Chapter - 03
DC Generator

Generator → machine that converts mechanical energy into electrical energy.
→ Based on the principle of Faraday's law of electromagnetic induction.

Constructions parts of DC Generators

i) Yoke | Frame
ii) Field poles
iii) Field windings
iv) Armature core
v) Armature windings
vi) Commutators
vii) Brushes

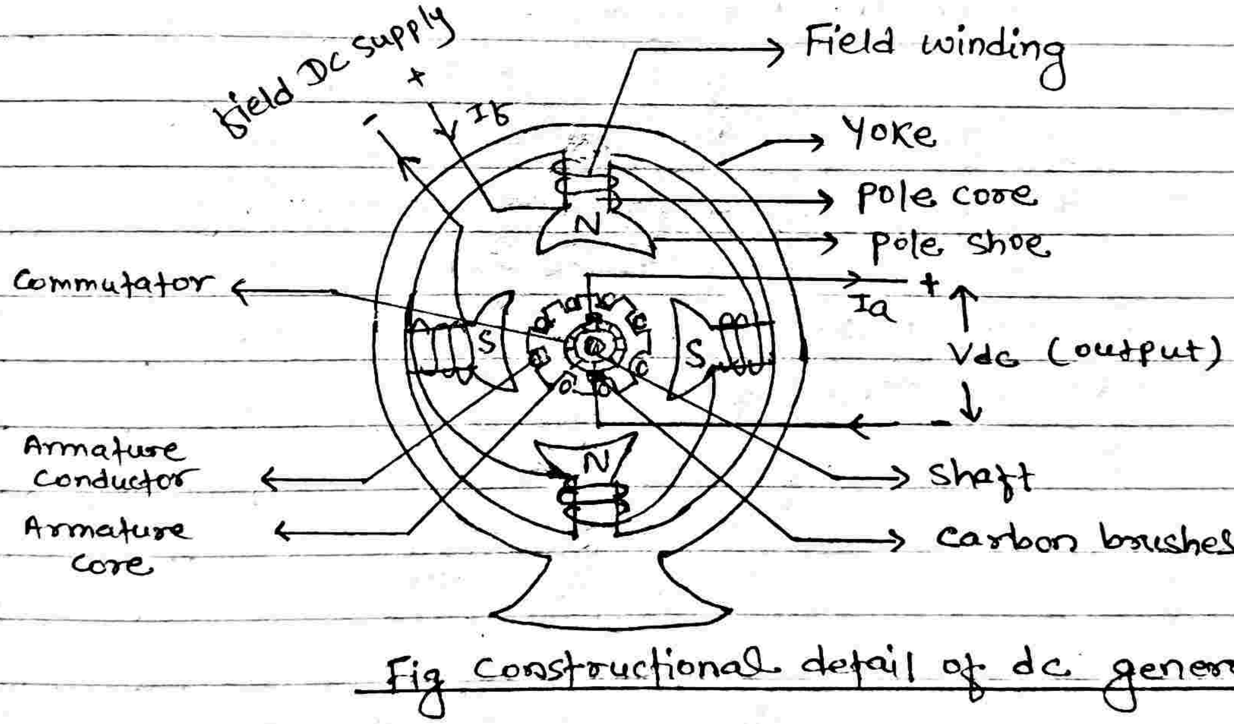


Fig Constructional detail of dc generators

i) Yoke → outermost frame.
→ Function | purposes → mechanical support for poles and cover for machines
→ carries magnetic flux produced by field poles.

Small machine → made of cast iron (for cheap)
large machine → made of cast steel | Rolled steel which have high permeability

ii) Field poles → Iron core projected from the yoke.
2 parts → a) pole core → upper part → support field winding
b) pole shoe → lower part
→ spread out flux in air gap and having larger cross sectional area which reduces reluctance of magnetic path.

iii) Field windings → copper wire wound on the field poles
→ windings are insulated from pole core
→ when dc currents passed through these coils, it will magnetise pole core and produce magnetic field in central space of machine.
→ Field coils are connected in such a way that adjacent poles have opposite polarity

iv) Armature core → Houses the armature conductor/winding and causes them to rotate and hence cut magnetic fluxes and emf is induced.

→ provides the path of very low reluctance to flux through armature from N-S pole
→ cylindrical shape, built of circular steel discs of lamination 0.5 mm thick.
→ The purpose of laminating the core is to reduce eddy current.

v) Armature windings →
→ The slots of armature core hold enamel insulated copper wire that are connected in suitable manner is known as armature windings.
→ This is the winding in which emf is induced.
→ The windings are connected in series - parallel connection.
Series connection → to increase voltage
parallel connection → to increase current.
→ Depending upon the manner in which armature conductor connected to the commutator segments, there are two types of armature windings in dc machine
a) Lap winding
b) wave winding

vi) Commutators →
→ mechanical rectifier which converts alternating voltage induced in the armature winding into direct voltage across the brushes.

→ Commutator converts ac into dc and vice versa

→ made up of copper Segments (known as commutator segment) insulated from each other by mica sheets and mounted on the shaft of machine little away from armature core.

→ The number of segments is equal to the number of armature coils.

vii) Brushes →

→ These are rectangular block shaped.

→ The brushes are housed in the rectangular box shaped brush holder.

→ The function of the brushes is to collect current from the commutator and supply it to the external load circuit.

→ Brushes are made up of carbon or graphite.

Types of armature windings

a) Lap windings

b) Wave windings

a) Lap windings → In this type of winding, finishing end(F1) of 1st coil is connected to the starting end S_2 of 2nd coil starting under the same pole as the starting end S_1 of 1st coil. The connector of F_1 and S_2 is connected to the commutator segment 2.

This process continue for the remaining of the coil.

→ Here coils overlaps each other so known as lap winding

→ No of parallel paths (A) = No of poles (P)

→ also known as parallel windings

→ Low emf induces compare to wave windings.

→ $\boxed{\text{No of brushes = Number of parallel paths} = A = P}$

→ used where Low voltage and high current is required.

→ For example : welding generator machine, Dynamometer etc.

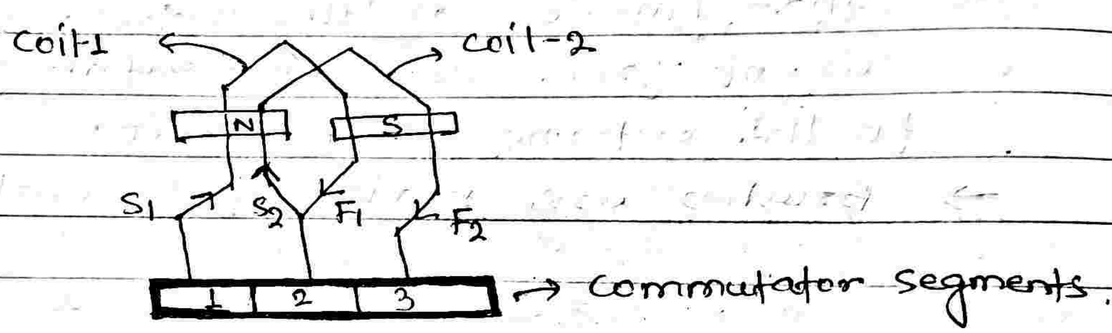


Fig Lap winding

b) wave windings → In this type of winding, finishing end of a coil is connected to the starting end of another coil under a different pole pair moving ahead. This process continues for remaining of the coils.

→ appearance of winding resembles that of a wave and is known as wave winding.

