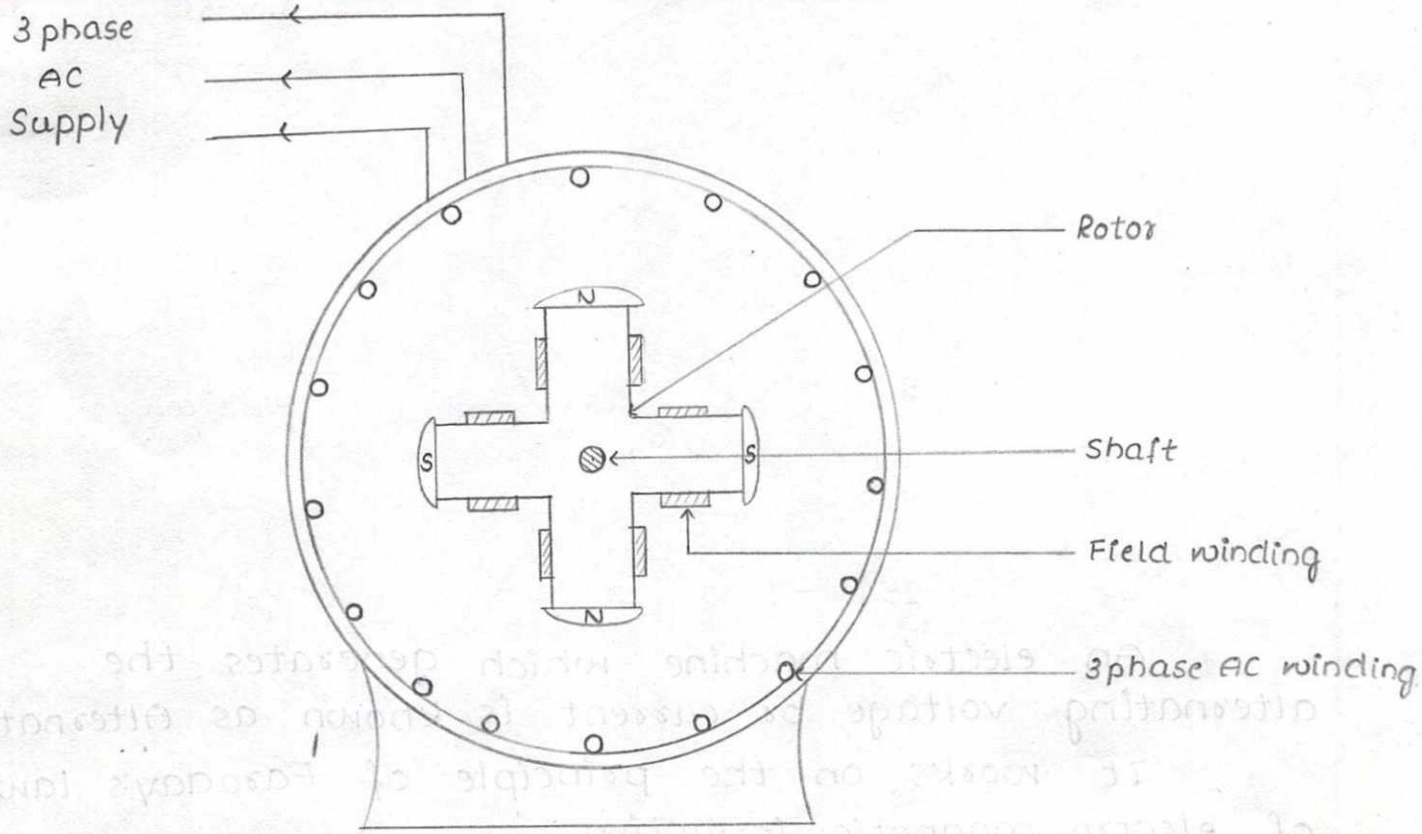
$$\boxed{N_1 = 1462.5\,rpm.}$$

∴ Change in speed = $N_o - N_1$

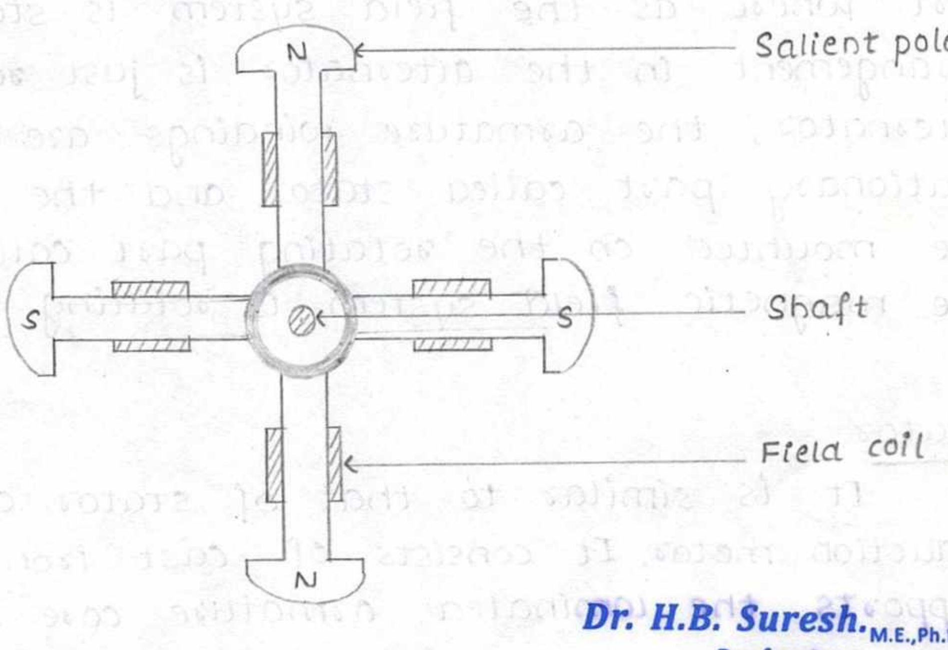
$$= \boxed{22.5\,rpm}$$

Synchronous Generator / Alternator.

Constructional features of Alternator.



Salient pole type rotor / Projecting pole type rotor.



300-600 rpm

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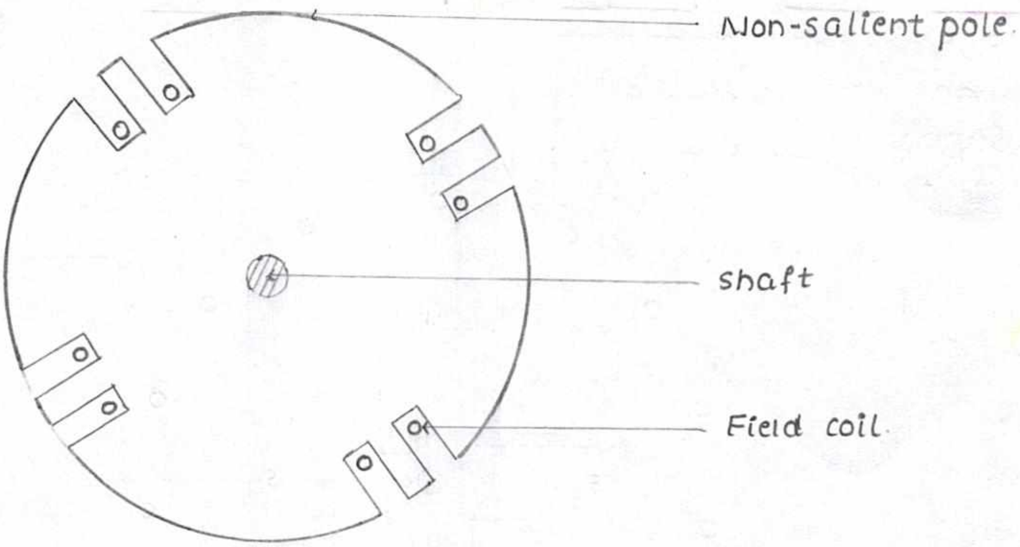
Smooth cylindrical type rotor / Non-salient pole type rotor.



1500 - 3000 rpm

An electric machine which generates the alternating voltage or current is known as Alternator.

It works on the principle of Faraday's laws of electro-magnetic induction.

It mainly consists of 2 parts, stator and rotor. In case of DC generator, the armature is the rotating part where as the field system is stationary. But the arrangement in the alternator is just reversed. In an alternator, the armature windings are mounted on the stationary part called stator. and the field windings are mounted on the rotating part called as Rotor. Here the magnetic field system is rotating.

Stator.

It is similar to that of stator of 3-phase induction motor. It consists of cast iron frame, which supports the laminated armature core having its slots on its inner surface, for housing the 3 phase AC winding.

Silicon steel is the material used for the armature core. The stator core is laminated to reduce the eddy current losses. The slots provided on the stator core of 2 types.

Open type. Semiclosed type.

Rotor.

It is the rotating part of an alternator. The rotating field system is excited from a seperate DC source known as exciter, which is mounted on the shaft of the alternator. The field system of the alternator rotates with in the armature range. The rotor of an alternator are of 2 types.

