

# UNIT-I D.C Generators

## Principle of operation:-

" whenever a conductor cuts magnetic lines of flux dynamically induced emf is produced in the conductor". This induced emf causes a current to flow if the conductor circuit is closed.

Consider a single turn coil ABCD rotating in the uniform magnetic field as shown in fig. The two ends of the coil are joined to two slip-rings  $s_1, s_2$  which are insulated from each other and from the shafts and these slip rings rotate along with the coil. Two stationary brushes  $b_1$  and  $b_2$  press against the slip-rings. The purpose of the brushes is to collect the current induced in the coil and to convey it to the external load resistance  $R$ .

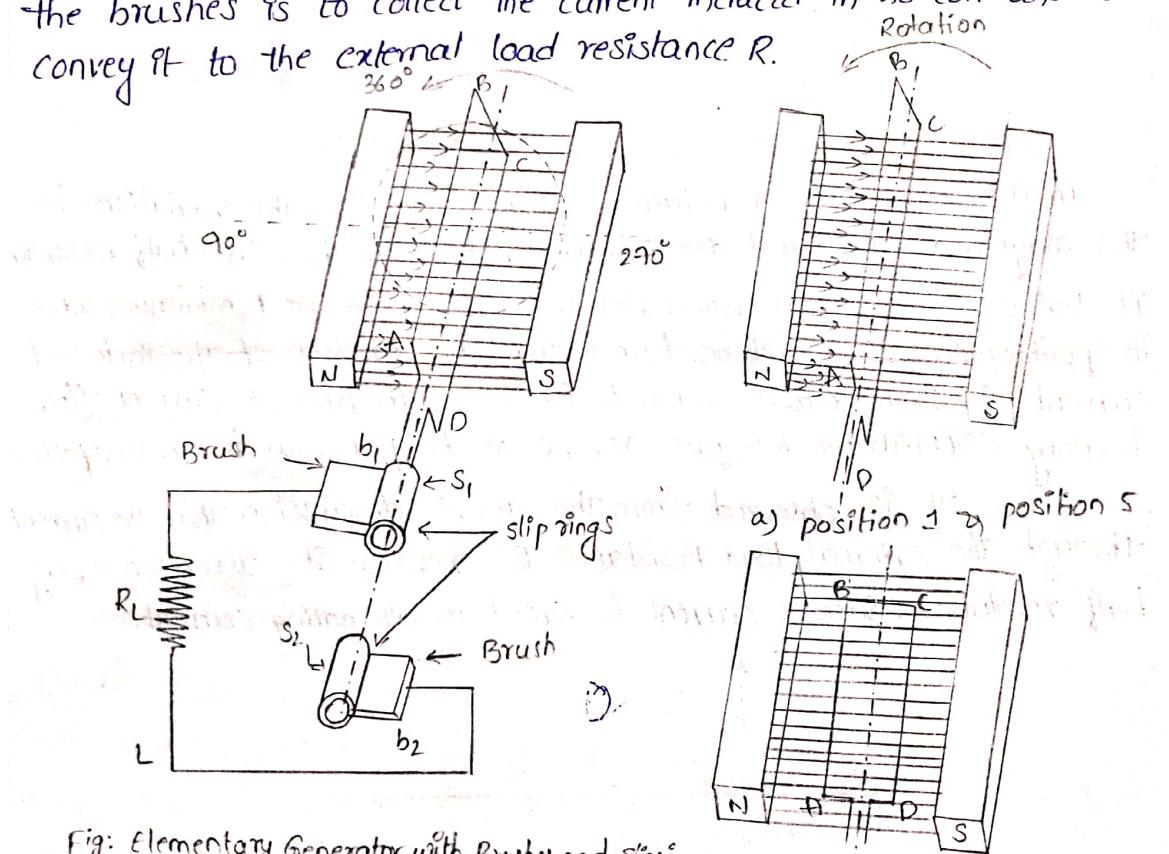
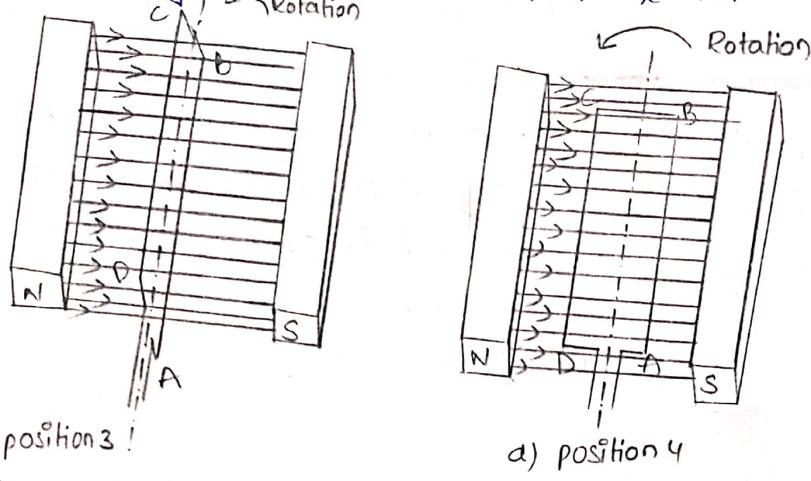


Fig: Elementary Generator with Brushes and slip rings

Let us take the vertical position of the coil as shown in fig. is the starting position and the coil be rotated in counter clockwise direction with constant angular velocity. In this position, the induced e.m.f is zero because the coil sides AB and CD are cutting no flux but are moving parallel to it.

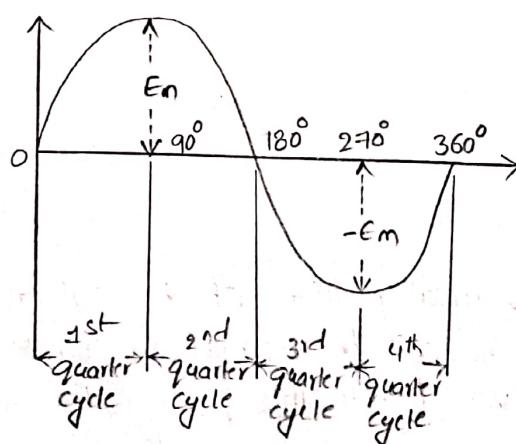
As the coil rotates further i.e. in position-2 as shown in fig, the coil sides AB and CD are right angles to the flux and core, therefore the rate of cutting flux linkages is maximum but flux linked with the coil is minimum. Hence at this instant, the e.m.f induced is maximum.

In the next quarter revolution, i.e. at position 3. The flux linked with the coil gradually increases but the rate of change of flux linkages decreases. Hence, e.m.f induced in this position is decreased to zero gradually. The current through the load resistance  $R$  flows from M to L during first half revolution of the coil.



In the next half revolution, as shown in fig. the variations in the magnitude of e.m.f are similar to those in the first half revolution. It value is maximum when coil is in position 4 and minimum when in position 1. But it will be found that the direction of the induced current is from C to D and A to B. Hence, the path of current flow is along CDLMAB which is just reverse of the previous direction of flow.

It is observed from the above discussion that the current through the external load resistance  $R'$  reverse its direction every half revolution. Such a current is called an alternating current.



It will be observed that in the first half revolution, current flows along BAMLD'CB. i.e., the brush  $b_1$ , in contact with segment  $S_{G_1}$ , acts as the positive terminal of the supply and brush  $b_2$ , in contact with segment  $S_{G_2}$ , act as the negative (-ve) terminal.

### Field winding:-

#### Functions:-

- ⇒ To carry the current due to which pole core, on which the field winding is placed behaves as an electromagnet, producing necessary flux.
- ⇒ It helps in producing the magnetic field that is existing at pole as an electromagnet. It is called field winding.

