

Subject - EC 1

Part - 1

Construction of D.C. machine

The DC machine basically consist of two main parts namely stator and rotor. The stator is the static part, where as the rotor is the rotating part of the machine. The stator consist of field pole assembly, yoke or frame of machines, brush assembly. The rotor consist of shaft, commutator, armature respectively.

Construction of DC Machine. —

Yoke. —

→ The outer covering of a DC machine is called as Yoke.

→ It is made up of Cast iron/steel.

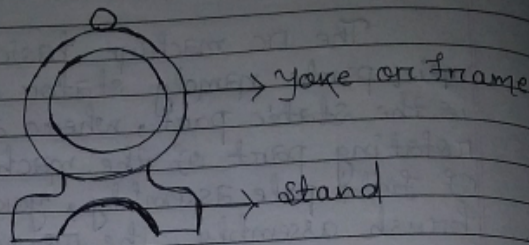
→ It serves as a protective covering for the machine internal parts i.e. rotor and other stator parts.

The yoke in the smaller machines is made up of Cast iron but for medium and large machine it is made up of Cast steel.

→ The saturation of the cast iron is at 0.8 tesla where as the saturation of Cast steel is at 1.5 tesla. So the steel frame is better than Cast iron frame.

→ The other function of the yoke is to provide a path for the magnetic flux to pass through it. That is it is a part of magnetic circuit of

the machine.



Field assembly :-

The field core is made up of magnetic material having higher permeability so as to increase the flux through the material and to enable larger flux per pole of the machine.

The field core is solid assembly for smaller machine but it is laminated for larger rating machine so as to decrease the heating of core.

The field winding which is made up of copper and is coated with varnish is wound over the field core.

The field assembly basically consist of the following parts, namely, field core, field winding and pole shoe.

The field core is made up of high permeable material such as iron, steel etc.

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Date

This will concentrate the magnetic flux lines in the core. The field core is attached to the pole shoe using bolt. The pole shoe is also made up of magnetic material of high permeability.

→ The field winding carries current with magnetizes the field core and hence the magnetic material get magnetized as a result it behaves as a magnet and produces flux. This flux passes through the magnetic path which comprises the field core, pole shoe, air gap, armature and the yoke. The intensity of the flux can be increased by increasing the current through the field winding.

→ The higher the field current the more powerful field is created by the field poles.

Brush assembly :-

The brush assembly comprises brush holder, rocker, spring adjustment over the brush. The brush is placed in a box type holder. The brush is passed by a spring whose tension can be adjusted with the help of a tension adjustment lever. The brush is kept in contact with the commutator segment. The contact should be such that there should not exist any air gap between them. If there is any air gap present between them then will be arcing and the arcing will lead to temperature rise which will cause

pitting of the commutator segments.

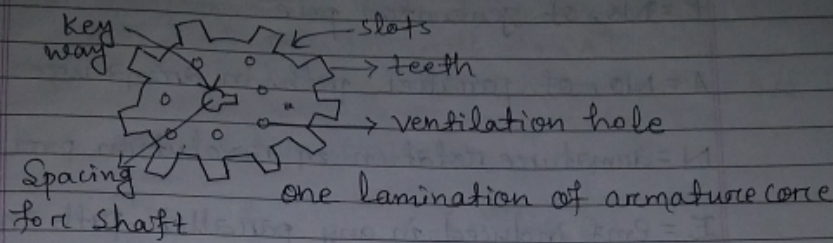
→ There is a copper pig tail, which is firmly connected to the other end of the brush which is free for external circuit connection.

End shields :-

The end shields are the side covering of the machine which consist of the set of bearing on which shaft rests. The end shields have voids or openings for letting the cold air to pass through the machines thus it maintains temperature of the rotor and stator. They are two in number and placed diametrically opposite to each other.

The other important part of machine is the rotor which comprises armature, armature windings, commutator, shaft etc.

The armature is made up of hard steel and is usually laminated to prevent the eddy losses. The lamination are of (0.35mm) to (0.5mm) thickness depending on the size of the machine. One lamination of the armature is shown. The lamination are insulated from each other and consist of a key way which is fixed over the shaft so that proper alignment of slots and teeth of the armature lamination is obtained.



- The ventilating duct enable the cool air to pass through the armature core.
- The slots of armature core can be semi-closed type or open type, practically semi-closed slots are preferred.
- The slot can have single layer or double layer depending on the rating of the machines. In double layer winding the two layers are separated by insulation.
- The armature winding are further divided into two main types i.e. lap winding and wave winding. Lap winding is used when the current rating of the machine is high.

Generated emf or emf eqⁿ of a generator -
 ϕ = flux/pole in weber

Z = total number of armature conductors
 = No. of slots $\times$ No. of conductor / slot

$P = \text{No. of generator pole}$

$A = \text{No. of parallel path in armature}$

$N = \text{armature rotation in revolution per minute}$

$E = \text{Emf induced in any parallel path in armature}$

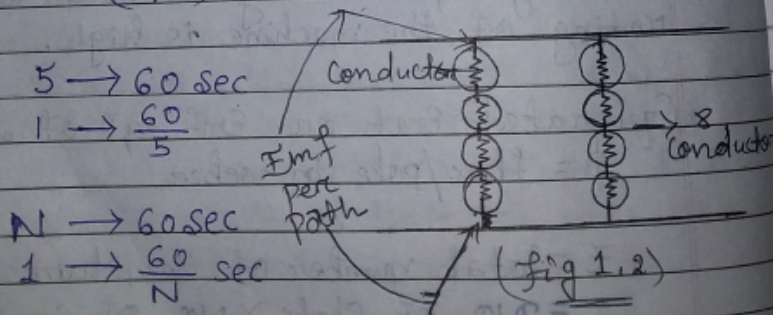
Emf generated per conductor $= \frac{d\phi}{dt}$ [Faraday's law of electromagnetic induction]

Total flux = Flux produced by each pole $\times$ No. of poles

Total flux $(\phi) = \phi \times p \text{ wb}$

Time required for a conductor to complete one revolution $(t) = 60/N$

$$\frac{d\phi}{dt} = e = \frac{\phi \times P}{(60/N)} = \frac{\phi P N}{60} \text{ volt}$$



For Simplex wave wound generator. —

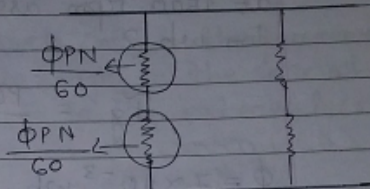
No. of parallel path = 2 = A

No. of conductor (in series) in one path = $Z/2$

Emf generated / path

$$= \frac{\Phi P N}{60} \times \frac{Z}{2}$$

$$= \frac{P \Phi Z N}{60 \times 2} = \frac{P \Phi Z N}{120}$$



(Fig 1.3)

$$\text{volt} = \frac{P \Phi Z N}{60 \times A} \text{ (volt)}$$

For Simple lap wound generator. —

A = No. of parallel paths = P

No. of conductors (in series) in one path = Z/P

$$\text{Emf generated path} = \frac{P \Phi N}{60} \times \frac{Z}{P}$$

$$= \frac{\Phi Z N}{60} \times \left(\frac{P}{A} \right)$$

$$= \frac{P \Phi Z N}{60 A}$$

$$\text{In general } E_g = \frac{P \Phi Z N}{60 A}$$

Q. A four pole generator, having lap-wound armature winding has 51 slots, each slot containing 20 conductors. what will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7 mwb ?

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

$$\phi = 7 \times 10^{-3} \text{ wb}, Z = 51 \times 20 = 1020$$

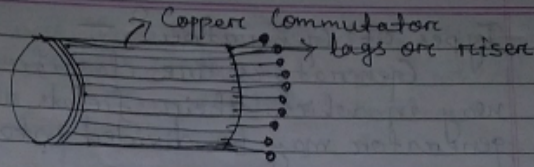
$$A = P = 4, N = 1500 \text{ rpm}$$

$$E_g = \frac{4 \times 7 \times 10^{-3} \times 1020 \times 1500}{60 \times 4} = 178.5 \text{ V}$$

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The other armature winding connection which is used for high voltage, low current machine is the wave winding. In this winding the number of parallel path is fixed and that is only two.

→ The armature conductors are connected to the commutator segment which is also made up of hard drawn copper. The armature conductor is connected to the commutator segments through lags or risers.



The commutator segments collect the current from the armature windings in the case of dc generator and send it to the external ckt through brush.

The current in the armature winding is ac which is converted to dc by the brush commutator combination and behave like a mechanical rectifier. The brush thickness is usually 1.5 times that of commutator segment thickness.

- The commutator segments are separated by micaite layer to prevent shorting of armature conductors.
- The shaft which is made up of steel passes through the rotor axially, the shaft is placed over the bearing which is fixed to the end shields. The bearing may be roller bearing or pedestal bearing depending on the size of M/c.
- A coil have one or more number of turns, but it has only two coil sides.
- The number of conductors per coil side is z if z is the number of turns per coil and number of conductors in the coil is $2z$.

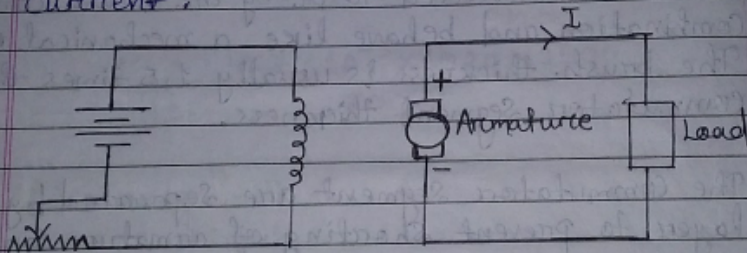
Types of Generator?

Generators are classified accⁿ to the way in which their fields are excited generator may be divided into

- (a) Separately excited generator
- (b) Self excited generators

(a) Separately excited Generator?

Are those whose field magnets are energised from an independent external source of d.c. current.



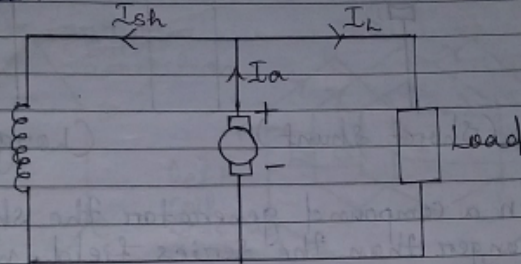
(b) Self excited generator?

Are those whose field magnets are energised by the current produced by the generator by themselves. Due to residual magnetism, there is always present some flux in the poles. When the armature is rotated, some emf and hence some induced current is produced which is partly or fully passed through the field coils thereby strengthening the residual pole flux.

There are three types of self-excited generator named according to the manner in which their field coils are connected to armature.

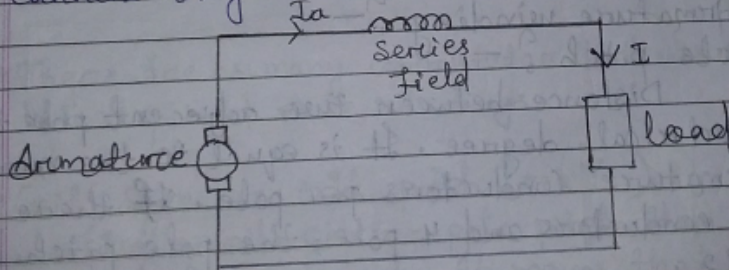
(i) Shunt wound :-

The field winding is connected parallel to the armature.



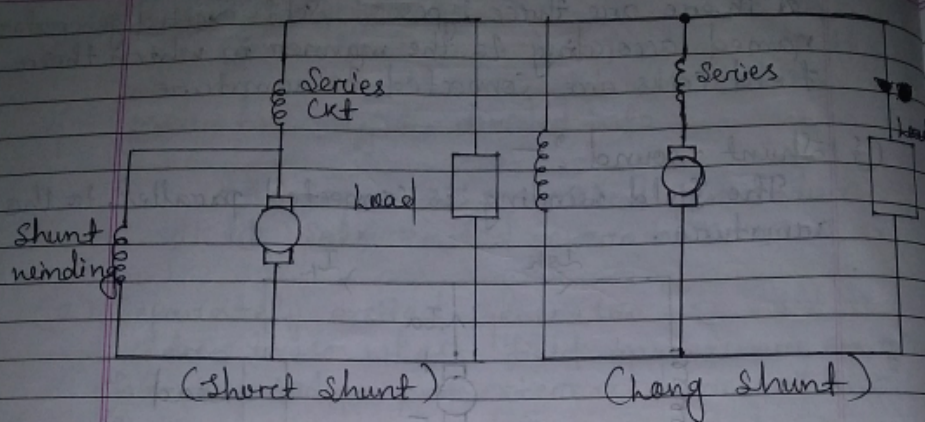
(ii) Series wound :-

Field windings are joined in series with the armature conductors. As they carry full load current they consist of few turns of thick wire.



