ENERGY CONVERSION - I

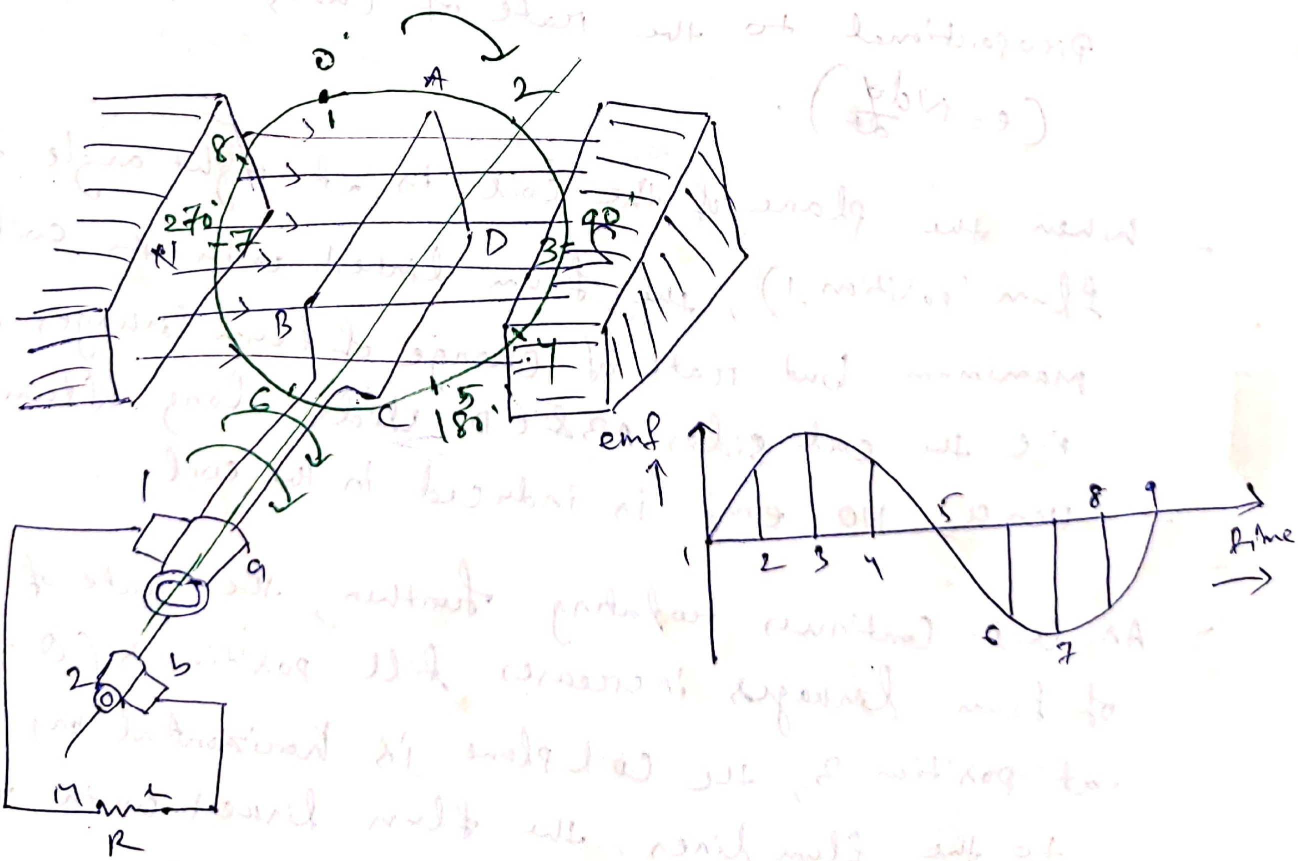
Prepared by
Srikanta Thakur

D.C. Generator

1.1 Operating Principle of Generator

- An Electrical Generator is a machine which converts mechanical energy into electrical energy.
- The energy conversion is based on the principle of the production of dynamically (or motionally) induced emf.
- Whenever a conductor cuts magnetic flux, dynamically induced emf is produced in it according to Faraday's Law of Electromagnetic Induction. This emf causes a current to flow ~~in the~~ if the conductor circuit is closed.

Construction



- The fig. shown is a single turn rectangular copper coil ABCD rotating about its own axis in the mag. field provided by either permanent magnet (or) electromagnets. The two ends of the coils are joined to two sliprings 'a' and 'b' which are insulated from each other and from the shaft. Two brushes are ~~con~~ press against the sliprings. The function of brushes is to collect current ~~fro~~ induced in the coil and convey to the external load resistance 'R'.

<u>Working</u>

- Imagine the coil is rotating in clockwise direction. The flux linked with the coil & cut the conductor. Hence, an emf is produced which is proportional to the rate of change of flux linkages $\left(e = N\frac{d\psi}{dt}\right)$.

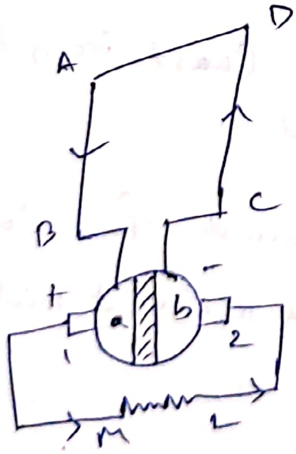
- When the plane of the coil is at right angle to the flux (position 1), the flux linked with the coil is maximum but rate of change of flux linkages is min. i.e the coil sides AB & CD slides along fluxes. Hence, NO emf is induced in the coil.

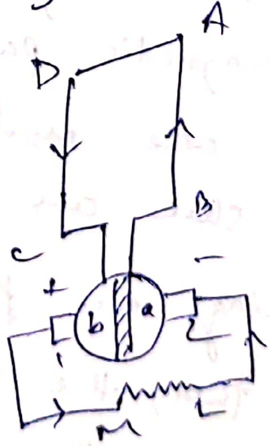
- As coil continues rotating further, the rate of change of flux linkages increases till position 3 ($\theta = 90°$). at position 3, the coil plane is horizontal (or) parallel to the flux lines. the flux linked with the coil is minimum but rate of change of flux linkages is maximum. Hence, maximum emf is induced in the coil.