#### choice of material:-

It has to carrying current hence obviously made up of some conducting materials. So, Al (or) Cu is the choice of Material.

#### Armature:-

It is further divided in to 2 parts.

1. -Armature core
- 2) Armature winding.

#### Armature core:-

Armature is cylindrical in shape mounted on the shaft. It consists of slots on its periphery and the air ducts to permit the air flow through armature which serves cooling purpose.

#### functions:-

- 1) -Armature core provides house for armature windings.
- 2) To provide a part of low reluctance to the magnetic flux produced by the field winding.

#### choice of Material:-

- ⇒ It has to provide a low reluctance for to the flux, it is made up of magnetic material like cast iron (or) cast-steel.
- ⇒ It is made up of laminative construction to keep eddy current loss as low as possible.

#### Armature winding:-

⇒ It is nothing but interconnection of armature conductors, placed in the slots provided on the armature core. When the armature is rotated in case of generator, magnetic flux gets cut by armature conductors and emf gets induced in them.

#### functions:-

- ⇒ Generation of emf takes place in the armature winding in case of generator.

- ⇒ To carry the current supplied in case of motors.
- ⇒ To do the useful work in the external circuit.

### choice of material:-

Armature winding carries entire current which depends on external load, it has to be made up of conducting material, which is copper.

### Commutator:-

The basic nature of emf induced in the armature conductors is alternating. This needs rectification in case of DC generator, which is possible by a device is called commutator.

### functions:-

- ⇒ To facilitate the collection of current from the armature conductors.
- ⇒ To convert internally developed alternating emf to unidirectional emf.
- ⇒ To produce unidirectional torque in case of motors.

### choice of material:-

- ⇒ As it collects the current from armature, it is also made up of cu segments.
- ⇒ It is cylindrical in shape and it is made up of wedge shaped segments of harddrawn, high conductivity copper. These segments are insulated from each other by thin layer of mica.

### Brushes:-

Brushes are stationary and resting on the surfaces of the commutator function:-

which collect current from commutator and make it available to the stationary external circuit.

### choice of material:-

Brushes are normally made up of soft material like carbon, Brushes are rectangular in shape. A flexible copper conductor called pig tail is used to connect the brush to the external circuit.

### Bearings:-

Ball-bearings are usually used as they are more reliable. For heavy duty machines, roller bearings are preferred.

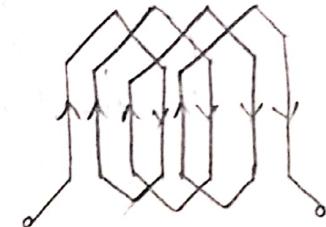
## Armature winding:-

We have seen that there are number of armature conductors, which are connected in specific manner as per the requirement, which is called armature winding. There are 2 types.

- a) lap winding
- b) wave winding.

### Lap winding:-

In this case, if connection is started from conductor in slot 1 then connections overlap each other as winding proceeds, till starting point is reached again.

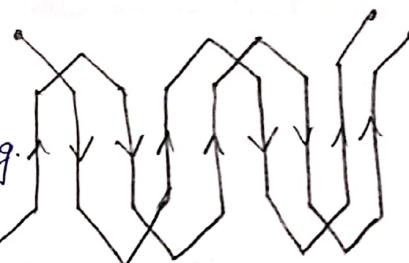


Developed view of part of the armature winding in lap fashion is shown in fig.

Large no. of parallel paths indicate high current capacity of machine hence lap winding is preferred for high current rating generators.

### Wave winding:-

In this type of connection, winding always travels ahead avoiding overlapping. It travels like a progressive wave hence called wave winding. To get an idea of wave winding a part of armature winding in wave fashion.



Both coils starting from slot 1 and slot 2 are progressing in wave fashion.

The no. of parallel paths in which armature conductors are divided into due to lap or wave fashion of connection is denoted as  $A$ . So,  $A = p$  for lap &  $A = 2$  wave connection.

Comparison b/w lap and wave:-

S.No	Lap winding	wave winding.
1.	No. of parallel paths $A = \text{pole} p$	No. of parallel paths $A = 2$
2.	No. of brush sets required is equal to no. of slots.	No. of brush sets required is always equal to two.
3.	preferable for high current, low voltage capacity generators.	preferable for high voltage, low current capacity generators.
4.	Normally used for generators of capacity more than 500A.	Normally used for generators of capacity less than 500A.

### Simplex lap winding :-

If there is only one set of closed lap winding in a machine then it is called simplex lap winding.

The back pitch  $y_b$  is an odd integer for this type of winding and is nearly equal to coil sides per pole.

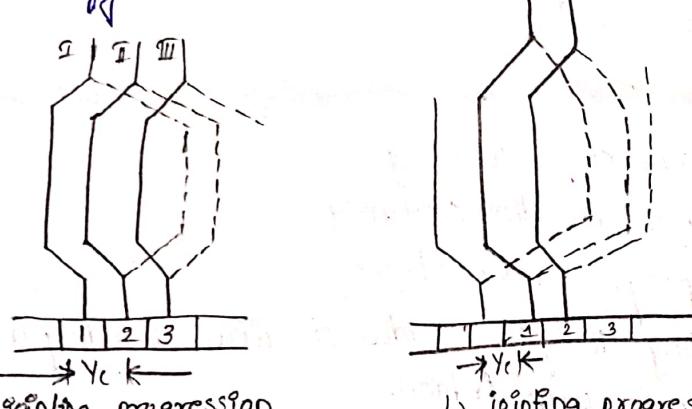
$$y_b = \frac{2C}{P} \pm k$$

where  
 $C$  = Number of coils in the armature.

$P$  = No. of poles

$k$  = Number which may be integer or fraction to make  $y_b$  an odd integer and approximately equal to  $\frac{2C}{P}$  i.e. coil sides per pole.

The armature coil sides can be connected to the commutator in two different ways i) progressive ii) reprogressive. In progressive winding, the joining of two coil sides to the commutator is in the same direction as the coils progress around the armature. It is shown in fig.



a) jointing progression

b) jointing progression

In this case, finish of coil I. is connected to the start of the coil II laying to its right. Hence for progressive lap winding.

$$Y = Y_b - Y_f = +2$$

$$Y_c = \frac{Y}{2} = +\frac{2}{2} = +1$$

Following points are to be considered in case of simplex lap winding:

1. The back and front pitches are odd and of opposite sign. They are not equal and differ by 2 or by its some multiple.

$$Y_b - Y_f = \pm 2$$

2. If  $y_b > y_f$  then  $y_b - y_f = 2$  i.e.  $y_b = y_f + 2$ . Here we get progressive or right-handed winding which progresses in the clockwise direction as seen from commutator end. Here  $y_c = 1$ .
3. If  $y_b < y_f$  then  $y_b - y_f = -2$  i.e.  $y_b = y_f - 2$ . Here we get regressive or left-handed winding which progresses in the anticlockwise direction.

direction as seen from commutator end. Here  $Y_c = \pm 1$

iii)

$$\left. \begin{array}{l} Y_f = \frac{2}{P} - 1 \\ Y_b = \frac{2}{P} + 1 \end{array} \right\} \text{for progressive winding}$$

$$\left. \begin{array}{l} Y_f = \frac{2}{P} + 1 \\ Y_b = \frac{2}{P} - 1 \end{array} \right\} \text{for retrogressive winding.}$$

Here  $z$  are number of conductors and  $2/P$  which must be even for feasibility of winding.

2. Both  $Y_b$  and  $Y_f$  should be nearly equal to pole pitch.

3. The average pitch  $Y_a = \frac{Y_b + Y_f}{2}$  it, must be equal to  $\frac{2}{P}$ .

4. The commutator pitch  $Y_c = \pm 1$ . Generally the commutator pitch  $Y_c = \pm m$  where  $m=1$  is for simplex lap winding,  $m=2$  for duplex lap winding and so on.