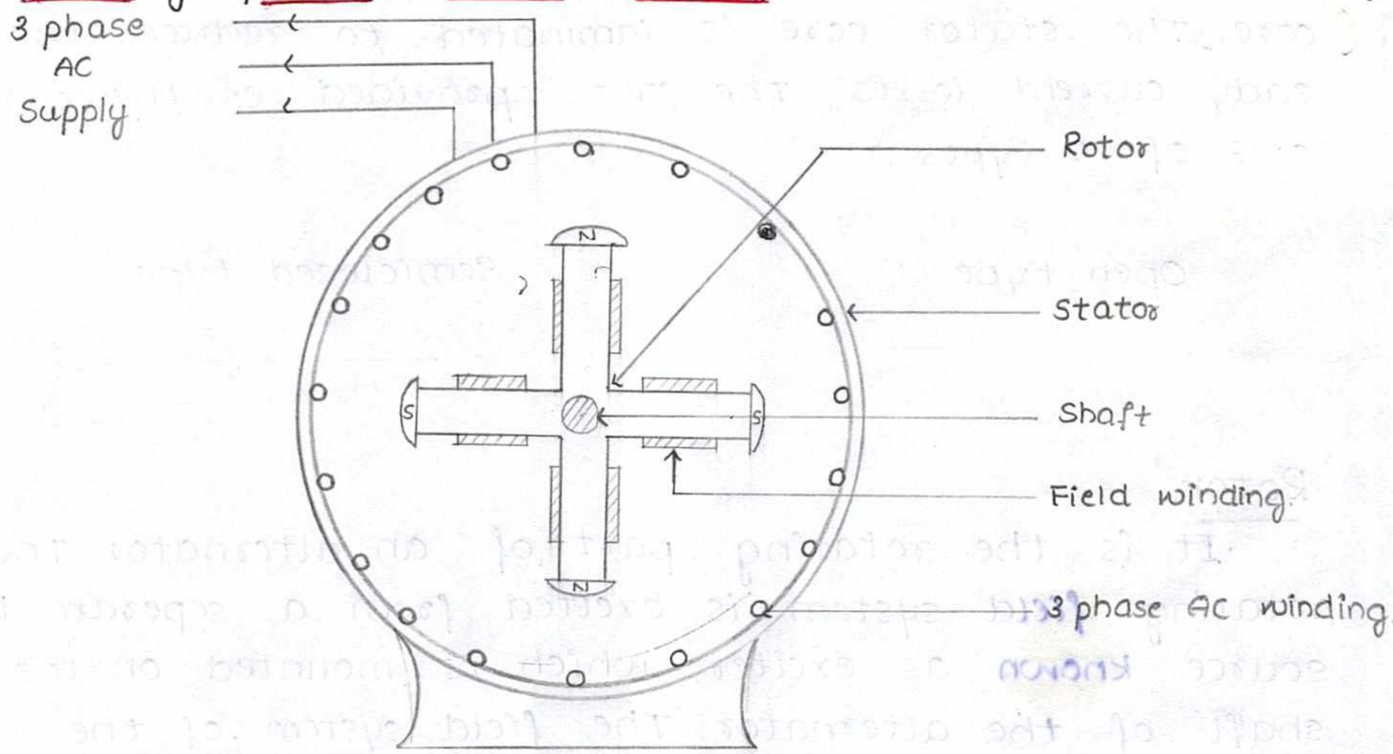
1. Salient pole type rotor/Projecting pole type rotor.

This type of rotor is used in slow and medium speed alternators. [300-600 rpm]. It has large number of projecting poles. These rotors have larger diameter and short axial length. Poles are laminated to minimize the eddy current losses. The alternator with this type of rotor is usually driven by an engine and it rotates on horizontal axis.

2. Non-salient pole type rotor/Smooth cylindrical type rotor.

This type of rotor is used in high speed alternator [1500-3000rpm], such rotors have two or four poles and are laminated. It has smaller diameter and a large axial length. It is usually rotates on vertical axis.

Working principle of alternator.



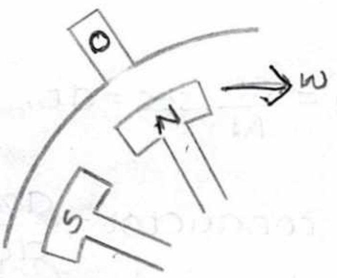
When the rotor is driven by a prime mover, the stator windings are cut by the magnetic flux, which are produced by the rotor poles. i.e The flux sweeps across the stator conductors. Hence an emf will be induced in the stator conductors. [according to Faraday's law]. The frequency of the induced emf is given by $f = \frac{PN}{120}$. and its direction can be found out by flemmings right hand rule. The emf generated in the stator conductor is taken off from the winding by suitable connections.

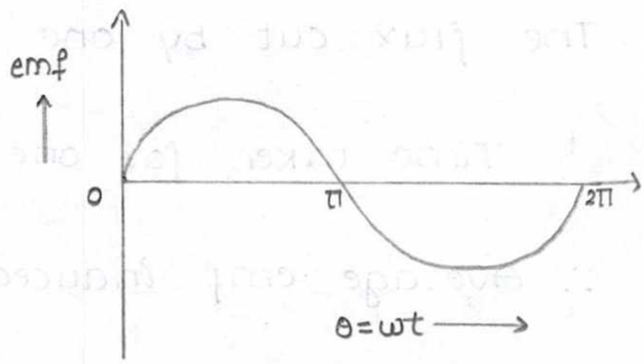
Advantages of Alternator. or stationary armature.

1. The terminal voltage of an alternator can be increased to a larger extent then DC generator.
2. Commutator is not required for an alternator.
3. If voltage is more, the power delivered by the alternator is large, as compare to DC generator.
4. The armature conductors are placed in the stationary part, hence it is possible to accomodate more number of armature conductors.

5. Easy cooling system can be provided due to the stationary armature.
6. Insultion problem is less because of stationary armature.

Frequency of Induced EMF.





Consider a single conductor placed in the slot of the stator, which is as shown in figure.

Let the Rotor with alternate North and South poles rotates with an angular velocity ω in clockwise direction. Positive half cycle of emf is induced in the conductor, when the north pole 'N' sweeps across it. Negative half cycle of emf is induced in the conductor, when the south poles 'S' sweeps across it. Hence one cycle of emf is induced in the conductor, when one pair of poles sweeps across it.

∴ Number of cycles of emf induced in the conductor in one revolution $= \frac{P}{2}$

where, P is the number of poles.

Let "N" be the speed of the rotor in rpm.

∴ Number of revolutions / sec $= \frac{N}{60}$

The frequency of induced emf is nothing but the number of cycles/sec.

∴ f = No. of cycles of emf induced/rev x No. of revolution/sec

$= P/2 \times \frac{N}{60}$ ∴ $\boxed{f = \frac{PN}{120} \text{ Hz}}$

EMF equation of Alternator.

Let, P be the number of poles

Z be the total number of stator conductor /phase

N be the speed of the rotor in rpm.

f be the frequency of induced emf in Hz.

ϕ be the flux /pole in webers.

The flux cut by one conductor in one revolution $= P\phi$ wb $= d\phi$

Time taken for one revolution $= \frac{60}{N}$ sec $= dt$.

$\therefore$ Average emf induced in one conductor $= \frac{d\phi}{dt}$

$$= \frac{P\phi}{60/N} = \frac{NP\phi}{60} \text{ volts}$$

The average emf induced in the stator conductor /phase

$$= \frac{NP\phi}{60} \times Z \text{ volts.}$$

We know that, $N = \frac{120f}{P}$ $\left[\because f = \frac{PN}{120}\right]$

Substitute the value of N in above eq^n, we get.

$$\text{Average emf/phase} = \frac{120f}{P} P\phi Z / 60$$

$$\therefore \boxed{E_{ph} = 2f\phi Z \text{ volts}}$$

For a sinusoidal voltage, the rms value of induced emf /phase,

$$E_{ph} = 2f\phi Z \times 1.1$$

$$E_{ph} = 2.22 f\phi Z \text{ volts}$$

But we know that $Z = 2T$ $(\because 1 \text{ turn} = 2 \text{ conductors})$

where, T is number of turns.

$$\therefore E_{ph} = 2.22 f\phi 2T$$

$$\therefore \boxed{E_{ph} = 4.44 f\phi T \text{ volts.}}$$

The above equation is derived by assuming the following points.

1. The stator winding is full pitched.
2. The emf induced in various conductors are equal in magnitude and does not have any phase difference.
3. The conductors / pole / phase are concentrated in a single slot.

But in practice, the coils are short pitched and are uniformly distributed in all the slots.

∴ EMF induced in an alternator is reduced by small quantity.