- In the next quarter revolution (90° to 180°), the flux linked with the coil gradually increases but the rate of change of flux linkages decreases. Hence, Induced emf decreases gradually till position 5 of the coil & reduces to zero value.

- In the next half revolution, i.e from 180° to 360°, the variations in the magnitude of emf are similar to those in first half revolution. Its value is maximum when coil is in position 7 and minimum when in position 1.

- For making the flow of current unidirectional in the external circuit, the slip rings are replaced by split rings.
- Split rings are insulated from each other by thin sheet of mica insulating material.





1.2 Constructional ~~feat~~ features of DC machines

Yoke

- The outer frame or yoke serves two purpose:
  - (1) It provides mechanical support for the poles and acts as a protecting cover for the whole machine.
  - (2) It carries magnetic flux produced by poles.
- Yokes are made up of cast iron in small generators and cast steel / rolled steel in large machines.

pole

1.2.1 Pole and field windings

- ~~Pole~~ The field magnets consists of pole cores and pole shoes.
- Pole shoes spread out the flux in the airgap and also being the large crossSection, reduce the reluctance of the magnetic path.
- The pole are made up of cast iron / cast steel. but pole shoe are laminated.
- field windings are former wound for correct dimension. Then, the former is removed and put ~~into~~ ~~place~~ over the poles.

1-21.2 Armature

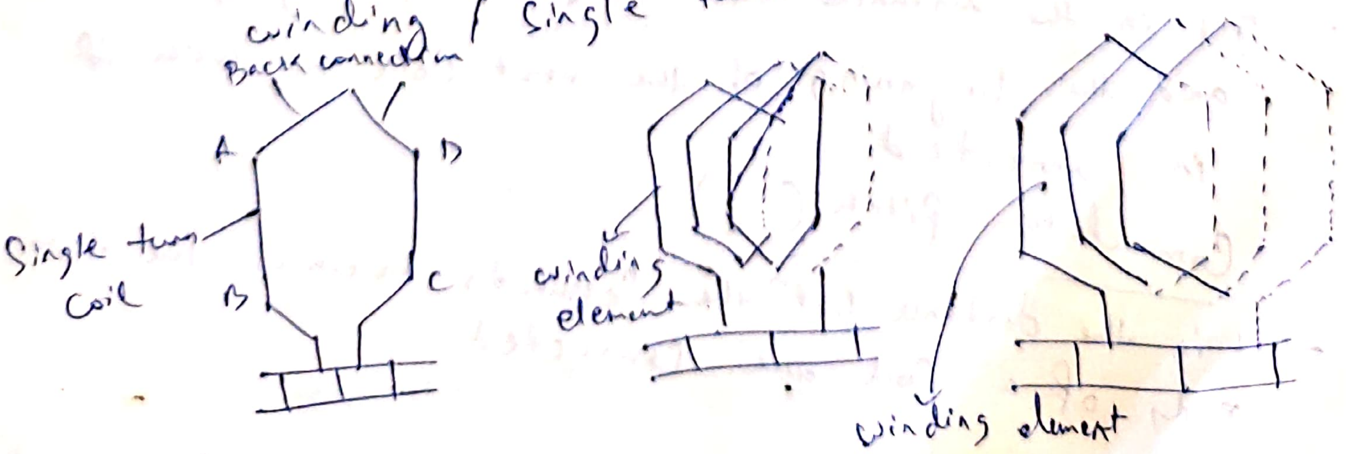
- The rotating part of the dc machine is called armature.
  The armature consists of a shaft upon which a laminated cylinder called armature core is mounted. The armature core has slots on its outer surface.
- The purpose of using lamination is to reduce the eddy current loss.
- The ~~armature~~ winding which is placed on the armature is called armature winding.

- Commutator

- To obtain direct current in the external circuit a commutator is needed. Commutator which rotates with the armature, is made from a no. of wedge shaped hard drawn copper bars insulated from each other and from shaft.
- Current is collected from the armature winding by using two or more carbon brushes mounted on the commutator.

Coil and winding element

- The two conductors AB and CD along with their end connections constitute one coil in armature winding / single turn coil.



- The side of a coil is called winding element.

Coil Span / Coil-pitch (Y_s)

- It is the distance between two sides of a coil.
- If the pole span (coil pitch) is equal to the pole pitch, the winding is called full pitched.

Pitch of the winding (Y)

- It is the distance between the ~~beggi~~ beginnings of two consecutive turns.

$$Y = Y_B - Y_F \quad \text{- for lap winding}$$

$$= Y_B + Y_F \quad \text{- for wave winding.}$$

Back pitch (Y_B)

- The distance between the conductors of a coil on the back of armature.

Front pitch (Y_F)

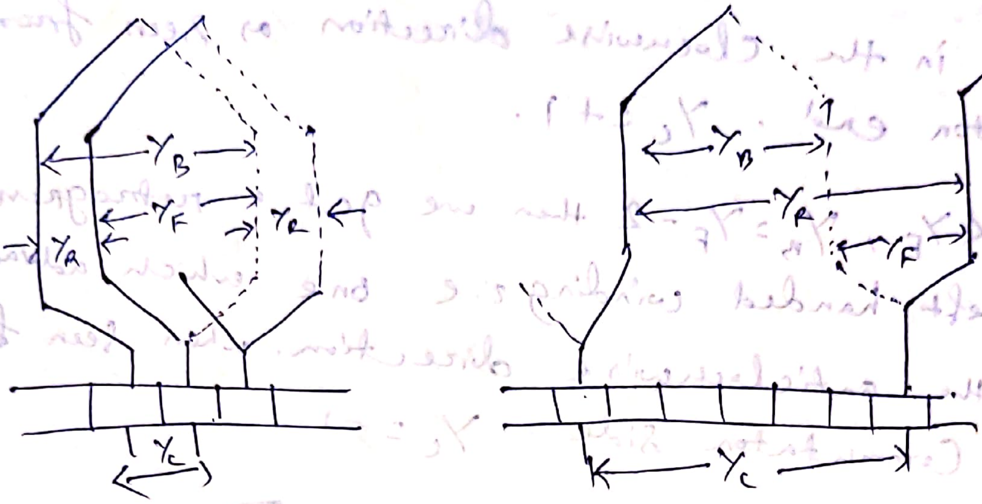
- The No. of armature conductors spanned by a coil on the front or commutator end of the armature.