5. The resultant pitch  $Y_r$  is even as the difference between two odd numbers  $Y_b$  and  $Y_f$  is always even.

6. The no. of slots for a double layer winding is equal to the no. of coils which are half the number of coil sides. The no. of commutator segments is also the same.

7. The no. of parallel paths in the armature is equal to  $m_p$  where  $m$  is multiplicity of the winding and  $p$  are no. of poles.

8. In general we have  $Y_b - Y_f = \pm 2m$  or  $Y_b + Y_f = \pm 2m$  where  $m=1$  for simplex lap winding,  $m=2$  for duplex lap winding and so on.

### Simplex wave winding :-

In Simplex wave winding, the back pitch  $Y_b$  is an odd integer and has a value  $Y_b = \frac{2c}{P} \pm k$ .

In case of wave winding, starting at one commutator segment and tracing the winding from coil to coil, after travelling around the armature which is completed after  $P/2$  coils, we come to a commutator segment next to the segment from which there was start. This arrival of segment may be either ahead or behind the starting segment. If it is ahead, then winding is progressive and if it is behind then winding is retrogressive. Alternatively we can also say that if after travelling once around the armature until the winding falls in a slot to the right of its starting point then the winding is progressive. If the winding falls in a slot to the left of its starting point then the winding is retrogressive.

left of its starting point, the winding is retrogressive.

let  $y_b$  = Back pitch,  $y_f$  = Front pitch

$$\text{Average pitch, } y_A = \frac{y_b + y_f}{2}$$

let  $z$  = Total no. of conductors or coil sides,  $p$  = No. of poles.

$$y_A \cdot p = z \pm 2$$

$$y_A = \frac{z \pm 2}{p}$$

Here  $z$  is always even while  $p$  is also even. Hence  $\frac{z \pm 2}{p}$  is also an even integer. positive sign will give progressive winding, while negative sign will give retrogressive winding.

The resultant pitch,  $y_R = y_b + y_f$

$$y_c = y_A$$

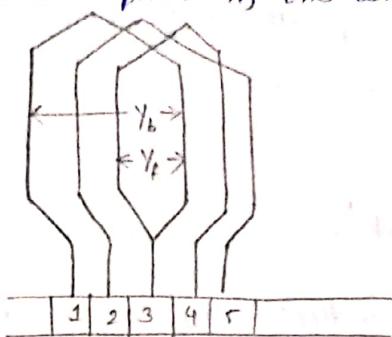
$$y_c = \frac{\text{No. of commutator bars} \pm 1}{\text{No. of pairs of poles}}$$

following points are to be considered in case of simplex wave winding.

1. the back and front pitches are odd and nearly equal to the pole pitch. They may be equal or differ by 2.
2. The Average pitch  $y_A = \frac{y_b + y_f}{2} = \frac{z \pm 2}{p}$   
Since  $z$  and  $p$  are even,  $\frac{z \pm 2}{p}$  is also even. For positive sign progressive wave winding is obtained while for negative sign retrogressive wave winding is obtained.
3. The commutator pitch  $y_c = y_A = \frac{\text{No. of commutator bars} \pm 1}{\text{No. of pairs of poles}}$
4. The no. of coils are given by  $N_c = \frac{p y_A \pm 2}{2}$ .
5. The no. of parallel paths for a simplex wave winding is always 2.
6. for a wave winding, the no. of armature conductors with  $z$  either added or subtracted, must be a multiple of the no. of poles.

## Duplex lap winding:-

The commutator pitch  $P_D$  in this winding is  $\pm 2$ , as shown in fig.



Multiplex winding  
The winding pitch  $y = 2y_c = \pm 4$

$y_b - y_f = +4$  for progressive winding.

$= -4$  for retrogressive winding.

Duplex lap windings may be either singly or doubly reentrant. In singly reentrant winding after tracing the total winding the starting point is reached.

In doubly reentrant winding the starting torque point is reached after tracing half the winding.

## Duplex wave winding:-

Here we have, 
$$y_c = \frac{c \pm 2}{P \cdot 2}$$

The duplex wave winding may consist of singly closed circuit or two entirely separate closed circuits.

## E.M.F Equation of D.C Generator:-

Let

$p$  = No. of poles of the Generator.

$\phi$  = Flux produced by each pole in wb.

$N$  = Speed of armature in r.p.m.

$Z$  = Total no. of armature conductors.

$A$  = No. of parallel paths.

$A = p$  for lap winding

$A = 2$  for wave winding.

Now e.m.f gets induced in the conductor according to Faraday's law of electromagnetic induction. Hence average value of e.m.f induced in each armature conductor is

$$e = \text{Rate of cutting the flux} = \frac{d\phi}{dt}$$

Now consider one revolution of conductor. In one revolution, conductor will cut total flux produced by all the poles i.e.  $\phi_p$ . While time required to complete one revolution is  $60/N$  seconds as speed is  $N$  r.p.m.

$$\therefore e = \frac{\phi_p}{\frac{60}{N}} = \phi_p \frac{N}{60}$$

This is the e.m.f induced in one conductor. Now the conductors in one parallel path are always in series. There are total 2 conductors with 2 parallel paths, hence  $\frac{2}{A}$  no. of conductors are always in series and e.m.f remains same across all the parallel paths.

$\therefore$  Total e.m.f can be expressed as,

$$E = \phi_p \frac{N}{60} \times \frac{2}{A} \text{ Volts.}$$

This is nothing but the e.m.f equation of d.c generator.

So

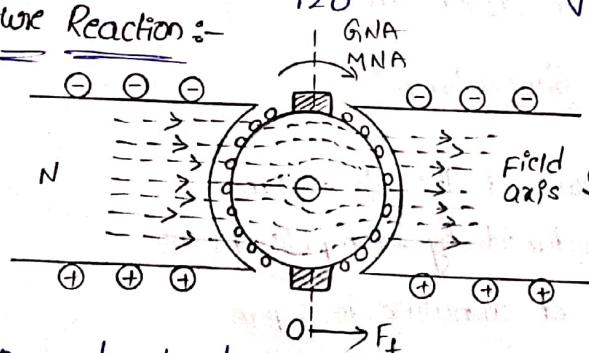
$$E = \frac{\phi_p N 2}{60 A}$$

e.m.f eqn.

$$E = \frac{\phi N 2}{60} \text{ for lap type as } p=1$$

$$E = \frac{\phi p N 2}{120} \text{ for wave type } -1=2$$

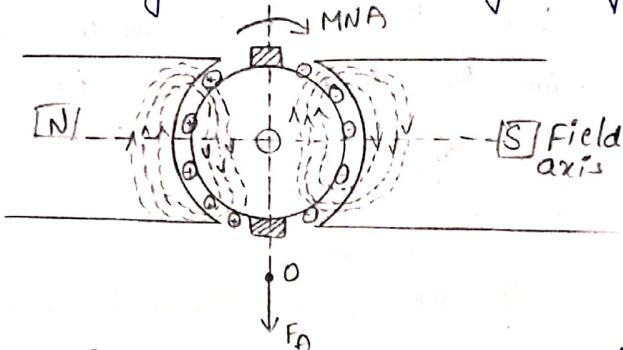
Armature Reaction :-



To understand the concept of armature reaction, consider a two pole d.c. generator. For simplicity we will assume that the brushes are touching the armature conductors directly, although, they touch commutator segments in actual practice.