∴ EMF eq^n is modified as follows.

$$E_{ph} = 2.22 f \phi z K_p K_d \text{ volts}$$

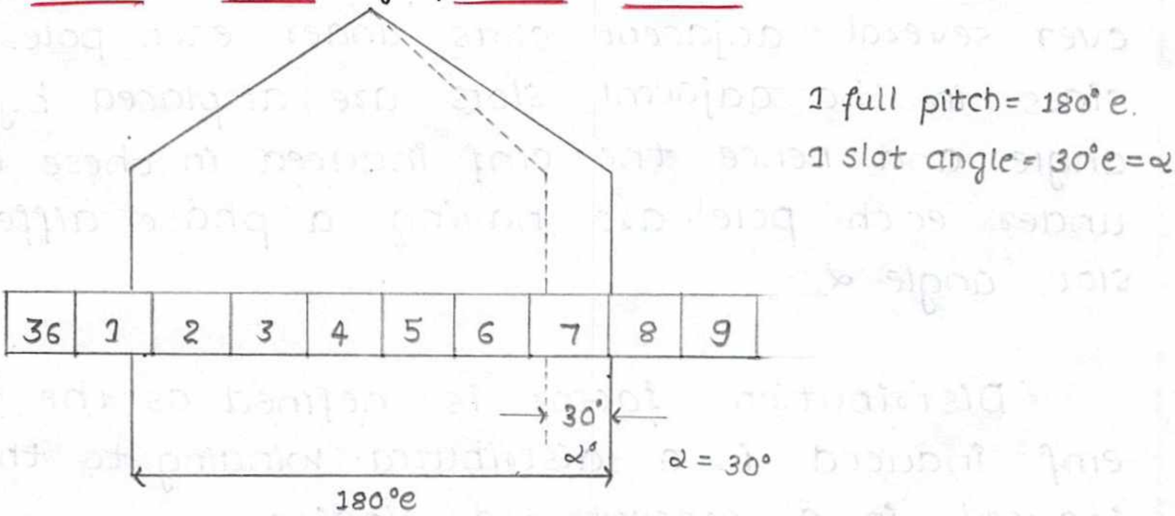
Where,

K_p → Pitch factor.

K_d → Distribution factor.

Winding Factor.

Pitch factor :- (chording factor) / K_p / K_c.



The pitch factor is also known as chording factor or coilspan factor.

Consider an alternator with 36 slots and having 6 poles

∴ Full pitch of the stator winding = $\frac{36}{6}$ = 6 slots/pole

$K_p = \frac{\cos\alpha}{2}$,

where, α is shortpitched angle.

If the 2 coil sides are placed in slot number 1 and 7, then the winding is said to be full pitched. If they are placed in slot number 1 and 6 then it is short pitched by one slot.

By using short pitched winding the generated voltage will be slightly reduced but it has some advantages.

1. Saving of copper in end connection.
2. The wave form is sinusoidal.
3. There is an increase in efficiency of an alternator.

Pitch factor is defined as the ratio of vector sum of emf induced per coil to the arithmatic sum of the emf induced per coil.

Distribution factor:- [Breadth factor] Kd.

In an AC generator coil sides of each phase are not concentrated in a single slot. But they are distributed over several adjacent slots under each pole. The coil sides in the adjacent slots are displaced by the slot angle and hence the emf induced in these coil sides under each pole are having a phase difference of slot angle α.

Distribution factor is defined as the ratio of emf induced in a distributed winding to the emf induced in a concentrated winding.

$$K_d = \sin\frac{n\beta}{2} / n\sin\beta/2$$

where,

$\beta \rightarrow$ slot angle $\rightarrow \frac{180}{3n}$

$n \rightarrow$ number of slots/pole/phase

Note:

In star connected winding (Y),

$V_{ph} = \frac{V_L}{\sqrt{3}}$. $I_L = I_{ph}$.

In delta connected winding (Δ).

$V_{ph} = V_L$. $I_{ph} = \frac{I_L}{\sqrt{3}}$

Efficiency of alternator.

It is defined as the ratio of output power in watts to the input power in watts.

$$\therefore \eta = \frac{\text{output power}}{\text{input power}}$$

$$\eta = \frac{\text{output power}}{\text{output power} + \text{Losses}}$$

Losses.

Stator copper loss.

Rotor copper loss

Stator core loss

Rotor iron loss

Friction and winding loss.

Note.

Input power to alternator = Mechanical power + Electrical power I/P to the field winding.

$$\eta = \frac{\text{output power}}{\text{input power}} = \frac{\text{input power} - \text{Losses}}{\text{input power}}$$

1. A 6 pole 3 phase star connected alternator has armature with 90 slots and 12 conductors/slots. It rotates with a speed of 1000 rpm. It has a flux/pole of 0.5 wb. Calculate EMF generated/phase, line voltage, if the winding factor is 0.97 and if the coil is full pitched.

Given,

$P = 6$

Number of slots = 90

Number of conductors/slots = 12.

$N_s = 1000$ rpm

$\phi = 0.5$ wb

$E_l = ?$

Solution:

∴ Total number of stator conductors = 90×12 = 1080.

∴ Number of conductors/phase = $\frac{1080}{3}$

∴ $\boxed{Z_{ph} = 360}$

Alternator

1. A 6 pole 3 phase star connected alternator has armature with 90 slots and 12 conductors per slot. It rotates with a speed of 1000 rpm. It has a flux per pole of 0.5 wb. Calculate the emf generated per phase, line voltage if the winding factor is 0.97 and if the coil is full pitched.

Given,

Star connected alternator.

$P=6$

Number of slots = 90

Number of conductors = 12.

$Z = 90 \times 12 = 1080$

$Z_{ph} = \frac{1080}{3} = 360$

$N = 1000$ rpm

$\phi = 0.5$ wb.

$E_{ph} = ?$

$E_L = ?$

$K_d = 0.97$

$K_p = 1.$

Solution:-

We know that.

$$E_{ph} = 2.22 f \phi z K_p K_d$$

But, $f = \frac{PN}{120}$

$= \frac{6 \times 1000}{120}$

$= 50 Hz.$

$$\therefore E_{ph} = 2.22 \times 50 \times 0.5 \times 360 \times 1 \times 0.97$$

$$\boxed{E_{ph} = 19380.6 V}$$

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$E_L = E_{ph} \times \sqrt{3}$$

$$\boxed{E_L = 33568.18 V}$$

2. A 3 phase 8 pole alternator has delta connected winding with 320 armature conductors per phase. The flux per pole is 40 miliwb and rotates with the speed of 800 rpm. The winding factor is 0.98. Calculate the phase and line voltage.

Given,

3 phase delta connected alternator.

$P = 8$

$Z = 320$

$\phi = 40 \times 10^{-3}$ wb

$N = 800$ rpm

$K_d = 0.98$

$E_{ph} = ?$

$E_L = ?$

We know that,

$$E_{ph} = 2.22 f \phi z k_p k_d$$

But

$$f = \frac{PN}{120}$$

$$= \frac{8 \times 800}{120}$$

$$= 53.33 \text{ Hz.}$$

$$\therefore E_{ph} = 2.22 \times 53.33 \times 40 \times 10^{-3} \times 320 \times 1 \times 0.98$$

$$\boxed{E_{ph} = 1485.2096 \text{ V}}$$

In delta connection,

$$E_{ph} = E_L$$

$$\therefore \boxed{E_L = 1485.2096 \text{ V}}$$

4. A 3 phase 16 pole synchronous generator has a star connected winding with 144 slots and 10 conductors per slot, flux per pole 30 milliwb, speed is 375 rpm. Find the frequency, phase and line voltages.

Given,

3 phase star connected alternator.

$P = 16$

Number of slots = 144.

Number of conductors/slot = 10

Number of conductors = $144 \times 10 = 1440$.

Total number of conductors/phase = $Z_{ph} = \frac{1440}{3} = 480$

$\phi = 30 \times 10^{-3}$ wb

$N = 375$ rpm

$f = ?$

$E_{ph} = ?$

$E_L = ?$

Solution:-

$$f = \frac{PN}{120}$$

$$= \frac{16 \times 375}{120}$$

$$\boxed{f = 50 Hz}$$

$$E_{ph} = 2.22 f \phi Z$$

$$= 2.22 \times 50 \times 30 \times 10^{-3} \times 480$$

$$\boxed{E_{ph} = 1598.4 \text{ volts}}$$

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$E_L = E_{ph} \times \sqrt{3}$$

$$\boxed{E_L = 2768.5 \text{ volts}}$$

3. A 3 phase 6 pole alternator has star connected winding with 300 armature conductors per phase. The flux per pole is 30 milliwb. and it rotates with a speed of 1000rpm. The winding factor is 0.9 and coil is full pitched. Calculate the line and phase voltage.

Given,

3phase star connected alternator.

$P=6$

$Z_{ph}=300$

$\phi = 30\times10^{-3}$ wb

$N = 1000$ rpm

$K_d = 0.9$

$K_p = 1$

$E_{ph} = ?$

$E_L = ?$

Solution:-

We know that,

$$f = \frac{PN}{120}$$

$$= \frac{6\times1000}{120}$$

$$= 50\text{ Hz}.$$

$$E_{ph} = 2.22 f \phi z\, k_p\, K_d$$

$$= 2.22\times50\times30\times10^{-3}\times300\times1\times0.9$$

$$\boxed{E_{ph} = 899.1\text{ v}}$$

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$E_L = E_{ph}\times\sqrt{3}$$

$$\boxed{E_L = 1557.29\text{ v}}$$

5. A 3phase star connected alternator driven at a speed of 900 rpm, is required to generate a line voltage of 460 volts at 60 Hz frequency on open circuit. The stator has two slots per pole per phase and 4 conductors per slot. Calculate the Number of poles and conductors per slot.