(iii) Compound wound :-

It is a combination of both series and shunt winding and can be either short shunt or long-shunt.



In a compound generator the shunt field is stronger than the series field. when series field aids the shunt field, generator is said to be cumulative compounded. on the other hand if series field opposes, the shunt field, generator is said to be differentially compounded.

Armature winding :-
Pole pitch :-

Distance between two adjacent pole in electrical degree. It is equal to the number of armature conductors per pole. If there are 48 conductors and 4 pole, the pole pitch is $\frac{48}{4} = 12$.

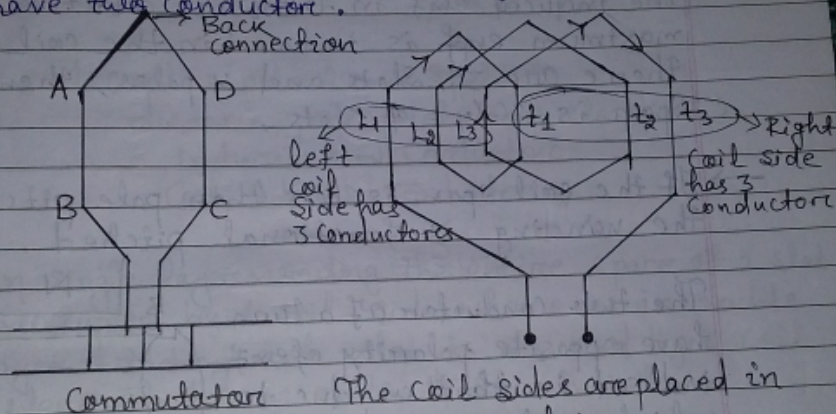
Conductor :-

Length of a wire lying in the magnetic field in which an emf is induced, is

called a conductor.

Coil :-

The two conductors AB and CD along with their end connection constitute one coil of the armature winding. A coil may be single turn or multi-turn coil. A single turn coil will have two conductors.



The coil sides are placed in armature slots.

Imp → There are as many commutator bars as coils for both lap and wave windings.

→ Coil span or coil pitch? - (Ys)

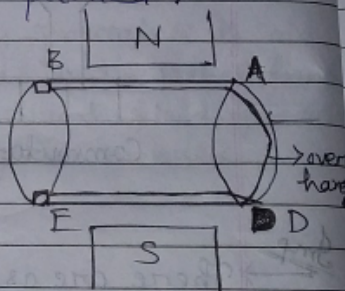
If the coil pitch = pole pitch then the winding is called full pitched. It means that coil span is 180° electrical degrees. In this case the coil sides lie under opposite poles. Hence the induced emf in them are additive. Therefore maximum emf is induced in the coil. If there are 36

slots and 4 poles, then coil span is $36/4 = 9$ slots.

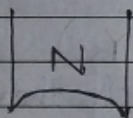
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→ If the coil span is less than pole pitch then the winding is fractional pitched.

The two conductors of a turn have opposite polarity of emf induced in them due to which net emf induced in a turn is double the emf/conductor.

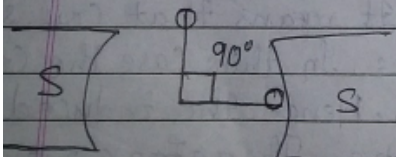


Separation between AB and DE is 180° mech

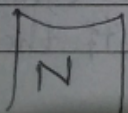


$$P = 2 \quad \theta_c = \theta_m$$

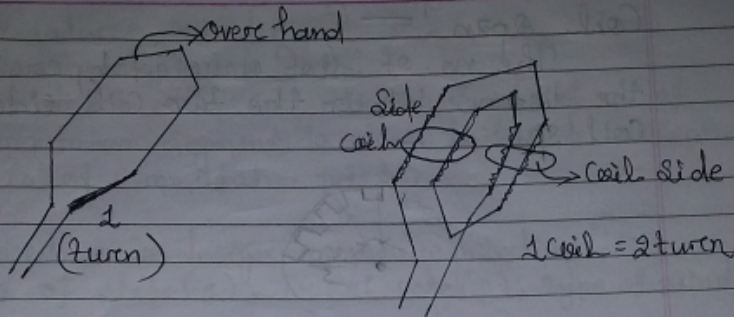
Separation = 180° electrical (pole pitch)



Separation = 90° mech
pole = 4

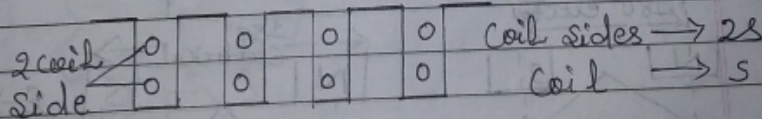
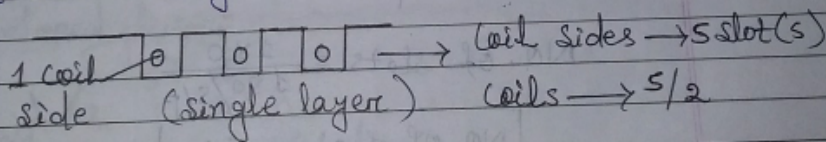


Separation = $4/2 \times 90 = 180^\circ$ electrical



1 cond N-pole 2 and 3 pole
 distance = pole pitch (180° electrical)
 N turn = 2 N conductors
 Coil side = N conductors //

In single layer winding the entire space of 1 slot is occupied by 1 coil side whereas as in double layer winding each slot is occupied by 2 coil side each belongs to different coil.



Imp $\rightarrow$ If one coil side of a coil lies in top slots then other coil side lies in bottom.

Coil Span? —

The no. of slot occupied by each coil or the distance between the two coil side is called Coil span.



$$\text{slot pitch} = \frac{360^\circ \text{ mech}}{S}$$

$$\theta_e = P/2 \theta_m$$

$$\text{slot pitch} = P/2 \times \left(\frac{360}{S}\right)$$

in electrical

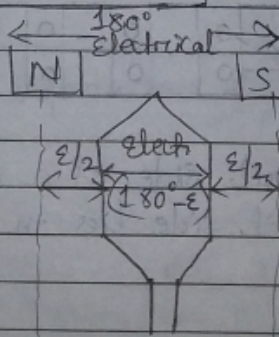
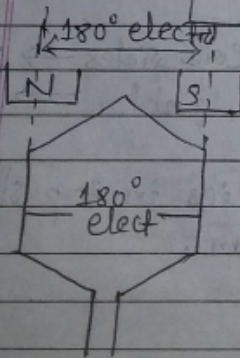
$$\theta_e = 180^\circ / S/P$$

Ideally one coil side N-pole other coil side S-pole.

$$\text{Coil Span} = 180^\circ \text{ electrical}$$

$$\text{No. of slots} = \frac{180}{180^\circ / S/P}$$

$$\text{No. of slots} = S/P$$



$\epsilon \rightarrow$ short
pitching
angle short
pitch winding

Armature winding —
Commutator pitch —

The distance in coil side in terms of no. of commutator segment to which both side are connected is called commutator pitch.

Procedure to design armature winding —

→ No. of slots (s), No. of pole (p), type of winding

→ Coil span = s/p (full pitch)

→ Commutator pitch

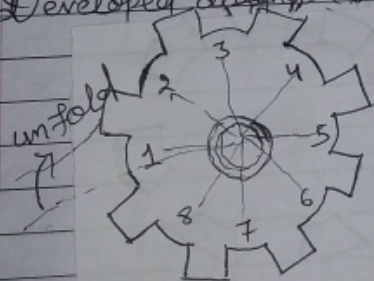
$$y_c = \pm 1 \text{ (lap)}$$

$$y_c = \frac{z}{p} (s \pm 1) \text{ (wave)}$$

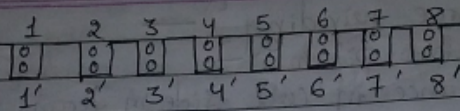
+ → progressive (left to right)

- → retrogressive (Right to left)

Developed diagram —



→ The commutator segments = No. of coils (double layer)



Lap winding :-

E.g. $S=8, P=4$

Coil span $= S/P = 2$

$y_c = +1$

→ Due to more no. of parallel path in lap winding compare to wave winding, lap winding is used for high current rating and low voltage rating where as wave is used for low current and high voltage rating.

Q. A 4 pole d.c. generator has 100 turns, and emf per turn of 10 volt and current rating of each path 10 amp, find voltage rating, current rating and power rating for lap winding.

$T=100$

emf per turn $= 10V$

Lap :- $A=P=4$

Turns per path $= \frac{100}{4} = 25$

emf $= 25 \times 10 = 250V \rightarrow$ low voltage

$I = 4 \times 10 = 40A \rightarrow$ high current

power $= 250 \times 40 = 10KW$

wave: —
 $A = 2$

turns per path = $100/2 = 50$

emf = $50 \times 10 = 500 \text{ V} \rightarrow$ High voltage

$I = 2 \times 10 = 20 \text{ A} \rightarrow$ low current

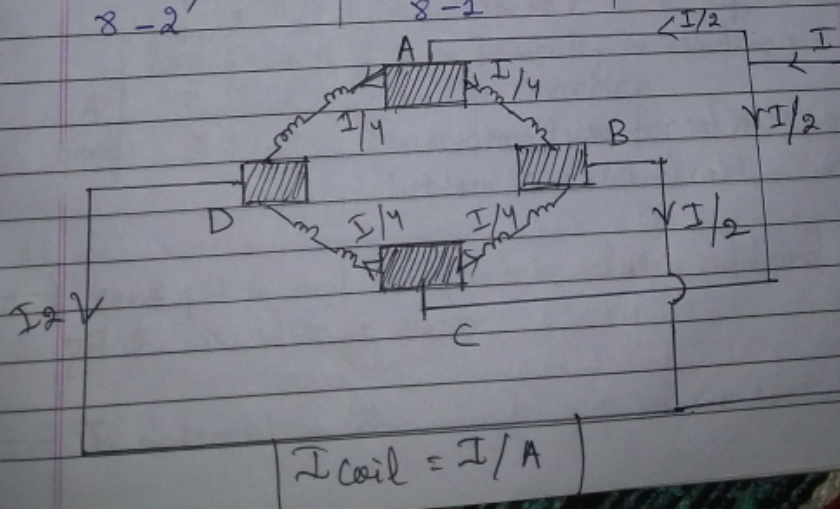
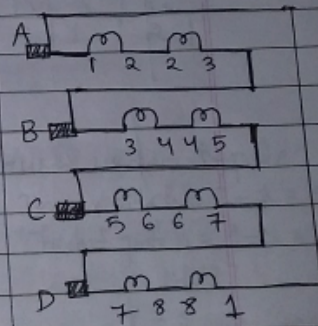
power = $500 \times 20 = 10 \text{ kW}$

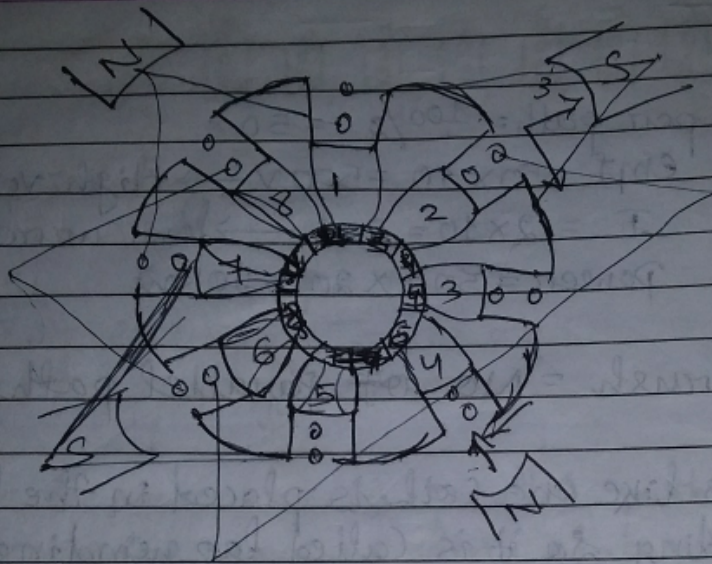
No. of brush = No. of parallel path = $A = P = 4$

→ It appears like one coil is placed in the lap of other winding so it is called lap winding.