The axis along which there is no e.m.f induced in the armature conductors is called magnetic neutral axis (MNA). From the fig. it can be seen that magnetic neutral axis and Geometric Neutral axis (GNA) coincides with each other. The geometric unit-1, page no: 10/27

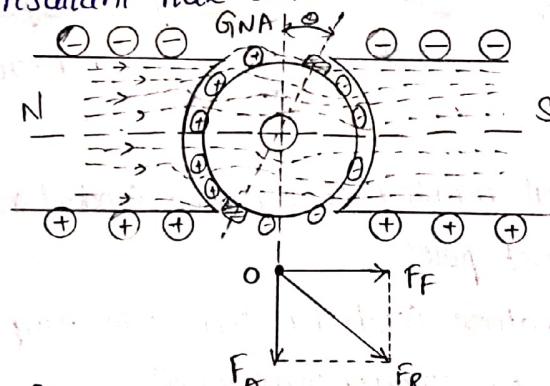
Neutral axis is nothing but the axis of symmetry between the poles.



As shown in figure vector  $F_A$  represents the mmf producing the main flux both in magnitude as well as in the direction. MNA is perpendicular to vector  $F_A$ .

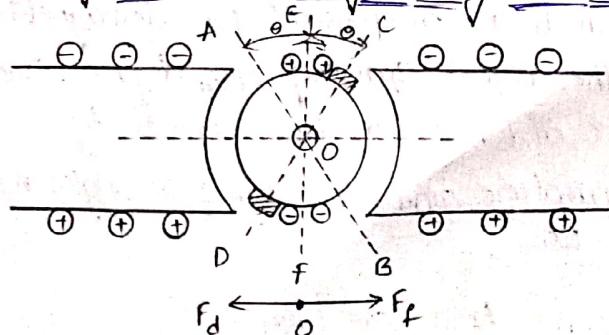
Now we will consider that the field coils are unexcited whereas the armature conductors are carrying current. Under this case the field set up by the armature conductors is as shown in the fig.

Now the flux through the armature is not uniform and symmetrical. The flux gets distorted. Due to interaction of two fluxes, the resultant flux distribution is changed as shown in fig.



The flux is crowded or concentrated at the trailing pole tips but weakened at the leading pole tips.

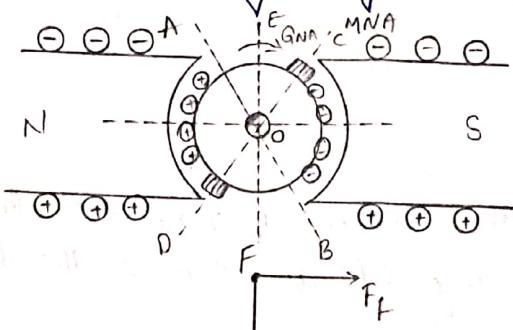
#### Demagnetising and cross Magnetising conductors:



The conductors which are responsible for producing demagnetising and distorting effects are shown in the Fig. unit-1, page no: 11/87

The brushes are lying along the new position of MNA which is at angle  $\theta$  from GNA. The conductors in the region

$AOC = BOD = 2\theta$  at the top and bottom of the armature are carrying current in such a direction as to send the flux in armature from right to left. Thus these conductors are in direct opposition to main field and called demagnetising armature conductors.



The remaining armature conductors which are lying in the region  $AOD$  and  $BOC$  carry current in such a direction as to send the flux pointing vertically downwards i.e. at right angles to the main field flux. Hence these conductors are called cross magnetising armature conductors which will cause distortion in main field flux. The conductors are shown in fig.

#### \* Calculation of Demagnetising and Cross Magnetising Amp-Turns.

Let us find the number of demagnetising and cross magnetising amp-turns.

Let

$Z$  = Total number of armature conductors.

$P$  = No. of poles.

$I$  = Armature conductor current in Amperes

=  $Ia/2$  for simplex wave winding.

=  $Ia/p$  for simplex lap winding.

$\Theta_m$  = forward lead of brush in mechanical degrees.

The conductors which are responsible for demagnetising ampere-turns are lying in the region spanning  $4\Theta_m$  degrees. The region is between angles  $AOC$  and  $BOD$ , as shown in the fig.

$\therefore$  Total no. of armature conductors lying in angles  $AOC$  and  $BOD$ .

$$= \frac{4\Theta_m}{360} \times Z$$

Since two conductors form one turn,

$$\text{Total no. of turns in these angles} = \frac{1}{2} \cdot \frac{4\Theta_m}{360} \times Z$$

$$= \frac{2\Theta_m}{360} \times Z$$

$$\therefore \text{Remagnetising amp-turns} = \frac{20m}{360} \times 72$$

$$\therefore \text{Demagnetising amp-turns/pole} = \frac{0m}{360} \times 72$$

$$\boxed{AT_d/\text{pole} = 2I \times \frac{0m}{360}}$$

The conductors which are responsible for cross magnetising ampere turns lying b/w the angles AOD and BOC, as shown in the fig.

$$\text{Total armature conductors/pole} = 2p$$

From above we have found an expression for demagnetising conductors per pole.

$$\text{Demagnetising conductors/pole} = 2 \times \frac{20m}{360}$$

$$\begin{aligned}\therefore \text{cross magnetising conductors/pole} &= \frac{2}{P} \left[ \frac{1}{P} + \frac{20m}{360} \right] \frac{2}{P} - 2 \times \frac{20m}{360} \\ &= 2 \left[ \frac{1}{P} - \frac{20m}{360} \right]\end{aligned}$$

$$\therefore \text{cross magnetising amp-conductors/pole} = 2I \left( \frac{1}{P} - \frac{20m}{360} \right)$$

Since two conductors form one turn

$$\begin{aligned}\text{cross magnetising amp-turns/pole} &= \frac{1}{2} \cdot 2I \left( \frac{1}{P} - \frac{20m}{360} \right) \\ &= 2I \left[ \frac{1}{2P} - \frac{0m}{360} \right]\end{aligned}$$

$$\therefore AT_c \text{ per pole} = 2I \left[ \frac{1}{2P} - \frac{0m}{360} \right]$$

#### \* Effects of Armature Reaction:-

1) The iron losses in the teeth and pole shoes are determined by the maximum value of flux density at which they work.

2) Due to armature reaction the maximum value of gap flux density increases. This will increase the maximum voltage b/w adjacent commutator segments at load.

#### \* Reduction of effects of Armature Reaction:-

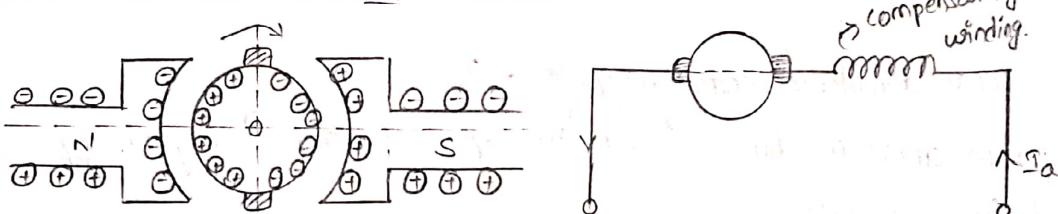
1) The armature Reaction causes the distortion in main field flux. This can be reduced if the reluctance of the path of the cross-magnetising field is increased.

2) If reluctance at pole tips is increased it will reduce distorting effect of armature reaction. Unit - 1 , page no: 13/37

3) The effect of armature reaction can be neutralized by use of compensating winding.

4) The armature reaction causes shifting the magnetic neutral axis. Therefore there will be some flux density at brush axis which produces e.m.f. coil undergoing commutation.

### use of compensating winding :-



The compensating windings are basically used to neutralize the armature flux in the pole arc region which will otherwise cause severe distortion of main field flux. These windings are of concentric type and are placed in axial slots in the pole faces as shown in fig.