Resultant pitch (Y_R)

- It is the distance between the beginning of one coil and the beginning of the next coil to which it is connected.

Commutator pitch (Y_a)

- It is the distance betn the segments to which the two ends of a coil are connected.



1.2.3 Simplex Lap winding

(1) The back and front pitches are odd and of opposite sign, but they cannot be equal. They differ by 2 or some multiple.

(2) Both Y_B and Y_F should be nearly equal to a pole pitch.

(3) The average pitch $Y_A = \frac{Y_B + Y_F}{2}$. pole pitch $= \frac{Z}{P}$.

(4) Commutator pitch, $Y_c = \pm 1$ $(\pm m)$

(5) Resultant pitch Y_R is even, i.e. $Y_B - Y_F = Y_R$

(6) The no. of slots for a 2-layer winding is equal to the no. of coils (i.e. half the no. of coil sides). The no. of commutator segments is also same.

(7) The no. of parallel paths in the armature $= mP$ where m is multiplicity of winding
$P =$ no. of poles.

(8) $Y_B = Y_F \pm 2$

(a) If $Y_B > Y_F$, $Y_B = Y_F + 2$, then we get a progressive or right handed winding i.e. a winding which progresses in the clockwise direction as seen from the Commutator end. $Y_c = +1$.

(b) If $Y_B < Y_F$, $Y_B = Y_F - 2$ then we get a retrogressive or Left handed winding i.e one which advances in the anticlockwise direction when seen from the Commutator side. $Y_c = -1$.

$Y_F = \frac{2}{P} - 1$, $Y_B = \frac{2}{P} + 1$ for progressive winding

$Y_F = \frac{2}{P} + 1$, $Y_B = \frac{2}{P} - 1$ for retrogressive winding.

Q. Draw a developed diagram of a simple 2-layer lap winding for a 4-pole generator with 16 coils. Hence, point out the characteristics of a lap winding?

Sol^n

No. of Commutator segments = 16

No. of Conductors / coil sides = $16 \times 2 = 32$

Pole pitch = $\frac{32}{4} = 8$

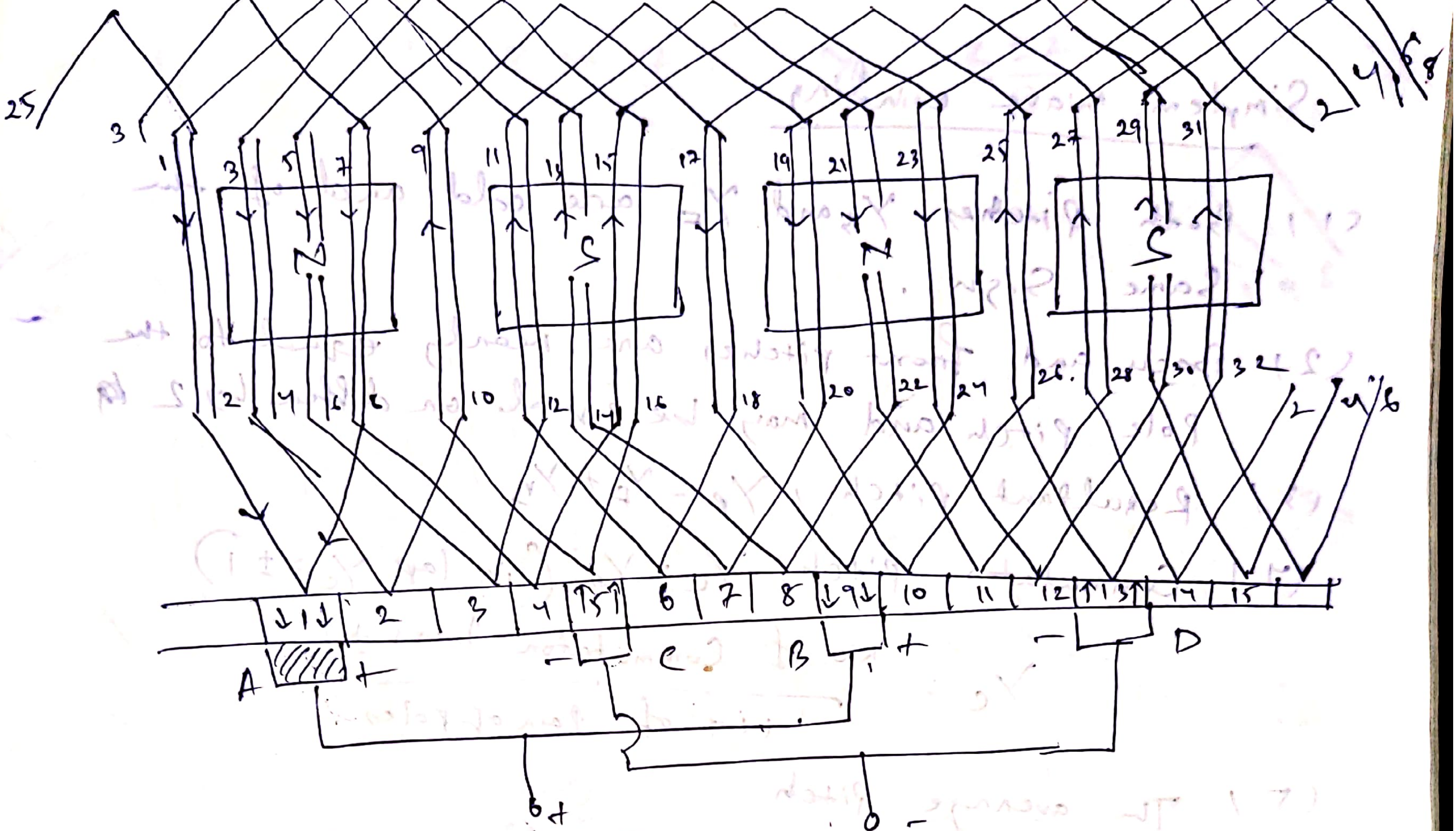
(1) Y_B & Y_F have to be odd.