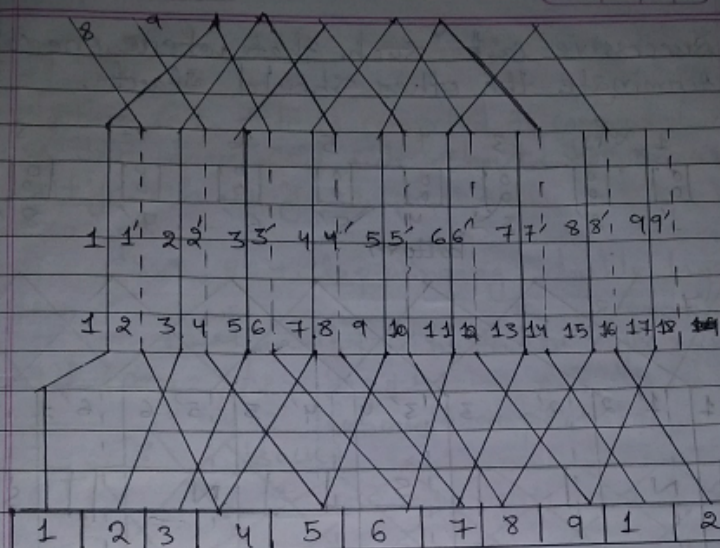
Span = 2 * $\gamma_c = 1$

Coil	Commutator
1-3'	1-2
2-4'	2-3
3-5'	3-4
4-6'	4-5
5-7'	5-6
6-8'	6-7
7-1'	7-8
8-2'	8-1





Span = 2
 $y_c = 1$



Slots = S

poles = p

One brush under N-pole other brush under S-pole.

$$\text{Back pitch} = 6 - 1 = 5$$

$$\text{Front pitch} = 9 - 4 = 5$$

Coil span = S/p (full pitch)

$$Y_c = \pm 1 \text{ (lap)}$$

$$= 2/p (S \pm 1) \text{ (wave)}$$

$$7 - 2 = 5 \text{ tap}$$

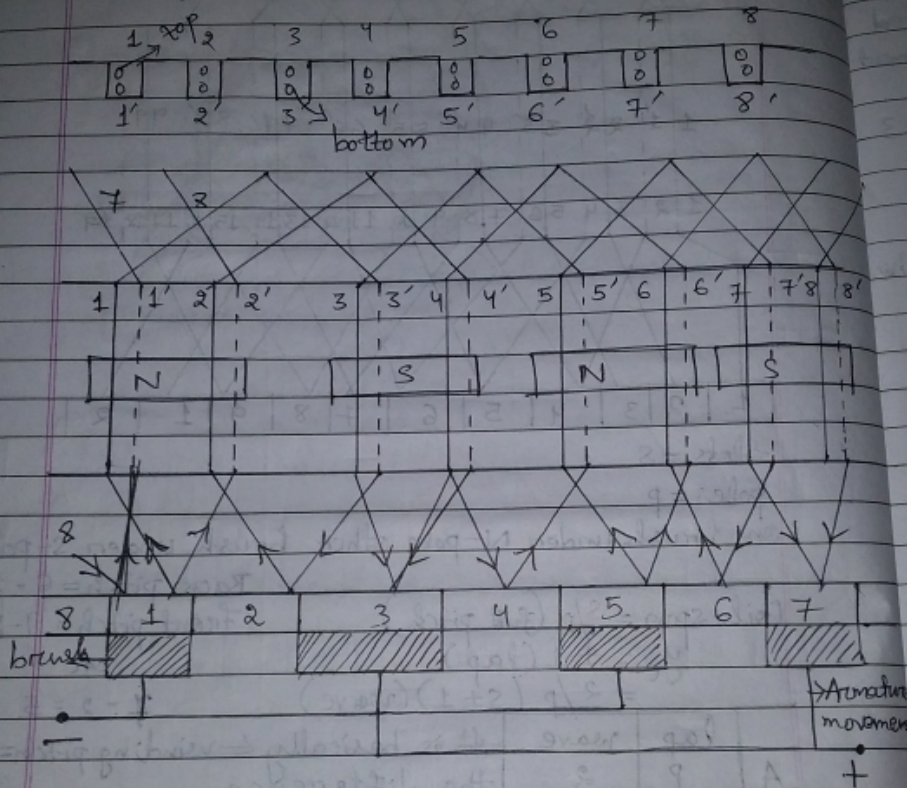
	lap	wave
A	P	2
brush	P	2

It is basically $\leftarrow$ winding pitch = $\frac{11}{2} = 5.5$
the difference between two top or bottom successive coil.
 $Y_b + Y_f = Y_w$

→ Front pitch and back pitch always odd and winding pitch is always even.

→ To determine the winding pitch we consider two

Successive coil such that where one coil terminate the other should start.



→ one coil side is present in slot (x) then its other coil side is present in $x + 5/p$.

E.g. → The coil side 1 is connected to $1 + 5/p$
 $= 1 + 2 = 3$. But we know that 1 is the top coil side so the other coil side must be bottom so it is 3'.

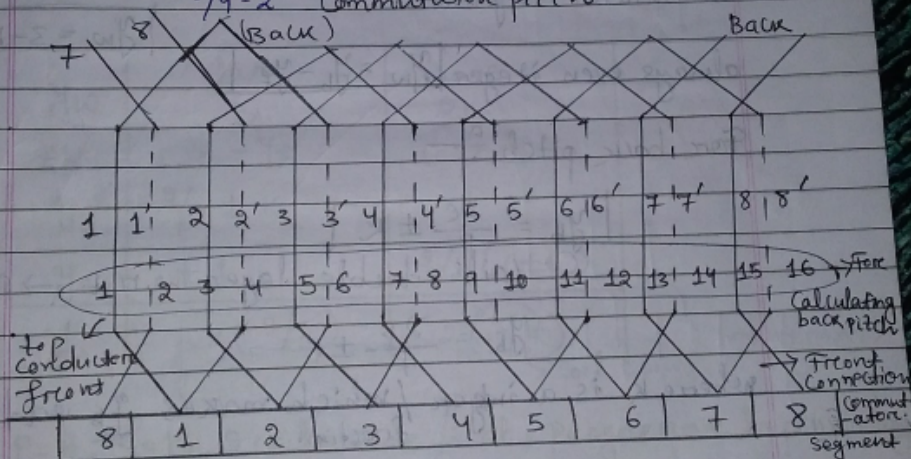
So the first coil having two coil side (1 and 3')

Example :-

$S=8$, $P=4$, lap winding, double layer.

Slot = coil $\rightarrow$ In double layer winding

Coil span = S/P , $y_c = +1$

$$= 8/4 = 2 \quad \text{Commutator pitch}$$


Back pitch (y_b): —

→ Back pitch (y_b).
It is the distance between the two coil side measured at the back of armature (one coil side top and the other must be bottom).

$$= 6 - 1 = 5$$

$$y_b = \frac{2c}{p} \pm k$$

Front pitch (y_f) :-
 $y_f - 1 = 3$

Imp :-
 → It is the distance between two coil sides connected to same commutator segment.

1 and 4 these two coil sides are joined to the common commutator segment (1) so front pitch = $4 - 1 = 3$.

Winding pitch :-

It is the distance between two top coil sides or two bottom coil sides connected to successive commutator segment.

$$y_w = 3 - 1 = 2$$

always even integer $y_w = y_b - y_f$

Back pitch :-

$$y_b = \frac{2C}{p} \pm K$$

C = coils, double layer winding $\rightarrow C = 8$

$$y_b = \frac{2S}{p} \pm K$$

where K is a integer / fraction which makes y_b odd.

Average pitch :-

$$(y_A) = \left(\frac{y_b + y_f}{2} \right) = \frac{5+3}{2} = 8/2 = 4 = 2 \left(\frac{S}{p} \right)$$

→ Avg. pitch should always be close to twice the coil span.

→ Winding pitch = $2 \times$ commutator pitch (y_c)

$$y_b = \frac{2 \times 8}{4} + K$$

$$= 4 \pm K$$

$$y_w = 2$$

$$y_b = 3065$$

$$y_w = y_b - y_f$$

$$2 = y_b - y_f$$

$$y_f = y_b - 2$$

$$y_b = 3$$

$$y_f = 3 - 2 = 1$$

$$y_1 = 5$$

$$y_f = 5 - 2 = 3$$

$$y_1 \rightarrow 3, 5$$

$$y_f \rightarrow 1, 3$$

$$2 \times (\text{Coil span}) = 4 = \frac{8}{2} - \frac{5+3}{2}$$

	lap	wave
y_w	$2y_r$	$2y_r$
y_w	$y_b - y_f$	$y_b + y_f$
y_b	$\frac{2C}{P} \pm K$	
y_c	± 1	$2/P (C \pm 1)$
y_A	$2 \times (S/P)$	$2 (S/P)$