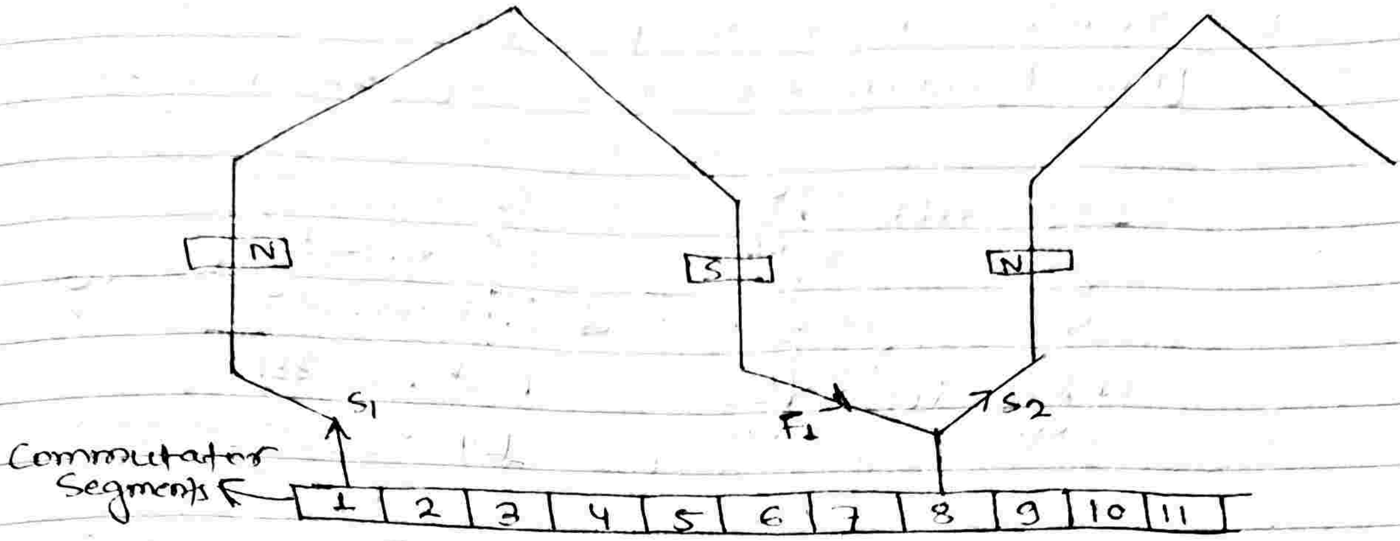


Fig wave winding.

→ Here Finishing end F_1 of the 1st coil is connected to the starting end S_8 of the 8th coil (for particular case) which is located under the similar pole (but one pole away) to one under which the 1st coil was started.

* (starting pole of coil-1 and coil-2 always same and ending pole of coil-1 and starting pole of coil-2 always opposite)

→ winding are connected in series so known as series winding

→ only two parallel path is provided between +ve and -ve terminal of brushes so $A = 2$ → No of parallel paths

→ $\boxed{\text{No of brush} = A = 2}$

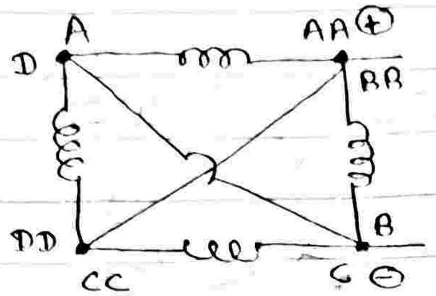
→ High emf is induced in this type of windings.

→ used where high voltage and low current is required.

→ increases machine efficiency.

Parallel path concept

→ Total number of path by which current will flow between terminal represented by -



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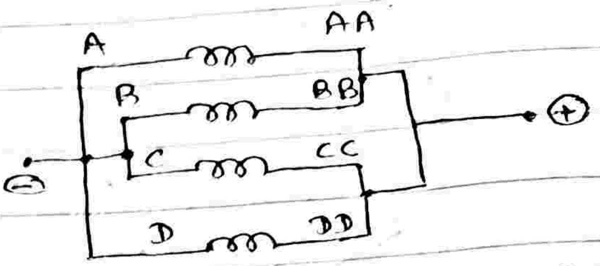
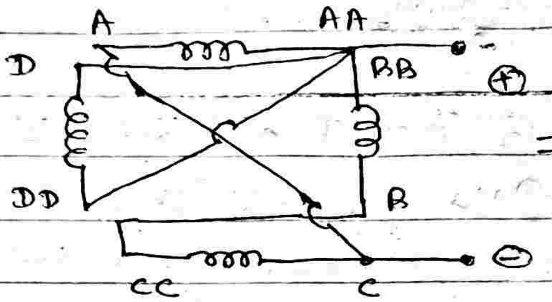


Lap winding arrangement



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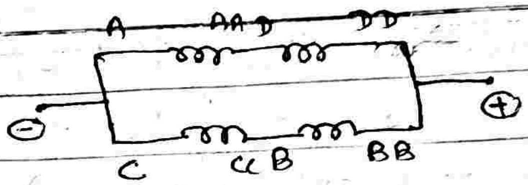


wave winding arrangement

Note -

a) Conductor - length of wire lying within magnetic field is known as conductor.

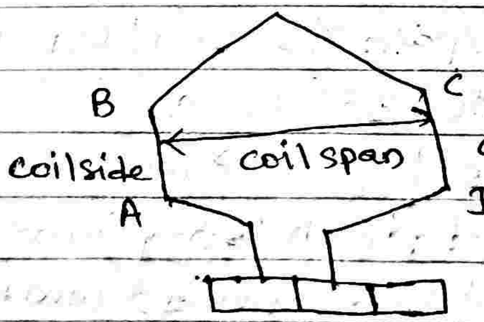
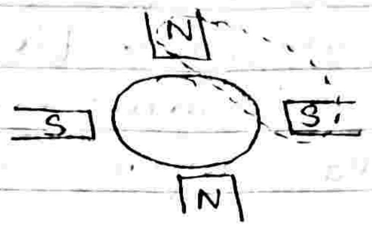


Fig ①

→ AB and CD are conductors but BC is not considered as conductor because emf will not induce in this part.

b) pole pitch → peripheral distance between two adjacent poles.



c) coil span → distance between two sides of a coil (as shown in fig ①).

cases -

i) If coil span = pole pitch (maxm emf induced)

→ winding is called full pitched winding

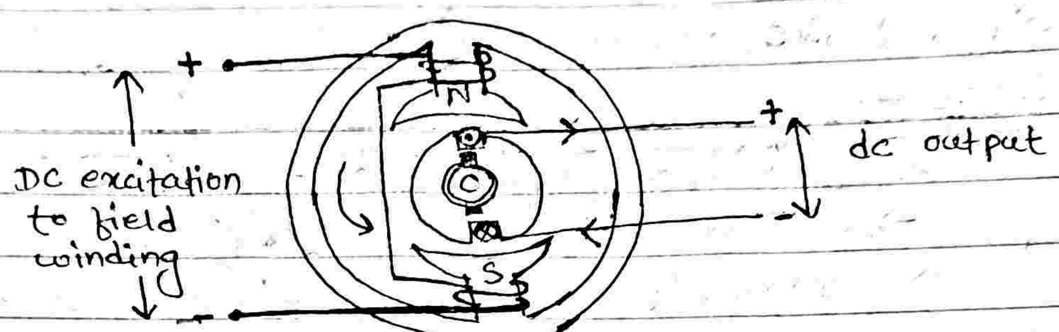
ii) If coil span < pole pitch (less emf induced)

→ the winding is called short pitched winding

Working principles and commutator action

→ The generator operates on the principle of Faradays law of electromagnetic induction, whenever a conductor is moved in a stationary (constant) magnetic field, an emf gets induced in the conductor which is known as dynamically induced emf.

→ Let us consider, 2pole dc machine



→ when field winding is excited by DC current, field pole gets magnetised and flux gets setup.

→ when armature is rotated continously by external force, armature conductor will cut magnetic flux continouly so according to Faradays law, emf will gets induced in armature coil.

→ The magnitude of emf is

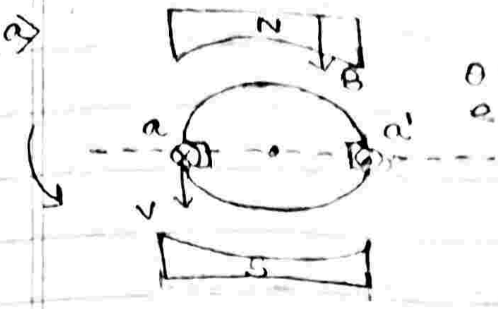
$$\boxed{e = Blv\sin\theta} \quad -\ (1)$$

where, B = magnectic flux density (wb/m^2)
l = length of the coil lying in magnetic field.
v = velocity of conductor
θ = angle between B and v.