(2) have to differ by 2

We get for a progressive winding

$Y_B = 9$, $Y_F = +7$

$Y_B \rightarrow \left(\frac{2}{P} + 1\right)$, $Y_F \rightarrow \left(\frac{2}{P} - 1\right)$



Back Connections

1 to (1+9) = 10
3 to (3+9) = 12
5 to (5+9) = 14
7 to (7+9) = 16
9 to (9+9) = 18
11 to (11+9) = 20
13 to (13+9) = 22
15 to (15+9) = 24
17 to (17+9) = 26
19 to (19+9) = 28
21 to (21+9) = 30
23 to (23+9) = 32
25 to (25+9) = 34 = (34-32) = 2
27 to (27+9) = 36 = (36-32) = 4
29 to (29+9) = 38 = (38-32) = 6
31 to (31+9) = 40 = (40-32) = 8

Front Connections

10 to (10-7) = 3
12 to (12-7) = 5
14 to (14-7) = 7
16 to (16-7) = 9
18 to (18-7) = 11
20 to (20-7) = 13
22 to (22-7) = 15
24 to (24-7) = 17
26 to (26-7) = 19
28 to (28-7) = 21
30 to (30-7) = 23
32 to (32-7) = 25
2 to (34-7) = 27
4 to (36-7) = 29
6 to (38-7) = 31
8 to (40-7) = 33 = (33-32) = 1

Simplex wave winding

(1) Both pitches Y_B and Y_F are odd and of the same sign.

(2) Back and front pitches are nearly equal to the pole pitch and may be equal or differ by 2.

(3) Resultant pitch, $Y_R = Y_F + Y_B$

(4) Commutator pitch, $Y_C = Y_A$ (in lap $Y_C = \pm 1$)

$$Y_C = \frac{\text{No. of Commutator bars} \pm 1}{\text{No. of pair of poles}}$$

(5) The average pitch

$$Y_A = \frac{Z \pm 2}{P} = \frac{\frac{Z}{2} \pm 1}{P/2} = \frac{\text{No. of Commutator bars} \pm 1}{\text{No. of pair of poles}}$$

(6) No. of coils,

$$N_C = \frac{PY_A \pm 2}{2}$$

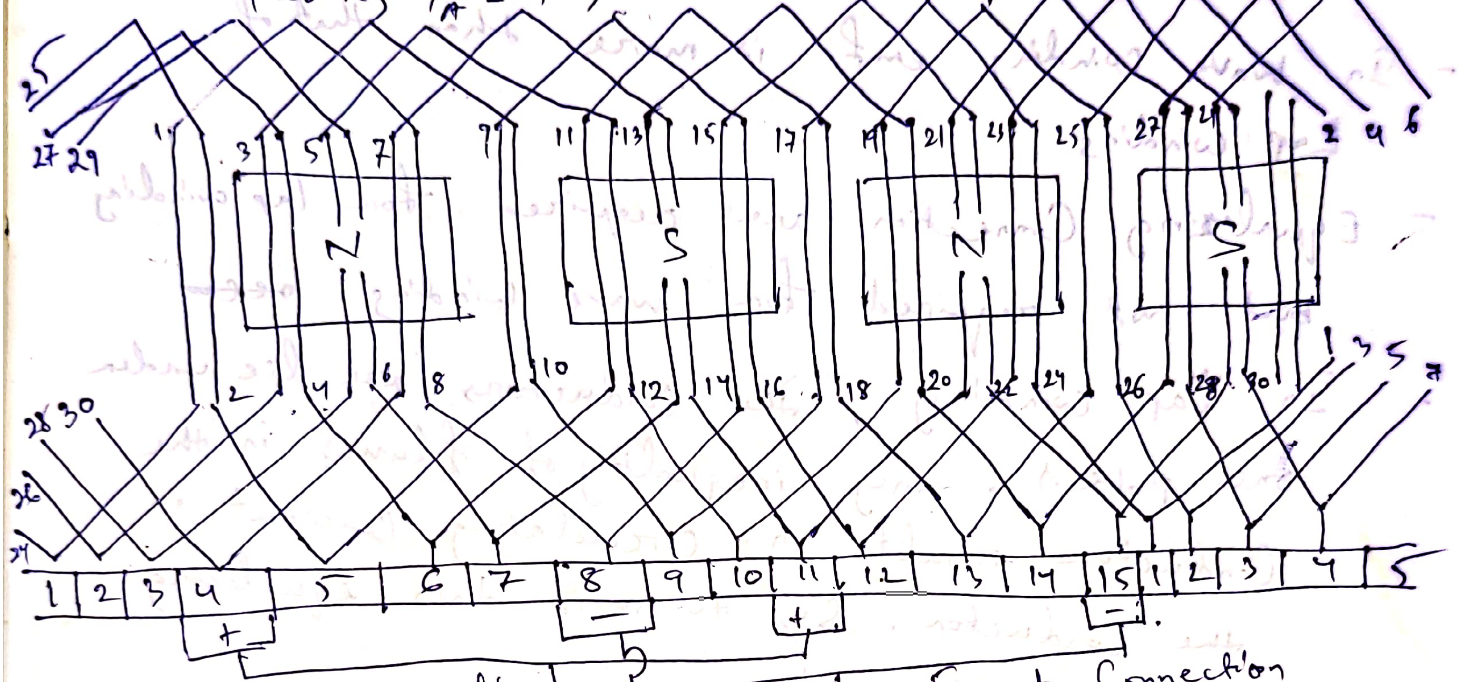
(7) The no. of armature conductors with 2 either added or subtracted must be a multiple of the no. of poles of the generator. This restriction eliminates many even numbers which are unsuitable for this winding

(8) The no. of armature parallel paths = 2m, m = multiplicity of winding.

Q. Draw a developed diagram of a Simplex 2-layer wave winding for a 4-pole dc generator with 30 armature Conductors. Hence, point out the Characteristics of a Simple wave winding.