Calculate the number of poles and useful flux per pole, if the winding factor is 0·66. Also calculate the output KVA, if the current in each phase is 50 Amperes.

Given,

3 phase star connected alternator.

$N = 900 rpm$

$E_L = 460 V$

$f = 60 Hz.$

Number of slots /pole/phase = 2.

Number of conductors /slot = 4.

$P = ?$

$\phi = ?$

$K_d = 0·66$

Output KVA = ? , if $I_{ph} = 50 A$.

Solution:-

$$f = \frac{PN}{120}$$

$$60 = \frac{P \times 900}{120}$$

$$\boxed{P = 8}$$

∴ Total number of slots = 2×8×3.
= $\boxed{48}$

∴ Total number of stator conductors = 48×4
= 192

Number of conductors per phase = $Z_{ph} = \frac{192}{3}$

= 64.

Since the winding is connected in star,

$$E_{ph} = \frac{E_L}{\sqrt{3}}$$

$$= \frac{460}{\sqrt{3}}$$

$$= \boxed{265.58 \text{ volts}}$$

We know that,

$$E_{ph} = 2.22 f \phi Z K_p K_d.$$

$$265.58 = 2.22 \times 60 \times \phi \times 64 \times 1 \times 0.66$$

$$\boxed{\phi = 0.0472 \text{ wb}}$$

We know that,

the output power of 3ϕ alternator.

$$P = \sqrt{3} V_L I_L \cos\phi \text{ watts.}$$

$$P = \sqrt{3} V_L I_L \text{ VA.}$$

Hence output KVA reading of alternator,

$$P = \frac{\sqrt{3} V_L I_L}{1000}$$

Since winding is connected in star,

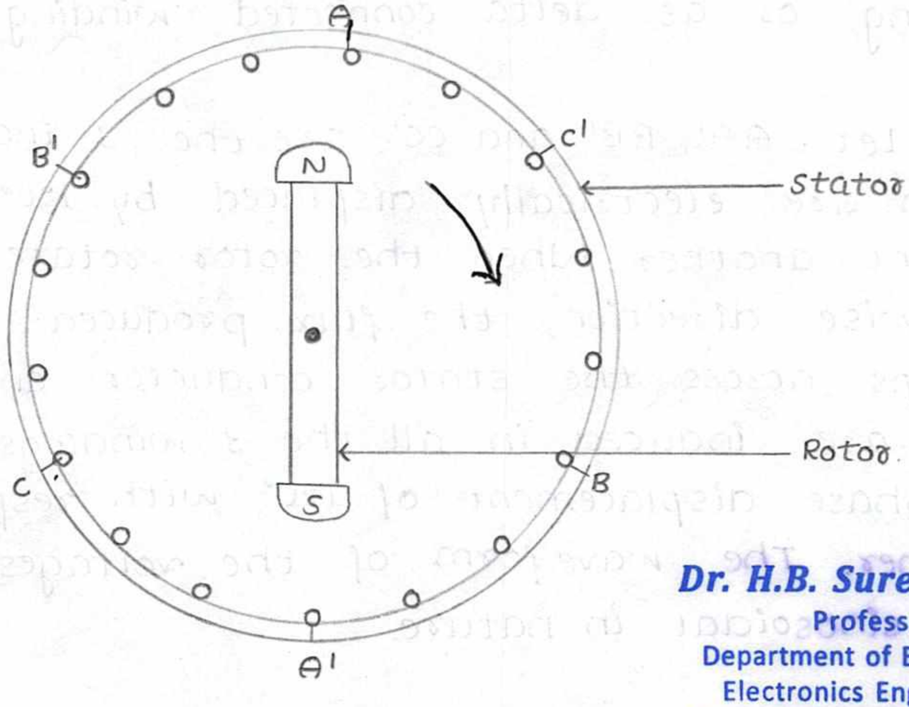
$$I_{ph} = I_L = 50 \text{ A}.$$

$$P = \frac{\sqrt{3} \times 460 \times 50}{1000}$$

$$\boxed{P = 39.83 \text{ KVA}}$$

Three phase AC circuits.

Generation of 3-phase EMF.



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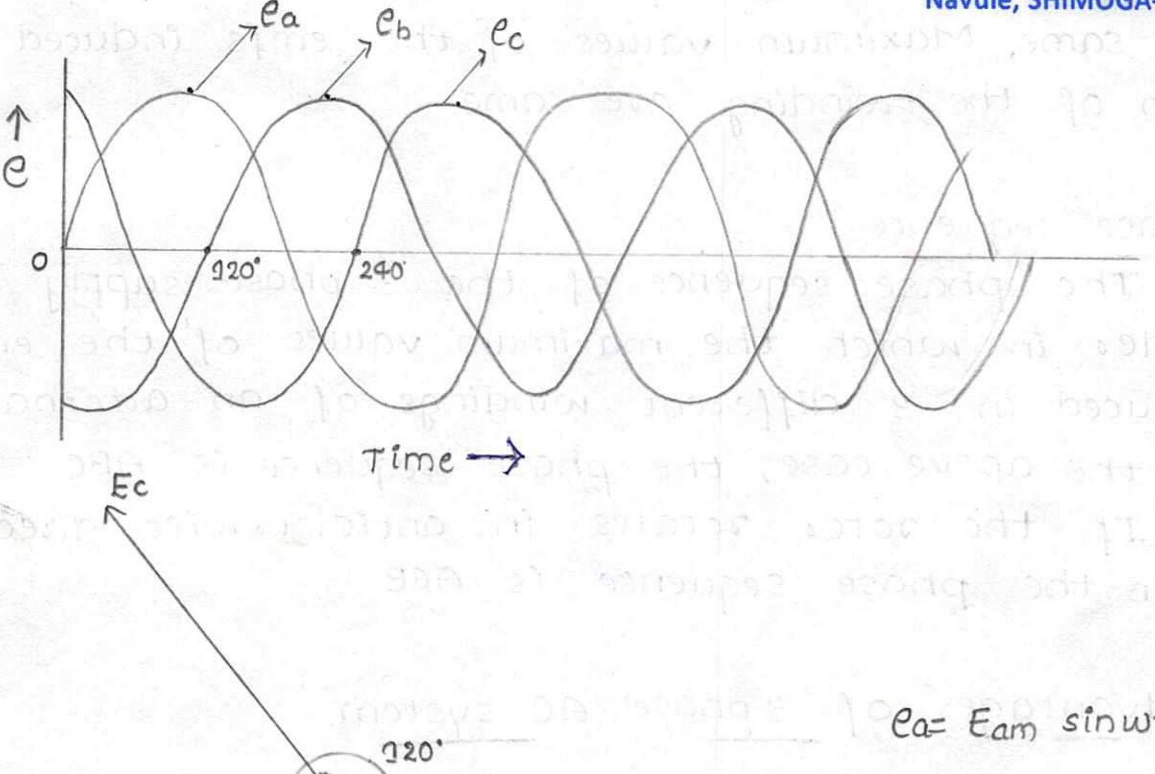
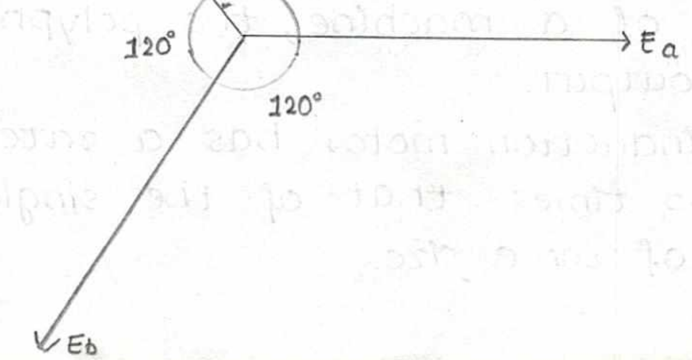




$e_a = E_{am} \sin \omega t$

$e_b = E_{bm} \sin(\omega t - 120^\circ)$

$e_c = E_{cm} \sin(\omega t - 240^\circ)$

The electrical machine which generates 3 phase voltages is called an alternator. It mainly consists of stator and rotor. In the stator, the 3 windings are placed and connected together either as star winding or as delta connected winding.

Let AA', BB', and CC' are the 3 independent coils, which are electrically displaced by 120° with respect to one another. When the rotor rotates in the clockwise direction, the flux produced by poles sweeps across the stator conductor and hence an emfs are induced in all the 3 windings, which have a phase displacement of 120° with respect to one another. The wave form of the voltages generated are sinosoidal in nature.

As the number of conductors in each winding are same, Maximum values of the emfs induced in each of the winding are same.

Phase sequence.