Coil span

Q. $P=4$, $S=14$, 2 coils side / slot, progressive lap winding
Coils = slots = 14

$$y_b = \frac{2C}{P} \pm K$$

$$= \frac{2 \times 14}{4} \pm K \rightarrow 0$$

$$y_w = y_b - y_f$$

$$2 = 7 - y_f$$

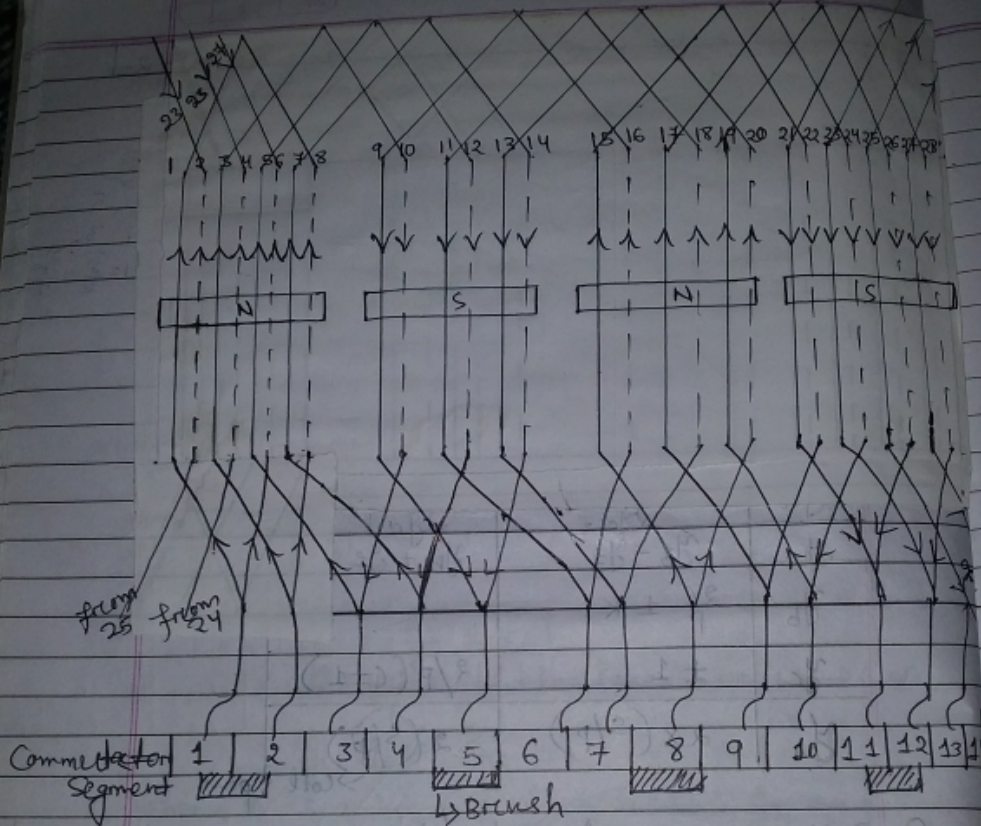
$$y_b = 7$$

$$y_f = 7 - 2 = 5$$

$$y_c = 1$$

$$y_w = 2 \times 1$$

$$y_f = 5$$



Simplex wave winding, progressive winding :-
4 pole, $S=11$, 2 coils / slot

$$\text{Coils} = \text{slots} = 11$$

$$y_c = \frac{2}{p} (C + 1)$$

$$= \frac{2}{4} (11 + 1) = 6$$

$$y_w = 2y_c = 12$$

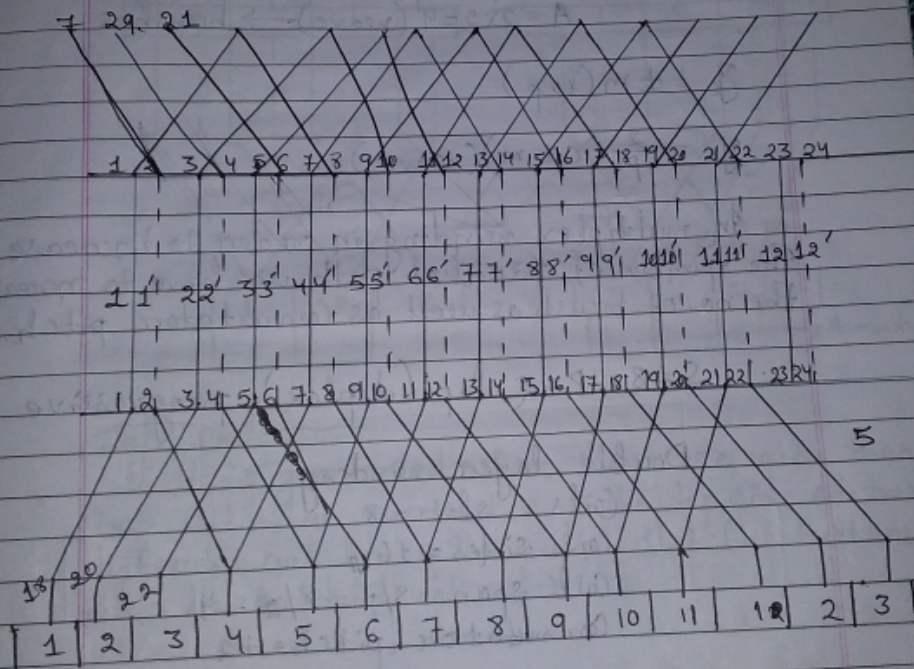
$$y_w = y_b + y_f$$

odd odd

$$12 = y_b + y_f$$

So take $y_b = 7, y_f = 5$

coil span $= 3 = s/p = 14/4$
The avg. pitch =
 $2(\text{coil span})$



Multiplex winding^a —

10 pole D.C. m/c

$A = P = 10$ (lap)

$A = 2$ (wave)

If $2 < A < 10 \rightarrow$ we use multiplex winding

For m order multiplex winding
 $A = mp(\text{lap})$
 $A = 2m(\text{wave})$

Example

Duplex ($m=2$)

$A = 2p(\text{lap}) \rightarrow$ brushes

$A = 2 \times 2 = 4(\text{wave}) \rightarrow$ brushes

$$y_c = \pm m(\text{lap})$$

$$y_c = \frac{2}{p}(c \pm m)(\text{wave}) \dots$$

In multiplex winding in order to increase the number of parallel path we have to increase the no. of brush as well as commutator pitch.

$S=8, P=2, \text{lap (duplex), progressive}$

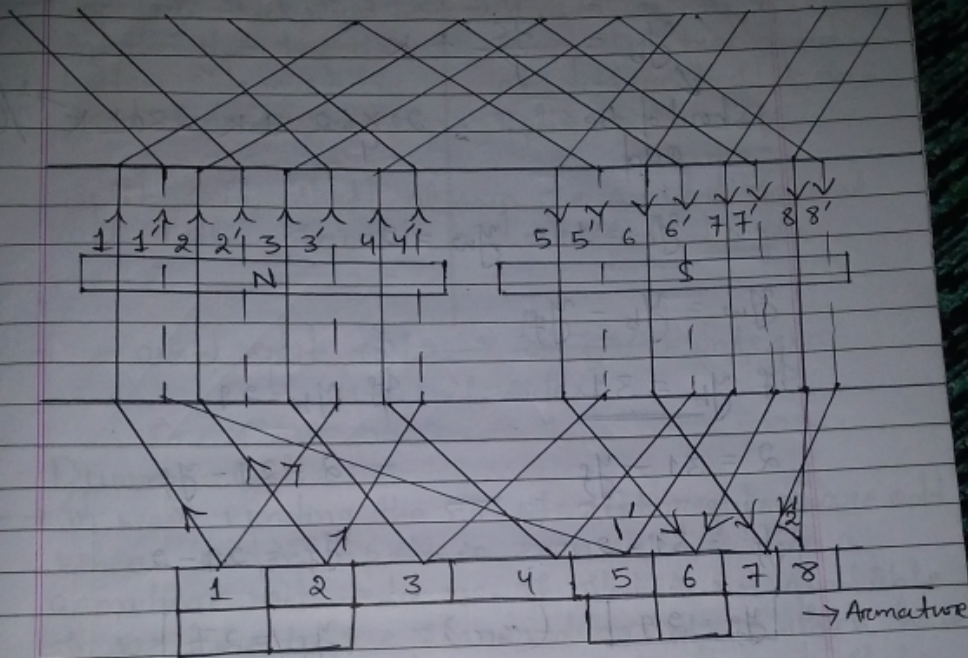
Double layer winding

Coils = slots = 8

Coil sides = 16

Coil span = $s/p = 8/2 = 4$

Commutator pitch = +2



Split Coil —

It is generated when there are more than two coil sides per slot and the top side of two different coil lie in the same slot but bottom side lies in different slot.

E.g. —

Simplex lap winding having 30 slots, 60 coils and 4 pole

$$\Rightarrow \text{Coil side} = 60 \times 2 = 120$$

$$\Rightarrow \frac{\text{Coil sides}}{\text{slot}} = \frac{120}{30} = 4$$

$$y_b = \frac{2c}{p} \pm K$$

should be odd $= \frac{20 \times 60}{4} \pm K = 30 \pm K \rightarrow (31/29)$

$$y_e = 1, y_w = 2$$

$$y_w = y_b - y_f$$

$$\text{If } y_b = 31 \quad \text{If } y_b = 29$$

$$2 = 31 - y_f \quad 2 = 29 - y_f$$

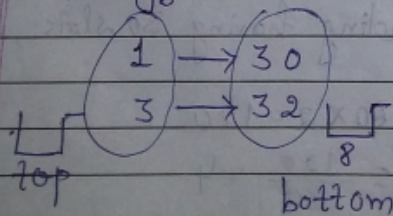
$$y_f = 31 - 2 \quad y_f = 29 - 2$$

$$y_f = 29 \quad (\text{corr}) \quad y_f = 27$$

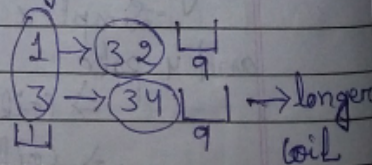
Top coil side $\rightarrow$ odd no.
bottom coil side $\rightarrow$ even no.

1	3					25	27	29	31	33	35
0	0	5	7			0	0	0	0	0	0
2	4					26	28	30	32	34	36
0	0	6	8			0	0	0	0	0	0
1	2					7	8				

$$\text{If } y_b = 29$$



$$y_b = 31$$



→ Top coil sides must be in the slot but their bottom side must lie in different slots.

→ If two coil started same slot but ended at different slot then split coil arises.

Split coil should always be avoided so that all coil should be identical length.

avoid split coil → $\frac{(Y_b - 1)}{u} = \text{Integer}$
u = coil sides

Dummy Coil. —

→ In wave winding the no. of slot required are odd where as in lap it is even. Some time a armature with odd no. of slot is not available so we have to use standard armature which have more than required no. of slot. If some slots are left unused their weight is less as compare to rest of slot so the rotor is mechanically unbalanced.

→ In order to achieve mechanically balanced structure we must construct winding even in extra slots.

→ But this winding should not be connected to commutation so that it does not take part in electro mechanical energy conversion but help to balance rotor.

→ Dummy coil. can be avoided if the armature have same no. of slot as required.

pole 4, D.C. generator total turns = 100
Current in each path = 10 amp.

Lap $A = p = 4$
turns per path = $\frac{100}{4} = 25$

$$E_{mf} = 25 \times 10 = 250 \text{ V}$$

$$I = 4 \times 10 = 40 \text{ A}$$

$$\text{Power} = 250 \times 40 = 10 \text{ kW}$$

Emf equation —

$$N \text{ rev} \longrightarrow 60 \text{ Sec}$$

$$1 \text{ rev} \longrightarrow \frac{60}{N} \text{ Sec}$$

In one revolution 2π radian is covered

$$2\pi \text{ radian} \longrightarrow \frac{60}{N} \text{ Sec}$$

$$\frac{2\pi}{\frac{60}{N}} = \omega = \frac{2\pi N}{60} \text{ rad/sec}$$

$$\text{Induced emf (E)} = \frac{PZ}{60A} N \phi \left[\frac{N}{60} = \frac{\omega \phi}{2\pi A} \right]$$

$$= \frac{PZ \omega \phi}{2\pi A}$$

$$= \frac{PZ}{2\pi A} = K_m = \text{machine Constant}$$

$$E = K_m \omega \phi$$

Torque equation? —

$$\text{Developed power} = E I_a = T_{dv} \times \omega$$

$$T_{dv} = \frac{E I_a}{\omega}$$

T_{dv} = Developed torque

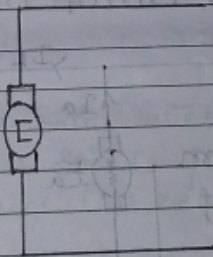
$$T_{dv} = \left(\frac{PZ}{2\pi A} \phi \right) \frac{I_a}{\omega}$$

$$T_{dv} = \left(\frac{PZ}{2\pi A} \right) \phi I_a$$

$$T_{dv} = K_m \phi I_a$$

Permanent magnet DC machine? —

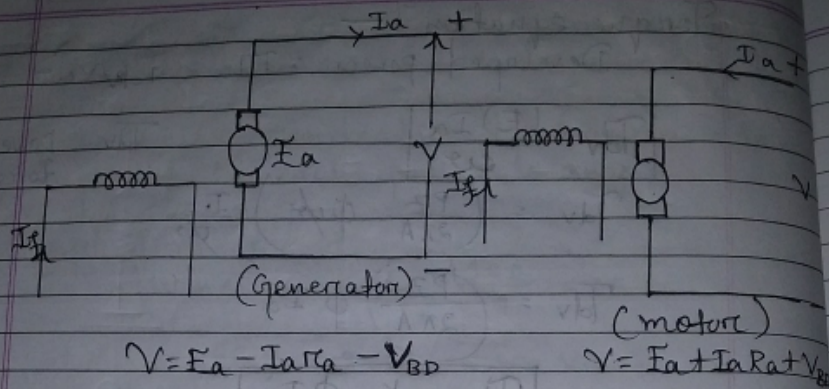
→ If the field magnet are permanent magnet instead of electromagnet it is a PMDC machine



Separately excited DC machine? —

If the field winding is excited from a separate source than armature than it is said to be separately excited D.C. machine.

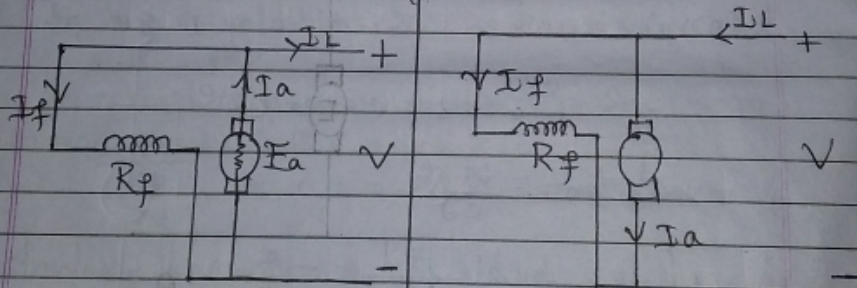
If the field winding is excited by a current source it is current excited and if by a voltage source it is voltage excited.