$Y_A = \frac{30 \pm 2}{4} = 8$ or 7. $\quad Y_A = \frac{Z \pm 2}{P}$

Taking $Y_A = 7$, we have $Y_B = Y_F$



Back connection → Front Connection

1 to (1+7) = 8 → 8 to (8+7) = 15

15 to (15+7) = 22 → 22 to (22+7) = 29

29 to (29+7) = 36 = (36 − 30) = 6 → 6 to (6+7) = 13

13 to (13+7) = 20 → 20 to (20+7) = 27

27 to (27+7) = 34 = (34−30) = 4 → 4 to (4+7) = 11

11 to (11+7) = 18 → 18 to (18+7) = 25

25 to (25+7) = 32 = (32−30) = 2 → 2 to (2+7) = 9

9 to (9+7) = 16 → 16 to (16+7) = 23

23 to (23+7) = 30 → 30 to (30+7) = 37 = (37−30) = 7

7 to (7+7) = 14 → 14 to (14+7) = 21

21 to (21+7) = 28 → 28 to (28+7) = 35 = (35−30) = 5

5 to (5+7) = 12 → 12 to (12+7) = 19

19 to (19+7) = 26 → 26 to (26+7) = 33 = (33−30) = 3

3 to (3+7) = 10 → 10 to (10+7) = 17

17 to (17+7) = 24 → 24 to (24+7) = 31 = (31−30) = 1

Uses of Lap and wave windings

- In wave winding emf is more than that of Lap winding
- Equalizing Connection are required for lap winding but not required for wave winding. ~~becau~~
- In lap winding, the conductors are lie under one poles, any inequality of fluxes in the Conductor results in circulating current in the Conductor. So, to avoid this, equalizing Connection is used.
- Lap winding used for high Current and low Voltage generators.
- wave winding used for Low Current and high Voltage generators.
- Parallel path for Lap winding, A = P
  for wave winding, A = 2.

1.3 Types of Generators

- Generators are classified according to excitation of fields and of two types.
- ~~Generators~~ (1) Separately excited generators
  (2) Self-excited generators.
- Separately excited Generators are those whose field magnets are energised from an independent external source.

(b) Self excited generators

- field magnets are energised by the Current Produced by the generators.

- There are 3 types of self excited generators

(i) Shunt wound.

- field windings are connected across with the armature windings.

(ii) Series wound

- field windings are Connected in Series with the armature windings.

- These are used as a boosters.

(iii) Compound wound

- It is a Combination of few Series and a few Shunt windings.

(a) Long shunt Compound machine

(b) Short shunt "

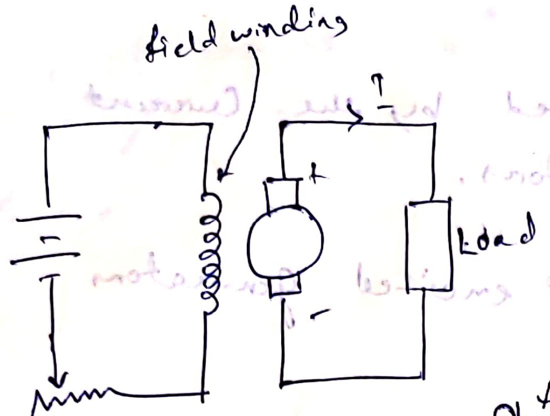
- When Series field aids the shunt field, generators is said to be Commutatively Compounded generators.

- When Series field opposes the shunt field, generators is said to be differentially Compounded generators.

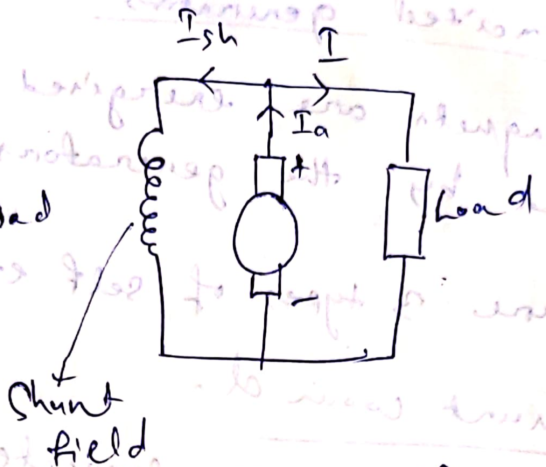
- A voltage drop occurs over the brush Contact resistance, when Current passes from Commutator segments to brushes.

for Carbon brushes, Volt. drop = 2 V.

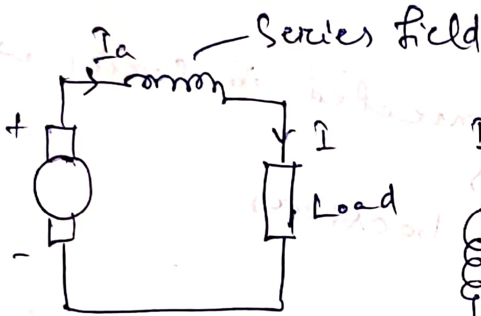
for metal-graphic " " = 0.5 V



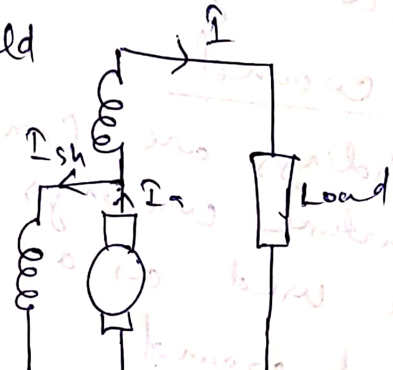
(Separately excited generator)



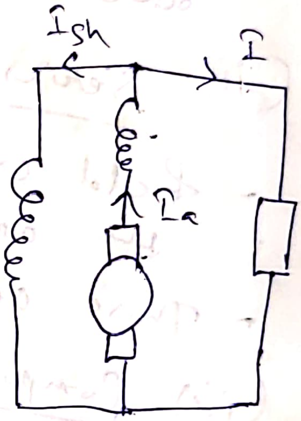
(Shunt wound)



(Series wound)

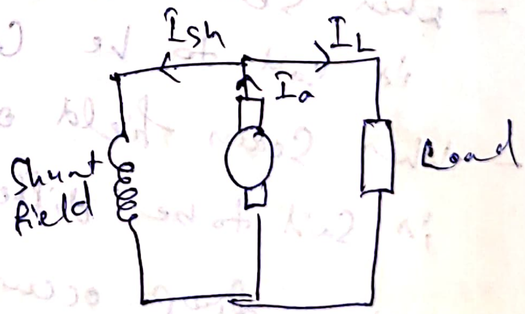


(Short-shunt Compound generator)



(Long-shunt Compound generator)

Q. A shunt generators delivers 450 A at 230 V and the resistance of the shunt field and armature 50 Ω and 0.03 Ω respectively. Calculate the generated emf ?