The phase sequence of the 3 phase supply is the order in which the maximum values of the emf induced in 3 different windings of an alternator. In the above case, the phase sequence is ABC.

If the rotor rotates in anticlockwise direction, then the phase sequence is ACB.

Advantages of 3 phase AC system.

1. For a given size of a machine, the polyphase system delivers larger output.

   Ex:- A 3 phase induction motor has a rated output which is 1.5 times that of the single phase AC motor of same size.

2. The power delivered by the single phase system is pulsuating in nature. ∴ It produces a pulsuating torque. Hence motors are not steady in their operation, efficiency decreases. But 3 phase motors have an uniform torque and its operation is smooth and steady.
3. Parallel operations of single phase alternators are not smooth as compared to the parallel operation of 3 phase alternator.
4. In order to transmit the same amount of power at the same voltage, the polyphase system requires less conductor material than the single phase system. ∴ There is a economy in the use of copper. The single phase induction motors are not self starting, where as polyphase motors are self starting.

Inter-connection of phasers.

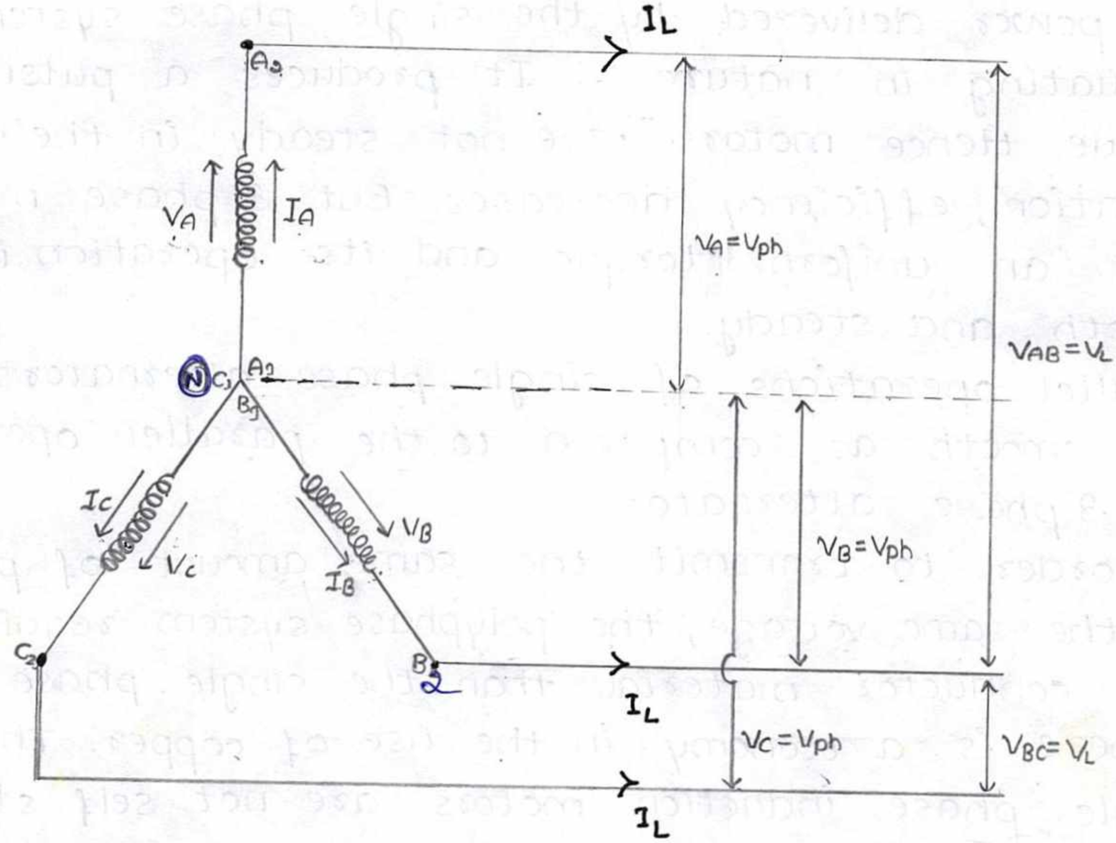
There are two methods of interconnection of phasers.

They are,

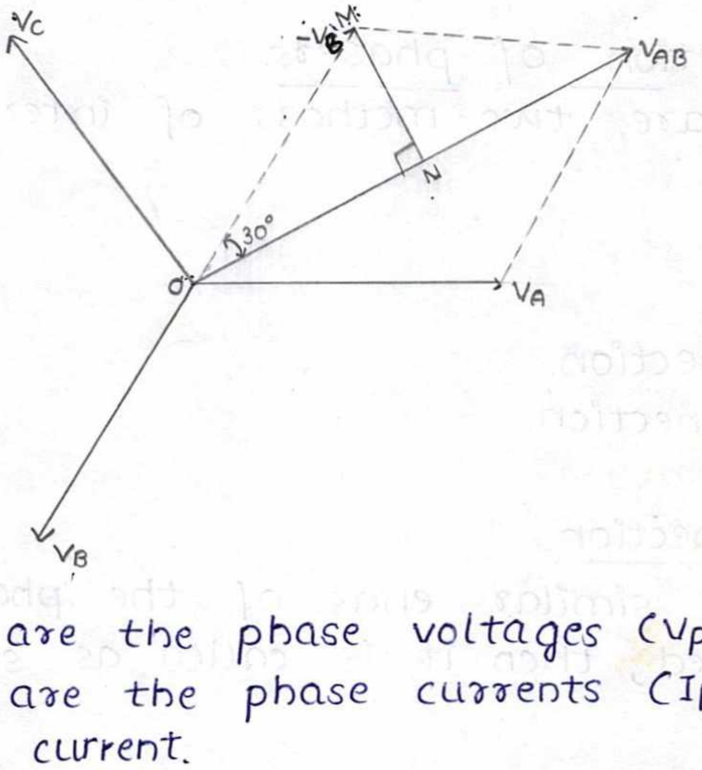
1. Star connection.
2. Delta connection.

1. Star connection.

If the similar ends of the phasers are interconnected, then it is called as star connection.



fig①



fig②

V_A, V_B, V_C are the phase voltages (V_{ph})

I_A, I_B, I_C are the phase currents (I_{ph})

I_L is line current.

V_{AB}, V_{BC}, V_{AC} are the line voltages.

Consider a star connected 3 phase 4 wire system, which is as shown in fig①.

From this, it is clear that, each line is connected to one terminal and it is in series with 1 phase.

∴ current carried by the line is same as that of the current induced in each phase.

∴ Line current = Phase current.

$$I_L = I_{ph}$$

In order to obtain the relationship between line and phase voltage, consider the phasor diagram shown in fig②.

The voltage between line A and line B is the phasor difference between V_A and V_B.

From the vector diagram,

$$V_{AB} = V_A \backsim V_B \text{ (Phasor difference).}$$

$$V_{AB} = 2\overrightarrow{ON} \rightarrow ①.$$

From the ΔONM,

$$\cos\theta = \frac{ON}{OM}$$

$$ON = OM\cos\theta.$$

Substituting in eqⁿ ①.