⊗ current flowing inside ($\phi \rightarrow$ clockwise)

⊙ current flowing outside ($\phi \rightarrow$ anticlockwise)

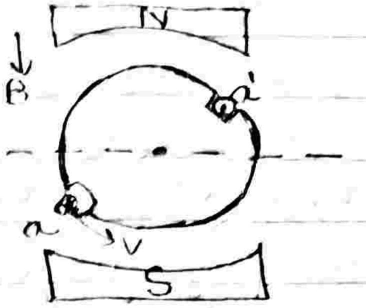
a)



$\theta = 0$

$e = Blv\sin\theta = 0$

b)

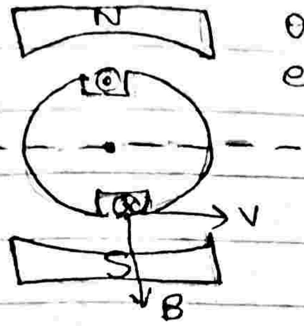


$\theta = 30^\circ$

$e = Blv\sin 30^\circ$

$= (E_m/2)$

c)

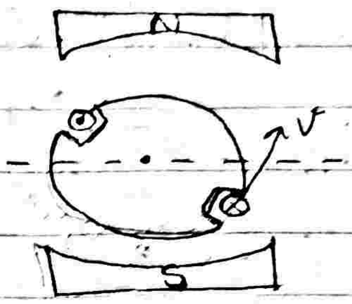


$\theta = 90^\circ$

$e = Blv\sin\theta$

$= (E_m)$

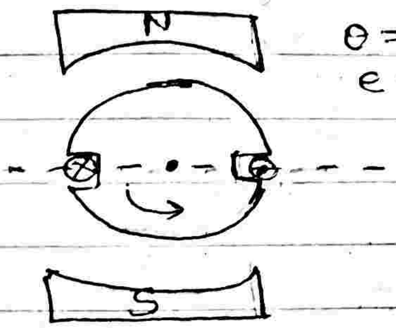
d)



$\theta = 135^\circ$

$e = 0.707\,E_m$

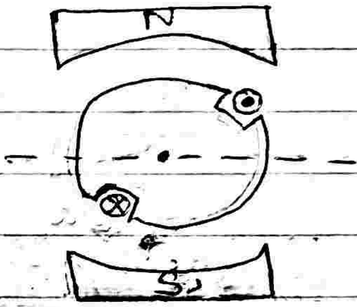
e)



$\theta = 180^\circ$

$e = 0$

f)



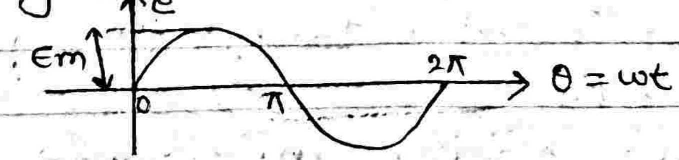
$\theta = 210$

$e = \left(-\frac{E_m}{2}\right)$

Similarly, $\theta = 270$, $e = -E_m$

$\theta = 360^\circ$, $e = 0$

The emf induced in coil terminal a-a' is alternating type -

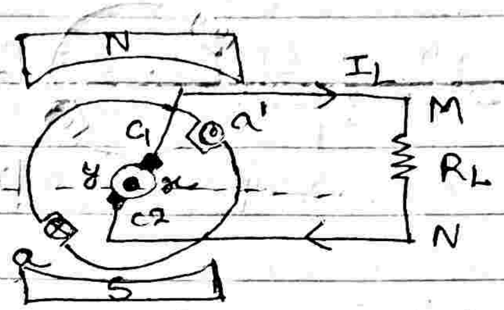


In absence of Commutator segments :

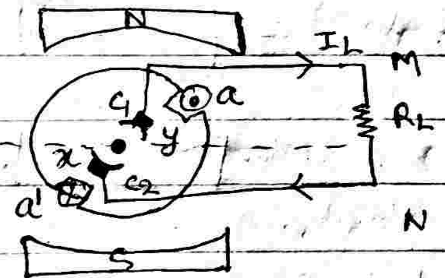
a) It is practically impossible to connect Stationary external load across the rotating armature. (brush used)

b) The emf induced across is ac so to obtain (convert) it into dc, commutator segments is required.

From figure (b) and (b)



$a' \rightarrow x \rightarrow c_1 \rightarrow M \rightarrow N \rightarrow c_2 \rightarrow y \rightarrow a$ (-ve cycle)



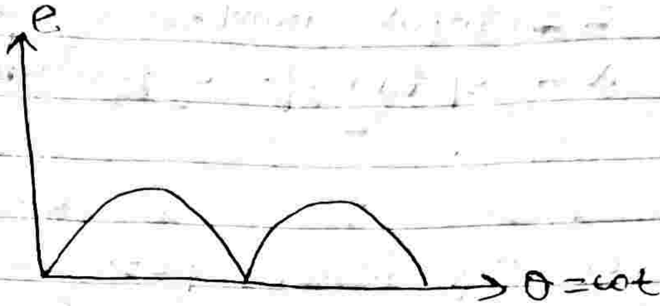
$a \rightarrow y \rightarrow c_1 \rightarrow M \rightarrow N \rightarrow c_2 \rightarrow x \rightarrow a'$ (+ve cycle)

→ The commutator segments rotated along with armature coil but carbon brush c_1 and c_2 are fixed touching over commutator segments surface.

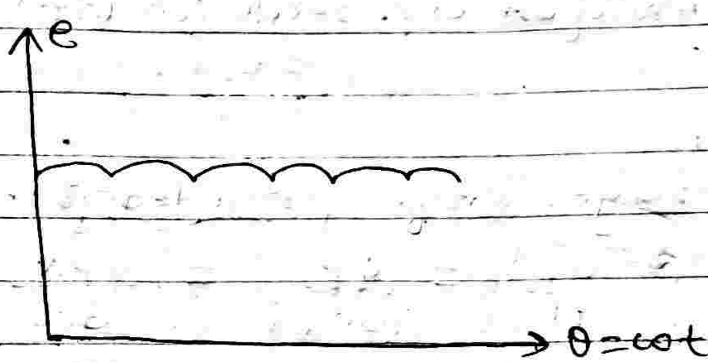
→ During half positive and negative cycle emf of coil condition current through load resistance.

flows in same direction after passing through commutator segments.

nature of emf across load will be unidirectional.



→ Finally, the o/p emf can be made smoother by adding number of armature coils.



Emf equation

Let, ϕ = magnetic flux per pole (wb)
P = magnetic pole number
Z = Total number of armature conductor.
N = speed of armature (rpm)

Now,

Average emf induced per conductor $= \frac{d\phi}{dt}$

magnetic flux cut by each conductor in one revolution $(d\phi) = \phi P$

Also,

Time for one revolution $(dt) = \left(\frac{60}{N}\right)$ Sec

Then,

Average emf generated per conductor

$$\left(\frac{d\phi}{dt}\right) = \frac{\phi P}{(60/N)} = \frac{\phi PN}{60} \text{ V}$$

A = no of parallel paths in armature windings

So, no of conductor in series $= \left(\frac{Z}{A}\right)$

$$\text{Total emf } (E) = \left(\frac{\phi PN}{60}\right) \times \frac{Z}{A}$$

$$\boxed{E = \frac{\phi PZN}{60A}} \text{ volts}$$

A = P for lap winding
A = 2 for wave winding

Types of DC generators

→ Generator is usually classified according to the way in which their fields are excited (methods of excitation):

- DC Generator
  - permanent magnet Generator
  - Seperately excited Generator
  - Self excited Generator
    - DC Shunt generator
    - DC series generator
    - DC compound generator
      - Long shunt DC generator
      - Short shunt DC generator

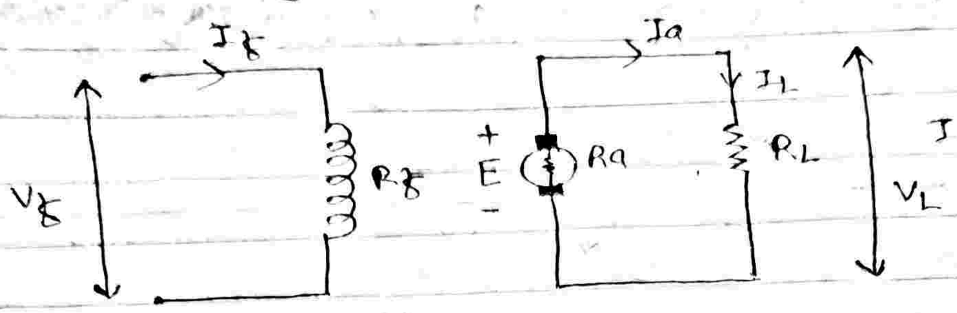
1) **Permanent magnet DC generator** -

When permanent magnets are used for establishing flux in magnetic circuit such generator is known as permanent magnent DC generator

→ employed only in small sizes like dynamos in cycle but not used in industrial applications.

2) **Seperately excited dc generators** -

A dc generator whose field windings is excited from an independent external dc source (battery) is known as seperately excited dc generators i.e there is no electrical connection between field and armature windings.