The armature reaction causes the displacement of main field flux. It affects the waveform of main field flux and makes it non-uniform. The effect of armature reaction depends upon armature current which in turn depends on the load on the machine.

-Ampere turns per pole for compensating winding

$$= \frac{\text{pole arc}}{\text{pole pitch}} \times \text{Armature ampere turns/pole.}$$

$$\text{Total ampere conductors per pole} = \frac{I_a}{A} \cdot \frac{Z}{P}$$

since two conductors form one turn,

$$\text{Total ampere turns per pole in armature} = \frac{1}{2} \cdot \frac{I_a}{A} \cdot \frac{Z}{P}$$

$\therefore$  -Ampere turns per pole for compensating winding

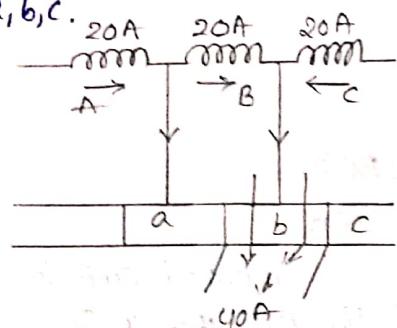
$$= \frac{I_a \cdot Z}{2AP} \times \frac{\text{pole arc}}{\text{pole pitch.}}$$

## \* Commutation:

The process by which the current in the short circuited armature coil is reversed while it crosses the magnetic neutral axis is called commutation.

### process of commutation-

let us consider a part of the ring winding for simplicity as shown in the fig. here the brush width is equal to the width of one commutator segment and one mica insulation. Armature coils are denoted by A, B, C and commutator segments are denoted by a, b, c.

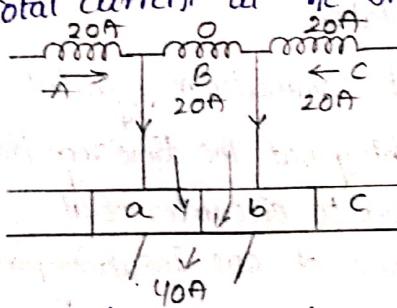


In fig. coil B is about to be short circuited. It is assumed that each coil carries 20A. so that brush current is 40A. In this figure coil B belongs to the group of coils laying to the left of the commutator.

segments. In coil B current is flowing from left to right. It is assumed that each coil carries 20A so that brush current is 40A.

In fig. coil B has entered its period of short circuit and is approximately at one third of this period. The current through coil B has reduced from 20 to 10A.

Now segment b carries 30A and segment c carries 10A. Total current at the brush being 40A.



The coil B is in the middle of short circuited period. The current through it has decreased to zero. The two currents of value 20A each pass to the brush directly from coil A and C as shown in the figure.

The brush contact areas with the two segments 'b' and 'a' are equal. Total current at the brush being 40A.

In fig. coil B has become part of

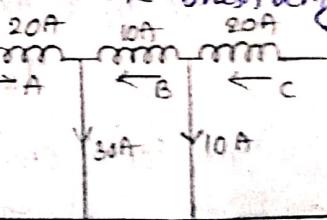
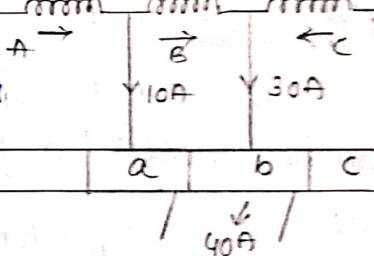
the group of coil lying to the right of the brush.

The brush contact area with segment 'b' is

decreasing whereas that with segment 'a'

is increasing. coil B now carries 10A in the

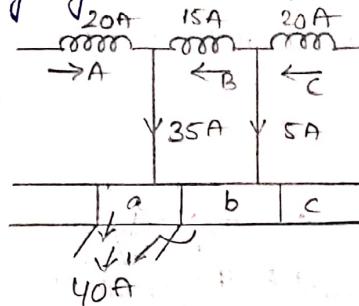
reverse direction which becomes combined with 20A of coil A to make 30A that passes from segment 'a' to the brush. The other 10A is



unit - 1 page no: 15/27

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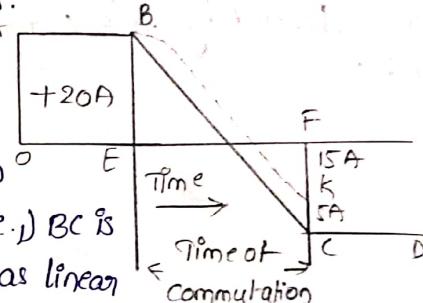
Supplied by coil 'c' and passes from segment 'b' to the brush giving a total of 10A at the brush.



In this fig. shows that the coil B is almost at the end of commutation or short circuit period. for ideal commutation current through it should have reversed by now.

But as shown it is carrying 15A instead of 20A. The difference of current between coils c and B (i.e.) 5A jumps directly from segment 'b' to the brush through air thus producing spark.

Fig. represents the changes of current through coil B are plotted on a time base of current through coil B changes from +20A to zero and then to -20A (i.e.) BC is a straight line. Then it is referred to as linear commutation. But due to the presence of self induced emf in coil B, the variation follows the dotted line BK, then it is referred to as under commutation.



#### \* Expression of Reactance Voltage :-

The e.m.f induced in the coil undergoing commutation can be calculated as follows,

Let

$w_b$  = Brush width

$w_m$  = width of mica insulation

$v$  = peripheral velocity of commutator segment.

The period of commutation is nothing but the time required by commutator to move a distance equal to circumferential thickness of the brush minus the thickness of one insulating plate.

If  $T_c$  is the time required for commutation then,

$$T_c = \frac{w_b - w_m}{v}$$

The total change in current during the process of commutation is  $\Delta I$ . Therefore self induced or reactance voltage is given by,

Self induced voltage = Co-efficient of self inductance  $\times$  Rate of change of current

$$\text{Self induced voltage} = L \times \frac{\Delta I}{T_c}$$

$$\text{Self induced voltage} = 1.11 \times L \times \frac{\Delta I}{T_c}$$

$L$  = Co-efficient of self inductance

$T_c$  = Time of commutation.

### Methods of Improving Commutation:-

There are two practical ways by which commutation may be improved. These methods are 1, Resistance commutation and 2, EMF commutation.

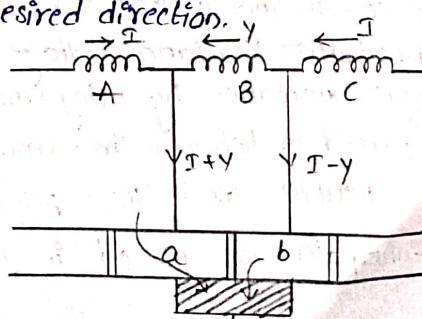
#### Resistance Commutation:-

In this method of improving commutation, the low resistance copper brushes are replaced by high resistance carbon brushes.

From the fig. it can be seen that the current  $I$  from coil  $C$  when passing through commutator segment 'b' has two parallel paths. one is straight from 'b' to brush while the other is through short circuited coil  $B$  to segment 'a' and then to the brush. By using low resistance copper brush the current will not prefer second path as it will prefer first low resistance path.

When carbon brushes having comparatively high resistance are used then current  $I$  through coil  $C$  will select the second path. as resistance  $r_1$  of first path will be increasing due to decrease in contact area of 'b' with brush and resistance  $r_2$  of second path will be decreasing due to increase in contact area of 'a' with brush.

Thus by increasing contact resistance b/w commutator segment and brushes, will limit short circuit current and reduce time constant ( $L/R$ ) of the circuit which will help in quick reversal of current in the desired direction.



### \* Advantages of Resistance commutation:-

- 1) upto some degree they are self lubricating and polish the commutator.
- 2) If sparking occurs, damage to commutator will be less as compared to when copper brushes are used.