$$V_{AB} = 2OM\cos\theta$$

$$V_L = 2 V_{ph}\cos 30$$

$$V_L = 2 V_{ph} \sqrt{3}/2$$

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

$$V_{ph} = \frac{V_L}{\sqrt{3}}$$

∴ Total power = 3 x Power/Phase

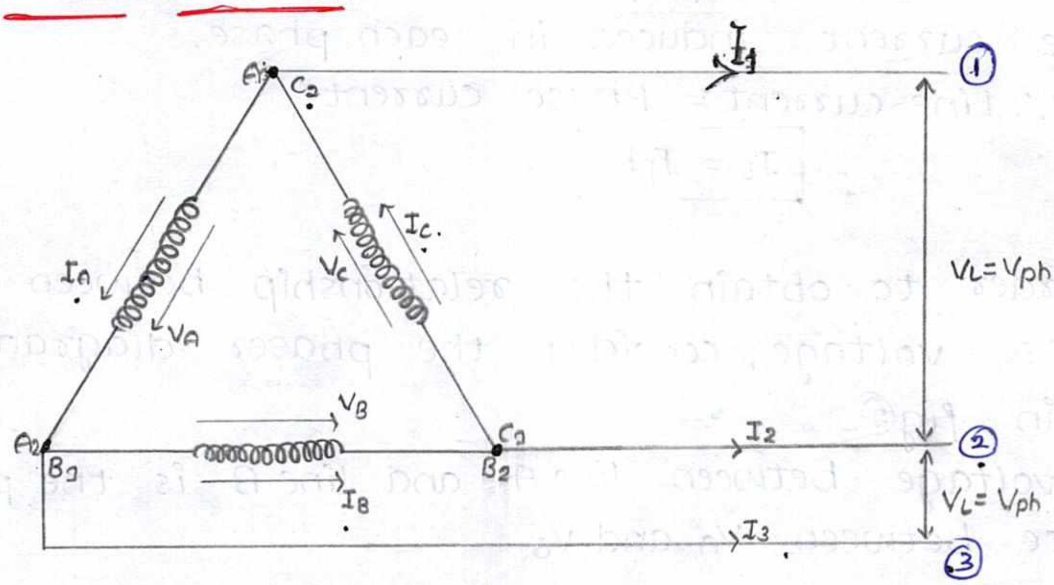
$$= 3 \times V_{ph} I_{ph} \cos\phi$$

$$= 3 \times \frac{V_L}{\sqrt{3}} I_L \cos\phi$$

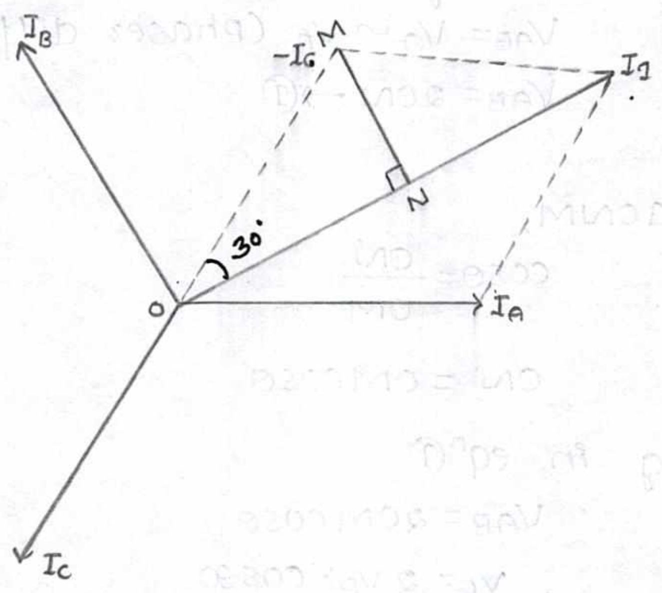
$$= \sqrt{3}\cdot\sqrt{3}\cdot\frac{V_L}{\sqrt{3}} I_L \cos\phi$$

$$P = \sqrt{3}\, V_L I_L \cos\phi$$

2. Delta connection.



fig①



fig②

Let us consider a delta connected windings, which is as shown in fig①

From the figure, it is clear that each winding is connected across 2 lines. Hence voltage induced in each winding is available across the lines.

∴ Phase voltage = Line voltage.

$$V_{ph} = V_L$$

To analyse the relationship between the phase current and line current, consider the phaser diagram shown in fig②.

From figure it is clear that, current I_1 is the phaser difference of current I_A and I_C.

∴ Line current I_1 = Phaser difference of I_A and I_C

$$I_1 = I_A \sim I_C$$

$$I_1 = 2ON \rightarrow (1).$$

From the ΔONM,

$$\cos\theta = \frac{ON}{OM}$$

$$\therefore ON = OM\cos\theta.$$

Substituting eqⁿ (1),

$$I_1 = 2OM\cos\theta$$

$$I_1 = 2I_C\cos 30$$

$$I_L = 2 \cdot I_{ph} \cdot \sqrt{3}/2$$

$$I_L = I_{ph}\sqrt{3}$$

$$\boxed{I_{ph} = \frac{I_L}{\sqrt{3}}}$$

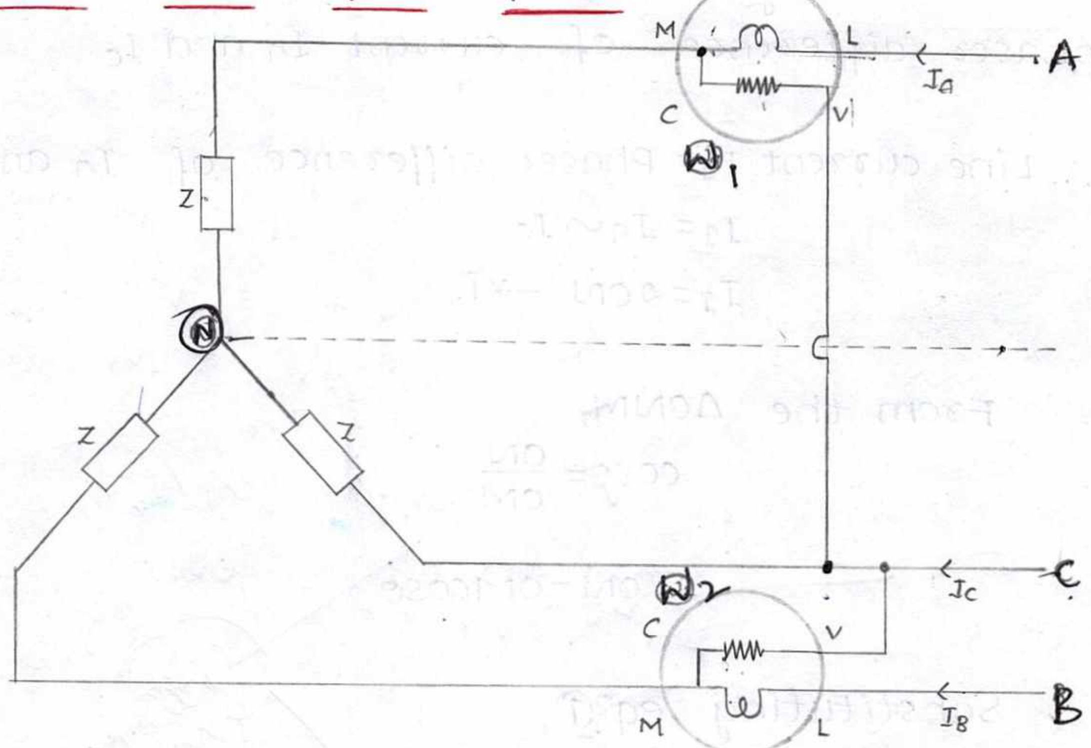
∴ Total power = 3 x power/phase

$$= 3 \times V_{ph} \cdot I_{ph} \cdot \cos\phi$$

$$= \sqrt{3} \cdot \sqrt{3} \cdot V_L \cdot \frac{I_L}{\sqrt{3}} \cdot \cos\phi$$

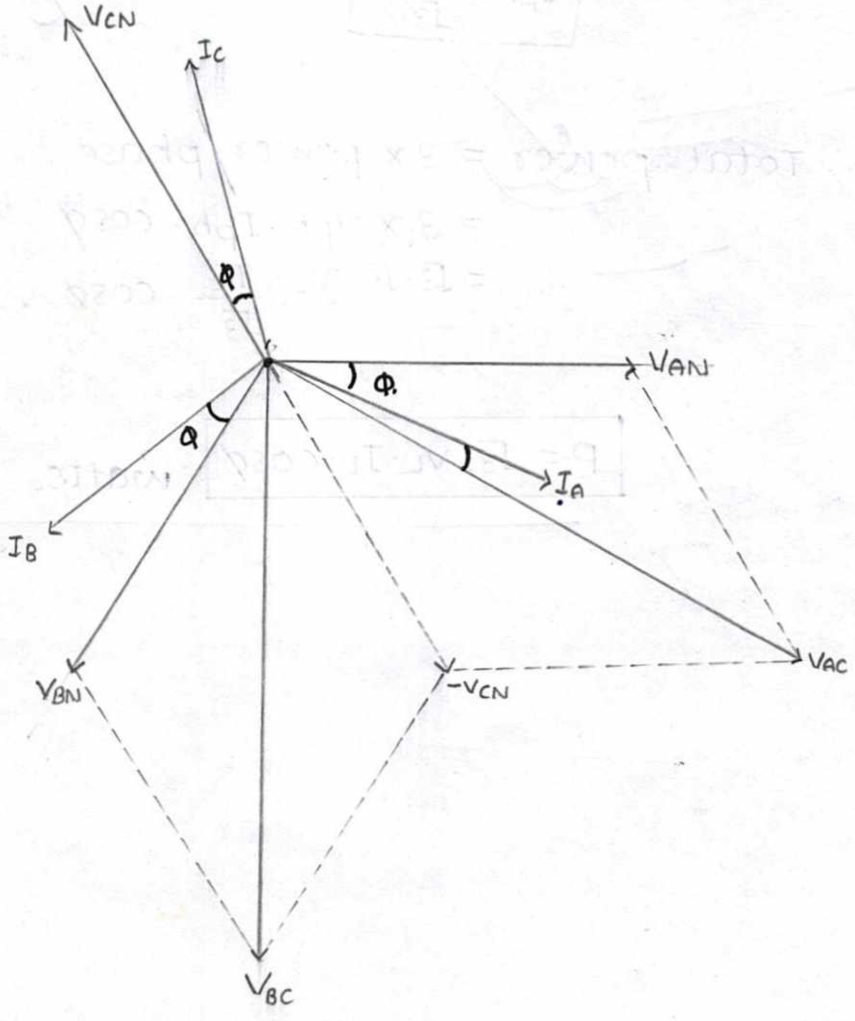
$$\boxed{P = \sqrt{3} \cdot V_L \cdot I_L \cdot \cos\phi} \text{ watts.}$$

Measurment of 3 phase power.