$I_a = I_L$

$\boxed{V_f = I_f R_f}$

$$E - I_a R_a - I_a R_L = 0$$

$$E - I_a R_a - I_L R_L = 0$$

$$E - I_a R_a - V_L = 0$$

$$\boxed{\therefore\ E = V_L + I_a R_a}$$

$$\boxed{E = V_L + I_a R_a + \text{Volt. drop of brushes}}$$

a) $V_f = I_f R_f$

b) $E = V_L + I_a R_a$

c) $E = V_L + I_a R_a +$ voltage drop of brushes [If V.d of brush given]

d) power developed by generator
$(P_G) = E I_a$

e) power delivered to load $(P_L) = V_L I_L$

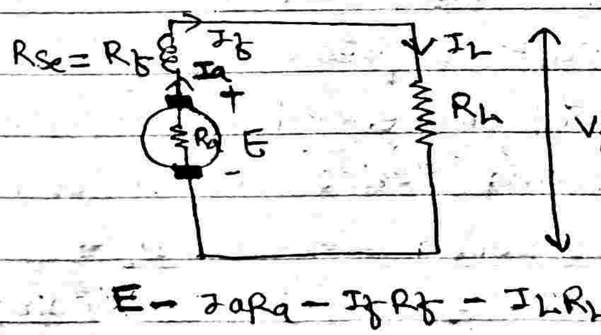
3) <u>Self excited dc generator</u> –
A dc generator whose field winding is excited by the current supplied by the generator itself is known as self excited dc generator.
→ i.e no external dc supply is required

→ In such machine, field winding are interconnected with armature winding either in series or parallel or partly series or partly parallel. Depending upon this, self-excited dc generator are categorised as:

a) DC series generator
b) DC shunt generator
c) DC compound generator → long shunt dc generator
→ short shunt dc generator

→ Due to residual magnetism, some flux is always present in the poles of such machines. When armature is rotated, a small voltage is induced in armature winding causes flow of small amount of current in field coils and increases flux per pole. Simultaneously, increase in flux, increases again induced voltage, field current and flux till rated voltage builds up.

3) a) <u>DC Series Generator</u> – Field winding is connected in series with armature winding so that whole current flows through the field winding as well as load.



$\boxed{I_a = I_f = I_L}$

$E - I_aR_a - I_fR_f - I_LR_L = 0$

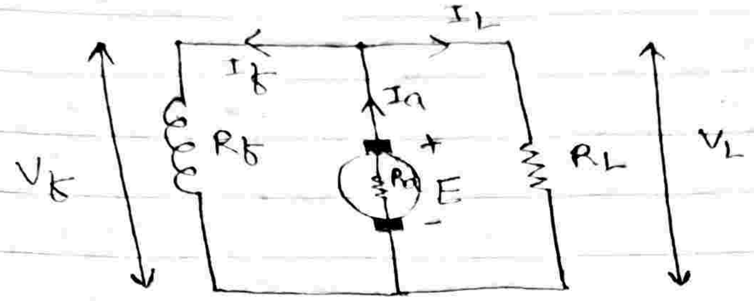
$E - I_aR_a - I_aR_f - V_L = 0$

$\boxed{E = I_a(R_a + R_f) + V_L}$

DC Series generator should always be started with load connected, otherwise no current flows then no I_f then no voltage build up.

3) b) Dc shunt Generator -

Field winding is connected across the armature circuit forming a parallel/shunt ckt.



$I_a = I_f + I_L$

$I_f = \frac{V_f}{R_f} = \frac{V_L}{R_f}$

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

$E - I_aR_a - I_LR_L = 0$

$E - I_aR_a - V_L = 0$

$\boxed{E = V_L + I_aR_a}$ or

$\boxed{E = V_f + I_aR_a}$

The dc shunt generator are always started without load because if started with load the voltage build up can not take place.

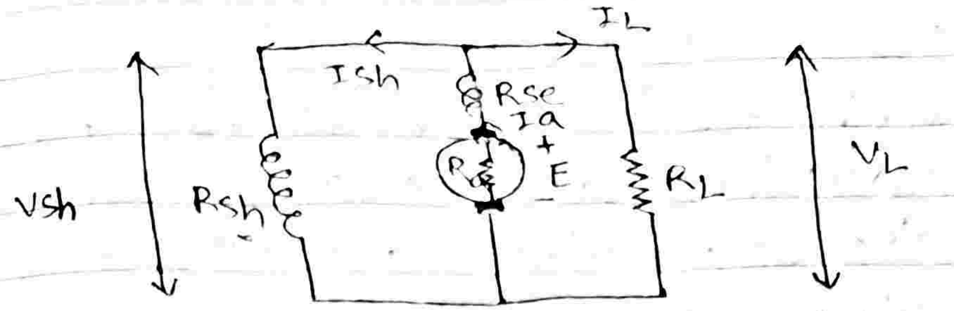
3)c) Dc compound Generator -

In this type of generator, there are two sets of field windings i.e one of them is connected in series with armature or load represented by Rse and another field winding set is connected across the armature circuit represented by Rsh.

→ Such generator will have mixed type of characteristics of shunt and series generator.

3)c) i) Long shunt dc compound generator -

In this type, series field winding (Rse) is connected in series with armature winding and shunt field winding (Rsh) is connected across the load.



Rse → series field winding

Rsh → shunt field winding.

$I_{sh} = \frac{V_L}{R_{sh}} = \frac{V_{sh}}{R_{sh}}$ $\boxed{I_a = I_{sh} + I_L}$

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

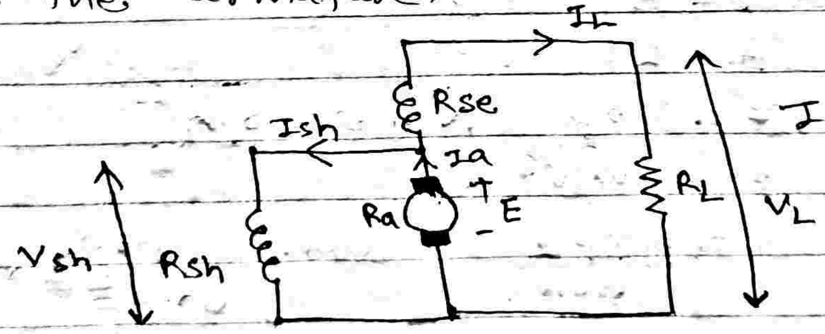
$E - I_aR_a - I_aR_{se} - I_LR_L = 0$

$E - I_a(R_a + R_{se}) - V_L = 0$

$\boxed{E = V_L + I_a(R_a + R_{se})}$

3)c)ii) <u>Short shunt DC compound generator</u> -

The series field winding (R_{se}) is connected in series with load and shunt field winding (R_{sh}) is connected across the armature.



$I_a = I_L + I_{sh}$

$I_{sh} = \frac{V_{sh}}{R_{sh}} = \frac{E - I_aR_a}{R_{sh}}$

$E - I_aR_a - I_LR_{se} - I_LR_L = 0$

$\boxed{E = I_aR_a + I_LR_{se} + V_L}$.

Note -

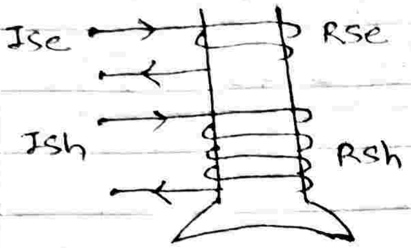
Compound generator also divided on two types:

a) Cumulative compound generator

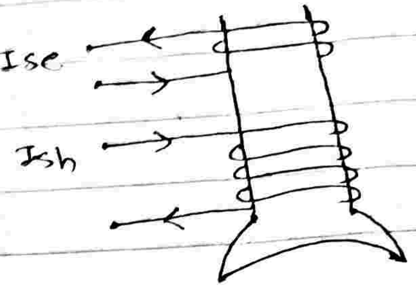
→ series field assist the shunt field

b) Differential compound generator

→ series field opposes the shunt field.



a) Cumulative compound generator



b) Differential compound generator

Q.1) A 4 pole, wave wound armature has 720 conductors and is rotated at 1000 rev/min. If the useful flux is 20mwb, calculate the generated voltage.

⇒ we have given

$P = 4$

$A = 2$

$Z = 720 \quad N = 1000$ rpm

$\phi = 20 \times 10^{-3}$ wb.

$$e = \frac{N \phi P Z}{60 A} = \frac{1000 \times 20 \times 10^{-3} \times 4}{60} \times \frac{720}{2}$$

$e = 480$ V

Generated voltage (e) = 480V.

Q.2) An 8-pole lap wound connected has 40 slots with 12 conductors per slot generates a voltage of 500V. Determine the speed at which it is running if the flux per pole is 50mwb.

=) Soln-

$P = 8 \qquad A = P = 8$

Z = No of slots × conductor per slot

$= 40 \times 12 = 480$

$E = 500V \qquad \phi = 50 \times 10^{-3}$ wb.