Self excited D.C. machine —

> If armature and field winding excited from a common source, two types

(a) Shunt excited DC machine —



$$I_f = V / R_f$$

$$V = E_a - I_a R_a - V_{BD}$$

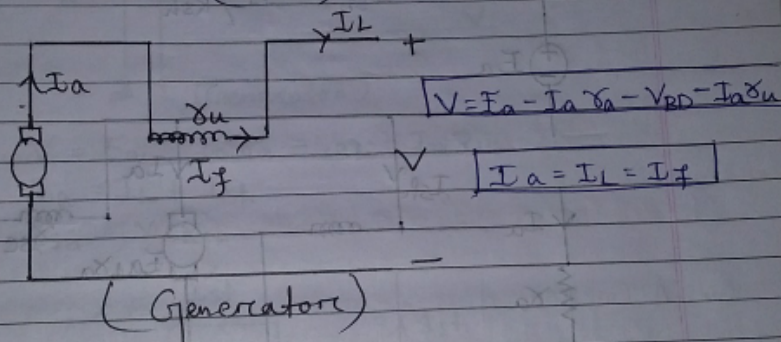
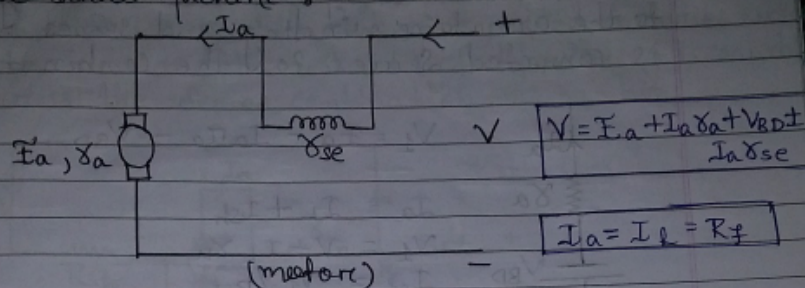
$$I_a = I_L + I_f$$

$$V = E_a + I_a R_a + V_{BD}$$

$$I_L = I_a + I_f$$

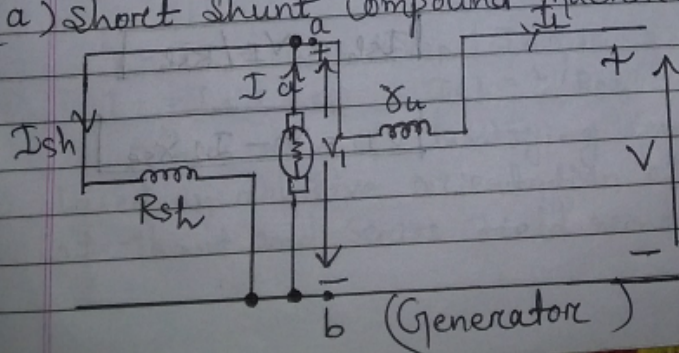
$$I_f = V / R_f$$

DC Series machine

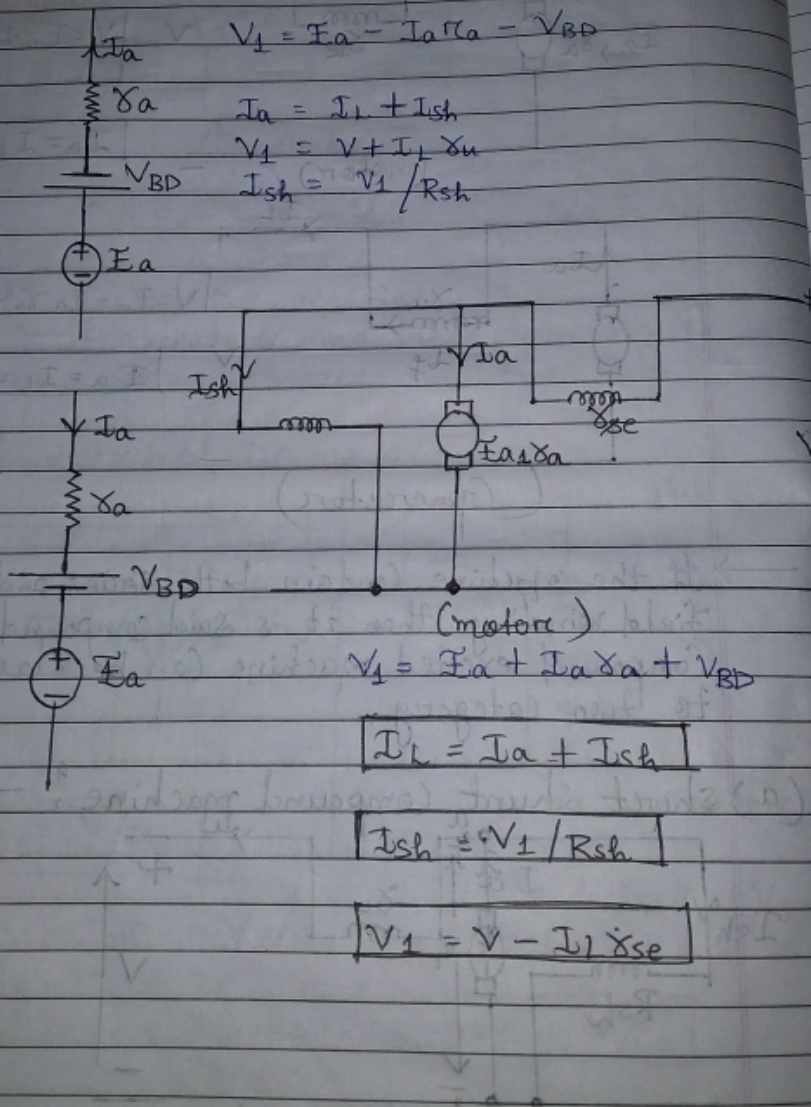


→ If the machine contain both series and shunt field winding then it is said compound excited. Compound excited machine can be classified in to two category.

(a) Short shunt compound machine

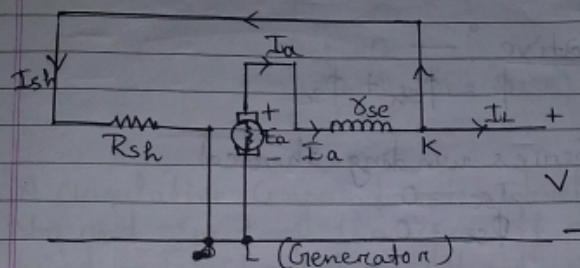


→ The shunt winding is connection only parallel to the armature winding and series winding is connected Series to the combination



Long Shunt Compound machine :-

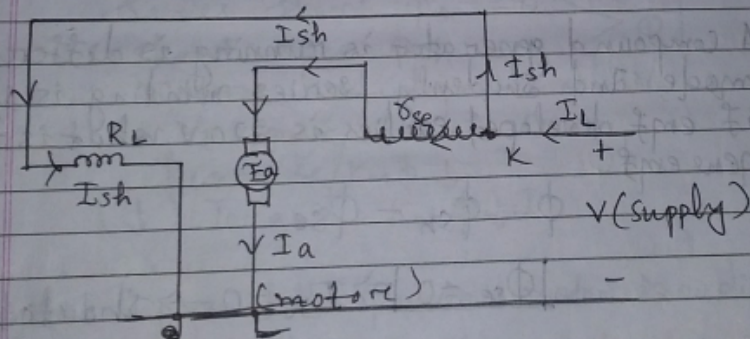
The Series field winding is added in series with armature and the shunt field winding is connected across the series combination.



$$V = E_a - I_a R_a - V_{BD} - I_a R_u$$

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

$$I_{sh} = V / R_{sh}$$



$$V = E_a + I_a R_a + V_{BD} + I_a R_u$$

$$I_L = I_a + I_{sh}, \quad I_{sh} = V / R_{sh}$$

Other way of classifying compound machine is based on relative orientation of magnetic field of shunt and series field winding.

Q. A compound generator is running in cumulative mode and generated emf is 220 V, suddenly series winding is shorted what happens to induced emf?

Solⁿ:-

Cumulative^a —

$$\phi = \phi_{sh} + \phi_{se}$$

Series winding shorted

$$I_{se} = 0$$

$$\phi_{se} = 0$$

$$\boxed{\phi = \phi_{sh} \text{ (reduces)}}$$

$$\boxed{E \propto \phi \text{ (reduces)}}$$

Q. A compound generator is running in differential mode and suddenly series winding is shorted if emf developed earlier is 220 V what is the new emf.

Solⁿ:-

$$\phi = \phi_{sh} - \phi_{se}$$

$$\boxed{\phi_{se} = 0} \Rightarrow I_{se} = 0 \rightarrow \text{Shorted Series winding}$$

$$\phi = \phi_{sh} \text{ (increased)}$$

$$E \propto \phi \text{ (increased)}$$

Q. In differential compound machine what would have happened if shunt winding is opened?

$$\Phi = \Phi_{sh} - \Phi_{se}$$

Shunt winding open

$$I_{sh} = 0$$

$$\Phi_{sh} = 0$$

$$\Phi = -\Phi_{se} \text{ (reverse)}$$

$$E \propto \Phi \text{ (reverse)}$$

Q. A cumulative Compound motor developed torque of 200 Nm and speed of 1500 rpm. If suddenly series winding is shorted or shunt winding open, what happen to developed torque and speed.

$$\Phi_f = \Phi_{sh} + \Phi_{se}$$

Series short $\Phi_{se} = 0$

shunt open $\Phi_{sh} = 0$

motor's emf depends on V_t

$$V_t = \text{const} \quad E_{mf} = \text{const}$$

$$\omega = E / K_m \Phi \downarrow$$

$$(\downarrow) \text{ Torque} = K_m \Phi \downarrow I_a$$

what happen if the previous motor is a differentially compounded motor.

$$\Phi = \Phi_{sh} - \Phi_{se}$$

shunt winding open

$$I_{sh} = 0$$

$$\Phi_{sh} = 0$$

$$\Phi = -\Phi_{se} \text{ (reverse)}$$

$$E = \text{const}$$

$$\omega = E / k_m \phi \quad (\text{reverse})$$

$$T = k \phi I_a \quad (\text{reverse})$$

Series winding Shorted $I_{se} = 0, \phi_{se} = 0$
 $\phi = \phi_{sh} (\text{increase})$ $I_f = \text{const.}$ $\omega_g = E / k_m \phi \downarrow$ $I_a = \frac{T}{k_m \phi}$

Long Shunt compound machine.
 (a) Cumulatively compound machine. —

$$\phi_f = \phi_{sh} + \phi_{se}$$

If the magnetic field of both series and shunt winding are supportive to each other or in one direction then the machine.

(b) differentially compound machine. —

If the shunt and series field winding field are in opposite direction to each other then they are called differentially compound machine.

$$|\phi_f = \phi_{sh} - \phi_{se}|$$

Cumulative Compounding is further divided into three category based on level of compounding

(a) over compound $(N_{se} \xrightarrow{\text{high}} \text{Series winding turns})$

(b) under compound $\rightarrow$ medium (N_{se})

(c) level compound $\rightarrow (N_{se} \rightarrow \text{low})$

Note:-

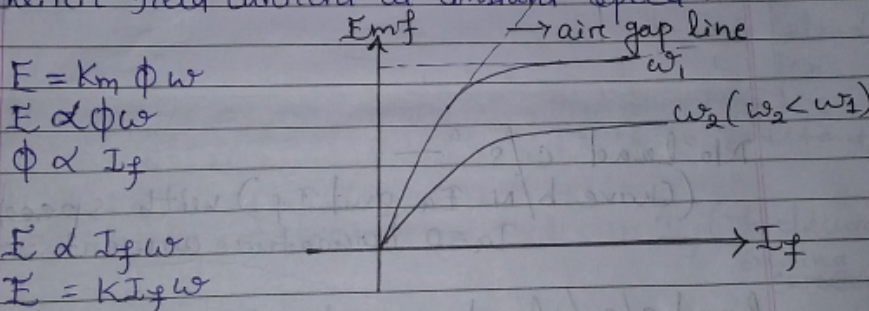
Mode of compounding can be change by reversing the orientation of either one winding but both their orientation should not be reverse.

Characteristics of DC machine:-

C/s refers to plot of certain machine parameter as some parameter as some parameter is varied such as generator voltage and current, motor speed and torque.

Magnetization Curve:- (o.c.c)

It is the plot of induced emf or no load voltage v.r.t field current at constant speed.



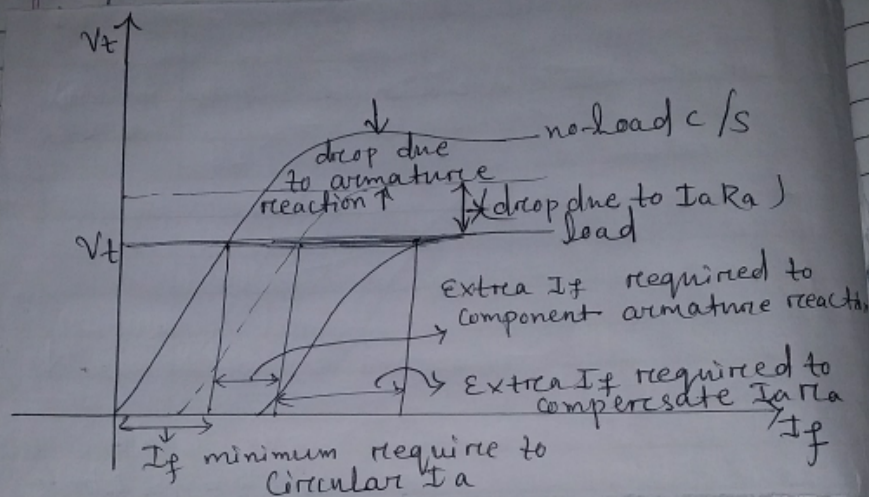
After a certain field current the flux saturate and becomes almost constant and hence emf comes constant.