Ans: given,

$V = 230V$

Load current, $I_L = 450A$

$R_{sh} = 50\,\Omega$

$R_a = 0.03\,\Omega$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{50} = 4.6\,A$$

$$I_a = I_L + I_{sh} = 450 + 4.6 = 454.6\,A$$

Armature volt. drop, $I_a R_a = 454.6 \times 0.03 = 13.6\,V$

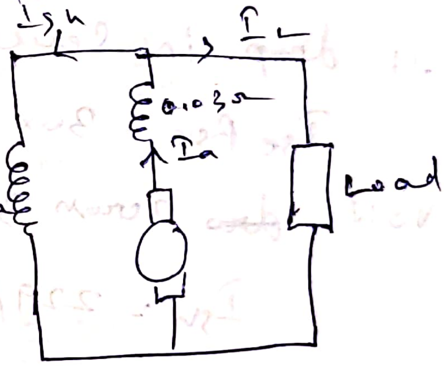
∴ emf generated in the armature, E_g

$E_g = V + I_a R_a$

$= 230 + 13.6 = 243.6V$

Q. A Long-Shunt Compounded generator delivers a load Current of 50A at 500V and has armature, Series field and Shunt field resistances of 0.05 Ω, 0.03 Ω and 250 Ω respectively. Calculate the generated voltage and armature Current. Allow 1V per brush for Contact drop.

Solⁿ Given data,



$I_L = 50A$, $V = 500V$

$R_a = 0.05Ω$, $R_{se} = 0.03Ω$

$R_{sh} = 250Ω$

Voltage drop = 1V

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

Current through the armature and Series winding is

$I_a = I_{se} = 50 + 2 = 52A$

Volt drop on Series winding = $I_{se} R_{se} = 52 \times 0.03$
$= 1.56V$

armature volt. drop, $I_a R_a = 52 \times 0.05 = 2.6V$

brush drop $= 2 \times 1 = 2V$

$E_g = V + I_a R_a + I_{se} R_{se}$ + brush drop.

$= 500 + 2.6 + 1.56 + 2 = 506.16V$

1.4 Emf equation of a Generator

Let ϕ = flux/pole in weber

Z = total no. of armature conductors

= No. of slots × No. of conductors/slot.

P = No. of generator poles

A = No. of parallel path in armature

N = armature rotation in revolution per minute (RPM)

E = emf induced in any parallel path in armature.

Generated emf E_g = emf generated in any parallel paths i.e E.

Average emf generated/conductor = $\frac{d\phi}{dt}$ volt. ($\because n=1$)

Now, flux cut/conductor in one revolution $d\phi = \phi P$ wb.

No. of revolution/second = $N/60$

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

Hence, according to Faraday's Laws of Electromagnetic Induction.

Emf generated/conductor = $\frac{d\phi}{dt} = \frac{\phi P N}{60}$ volt.

For a simplex wave-wound generator,

No. of parallel path = 2

No. of conductors in one path = $Z/2$

Emf generated/path = $\frac{\phi P N}{60} \times \frac{Z}{2} = \frac{P \phi Z N}{120}$ Volt.

seen
24/12/24

For a simplex lap-wound generator,

No. of parallel paths = P

No. of conductors in one path = Z/P

Emf generated/path = $\frac{\phi P N}{60} \times \frac{Z}{P} = \frac{\phi Z N}{60}$ Volt.

In general, $E_g = \frac{\phi Z N}{60} \times \left(\frac{P}{A}\right)$ Volt.

$A = 2$ - Simplex wave winding

$= P$ - Simplex Lap winding.

Q. A four-pole generator, having wave wound armature winding has 51 slots, each slot containing 20 conductors. What will be the voltage generated in the machines when driven at 1500 rpm assuming the flux per pole to be 7.0 mWb?

Sol^n $E_g = \frac{P \phi Z N}{60 A}$ volts.

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

$A = 2$, $N = 1500$ rpm.

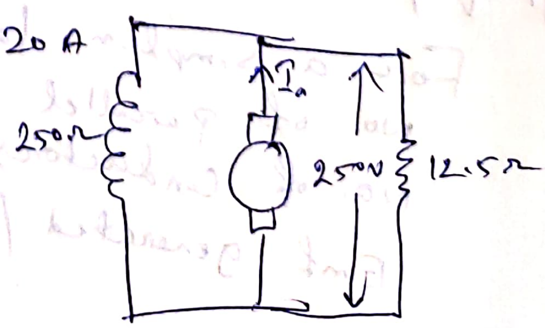
$$E_g = \frac{4 \times 7 \times 10^{-3} \times 1020 \times 1500}{60 \times 2} = 178.5V.$$

Q. An 8-pole dc shunt generator with 778 wave connected armature conductors and running at 500 rpm supplies a load of 12.5 Ω resistance at terminal volt. of 250 V. The armature resistance is 0.24 Ω and field resistance is 250 Ω. Find the armature current, induced emf, flux per pole?

Sol^n Load Current $= \frac{V}{R} = \frac{250}{12.5} = 20$ A

Shunt Current $= \frac{250}{250} = 1$ A

$I_a = 20 + 1 = 21$ A.