$N = ?$

$$E = \frac{N\phi PZ}{60A}$$

$$N = \frac{E \times 60 \times A}{\phi PZ} = \frac{500 \times 60}{5 \times 10^{-3} \times 480} = 1250 \text{ rpm}.$$

Q.3) A 8 pole generator has 500 armature conductors and has useful flux per pole of 0.065 wb. what will be emf generated if it is lap connected and runs at 1000 rpm? what must be the speed at which it is to be driven to produce the same emf if it is wave wound?

=) Soln-

<u>For lap wound</u>

$P = 8 \qquad Z = 500 \qquad A = P = 8$

$\phi = 0.065$ wb $\qquad N = 1000$ rpm $\qquad E = ?$

$$E = \frac{N\phi PZ}{60A} = \frac{1000 \times 0.065 \times 500}{60} = 541.67 \text{ V}$$

$E = 541.67$ V

For wave wound

$P = 8$ $Z = 500$ $A = 2$

$\phi = 0.065\,wb$ $E = 541.67V$ $N = ?$

$$E = \frac{\phi NPZ}{60A}$$

$$N = \frac{E \times 60 \times A}{\phi \times P \times Z} = \frac{541.67 \times 60 \times 2}{0.065 \times 8 \times 500} = 250\,rpm$$

$\therefore N = 250\,rpm$

Q.4) A seperately excited generator when running at 1000rpm supplied 200A at 125V. what will be the load current when speed drops at 800rpm if I_f is unchanged? Given $Ra = 0.04\Omega$ and brush drop = 2V.

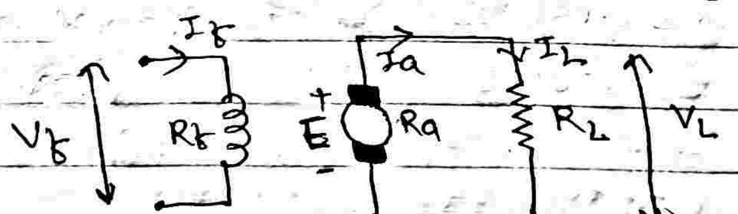
⇒ soln

we have given,

$N_1 = 1000\,rpm$ $Ra = 0.04\Omega$ $V_{brush} = 2V$

$I_{L1} = 200A$ $V_{L1} = 125V$

$I_{L2} = ?$ $N_2 = 800\,rpm$ (I_f = same)



$(I_a = I_L)$

$I_a = I_L$

$E_1 = V_{L1} + \overbrace{I_a}^{I_{L1}} R_a + V_{brushes}$

$E_1 = 125 + 200 \times 0.04 + 2 = 135\ V$

$E \propto \phi N \quad \hookrightarrow I_{L1}$

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

$$E_2 = \frac{800}{1000} \times 135 = 108\ V$$

Now, for new load current,

$E_2 = V_{L2} + I_{L2} R_a + V_{drop\ brushes}$

$108 = V_{L2} + I_{L2} \times 0.04 + 2$

$V_{L2} = 108 - I_{L2} \times 0.04 - 2$

$V_{L2} = (106 - I_{L2} \times 0.04)\ V$

Load resistance $(R_L) = \frac{V_{L1}}{I_{L1}} = \left(\frac{125}{200}\right) = 0.625$

$R_L = 0.625\Omega$

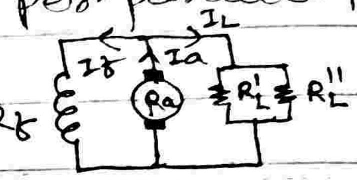
$$I_{L2} = \frac{V_{L2}}{R_L} = \frac{106 - I_{L2} \times 0.04}{0.625}$$

or, $0.625 I_{L2} = 106 - I_{L2} \times 0.04$

$\therefore I_{L2} = 159.4A$

Q.5) A 4 pole lap connected armature d.c. shunt generator is required to supply the loads connected in parallel, 5kw heater at 250V and 2.5kw light lamps at 250V. The generator has an armature resistance of 0.2 Ω, field resistance of 250 Ω. The armature has 120 conductors in slots and runs at 1000 rpm. Allowing 1V per brush for drop. find, i) flux per pole ii) Armature current per parallel path.

⇒ Soln -



We have given,

no of pole (P) = 4 $\quad V_L = 250V$

Total loads at 250V = (5+2.5) kw = 7.5kw

Armature resistance (R_a) = 0.2 Ω

field resistance (R_f) = 250 Ω

Total armature conductor (Z) = 120

Speed (N) = 1000 rpm

Brush Voltage drop = 1V/brush

flux/pole(ϕ) = ?

Armature current per path = ?

Load current (I_L) = $\frac{\text{total load}}{\text{Voltage}}$ = $\frac{7.5 \times 1000}{250}$

$I_L = 30A$

shunt field current (I_f) = $\frac{V_L}{R_f}$ = $\frac{250}{250}$ = 1A

Armature current (I_a) = $I_f + I_L$ = 1+30 = 31A

Now,

Generated emf $(E) = I_a R_a + V_L +$ Brushdrop

$= 31 \times 0.2 + 250 + 2 \times 1$

$E = 258.2V$

$$E = \frac{P\phi ZN}{60A}$$

$$\text{or, } \phi = \frac{E \times 60A}{PZN} = \frac{260.2 \times 60 \times 4}{4 \times 120 \times 1000} \quad [A = P]$$

$\therefore \phi = 129.1$ mwb

Flux per pole $(\phi) = 129.1$ mwb

Armature current per parallel path $= I_a / A$

$= \frac{31}{4}$

$= 7.75A$

Q.6) A short-shunt compound generator delivers a load current of 30A of 220V and has $R_a = 0.05\Omega$, $R_{se} = 0.30\Omega$, and $R_{sh} = 200\Omega$. Calculate the induced emf and armature current. Allow 1V per brush for contact drop.

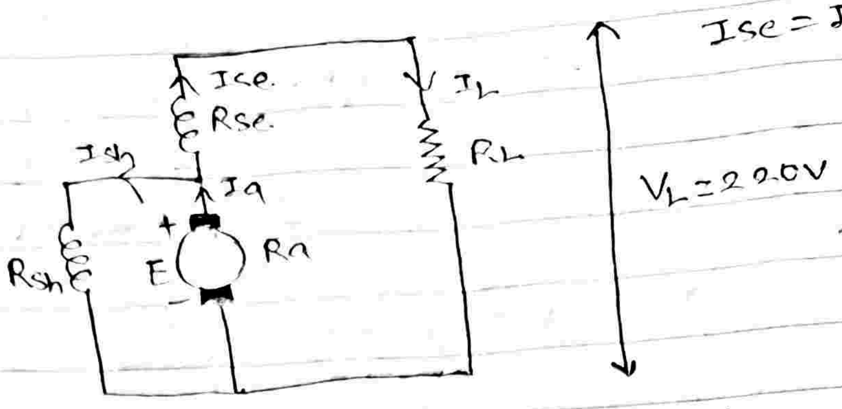
$\Rightarrow$ Soln –

we have given,

$I_L = 30A$ $V_L = 220V$

$R_a = 0.05\Omega$ $R_{se} = 0.3\Omega$ $R_{sh} = 200\Omega$ $V_{brush} = 1V$ per brush

$E = ?$ and $I_a = ?$



Voltage across shunt field winding

$(V_{sh}) = I_L R_{se} + V_L$

$= 30 \times 0.3 + 220$

$V_{sh} = 229V$

Current in shunt field winding $(I_{sh}) = \frac{V_{sh}}{R_{sh}}$

$= \frac{229}{200}$

$= 1.145A$

$I_{sh} = 1.145A$

Armature current $(I_a) = I_{sh} + I_L = 30 + 1.145$

$= 31.145A$

Induced emf $(E) = I_a R_a + I_L R_{se} + V_L + V_{brush}$

$= 31.145 \times 0.05 + 30 \times 0.3 + 220 + 2 \times 1$

$= 232.55V$

$E = 232.55V$

Characteristics of generator

→ Generator characteristics given the relation between terminal voltage and load current

→ It is important in judging the suitability of a generator for particular purpose.