### Disadvantages:-

1) There is a loss of approximately 2 volts due to high contact resistance. Hence this is not used in small machines.

2) larger brush holders are required due to lower current density (about  $7-8 \text{ A/cm}^2$ ).

### 2) EMF Commutation:-

The method in which reactance voltage produced is neutralized by the reversing e.m.f in short circuited coil is called e.m.f commutation. There are two ways of proving e.m.f commutation:

a) By giving a forward lead to the brushes.

b) By using interpoles.

### \* Giving Brush shift:-

If the brushes are shifted or forward or backward depending on generator or motor, a little beyond to magnetic neutral axis, the short circuited coil will come under the influence of main pole of opposite polarity. This will partly neutralized the reactance voltage which will help in quicks current reversal. This method is rarely used in practice as it will lead to many practical difficulties.

### \* Inter poles:-

This method is more suitable and actually used in



inter practice. In this method reversing e.m.f required to neutralize Reactance voltage is induced in the coil undergoing commutation by using small poles fixed to the yoke and placed in between the main poles. i.e along geometrical neutral axis. These poles are called Interpoles. practically interpoles are placed in b/w the main poles.

### \* Methods of Excitation:-

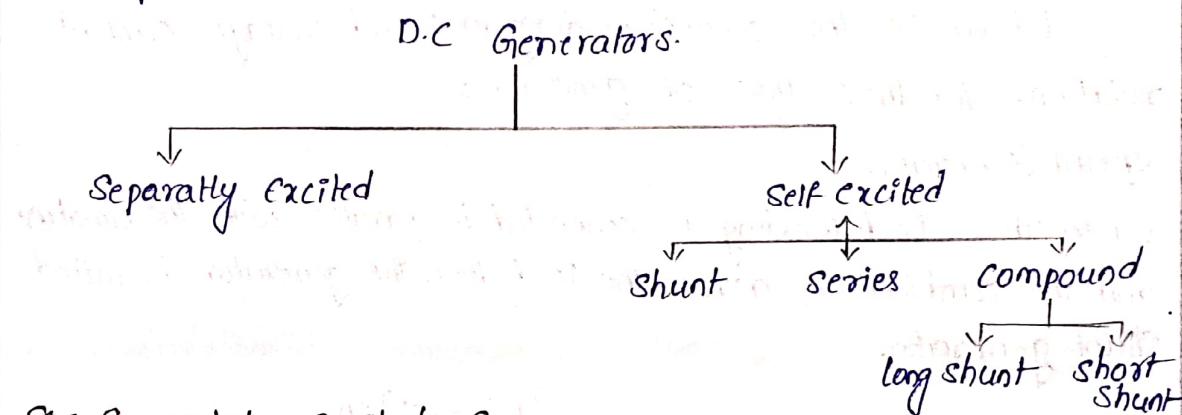
The magnetic field required for the operation of a.d.c generator is produced by an electromagnet. This electromagnet carries a field winding which produces required magnetic flux when current is passed through it.

thus supplying current to the field winding is called excitation and the way of supplying the exciting current is called Method of excitation.

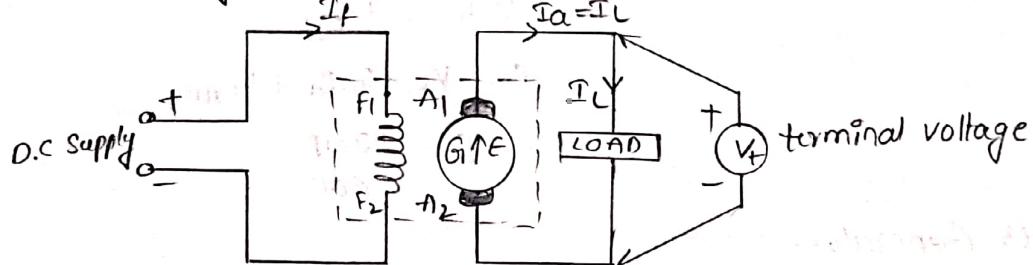
There are two methods of excitation used for d.c generator,

1. Separate excitation

2. Self excitation.



### \* Type Separately Excited Generators:-



when the field winding is supplied from external, separate d.c supply i.e. excitation of field winding is separate then the generator is called separately excited generator. Schematic representation of this type as shown in fig.

The field winding of this generator has large number of turns of thin wire. so length of such winding is more with less cross-sectional area. so reactance of this field winding is high in order to limit the field current.

### \* Self Excited Generators:-

when the field winding is supplied from the armature of the generator itself then it is said to be self excited generator.

practically through the generator is not working, without any current through field winding, the field poles possess some magnetic flux. This is called residual flux and the property is called residual magnetism.

Based on how field winding is connected to the armature to derive its excitation, this type is further divided into following three types.

i) Shunt Generator.

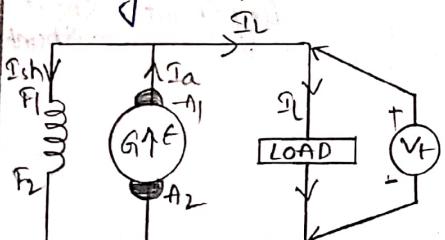
ii) Series Generator

iii) Compound Generator.

Let us see the connection diagrams and voltage, current relations for these types of generators.

### Shunt Generator:

When the field winding is connected in parallel with the armature and the combination across the load then the generator is called Shunt generator.



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

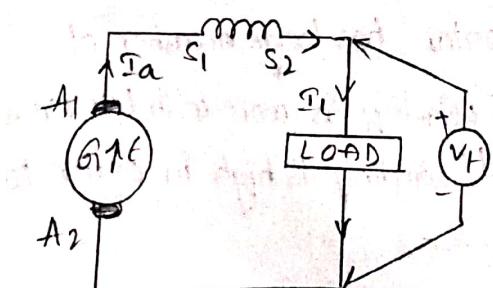
$$\therefore I_{sh} = \frac{V_t}{R_{sh}}$$

$$\therefore E = V_t + I_a R_a + V_{brush}$$

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

### Series Generator:

When the field winding is connected in series with the armature winding while supplying the load then the generator is called series generator. It is shown in fig.



$$\therefore I_a = I_{se} = I_L$$

$$\therefore E = V_t + I_a R_a + I_a R_{se} + V_{brush}$$

$$E = V_t + I_a (R_a + R_{se}) + V_{brush}$$

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

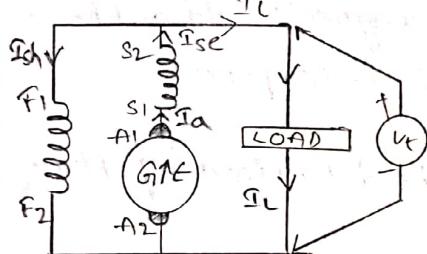
## \* Compound Generator:-

compound Generator are classified as 2 types.

- long shunt compound Generator.
- short shunt compound Generator.

## \* Long shunt compound Generators-

In this type, shunt field winding is connected across the series combination of armature and series field winding as shown in fig.



$$\therefore I_a = I_{sc}$$

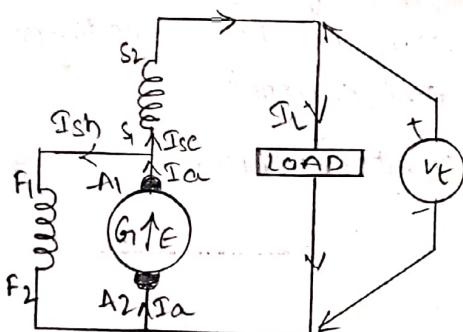
$$I_a = I_{sh} + I_L$$

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

$$E = V_t + I_a R_a + I_a R_{sc} + V_{brush}$$

## \* Short shunt compound Generators-

In this type, shunt field winding is connected, only across the armature, excluding series field winding as shown in fig.