Induced emf = 250 + (21 × 0.24) = 255.04 V

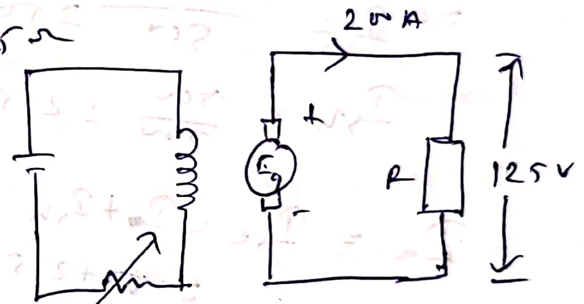
$$E_g = \frac{P \phi Z N}{60 \times A} \Rightarrow 255.04 = \frac{8 \times \phi \times 778 \times 500}{60 \times 2}$$

$$\Rightarrow \phi = 9.83 \text{ mWb}$$

Q. A separately excited generator, when running at 1000 rpm, supplied 200 A at 125 V, what will be the load current when the speed drops to 800 rpm, if I_f is unchanged? Given that the armature resistance = 0.04 Ω and brush drop = 2 V.

Soln

Load Resistance $= \frac{125}{200} = 0.625\ \Omega$



$E_{g1} = V + I_a R_a +$ Brush drop

$= 125 + (200 \times 0.04) + 2$

$E_{g1} = 135$ V

$N_1 = 1000$ rpm

$N_2 = 800$ rpm

$E_g \propto N \Rightarrow \frac{E_{g2}}{E_{g1}} = \frac{N_2}{N_1}$

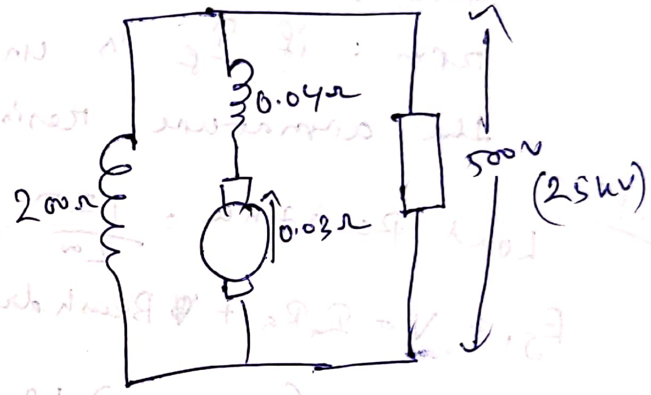
$\Rightarrow E_{g2} = \frac{800}{1000} \times 135 = 108$ V

$V = 108 - 0.04 \times I - 2 = 106 - 0.04 I$

~~Let~~ If I be the new load current, the terminal voltage V is ~~given~~ ∴

$I = \frac{V}{R} = \frac{(106 - 0.04 I)}{0.625} \Rightarrow I = 159.4$ A.

Q. A 4-pole, long shunt lap wound generator supplies 25 kW at a terminal volt. of 500 V. The armature resistance is 0.03 Ω, series field resistance is 0.04 Ω and shunt field resistance is 200 Ω. The brush drop is 1.0 V. Det^n emf generated. Calculate also no. of conductors if the speed is 1200 rpm and flux per pole is 0.02 wb. Neglect armature reaction ?



Sol^n

$P = VI$

$\Rightarrow I = \frac{25000}{500} = 50\,A$

$I_{sh} = \frac{500}{200} = 2.5$

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

$= 50 + 2.5 = 52.5\,A$

Series field drop $= 0.04 \times 52.5 = 2.1\,V$

Armature drop $= 0.03 \times 52.5 = 1.575\,V$

Brush drop $= 2 \times 1 = 2\,V$

$E_g = 500 + 2.1 + 1.575 + 2 = 505.67\,V$

$E_g = \frac{P\phi Z N}{60 A} \Rightarrow 505.67 = \frac{4 \times 0.02 \times Z \times 1200}{60 \times 4}$

$\Rightarrow Z = 1264$ (Ans)

1.5 Losses of DC generator

- In DC generator, there are basically three losses (1) Iron losses
  (2) Copper losses
  (3) mechanical losses.

Scanned with OKEN Scanner

(1) Iron Losses

- Due to rotation of the iron core of the armature in the magnetic flux of ~~field~~ field poles, there are some losses are taking place continuously in the core and are known as Iron / core losses.

- Iron losses consists of Hysteresis losses and eddy current losses.

(1) Hysteresis loss (W_h)

- This loss is due to reversal of magnetisation of the armature core. Every portion of the rotating core passes under N and S pole alternatively, thereby attaining S and N polarity respectively. The core undergoes one complete ~~cy~~ cycle of magnetic reversal after passing under one pair of poles.

- The hysteresis loss is given by Steinmetz formula,

$$W_h = \eta B_{max}^{1.6} f V \text{ watts.}$$

V = Volume of core in m^3

η = Steinmetz hysteresis co-efficient

f = frequency

B_{max} = max. flux density.

(2) Eddy Current loss (W_e)

- When the armature core rotates, it cuts the magnetic flux. Hence, an emf is induced in the body of the core according to the laws of electromagnetic induction. This emf though small, sets up large

Current in the body of the Core due to its small resistance. This current is known as eddy current. The power loss due to flow of this current is called eddy current loss.

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

B_{max} = Max. flux density, f = freq. of magnetic reversals.

t = thickness of each lamination, V = Volume of armature core.

(2) <u>Copper Losses</u>

- The Copper loss occur in armature is called armature Cu. loss ($I_a^2 R_a$)
- The Copper loss occur in field winding is called field Cu. loss ($I_{sh}^2 R_{sh}$)/($I_{se}^2 R_{se}$)

(3) <u>Mechanical losses</u>

- friction loss at bearings and Commutator
- Windage loss of rotating armature.

- usually magnetic (iron loss) and mechanical losses are collectively known as <u>Stray losses</u>.

- There are 3 types of generator efficiencies :

(1) Mechanical efficiency

$$\eta_m = \frac{\text{total watts generated in armature } (E_g I_a)}{\text{mech. power supplied}}$$

(2) Electrical efficiency,

$$\eta_e = \frac{\text{watts available in load circuits } (VI)}{\text{total watts generated } (E_g I_a)}$$

(3) Overall or Commercial efficiency.

$$\eta_c = \frac{\text{watts available in load circuit } (VI)}{\text{mech. power supplied}}$$

overall efficiency, $\eta_c = \eta_m \times \eta_e$

Condition for max. efficiency.