Types of characteristics

a) No load characteristics

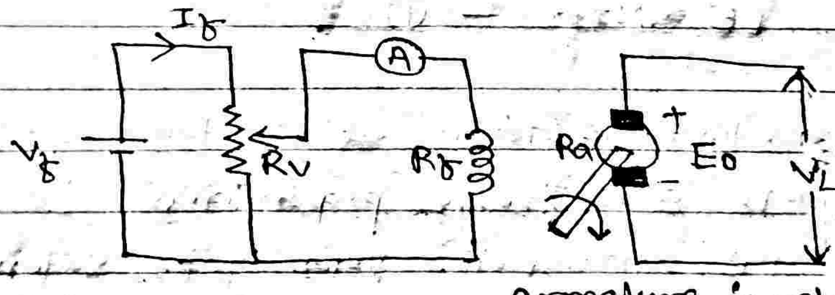
b) Load characteristics

a) **No load characteristics** –

→ It is a curve showing the values of emf generated across the armature at no-load for different value of field current at constant speed.

→ It is just a magnetisation curve for material of the electrical machine.

→ No load characteristics of seperately excited or self-excited generators can be obtained in similar way and shape of curves are same.



V_{Lo} = no load voltage

armature is rotated at constant speed

→ The armature of generator is rotated by a prime mover at constant speed and emf(E_0) is induced across the armature at different values of field current (I_f).

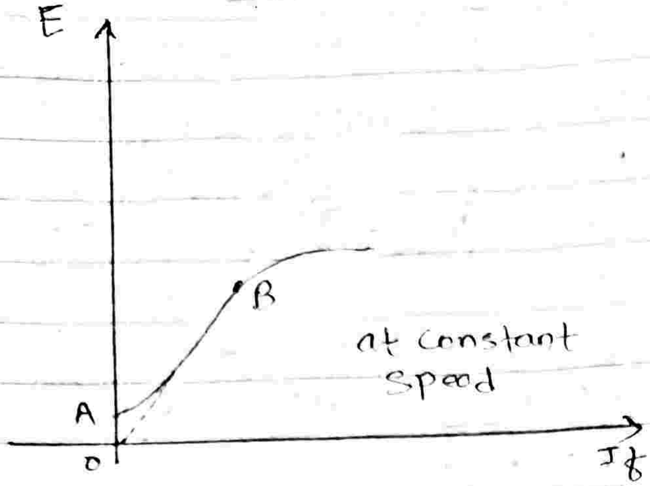


Fig open circuit curve

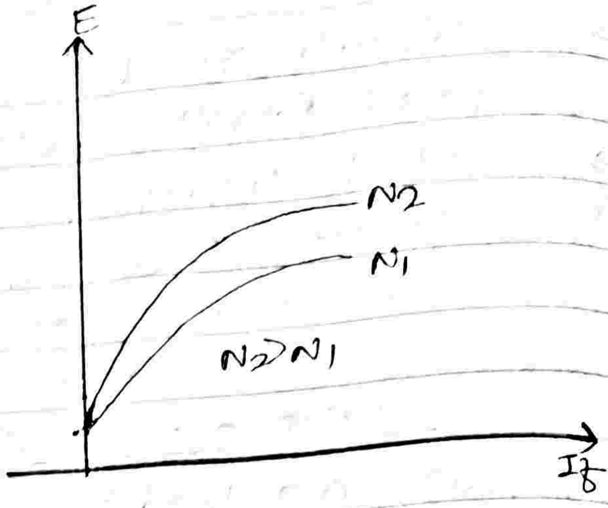


Fig OCC for different speed

→ From OCC curve, 'OA' is the emf generated across the armature due to residual flux in the pole even in the absence of field current (I_f).

→ we know,

$$E = \frac{N\phi P Z}{60 A} \quad \text{and} \quad \phi \propto I_f$$

$$E \propto N\phi \propto N I_f$$

$$\boxed{E \propto N I_f \quad - (1)}$$

→ Since armature is driven at constant speed so $E \propto I_f$ i.e up to B, E is directly proportional to field current

→ After point B, magnetic poles gets saturated and emf does not increase even if I_f increases

→ Also OCC for higher speed would lie above this curve and for a lower speed, would lie below it.

b) Load characteristics -

i) DC Series generator -

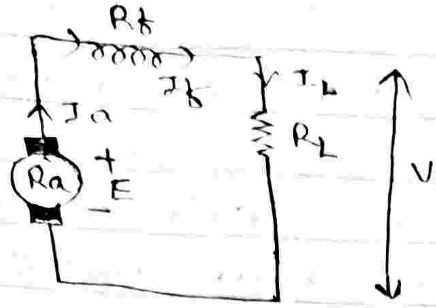


Fig. DC Series generator

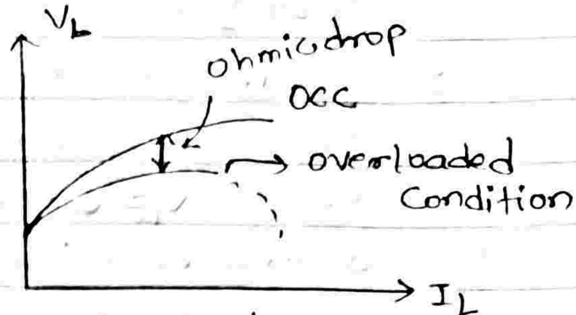


Fig Load characteristics

→ In this generator, $I_f = I_a = I_L$, So when I_L increases, I_f and I_a will also increases then voltage drop I_aR_a in armature will increase which will cause terminal voltage V_L to decrease.

$$E - I_aR_a - I_fR_f - I_LR_L = 0$$

$$\boxed{V_L = E - I_aR_a\uparrow - I_fR_f\uparrow}$$

→ On the other hand, I_f increases so flux per pole (ϕ) will increase which also increases emf ($E \propto \phi$) so terminal voltage (V_L) tends to increase up to saturation.

→ But at overloaded condition, the terminal voltage starts decreasing (as shown in dotted line) due to excessive demagnetising effect of armature reaction and saturation effect.

ii) DC Shunt generator -

→ For no-load, $I_L = 0$ and $I_a = I_f$ which is very small current than full load current so voltage drop in

armature i.e. I_aR_a is very small. $[V_L = E - \overset{0}{I_aR_a}]$
Hence, terminal voltage (V_L) is nearly equal to E
$[V_L = E]$

→ when generator is loaded, $I_L \uparrow$, $I_a = (I_L + I_f) \uparrow$
So, voltage drop in armature cannot be neglected
So, $V_L = E - I_aR_a$. Then terminal voltage (V_L) will decrease with increase in load current.

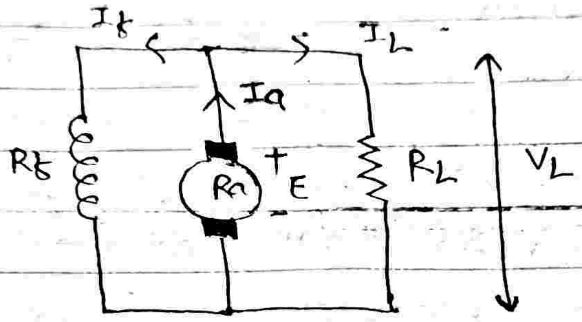


Fig. DC shunt generator

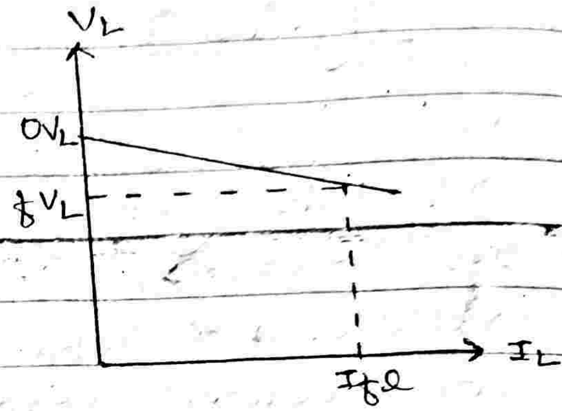


Fig. Load characteristics

Let,

oV_L = No load terminal voltage
fV_L = full load terminal voltage

$$\% \text{ Voltage regulation} = \frac{oV_L - fV_L}{fV_L} \times 100 \%$$

iii) DC Compound generator -

→ For DC shunt generator (DC shunt field winding) → dropping voltage characteristics.

→ For DC series generator (DC series field winding) → rising voltage characteristics.

→ So in either case, voltage regulation (VR) from No load to full is quite poor.

→ A compound generator has a characteristics between shunt and series generators which is formed by modifying a dc shunt generators to supply constant voltage by adding few turns of field winding in series with load or armature.