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

$$I_{se} = I_L$$

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

$$I_{sh} = \frac{E - I_a R_a}{R_{sh}}$$

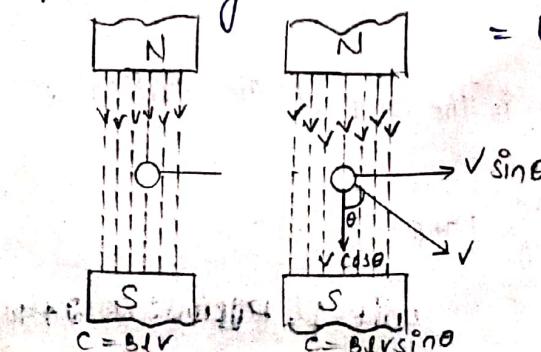
$$E = V_t + I_a R_a + I_a R_{se}$$

## \* Build-up of E.M.F-

consider a single conductor of length l meters moving at right angles to a uniform magnetic field of flux density B wb/m<sup>2</sup>. with a velocity of v meters/second. Suppose the conductor moves through a small distance dx in dt seconds. Then area swept by the conductor  $\theta_s = l \times dx$

$\therefore$  flux cut by conductor  $d\phi = \text{flux density} \times \text{area swept}$

$$= Bd dx \text{ wb.}$$



According to Faraday's laws of electromagnetic induction  
emf  $e$  induced in the conductor is given by

$$e = N \frac{d\phi}{dt}$$

$$= \frac{B I dx}{dt}$$

If the conductors moves at an angle  $\theta$  to the magnetic field  
then the velocity at which the conductor moves across the field is  $v \sin \theta$ .

The component  $v \cos \theta$  is parallel to magnetic field and hence no emf is induced in the conductor due to this component.

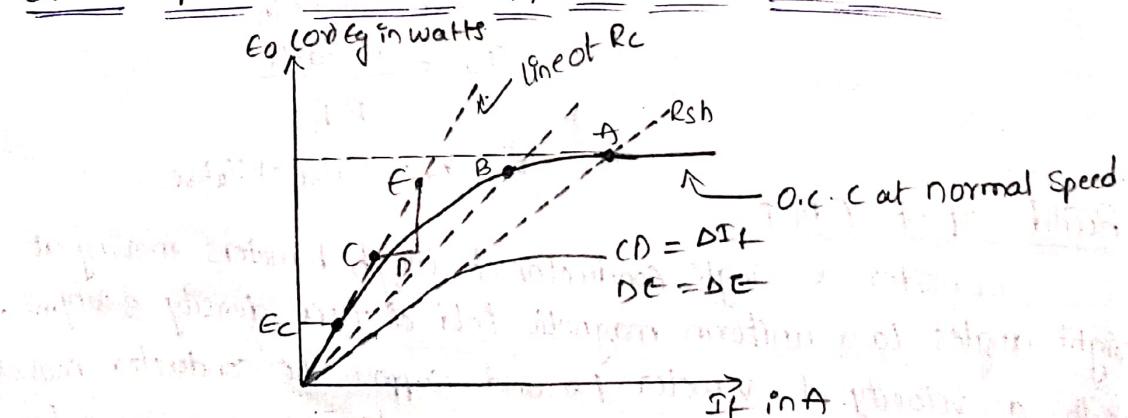
$$e = B I v \sin \theta$$

The direction of induced emf can be determined by Fleming's right hand rule.

#### \* Fleming's Right hand Rule:-

"stretch out the forefinger, middle finger and thumb of your right hand so that they are at right angles to one another. If the forefinger points in the direction of magnetic field, thumb in the direction of motion of the conductor, then the middle finger will point in the direction of induced emf. current".

#### \* Critical Field Resistance in D.C shunt Generators:-



"The value of the resistance represented by the tangent to the curve is known as critical resistance  $R_c$  for a given speed."

The critical resistance is the slope of the critical resistance line.

$$R_c = \frac{\Delta E}{\Delta I_f} = \frac{\Delta E}{C I}$$

### \* Critical Speed $N_c$ :

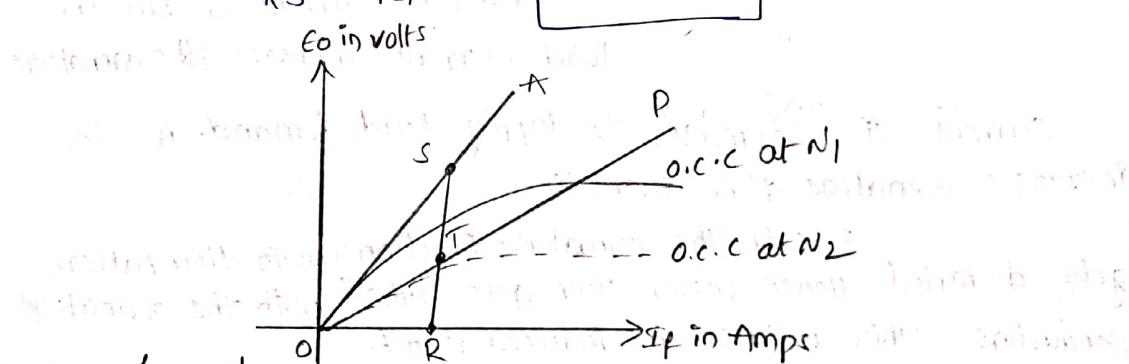
It is known that as speed changes, the open circuit characteristics also changes, similarly for different shunt field resistances, the corresponding lines are also different.

Thus if the line is drawn representing given  $R_{sh}$  then O.C.C drawn for such a speed to which this line is tangential to the initial portion, is nothing but the critical speed  $N_c$ .

Graphically critical speed can be obtained for given  $R_{sh}$ . The steps are,

1. Drawn O.C.C for given speed  $N_1$ .
2. Draw a line tangential to this O.C.C say OA.
3. Draw a line representing the given  $R_{sh}$  say OP.
4. Select any field current say point R.
5. Draw vertical line from R to intersect OA at S and OP at T.
6. Then the critical speed  $N_c$  is,

$$\frac{RT}{RS} = \frac{N_c}{N_1} \text{ i.e. } N_c = N_1 \frac{RT}{RS}$$

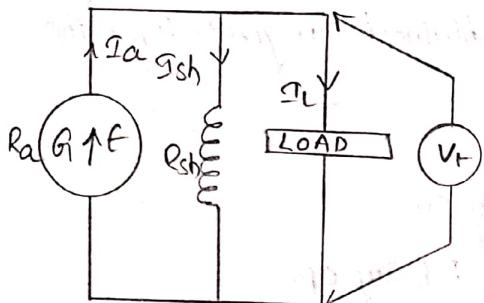


### \* Causes of failure to excite self excited Generators

S.NO	cause	Method of detection	Remedy
1.	Absence of residual magnetism due to ageing.	Zero Reading on voltmeter after rotating armature	Operate the generator as separately excited first and then as a self excited.
2.	wrong field winding connections. Due to this, flux gets produced in opposite direction to residual flux. so residual flux cancels the main flux	voltmeter Reading decreases rather than increasing as generator is started.	Interchange the field connections.

3.	field resistance is more than the critical Resistance.	voltmeter shows zero reading.	Reduce the resistance of field circuit using proper field divisor.
4.	Generator is driven in opposite direction.	This wipes out the residual flux and fails to excite.	Drive the generator in proper direction.