Z = Load

W1 and W2 = Wattmeters.



Consider a star connected load as shown in fig①.

The 2 wattmeters W_1 and W_2 are connected in the circuits. It consists of 2 coils, current coil and voltage coil.

The current coil carries line current and voltage coil connected across 2 lines, to measure the line voltage.

∴ The reading of wattmeter,

$$W_1 = V_{AC} I_A \cos(V_{AC}, I_A) \rightarrow ①$$

Similarly

$$W_2 = V_{BC} I_B \cos(V_{BC}, I_B) \rightarrow ②$$

Where,

$\cos(V_{AC}, I_A)$ is the cosine of angle between line voltage V_{AC} and line current I_A. Similarly $\cos(V_{BC}, I_B)$.

From the vector diagram, angle between V_{AC} and I_A is $(30-\phi)$.

and the angle between V_{BC} and I_B is $(30+\phi)$.

We know that,

V_{AC}, V_{BC} are line voltages, I_A, I_B are the line currents.

Substituting in eqⁿ① and eqⁿ②.

$$\therefore W_1 = V_L I_L \cos(30-\phi) \rightarrow ③$$

$$W_2 = V_L I_L \cos(30+\phi) \rightarrow ④$$

Adding eqⁿ③ and eqⁿ④,

$$W_1 + W_2 = V_L I_L (\cos(30-\phi) + \cos(30+\phi))$$

$$= V_L I_L (\cos 30 \cos\phi + \sin 30 \sin\phi + \cos 30 \cos\phi - \sin 30 \sin\phi)$$

$$\therefore W_1 + W_2 = V_L I_L (2 \cdot \sqrt{3}/2 \cos\phi)$$

$$\therefore \boxed{W_1 + W_2 = \sqrt{3} \cdot V_L \cdot I_L \cos\phi} \rightarrow ⑤$$

This shows that 2 wattmeters are sufficient to measure 3 phase power.

Consider, eqⁿ③ - eqⁿ④,

$W_1 - W_2 = V_L I_L (\cos(30-\phi) - \cos(30+\phi))$

$= V_L I_L (\cos 30 \cos\phi + \sin 30 \sin\phi - \cos 30 \cos\phi + \sin 30 \sin\phi)$

$= V_L I_2\, 2 \sin 30 \sin\phi$

$W_1 - W_2 = V_L I_L (2 \cdot 1/2 \cdot \sin\phi)$

$W_1 - W_2 = V_L I_L \sin\phi \longrightarrow ⑥$.

Deviding eqⁿ⑥ by eqⁿ⑤,

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = 1/\sqrt{3} \tan\phi$$

$$\therefore \phi = \tan^{-1} \sqrt{3} \left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

This shows that power factor angle can also be determined using 2 wattmeters.

Effect of powerfactor on two wattmeter reading.

We know that,

$W_1 = V_L I_L \cos(30-\phi)$

$W_2 = V_L I_L \cos(30+\phi)$

case 1:- when $\phi = 0$, $\cos\phi = 1$

$W_1 = V_L I_L \cos(30-0)$

$= \sqrt{3}/2\, V_L I_L$

$W_2 = V_L I_L \cos(30+0)$

$= \sqrt{3}/2\, V_L I_L$

The wattmeter readings are +ve and equal.

case 2:- when $\phi = 60$, $\cos 60 = 1/2$

$$W_1 = V_L I_L \cos(30-60)$$
$$= \sqrt{3}/2 \, V_L I_L$$

$$W_2 = V_L I_L \cos(30+60)$$
$$= 0$$

One of the wattmeter reads zero.

case 3:- When $\phi = 90$, $\cos 90 = 0$

$$W_1 = V_L I_L \cos(30-90)$$
$$= 1/2 \, V_L I_L$$

$$W_2 = V_L I_L \cos(30+90)$$
$$= -1.$$

One of the wattmeter reads -ve.

From the above discussion, we can conclude that, for power factor lying between 0 - 0.5, one of the wattmeter reads -ve. when powerfactor is 0.5, one of the wattmeter reads zero. when power factor lies between 0.5 - 1, both wattmeter readings are +ve. When powerfactor is 1, readings of both the wattmeters are equal.

1. When 3 phase balanced impedences are connected in star, across 3 phase, 415 volts, 50 Hz supply. The line current drawn is 20 A, at a lagging powerfactor of 0.4. Determine the parameters of impedence in each phase.

Given,

$V_L = 415$ volts.

$\cos\phi = 0.4$

$f = 50$ Hz.

$I_L = 20A$.

Parameter of impedence = ?

Solution:

load is connected in star,

$$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{415}{\sqrt{3}} = \boxed{239.6\ V}$$

$$I_{ph} = I_L = 20\ A.$$

∴ Impedence per phase $= Z_{ph} = \frac{V_{ph}}{I_{ph}}$

$$\boxed{Z_{ph} = 11.98\ \Omega}$$

We know that,

$$\cos\phi = \frac{R}{Z}$$

$$\boxed{R = 4.792\ \Omega}.$$

We know that, $Z = \sqrt{R^2 + X_L^2}$

$$X_L^2 = Z^2 - R^2$$

$$= 143.5204 - 22.96.$$

$$X_L = 10.98$$

$$X_L = 2\pi f L$$

$$10.98 = 2(\pi)(50)L.$$

$$\boxed{L = 0.035\ \text{Henry}.}$$

2. A 3phase, 400 volts motor takes an input of 40 KW at 0.45 powerfactor lagging. Find the readings of each of 2 single phase wattmeter connected to measure the input power.

Given,

$V_L = 400\,V$

$P = 40\,kW$

$\cos\phi = 0.45$

$W_1 = ?$

$W_2 = ?$

Solution:

$$W_1 + W_2 = 40\,kW \rightarrow (1)$$

we know that, $\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$

But $\therefore \phi = \cos^{-1}(0.45)$

$= 63.25$

$$\therefore \tan 63.25 = \frac{\sqrt{3}}{40}[W_1 - W_2]$$

$$\therefore W_1 - W_2 = 45.81 \rightarrow (2)$$

$$W_1 + W_2 = 40$$
$$W_1 - W_2 = 45.81$$
$$2W_1 = 85.81$$

$$\boxed{W_1 = 42.9\,kW}$$

$\therefore$ $W_2 = 40 - 42.9$

$$\boxed{W_2 = -2.9\,kW}$$

3. If the readings of the 2 wattmeters in 3phase balanced load are 836 and 224 watts, the latter reading being is obtained after the reversal of current coil connection. Calculate the power and power factor.

Given,

$W_1 = 836$ watts

$W_2 = -224$ watts [$\because$ current coil connection is reversed]

$P = ?$

$\cos\phi = ?$

Solution:

$$P = W_1 + W_2$$

$$\boxed{P = 612 \text{ watts}}$$

$$\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$= \tan^{-1}\sqrt{3}\left[\frac{1060}{612}\right]$$

$$= \tan^{-1}[\sqrt{3} \times 1.732]$$

$$\phi = 71.56.$$

$$\therefore \boxed{\cos\phi = 0.316.}$$

$$P = W_1 + W_2$$

$$= 836 + (-224)$$

$$\boxed{P = 612} \text{ W}$$

4. A 3 phase star connected load draws a line current of 25 A. A load kVA and kW are 20 and 16 respectively. Find the 2 wattmeter reading use to measure 3 phase power.

Given, star connected load.

$I_L = 25A$

$KVA = 20$

$KW = 16$

$W_1 = ?$

$W_2 = ?$

Solution:

$$W_1 + W_2 = 16 \rightarrow (1)$$

we know that, $\cos\phi = \frac{KW}{KVA} = \frac{16}{20} = 0.8$

$$\phi = \cos^{-1}(0.8)$$

$$= 36.86$$

$$\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$36.86 = \frac{\tan^{-1}\sqrt{3}}{16}[W_1 - W_2]$$

$$\therefore W_1 - W_2 = 6.92 \rightarrow (2)$$

$$W_1 + W_2 = 16$$

$$W_1 - W_2 = 6.92$$

$$2W_1 = 22.92$$

$$W_1 = 11.46 \text{ kW}$$

$$\therefore W_2 = 16 - 11.46$$

$$W_2 = 4.54 \text{ kW}$$

5. A star connected load consists of 6 Ω resistance and 8 Ω inductive reactance in each phase. A supply of 440 volts at 50Hz frequency is applied to the load. Find the line current, power factor and power consumed by the load.

Given,

$V_L = 440V$

$f = 50 Hz$

$R = 6\Omega$

$X_L = 8\Omega$.

Solution: $Z = \sqrt{R^2 + X_L^2}$

$= \sqrt{36+64}$

$= 10\ \Omega$

Impendence per phase $= \boxed{10\Omega}$

Since the load is star,

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}} = \boxed{254.03V}$

$Z_{ph} = \frac{V_{ph}}{I_{ph}}$

$\therefore \boxed{I_{ph} = 25.4\ A}$

∴ In case of star, $I_{ph} = I_L$

$\therefore I_L = 25.4 A$.

$\therefore \cos\phi = \frac{R}{Z} = \frac{6}{10} = 0.6$.