→ Air gap line represents c/s of unsaturated machine which gives linear graph.

→ Under no load condition the current is almost

Zero so $V_T = \text{Induced emf}$

→ In presence of armature current there



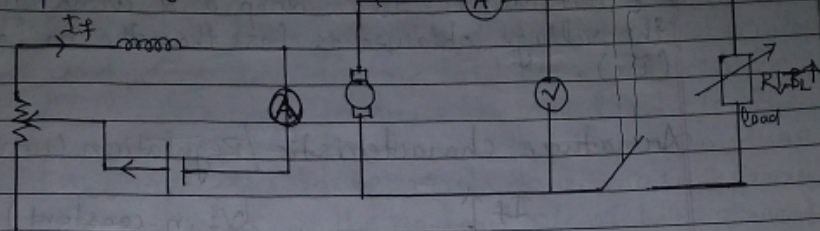
No load c/s —

(Curve b/N E_a and I_f) with speed const
 $I_a = 0$ [armature current = 0]

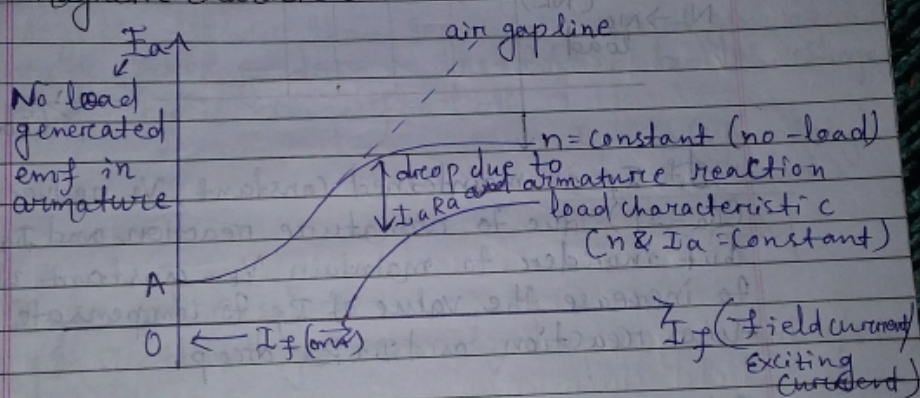
Load c/s / load magnetization curve —

Curve b/N V_t and I_f with I_a and N remaining const.

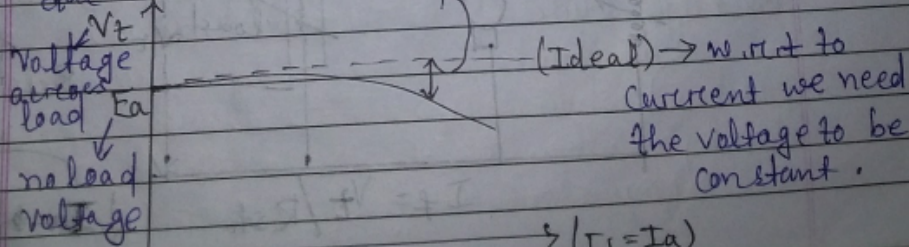
Separately excited Generator -



No load characteristics / open circuit characteristics / magnetic characteristic :-



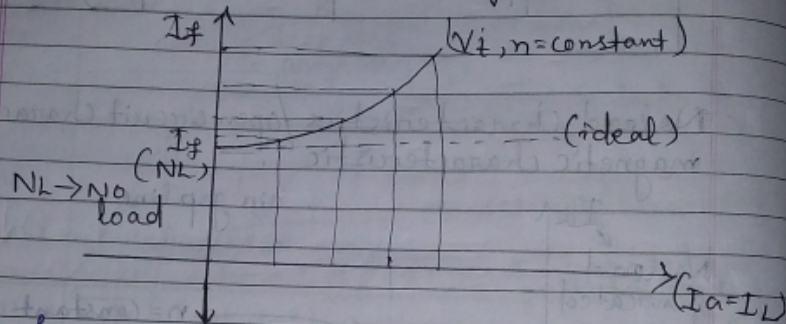
Extend characteristic :- $V_t = f(I_L)$ with I_f and n constant
due to armature reaction and $I_a R_a$ drop



$I_L = I_a$

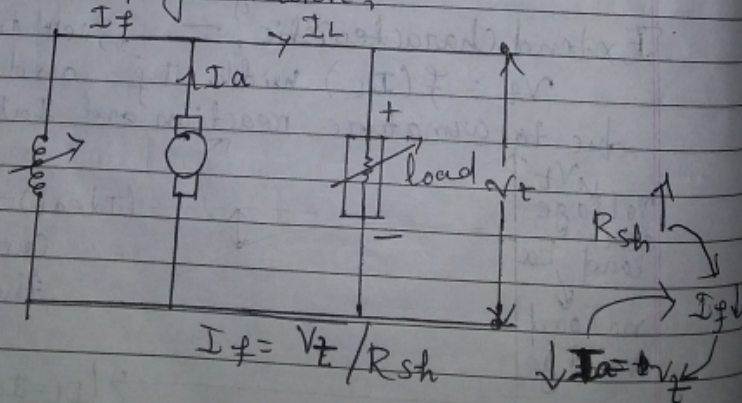
Ideally the voltage should be constant w.r.t. I_a but due to $I_a R_a$ drop and armature reaction the voltage obtained is less than the no load value (E_a).

Armature characteristic / Regulation curve⁹ —



If I_f is maintained constant, V_t reduces with ($I_a = I_L$) due to armature reaction and $I_a R_a$ drop but in order to maintain $V_t = \text{constant}$ we need to increase the value of R_f to compensate armature reaction and $I_a R_a$ drop.

Self excited generator⁹ —



No load c/s :-

In shunt generator the field current depend on induced emf and the induced emf depend of field current and hence drawing no load c/s is not possible to draw. In order to draw the no-load c/s the field winding should be disconnected from armature and the m/c should be made to run as a separately excited generator. So the no load c/s of both generator are identical.

→ In shunt generator the armature current is slightly higher than separately excited generator as the voltage drop is also higher but the shape of the ~~c/s~~ is same for both.

$$I_L = I_a (\text{separately})$$

$$I_a = I_L + I_{sh} (\text{shunt})$$

$$I_f = V_t / R_{sh}$$

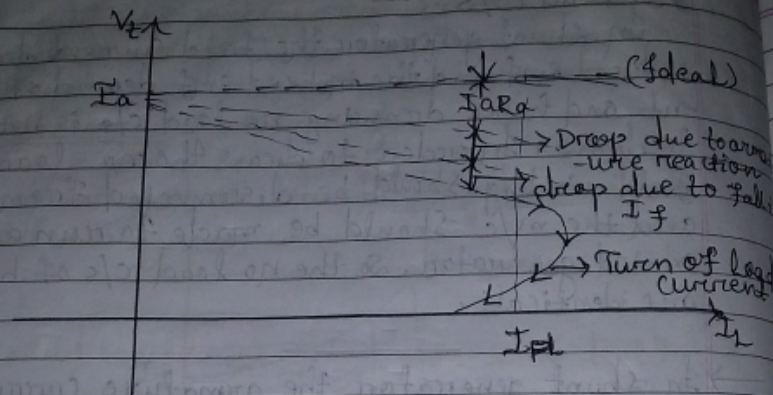
External c/s :-

In a shunt generator the drop in external c/s is due to

(a) $I_a R_a$ drop

(b) If the V_t reduced I_f also reduces which reduces the flux and induced emf and V_t further.

(c) drop due to armature reaction.



$\downarrow$ (load resistance decrease) $\rightarrow$ (load current increase)
 $\rightarrow$ Armature current $\uparrow$ ($\uparrow I_a = (\pm_c) \uparrow \rightarrow I_{sh}$) $\rightarrow$ Armature reaction increases $\rightarrow$ Net flux $\downarrow \rightarrow$ $E_m f \downarrow \rightarrow V_t \downarrow$
 $\rightarrow \downarrow I_L = \downarrow V_t / R_L (\downarrow)$

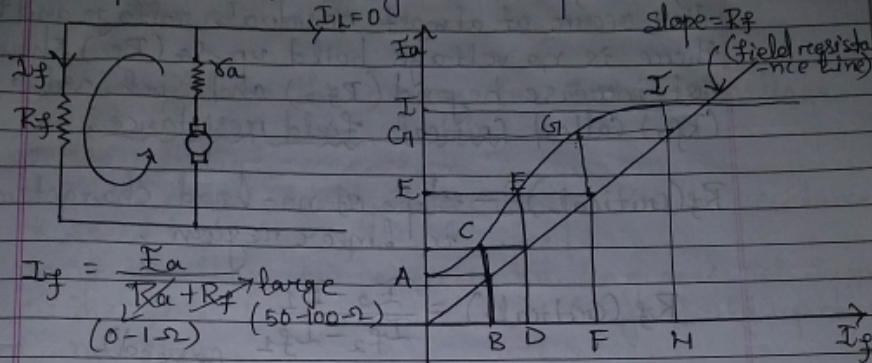
Armature characteristic —

The field current depends on terminal voltage and for constant terminal voltage the field current also remain constant. So armature characteristic can't be drawn. In order to draw armature c/s the m/c should be run as a separately excited generator.

voltage build up in shunt generator —

In shunt field winding current is produced when emf developed and emf is developed when field current exist, so both are independent and it is interested to study

the process of voltage build up.



$$I_f = \frac{E_a}{R_a + R_f} \rightarrow \text{large} \quad (0-1\Omega) \quad (50-100\Omega)$$

$$I_f = \frac{E_a}{R_f}$$

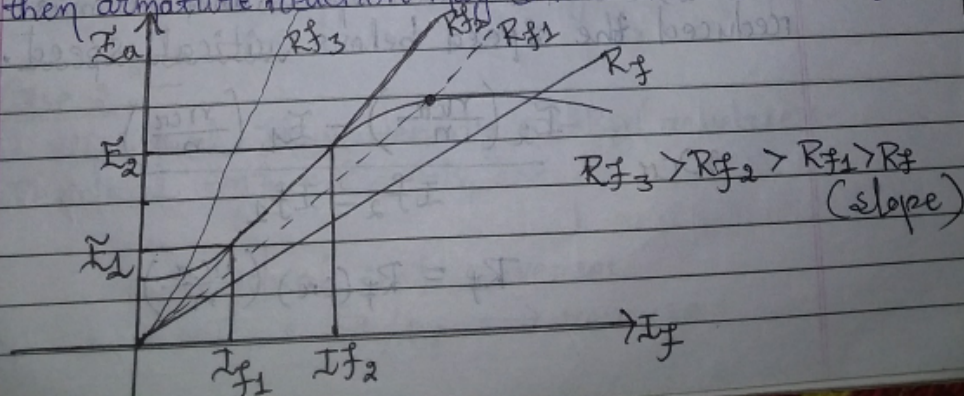
$$E_a = I_f R_f$$

$$y = m x$$

Slope

Due to residual voltage a field current is produced which further increases the flux and induced emf which increase the field current and this regenerative process continues still

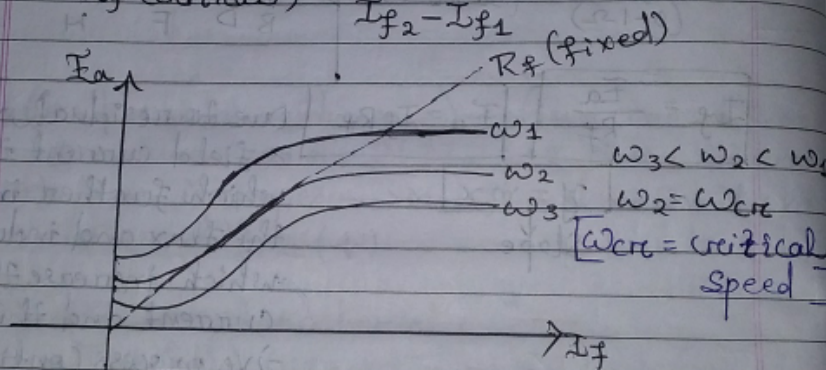
we reach at a steady state condition where both graph intersect. we have been the machine in no-load condition because if it run on-load cond then armature reaction may cancel the residual flux.