$I_a = I_L + I_{sh}$

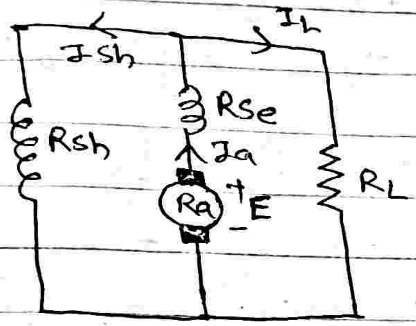


Fig long Shunt

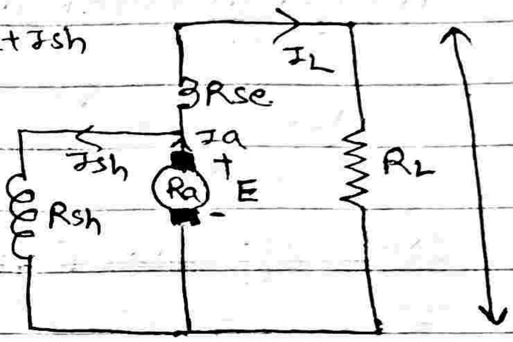


Fig. Short shunt

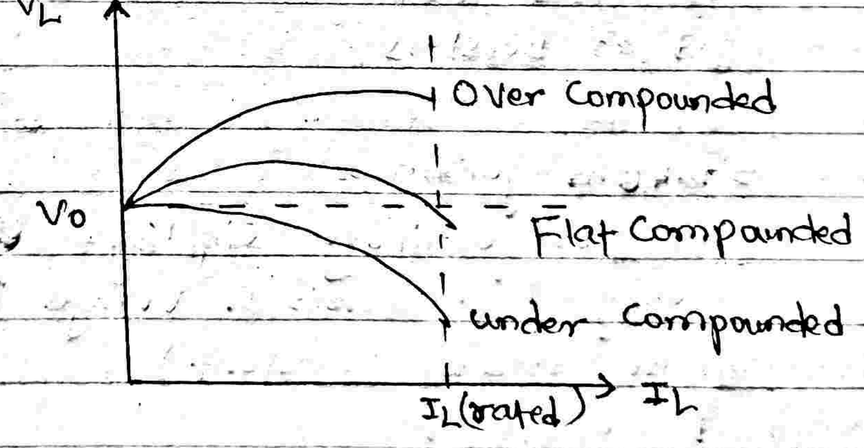


Fig. characteristics of compound generator

→ As load current $(I_L)\uparrow$ → current through series field winding also increases, thereby increasing the flux per pole. (ϕ) and $(E \propto \phi)$ emf also increases.

Therefore by adjusting no of series field winding turns, terminal voltage can be adjusted in different ways.

i) If series field amp-turns are such to produce same voltage at rated load as at no-load ⇒ gen is known as flat compound generator.

ii) voltage at rated load > no load voltage ⇒ over compound generator

iii) voltage at rated load < no load voltage ⇒ under compound generator.

Uses of DC Generators

1) DC Series generator

→ not used in power supply because of its rising voltage characteristics

→ used as boosters.

2) DC shunt generator

→ used for ordinary lighting, charging batteries, power supply (its terminal voltage is almost constant or can be made constant).

3) DC compound generator

a) cumulatively compound generator

→ widely used (lamp loads, motor driving at constant voltage)

b) Differential compound generator
→ Arc weilding

Losses in DC generators

There are various losses in a generator which are sub-divided as :

a) Copper losses – includes power loss in heating the shunt field, armature circuits (windings, brushes), series field, etc. Actual copper losses of the winding will depend upon effective resistance of windings for an operating condition.

i) Armature copper loss = $I_a^2 R_a$

R_a = armature resistance

→ This is about (30–40)% of full load losses.

ii) Field copper losses = $I_{sh}^2 R_{sh}$ or $I_{se}^2 R_{se}$.

→ This is about (20–30)% of full load losses.

b) Iron/core losses –

i) Hysteresis loss (W_h) –

→ loss due to reversal of magnetisation of armature core

→ Every portion of the rotating core passes under N and S poles alternatively, thereby attaining S and N polarity respectively. The core goes one complete cycle of magnetic reversal after passing under one pairs of poles.

$$\boxed{W_h = \eta B_{max}^{1.6} f V \text{ watt}}$$

where, V = volume of core (m^3)

η = Steinzman's constant

f = frequency of magnetic reversal

$f = (PN/120)$

ii) Eddy current loss (W_e) -

→ loss due to eddy currents set up in iron core.

→ This loss is considerable if solid iron is used so core is made up of thin laminations to reduce it.

$$\boxed{W_e = K B_{max}^2 f^2 t^2 V^2 \text{ watt.}}$$

⇒ Iron losses is practically constant for Shunt and Compound generator because of approximately constant field current.

⇒ (20-30) % of full load losses.

c) Mechanical losses -

→ power losses due to friction of the bearings, air friction or windage losses of rotating armature.

→ friction between brushes and commutators

→ (10-20) % of full load losses

→ Constant in machine operating at constant speed and independent of load.

Total losses

- Mechanical losses
  - Windage losses
  - Friction losses
- Iron losses
  - Eddy current losses
  - Hysteresis loss
- Copper losses
  - Field copper loss
  - Armature copper loss.

Stray losses

- Rotational losses
  - magnetic losses → constant loss
  - mechanical losses → constant loss

Constant loss → Field cu losses is constant in Shunt and compound generator when load voltage is constant. So stray losses plus Shunt cu losses are known as constant loss (Wc).

Power Stages

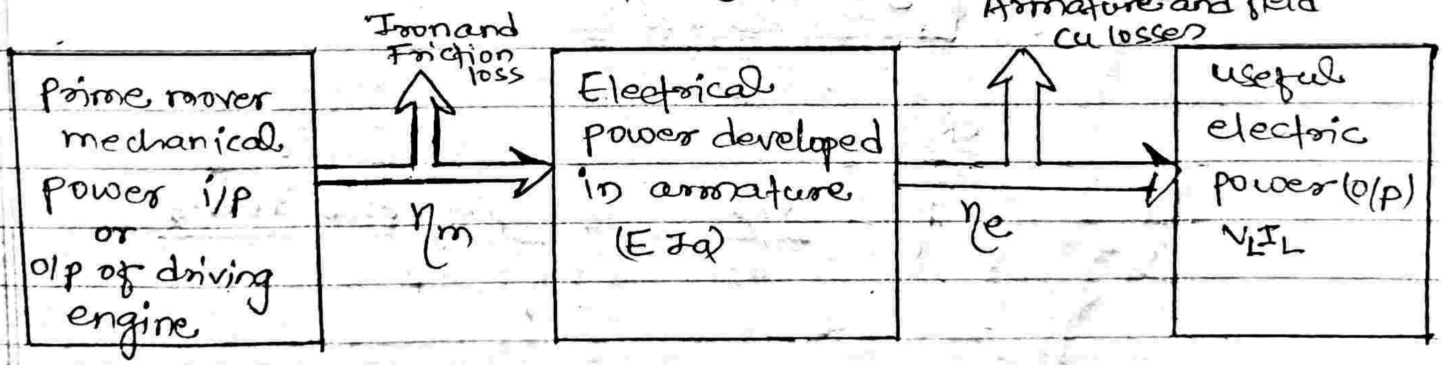


Fig. different power stages in dc generators

1) Mechanical efficiency (η_m) -

$$\eta_m = \frac{\text{total watts generated in armature}}{\text{mechanical power supplied}}$$

$$\eta_m = \frac{E I_a}{\text{BHP of prime mover} \times 735.5}$$

2) Electrical efficiency (η_e) -

$$\eta_e = \frac{\text{watt available in load ckt}}{\text{Total watts generated}}$$

$$\boxed{\eta_e = \frac{V_L I_L}{E I_a}}$$

3) Commercial / overall efficiency (η_c) -

$$\eta_c = \frac{\text{watt available in load ckt}}{\text{mechanical power supplied}}$$

$$\boxed{\eta_c = \eta_m \cdot \eta_e}$$

OR

$$\eta = \frac{o/p}{i/p} = \frac{i/p - \text{total losses}}{i/p} \text{ or } \frac{o/p}{o/p + \text{total losses}}$$