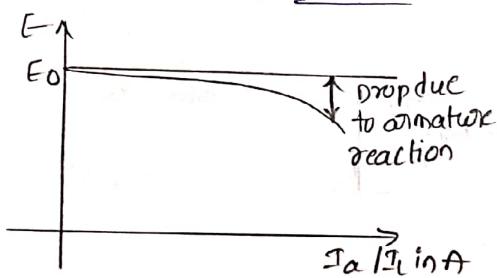
### \* Load characteristics of D.C shunt Generator:



consider the d.c shunt generator shown in fig. The internal characteristics is  $E$  vs  $I_a$ , while the external characteristics is  $V_t$  against  $I_L$ .

let us see the nature of this two characteristics.

#### Internal characteristics:

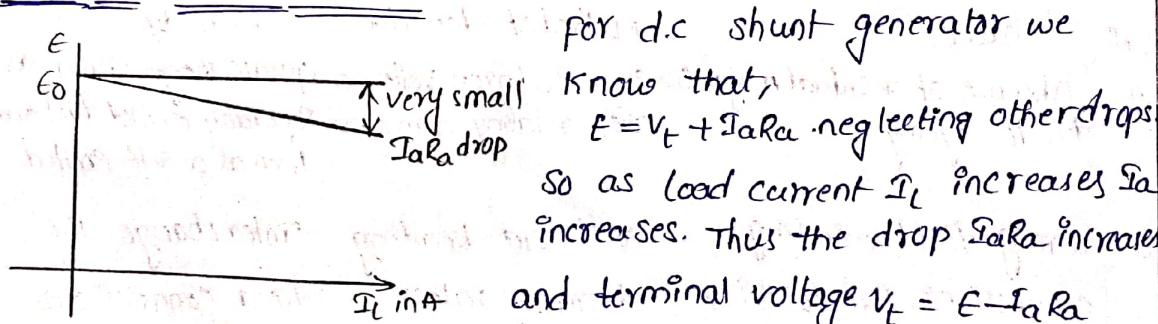


Ideally induced e.m.f is not dependent on the load current  $I_L$  or armature current  $I_a$ . But as load current increases, the armature

current  $I_a$  increases to supply load demand. As  $I_a$  increases, armature flux increases.

Due to the armature Reaction, main flux pattern gets distorted. Hence lesser flux gets linked with the armature conductors. This reduces the induced e.m.f.

#### External characteristics:



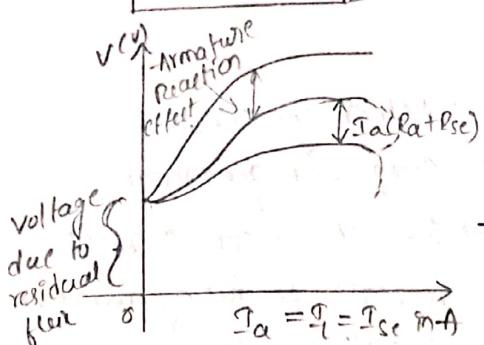
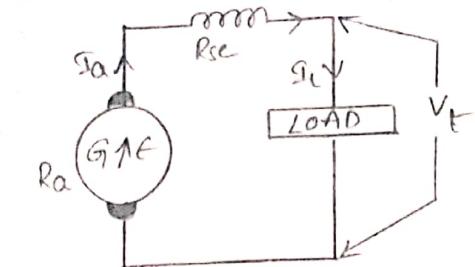
for d.c shunt generator we

know that,  $E = V_t + I_a R_a$  neglecting other drops

so as load current  $I_L$  increases  $I_a$  increases. Thus the drop  $I_a R_a$  increases and terminal voltage  $V_t = E - I_a R_a$  decreases. But the value of armature

Resistance is very small, the drop in terminal voltage as  $I_L$  changes from no load to full load is very small. This is shown in fig. Hence d.c shunt generator is called constant voltage generator.

## load characteristics of D.C series Generator:-



consider a series generator as shown in fig.

In case of series generator,

$$I_a = I_{se} = I_L$$

As load current increases,  $I_{se}$

increases. The flux  $\phi$  is directly proportional to  $I_{se}$ , so flux also increases.

The induced emf  $E$  is proportional to flux hence induced emf also increases. Thus

The characteristics of  $E$  against i.e internal characteristics is of increasing nature. As  $I_a$  increases, armature reaction increases

but its effect is negligible compared to increase in  $E$ . But for high load current, saturation occurs and flux remains constant.

In such case due to the armature reaction  $E$  starts decreasing as shown by dotted line in the fig.

Now as  $I_L = I_a$  increases, thus the drop  $I_a(R_a + R_{se})$  increases.

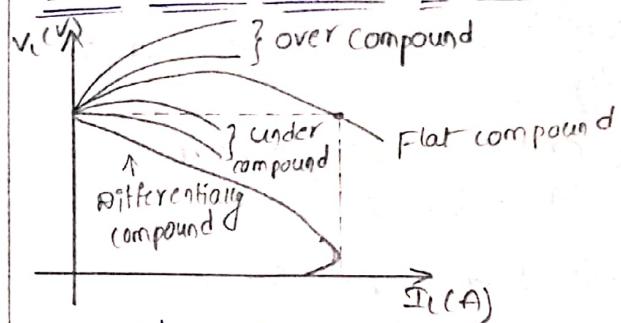
$$V_t = E - I_a(R_a + R_{se})$$

Thus the external characteristics is also of rising nature as  $I_L$  increases but it will be below internal characteristics due to drop  $I_a(R_a + R_{se})$ . This is shown in fig.

In self excited series generator, o.c.c can not be obtained. In o.c.,  $I_a = I_L = 0$ . hence induced e.m.f is zero. Thus o.c.c is possible only by separately exciting the field winding. It is also shown in fig.

In practice when there is no load  $I_L = 0$ , then there exists certain induced e.m.f due to residual flux retained by the field winding.

## \* Load Characteristics of D.C compound Generators:-



The characteristics depends on whether generator is cumulatively compound or differentially compound generator. In cumulatively compound,  $\phi_T = \phi_{sh} + \phi_{se}$ . As load current increases,  $I_a$  increases hence  $\phi_{se}$  also increase producing more flux. thus induced e.m.f increases and terminal voltage also increases.

But as  $I_a$  increases, the various voltage drops and armature reaction drop also increases. Hence there is drop in the terminal voltage.

If drop in  $V_t$  due to increasing  $I_L$  is more dominating than increase in  $V_t$  due to increase in flux then generator is called under compounded and its characteristics is dropping in nature.

If drop in  $V_t$  due to armature Reaction and other drops is much less than increase in  $V_t$  due to increase in flux then generator is called over compounded and its characteristics is rising in nature, as shown in fig. If the effects of the two are such that on full load current  $V_t$  is same as no load induced e.m.f i.e the effects are neutralising each other on full load then generator is called flat compounded or level compounded. Its characteristics is shown in fig.

In differentially compound,  $\phi_T = \phi_{sh} - \phi_{se}$ . The net flux is difference between the two. As  $I_L$  increases,  $\phi_{sh}$  is almost constant but  $\phi_{se}$  increases rapidly. Hence the resultant flux  $\phi_T$  reduces. Hence the induced e.m.f E and hence the terminal voltage also decreases drastically. There is drop due to armature resistance, series field resistance, armature reaction due to which terminal voltage drops further. Thus we get the characteristics of differentially compound generator as shown in fig.

\* Applications of DC Generators:-

S.NO	Type of Generator	Applications.
1.	Shunt Generator	Lighting and power supply purposes. Charging batteries.
2.	Series Generator	Arc lighting, series incandescent lighting, series booster, special purpose like supplying field current for regenerative breaking of DC locomotives.
3.	Compound Generator	level compounded generators are used to maintain constant voltage in DC distribution networks. over compounded generators are used to offset the voltage drop in feeders. Lighting and power services, Arc welding etc.

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