→ If R_f is increased above R_{f2} than intersection occur at almost residual voltage and hence there is no voltage build up so (R_f) should not increase beyond (R_{f2}) and such value of (R_{f2}) called critical field resistance.

$R_{f(\text{critical})} = \text{slope of no-load characteristic in linear region.}$

$$R_{f(\text{critical})} = \frac{E_2 - E_1}{I_{f2} - I_{f1}}$$



If the speed of generator reduced below ω_2 than field resistance line and no-load c/s do intersect and hence there is no voltage build up so (ω_2) called critical speed, and we must not reduced the speed below critical speed.

$$\omega_{cr} = \frac{E_2 \left(\frac{n_{cr}}{n} \right) - E_1 \left(\frac{n_{cr}}{n} \right)}{I_{f2} - I_{f1}}$$

$$R_f = R_{f(cr)} \left(\frac{n_{cr}}{n} \right)$$

$$\frac{R_f}{R_f(\text{cr})} = \frac{N\phi_r}{n}$$

what might be the reason for failure of voltage build up?

- * No residual magnetism.
- * Field resistance greater than critical resistance
- * Speed less than critical speed.
- * If the flux due to field winding does not support the flux (residual) then voltage build up does not occur.

Q. If the shaft of generator rotated in opposite direction will voltage build up occur?

* residual flux density = B_r

* residual emf = $B_r l v$

if v is opposite

residual emf reverse

$$I_f = \frac{E_a}{R_f} \text{ (reverse)}$$

field due to I_f reverse

both field oppose so voltage build up not occur.

Case 2:-

residual flux density = $-B_r$ (reverse)

Residual emf = $E_r = -B_r l v$

residual emf reverses

$$I_f = \frac{E_a}{R_f} \rightarrow \text{reverse}$$

field due to I_f reverses both fields are added voltage build up occurs.

Case - 3

(rotation reverse)

$$\text{velocity} = -v (\text{Reverse})$$

$$\text{residual flux density} = -B_r (\text{reverse})$$

$$E_r = B_r l v$$

$$\text{residual emf} = \text{same}$$

$$I_f = \frac{E_a}{R_f} (\text{same})$$

$$\text{flux due to } R_f (\text{same})$$

both field subtract

no voltage build up occur.

Q. If the speed of rotation and orientation of field winding reverses than predict about the voltage build up mechanism?

$$\text{residual flux density} = B_r$$

$$\text{residual emf} = B_r l v$$

if v is opposite

residual emf reverses

$$I_f = \frac{E_a}{R_f} (\text{reverse})$$

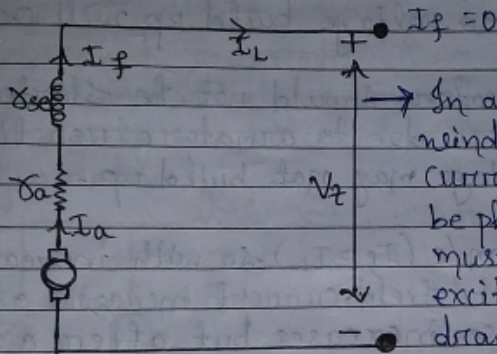
field due to I_f same (as the orientation changed to anticlockwise) both field are added.

Series excited generator? -

$$I_f = I_a = I_L$$

No load c/s? -

$$E_a \quad V_s \quad I_f \rightarrow I_L = 0, \quad n = \text{constant}$$



→ In absence of load the field winding does not carry any current so no load c/s can't be plotted and hence the m/c must be run as a separately excited m/c in order to draw no load c/s.

Load c/s? -

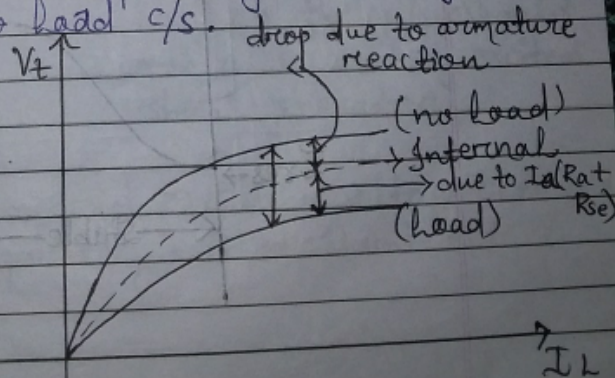
$$V_t \quad V_s \quad I_f, \quad I_a, \quad n \rightarrow \text{const}$$

$$I_f = I_a$$

→ If I_a remain const. then I_f can't be varied hence it must be run as a separately excited generator in order to draw load c/s.

External c/s? -

$$V_t \quad V_s \quad (I_L = I_f)$$

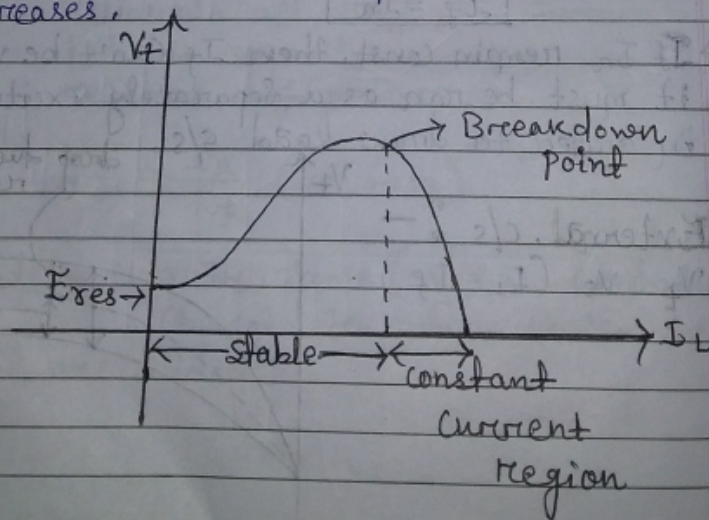


→ While taking the voltage drop in Series generator we must consider Series winding resistance in ohmic resistance drop.

→ Series generator can't be started at no load because the field current would be zero at no load and no voltage build up will occur.

→ Shunt generator should not be started with load otherwise due to armature reaction the flux and voltage may not build up.

In series m/c ($I_f = I_L$) so with increase with load current the field current increases and hence the voltage also increases but after a certain field current the field flux saturate and voltage no longer increase so if the load current further increase due to armature reaction and ohmic drop the terminal voltage decreases.



Armature c/s :-

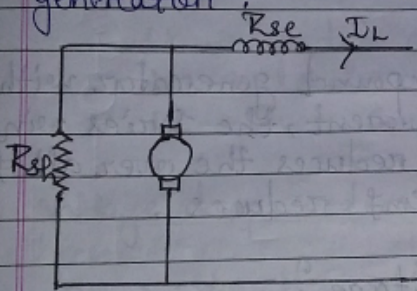
If V_s I_a $\rightarrow V_t$ const.
machine should run as separately excited generator

Application :-

voltage booster as in D.C. transmission.

Compound generator :-

Cumulatively compound generators are more commonly use as compare to differentially compound generator

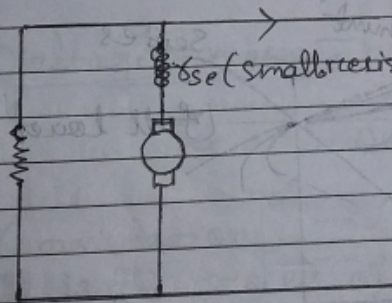


No load c/s :-

$I_L = 0$

short shunt no role of x_{se}
long shunt x_{se} small current

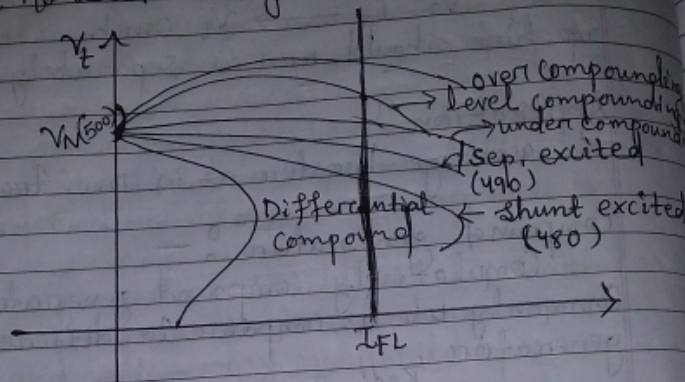
$\rightarrow$ In both case series winding does not play major role
as it act as a shunt generator.



$\rightarrow$ For no load and for load c/s the m/c should run as separately excited shunt generator.

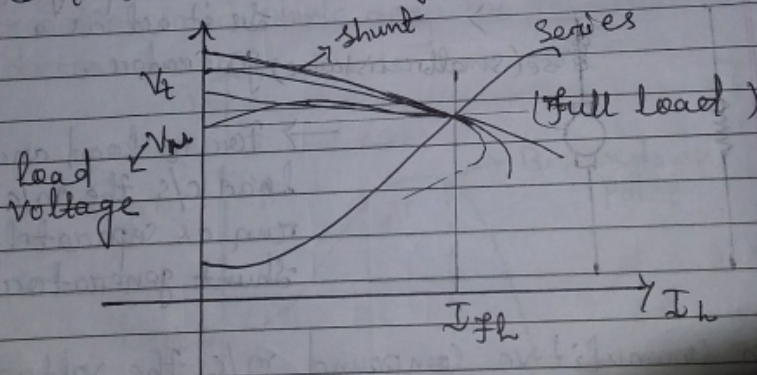
$\rightarrow$ In cumulatively compound m/c the voltage obtained is higher than separately excited shunt m/c.

Same no load voltage.

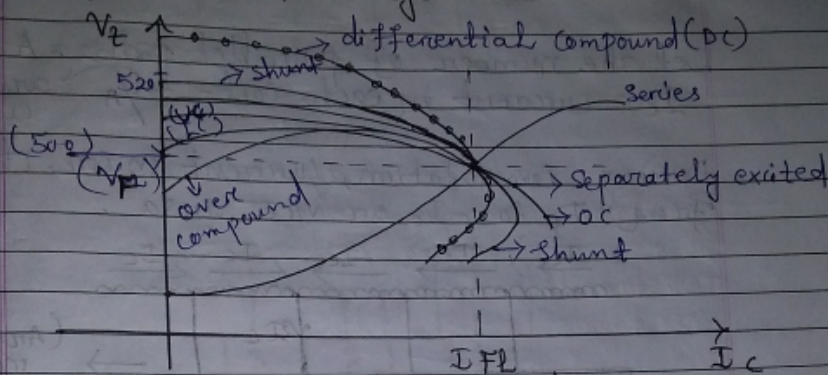


→ In differential compound generator with increase in load current, the series winding flux increases with reduces the over all flux and hence induced emf reduces.

(2) Same Full load voltage.



② Same full load voltage :-



UC $\rightarrow$ under compound
LC $\rightarrow$ level compound
OC $\rightarrow$ over compound

Voltage drop orders :-

DC > Shunt > Separately excited > UC > LC

Voltage increment :-

Series > OC

Commutation :-

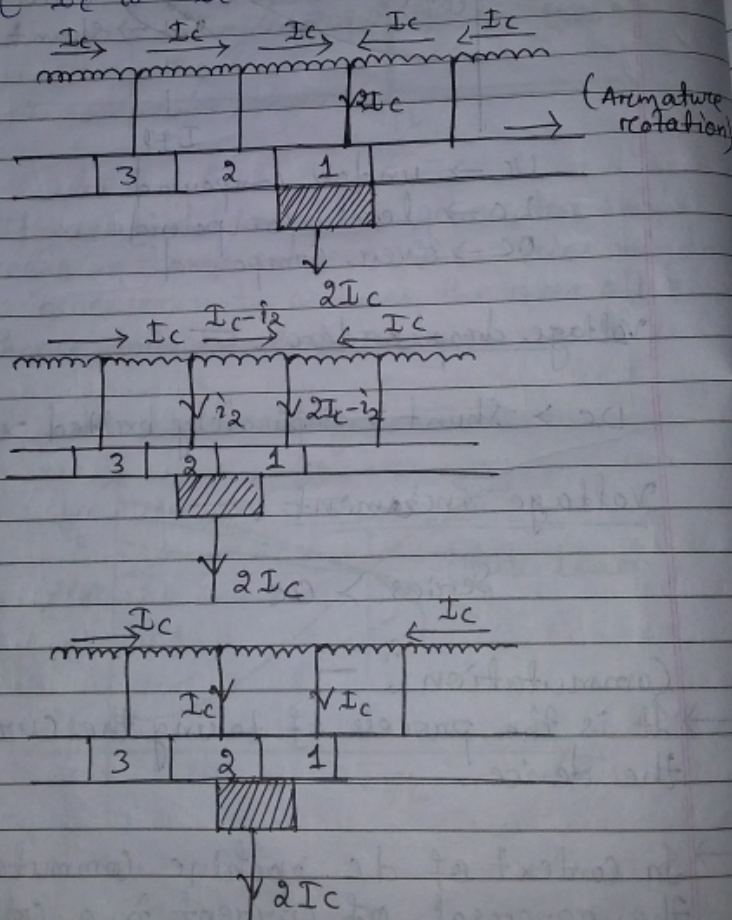
$\rightarrow$ It is the process of taking the current away from the device.