$\phi = 53.130$.

$\therefore P = \sqrt{3}\, V_L I_L \cos\phi$

$= \sqrt{3} \times 440 \times 25.4 \times 0.6$

$= 11614.43\ W$.

6. A delta connected load consists of resistance of 10Ω and capacitance of 100μF in each phase. A supply of 410V at 50Hz frequency is applied to load. Find line current, power factor and power consumed by the load.

Given, $R = 10\Omega$.

$C = 100\ \mu F$

$V_L = 410V$

$f = 50 Hz$.

Solution: $X_C = \frac{1}{2\pi f C} = \frac{1}{2 \times 3.142 \times 50 \times 100 \times 10^{-6}}$

$= 31.84\Omega$.

$$Z_{ph} = \sqrt{R^2 + X_C^2}$$
$$= \sqrt{(10)^2 + (31.84)^2}$$
$$= 33.37\,\Omega.$$

In delta connection,

$$V_{ph} = V_L = 410\,V.$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}}$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}}$$

$$= \boxed{12.28\,A}$$

In delta connection, $I_{ph} = \frac{I_L}{\sqrt{3}}$

$$= \boxed{21.28\,A}$$

$$\cos\phi = \frac{R}{Z} = \frac{10}{33.37} = 0.2996.$$

$$\therefore \phi = 72.56.$$

$$\therefore P = V_L I_L \cos\phi \sqrt{3}$$
$$= \boxed{4.527\,KW}$$

7. 2 wattmeters are connected to measure the input to a 3ϕ, 12 Hp, 50 Hz induction motor, which works at an efficiency of 85% at a powerfactor of 0.8. Find the reading of 2 wattmeters.

Given,

12 HP

$f = 50\,Hz$

$\cos\phi = 0.8$

$\eta = 85\%$

$W_1 = ?$

$W_2 = ?$

We know that,

$$1\,HP = 735.5 \text{ watts}.$$

$$\therefore \text{output power} = P = 12 \times 735.5$$
$$= 8826 \text{ watts}.$$

Now, $$\eta = \frac{\text{output power}}{\text{input power}}$$

$$\therefore \text{input power} = \frac{8826}{0.85}$$

$$= 10383.52 \text{ watts}.$$

$$W_1 + W_2 = 10383.52 \longrightarrow (1).$$

$$\cos\phi = 0.8$$

$$\therefore \phi = 36.86$$

$$\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1-W_2}{W_1+W_2}\right]$$

$$\frac{\tan(36.86) \times 10383.52}{\sqrt{3}} = W_1 - W_2$$

$$W_1 - W_2 = 4494.57 \rightarrow (2)$$

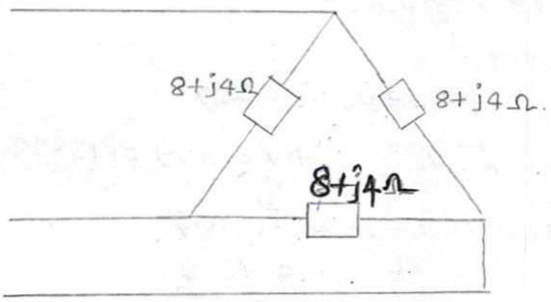
$$W_1 + W_2 = 10383.52$$
$$W_1 - W_2 = 4494.57$$

$$2W_1 = 14,878.098$$

$$\boxed{W_1 = 7439.04 \text{ watts}}$$

$$\boxed{W_2 = 2944.47 \text{ watts}}$$

8. A delta connected load is arranged as shown in figure. A supply 415 v, 50 Hz is a applied to it. Calculate phase current, line current and total power.?



Given,

$V_L = 415$ v

$f = 50$ Hz

$R = 8\Omega$

$X_L = 4\Omega$

$I_{ph} = ?$

$P = ?$

$I_L = ?$

Solution :-

Solution:-

$$Z = \sqrt{R^2 + X_L^2}$$
$$= \sqrt{64+16}$$
$$Z = 8.944\ \Omega$$

$$Z_{ph} = \frac{V_{ph}}{I_{ph}}$$

$$I_{ph} = \frac{V_{ph}}{Z_{ph}} = \frac{415}{8.944} = 46.399$$

$$I_{ph} = \frac{I_L}{\sqrt{3}}$$

$$I_L = I_{ph} \times \sqrt{3}$$
$$= 80.365$$

$$P = \sqrt{3}\ V_L I_L \cos\phi$$
$$= \sqrt{3} \times 415 \times 80.365 \times 0.89$$
$$= 51412.13 \text{ kW}.$$

9. 2 wattmeters are connected to measure a power of 3 phase circuit, reads as 5 KW and 1 KW. The latter reading being obtained after the reversal of current coil. Calculate the power, power factor, total volt ampere, reactive volt ampere.

Given,

$W_1 = 5\,KW$

$W_2 = -1\,KW$ (reversal)

Solution :-

$P = W_1 + W_2$

$= 5 - 1$

$= 4\,KW.$

$$\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

$$\phi = \tan^{-1}\sqrt{3}\,[6/4]$$

$= 68.94.$

$\boxed{\cos\phi = 0.359}$

$\sin\phi = 0.933.$

$\therefore$ Total volt ampere $= \sqrt{3}\, V_L I_L$.

we know that,

$P = \sqrt{3}\, V_L I_L \cos\phi$

$\sqrt{3}\, V_L I_L = 4 \times 0.359 = \boxed{11.14\ KVA.}$

$\therefore$ Reactive volt ampere $= \sqrt{3}\, V_L I_L \sin\phi$

$= 11.14 \times 0.93$

$= \boxed{10.39\ KVAR}$

10. Each of 2 wattmeters connected to measure the input of 3ϕ circuit reads 20 KW. What does each instrument reads, when power factor is 0.866, with the total 3 phase power remaining unchanged in altered condition.

Given,

$W_1 = 20\,KW$

$W_2 = 20\,KW.$

$W_1 = ?$ $W_2 = ?$ when $\cos\phi = 0.866.$

Solution:

$W_1 + W_2 = 40\,KW \rightarrow (1).$

$\cos\phi = 0.866$

$\boxed{\phi = 30^\circ}$

$$\phi = \tan^{-1}\sqrt{3}\left[\frac{W_1 - W_2}{W_1 + W_2}\right]$$

12. A 3ϕ feeder carries 2 balanced loads power absorbed by each is measured by 2 wattmeters and it gives the following readings.

I load → $W_1 = 96\,kW$, $W_2 = 160\,kW$.

II load → $W_1 = 90\,kW$, $W_2 = 48\,kW$.

What is the combined load on the feeder and the combined powerfactor?

Solution.

Combined load on feeder = I load + II load.

$$= (W_1+W_2) + (W_1+W_2)$$
$$= 394.$$

Power factor of 1st load.

$$\phi_1 = \tan^{-1}\sqrt{3}\left[\frac{-64}{256}\right]$$
$$= \tan^{-1}(-0.433)$$
$$\phi_1 = -23.41$$
$$\cos\phi_1 = 0.917.$$

Power factor of 2nd load.

$$\phi_2 = \tan^{-1}\sqrt{3}\left[\frac{42}{138}\right]$$
$$\phi_2 = 27.79.$$
$$\cos\phi_2 = 0.884.$$

∴ combined powerfactor on the load,

$$\phi = \sqrt{\phi_1^2 + \phi_2^2 + 2\phi_1\phi_2\cos(\phi_1-\phi_2)}$$
$$= \sqrt{(23.41)^2 + (27.79)^2 + 2(-23.41)(27.79)\cos(-23.41-27.79)}$$
$$\phi = \boxed{22.47}$$

$$\therefore \cos\phi = 0.924$$

$\tan 30 = \sqrt{3} \frac{W_1 - W_2}{W_1 + W_2}$

$\therefore W_1 - W_2 = 13.33 \rightarrow (2)$.

$W_1 + W_2 = 40$

$W_1 - W_2 = 13.33$

$2W_1 = 53.33$

$\boxed{W_1 = 26.6 \text{ KW}}$

$\boxed{W_2 = 13.33 \text{ KW}}$

11. 3 coils each having a resistance of 10Ω and inductance of 0.02 henry, are connected in star across 440 volts, 50 Hz, 3 phase AC supply. Calculate the line current and total power consumed.

Given,

$R = 10\Omega$

$L = 0.02H$

$V_L = 440V$

$f = 50Hz$.

Solution:

Load connected in star.

$V_{ph} = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}} = 254.03V$.

$X_L = 2\pi f L$

$= 2 \times 3.142 \times 50 \times 0.02$

$= 6.284\Omega$.

$Z_{ph} = \sqrt{R^2 + X_L^2}$

$= \sqrt{(100)^2 + (6.284)^2}$

$= 11.81\Omega$.

$Z_{ph} = \frac{V_{ph}}{I_{ph}}$

$I_{ph} = \frac{254.03}{11.81}$

$= 21.5$.

$\therefore I_{ph} = I_L$

$\therefore \boxed{I_L = 21.5 \text{ A}}$