Condition for maximum efficiency

Generator o/p $= V_L I_L$

Generator i/p $=$ (o/p + losses) $= V_L I_L +$ Armature cu. loss + constant loss

$$= V_L I_L + I_a^2 R_a + W_C$$

$$= V_L I_L + (I_L + I_{sh})^2 R_a + W_C$$

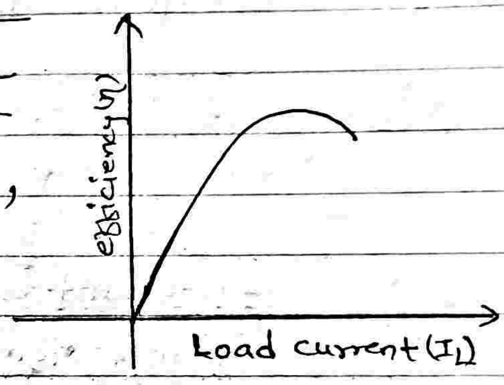
Ish is very small compared to I_L

$[I_a = I_L]$

$$\eta = \frac{o/p}{i/p} = \frac{V_L I_L}{V_L I_L + I_L^2 R_a + W_C}$$

$$\eta = \frac{V_L I_L}{V_L I_L + I_L^2 R_a + W_C}$$

$$\eta = \frac{1}{1 + \frac{I_L R_a}{V_L} + \frac{W_C}{V_L I_L}}$$



For maximum condition,

$$\frac{d\eta}{dI_L} = 0$$

$$\boxed{I_L^2 R_a = W_C}$$

$\therefore$ Variable loss = Constant loss

$$\therefore \; I_L = \sqrt{\frac{W_C}{R_a}}$$

where R_a is the total resistance of armature circuit (including brush resistance and resistance of series, interpole and compensating windings)

Voltage Regulation

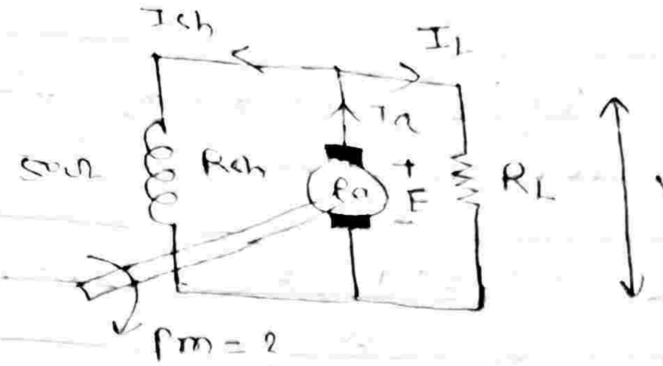
The change in terminal voltage of generator from full load to no load condition as a percentage of the terminal voltage of full-load

$$\boxed{V.R = \frac{OV_L - FV_L}{FV_L} \times 100\%}$$

→ used for determing the performance of generator
Lower the V.R → better it is.
i.e Generator with low V.R will have least variation in terminal voltage when load is reduced.

Q.1) A shunt generator delivers 195A at terminal P.d of 250V. The armature resistance and shunt field resistance are 0.02 Ω and 50 Ω respectively. The iron and friction losses are 950W. Find
a) emf generated b) Copper losses
c) o/p of prime mover d) η_c, η_m and η_e

⇒ soln -
We have given,
$V_L = 250V$
$I_L = 195A$ $R_a = 0.02\Omega$ $R_{sh} = 50\Omega$.



$I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{50}$

$I_{sh} = 5A$

$I_a = I_L + I_{sh} = 195+5$

$I_a = 200A$

a) Generated emf (E)

=> $E = I_aR_a + I_LR_L = 200 \times 0.02 + 250$

$= 254V.$

b) Total copper loss $= I_a^2R_a + I_{sh}^2R_{sh}$

$= (200)^2 \times 0.02 + (5)^2 \times 50$

$= 2050$ watt.

c) useful electrical power o/p = Pout = 250×195 = 4870 W

Total losses = (Copper + WC)

= 2050+950 = 3000W.

Total i/p electrical power (Pin) =(4870 + 3000)

= 51750 W.

Finally o/p power from prime mover

= total i/p electrical power

= 51750 W

d) $\eta_c = \frac{\text{useful power o/p (Pout)}}{\text{total i/p power}} \times 100\%.$

$\eta_c = \frac{48750}{51750} \times 100\% = 94.72\%.$

$$\eta_m = \frac{\text{Electrical power delivered}}{\text{Total i/p power}} \times 100\%$$

$$= \frac{48750 + 2050}{51750} \times 100\%$$

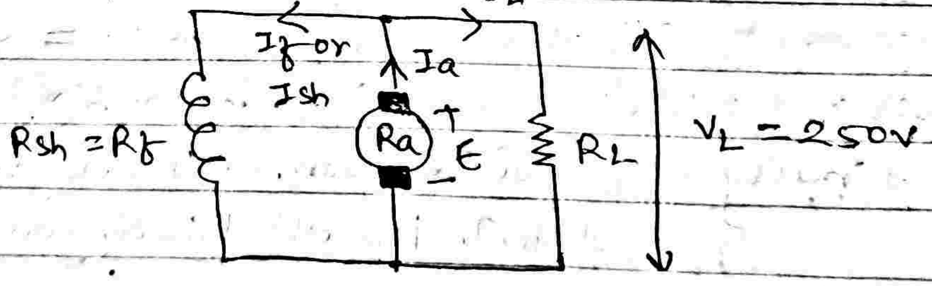
$$\eta_m = 98.16\%$$

$$\eta_e = \frac{\text{useful power o/p}}{\text{electrical power i/p}} \times 100\%$$

$$\eta_e = \frac{48750}{50800} \times 100\% = 95.96\%$$

Q.2) Calculate the overall efficiency of 250V, 100kW dc shunt generator at full load if the $R_a = 0.006$, $R_f = 25\Omega$. The core, friction and windage losses together are 3.2kW.

⇒ Soln -



$$V_L = 250V$$

$$P_{out} = 100kW$$

$$P_{out} = V_L I_L$$

$$100 \times 10^3 = 250 \times I_L$$

$$I_L = \frac{100\times10^3}{250} = 400A$$

$$I_f = V_L/R_f = 250/25 = 10A$$

$$I_a = I_f + I_L = 10 + 400 = 410A$$

Total copper losses $= (I_a^2 R_a + I_f^2 R_f)$

$= (410)^2 \times 0.006 + (10)^2 \times 25$

$= 3508.6\ W$

Constant loss $(W_c) = 3.2\times10^3\ W$

Total losses $= (3508.6 + 3.2\times10^3)\ W$

$= 6708.6\ W$

i/p power = o/p power + total losses

$= (100\times10^3 + 6708.6)$

$= 106708.6$

$$\eta = \frac{o/p}{i/p}\times100\% = \frac{i/p - \text{total losses}}{i/p}\times100\%$$

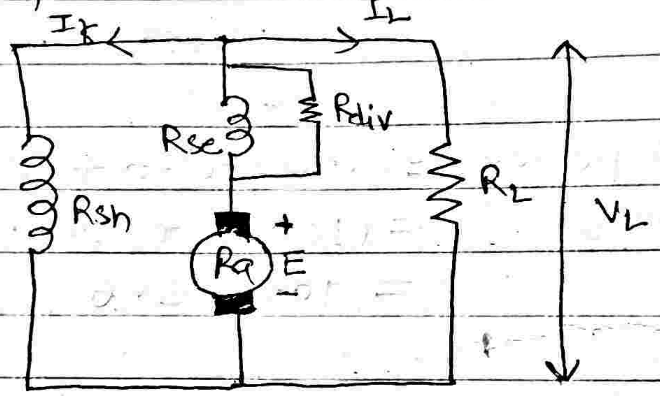
$$= \frac{106708.6 - 6708.6}{106708.6}\times100\%$$

$$\eta = 93.8\%$$

Q:3) In a long shunt compound generator, the terminal voltage is 230 V when it delivers 150 A. Determine i) Induced emf
ii) Total power generated by armature

Given,
Shunt field resistance $(R_{sh}) = 92\,\Omega$
Series field resistance $(R_{se}) = 0.015\,\Omega$
" " diverter $(R_{div}) = 0.03\,\Omega$
Armature resistance $(R_a) = 0.032\,\Omega$

⇒ soln -
Here,



$I_L = 150A$ $V_L = 230V$

Field current in shunt field winding $(I_f) = \frac{V_L}{R_{sh}}$

$= \frac{230}{92}$

$I_f = 2.5A$

Armature current $(I_a) = I_L + I_f = 150 + 2.5$
$= 152.5\ A$

Now,

Equivalent resistance of Rse and Rdiv be,

$$R_{se}' = \frac{R_{se} \cdot R_{div}}{R_{se} \cdot R_{div}} = \frac{0.015 \times 0.03}{0.015 + 0.03} = 0.01\Omega$$

i) $E - I_a(R_a + R_{se}') - V_L = 0$

$$E = 230 + 132.5(0.032 + 0.01) = 236.4V$$

= induced emf

ii) Total power generated by armature $(P_g) = I_a E$

$= 152.5 \times 236.4$

$= 36051.76W$.