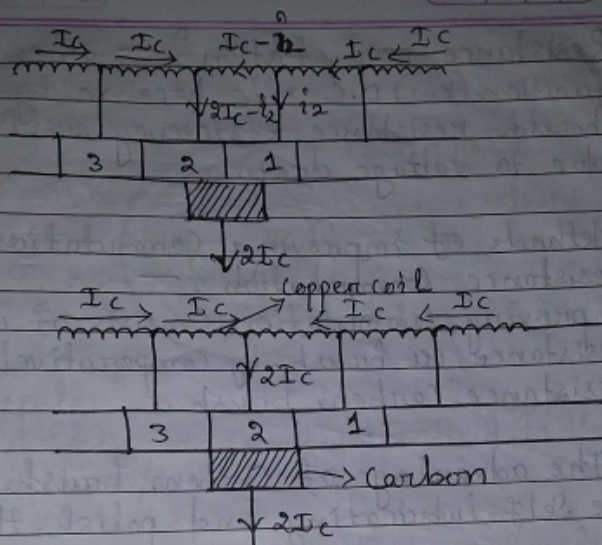
$\rightarrow$ In context of d.c. machine commutation implies the reversal of current in a coil. when every coil crosses a brush the current in the coil.

Reverse.

Let the number of parallel path = A
 I_c = current in each coil = I_a/A → armature current

During commutation, current in coil changes from I_c to $-I_c$ or vice versa.





Commutation period :-

- It is the time required for the brush to move from one commutator segment to another segment.
- If current reversal not happened during the commutation period it is called under commutation.
- If the current reversal takes less time than the commutation period it is called over commutation.
- The problem in commutation is if the voltage of the coil under going commutation is non-zero then high current produces which causes sparking, which can be minimize by using high resistance carbon brush.

Resistance Commutation? — is employed in fraction (kw) D.C. m/c because by increasing brush resistance efficiency will decrease due to voltage drop.

Methods of improving commutation? —

Resistance Commutation —

Improving commutation consists of replacing low resistance Cu brush by comparatively high resistance Carbon brush.

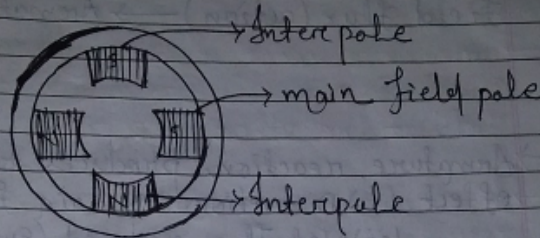
The advantage of Carbon brush is that they are self lubricating and polish the commutator.

The minor disadvantage is due to their high contact resistance a loss of approximately 2 volt is caused.

EMF Commutation? —

In this method arrangement is made to neutralize the reactance voltage by producing a reversing emf in the short circuited coil under commutation. This reversing emf as the name shows, is an emf in opposition to the reactance voltage and if its value is made equal to the latter, it will completely wipe it off thereby producing quick reversal of current in the short circuited coil which will result in Sparkless Commutation.

→ The reversing emf may be produced by using interpoles.



Interpoles :-

These are small poles fixed to the yoke and spaced in b/n the main poles.

→ They are wound with copper wire turns and are connected in series with the armature so that they carry full armature current.

→ Their polarity in the case of generator is the same as that of the main pole ahead in the direction of rotation.

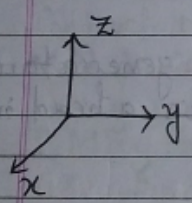
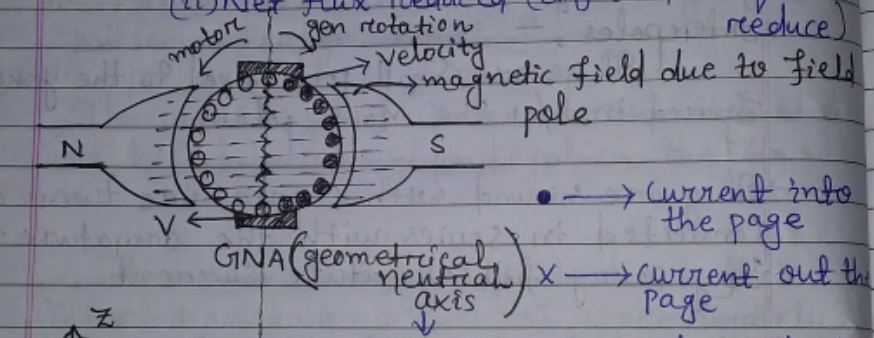
→ Interpoles help in the reversal of current by inducing reversing emf. This reversing emf neutralizes the reactance emf thereby making commutation sparkless.

→ Interpoles carry armature current, their commutating emf or reversing emf is proportional to the armature current.

③ Armature reaction :-

Field flux (action) $\rightarrow$ Armature emf $\rightarrow$ Armature current $\downarrow$ (Reaction) Armature flux

$\rightarrow$ Armature reaction produces two undesirable effect (i) Distortion of main field flux waveform (ii) Net flux reduced (emf and torque reduce)

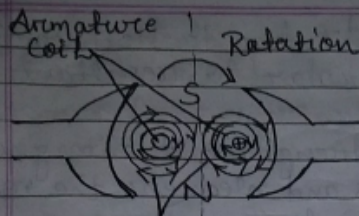


It represents the axis along which coil lies induced emf is zero.

$\rightarrow$ F_d (d-axis)
(90° electrical)

$$e = (\mathbf{v} \times \mathbf{B}) \cdot d\mathbf{l}$$

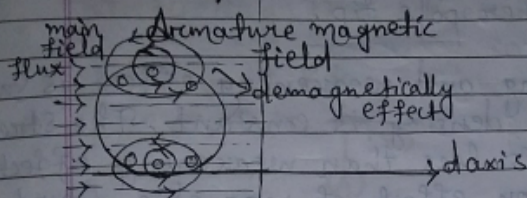
Q (axis)



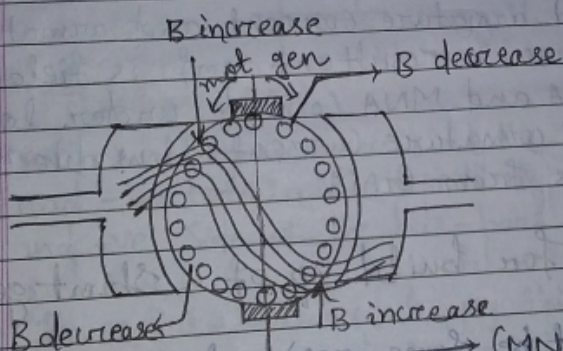
$$T \propto \Phi_F \Phi_{ar} \sin \lambda$$

$$\lambda = 90^\circ$$

$$T = \max$$



$\sqrt{\Phi_a}$ (armature mmf)



B decrease
(GNA)
B increase

(MNA) → magnetic neutral axis

axis perpendicular to the resultant

mmf, any coil

in this axis

has zero induced emf.

Φ_{ar}

GNA axis perpendicular to field mmf.
MNA axis perpendicular to resultant mmf.

→ Armature reaction strengthens the magnetic field at one pole tips and weakens the magnetic field at the other pole tip.

→ If strengthening and weakening effect is same resultant flux density is constant. The strengthening effect is less than weakening effect due to saturation effect of magnetic material. So resultant flux density reduces magnetic field and it is called as demagnetizing effect.

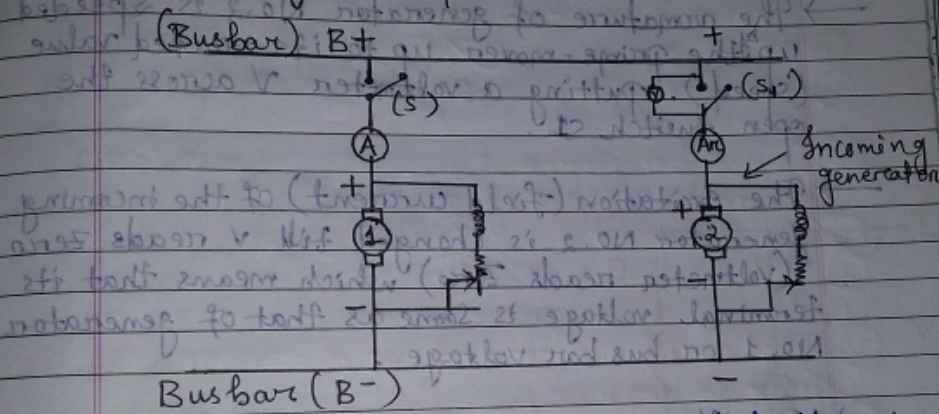
→ At no load armature current and armature mmf is zero so resultant mmf is field mmf hence GNA and MNA coincide. Under loaded condition armature current flows due to which MNA shifts from GNA.

Condition for build up of a shunt generator or —

- ① There must be some residual magnetism in the generator poles.
- ② For the given direction of rotation, the shunt field coils should be correctly connected to the armature that means the field flux must support residual flux.

- ⑤ Shunt field resistance should be less than the critical resistance.
Shunt field resistance should be more than a certain minimum value of resistance.

Paralleling D.C. Generator? —



→ Whenever generators are in parallel, their +ve and -ve terminal respectively connected to the +ve and -ve side of the bus-bars.

→ These bus-bars are heavy thick copper bars and they act as +ve and -ve terminal of the whole power station.

→ If the polarity of the incoming generator is not the same as the bus-bar polarity, serious short circuit will occur when (S1) switch is closed, which results in brush damage, commutator damage and blacked out plant.

→ In the diagram, a shunt generator (No. 1) connected across the bus-bar BB and supplying some of the load. For putting generator No. 2 in parallel with the bus-bar need following procedure.

→ The armature of generator No. 2 is speeded up by the prime-mover up to its rated value (speed). putting a voltmeter V across the open switch S_1 .

→ The excitation (field current) of the incoming generator No. 2 is changed till V reads zero (voltmeter reads zero) which means that its terminal voltage is same as that of generator No. 1 or bus bar voltage.

→ After this switch S_1 is closed and so the incoming machine is parallel to the system.

→ Under these condition, however generator No. 2 is not taking any load, because its induced emf is same as bus-bar voltage and there can be no flow of current between two points at the same potential. The generator is said to be floating on the bus-bar. If generator 2 is to deliver any current, then its induced emf E should be greater than the bus bar voltage (voltage across the two bus-bar).

→ The induced emf of the incoming generator is increased by strengthening its field till it supply its parts of load current.

$$(P_m) = VI_a - I_a^2 R_a$$

Differentiating b.t.s w.r.t I_a and equating to zero.

$$\frac{d(P_m)}{dI_a} = \frac{d}{dI_a} (VI_a - I_a^2 R_a) = 0$$

$$V \frac{d}{dI_a} I_a - 2I_a R_a = 0$$

$$V - 2I_a R_a = 0$$

$$V = 2I_a R_a$$

$$V/2 = I_a R_a$$

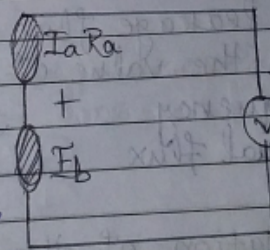
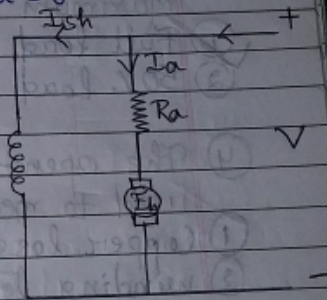
We know that

$$V = E_b + I_a R_a$$

$$V = E_b + V/2$$

$$V - V/2 = E_b$$

$$V/2 = E_b$$



Thus gross mechanical power developed by a motor is maximum when back emf is equal to half the applied voltage.