Generator o/p = VI

Generator i/p = output + losses = $VI + I_a^2 R_a + W_c$

$= VI + (I + I_{sh})^2 R_a + W_c$ $\quad (I_a = I + I_{sh})$

$\therefore I_{sh}$ is negligible as compared to I_L, $I_a = I$

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{VI}{VI + I_a^2 R_a + W_c} = \frac{1}{1 + \left(\frac{IR_a}{V} + \frac{W_c}{VI}\right)}$$

Now, efficiency is maximum when denominator is min. i.e

$$\frac{d}{dI}\left(\frac{IR_a}{V} + \frac{W_c}{VI}\right) = 0 \Rightarrow \frac{R_a}{V} - \frac{W_c}{VI^2} = 0$$

$$\Rightarrow I^2 R_a = W_c$$

Hence, generator efficiency is maximum when

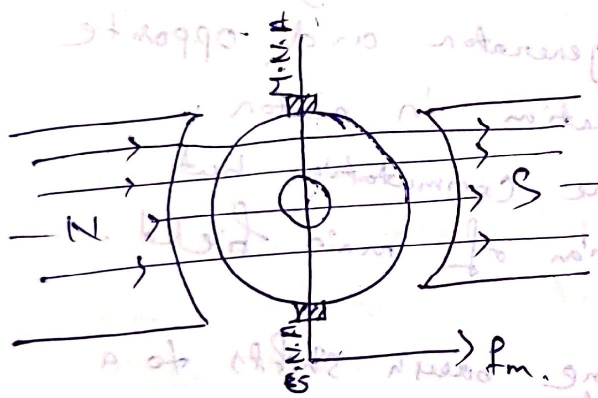
Variable losses = ~~Const~~ Constant losses.

- The Load Current Corresponding to maximum efficiency is given by $I^2 R_a = W_c \Rightarrow$ $\boxed{I = \sqrt{\frac{W_c}{R_a}}}$

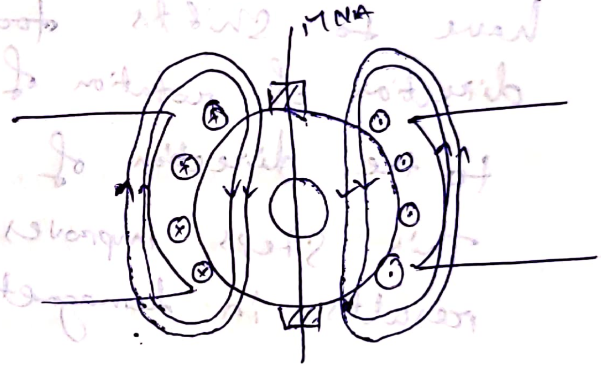
1.6 Armature Reaction in D.C Machine

- Armature reaction is the reaction of armature conductor flux on the main field flux of a generator. The armature magnetic field has two effects:
    (1) demagnetising effect.
    (2) Cross magnetising effect.

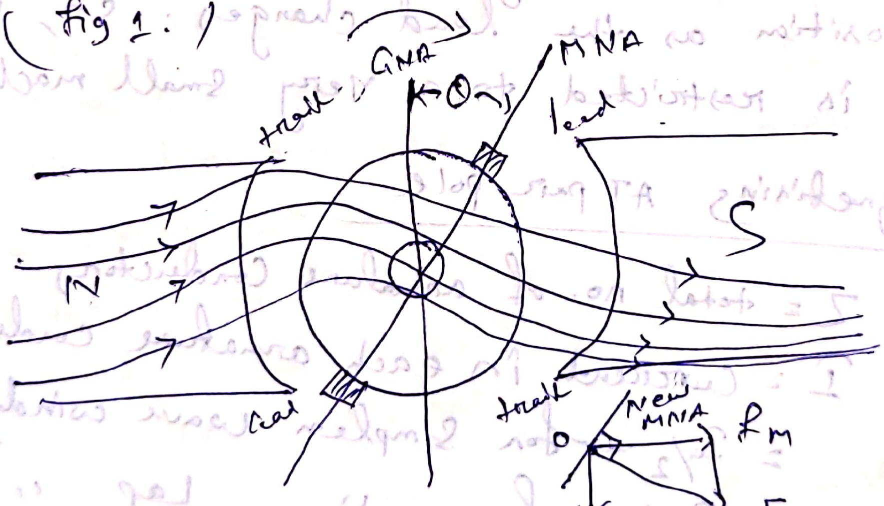
- The magnetic flux is distributed symmetrically w.r.to polar axis.
- The magnetic Neutral axis (MNA) coincides with geometrical neutral axis (GNA)



(fig 1.)



(fig 2.)



(fig. 3)

- Fig. 1. Shows the flux distribution of a bipolar generator when there is no current in the armature conductors.
- Fig 2. Shows the flux set up by the armature conductors alone when carrying current, the field coils being unexcited.

- From fig 3, It is seen that the flux through the armature is no longer uniform and symmetrical about the pole axis rather it is distorted.

- The flux is seen to be crowded at the trailing pole tips but weakened at the leading pole tips. in generator and In motor, flux is seen to be strengthening at the leading pole tips but weakend at the trailing pole tips.

- To resolve the Cross magnetisation, the brushes have to shifts ~~towards the~~ along the direction of rotation of generator and opposite to the direction of rotation in motor. This steps improves the commutation but results in demagnetisation of main field.

- The limitation is every time brush shifts to a new position as the load changes. So, brush shift is restricted to a very small machine

Demagnetising AT per pole

Let Z = total no. of armature conductors.

I = Current in each armature conductors.

$= I_a/2$ — for simplex wave winding

$= I_a/P$ — for " Lap "

θ_m = forward lead in mechanical (or) geometrical (or) angular degree.

$$\text{Demagnetising AT/pole} = \frac{\theta_m}{360} \times Z I$$

$$\text{Cross magnetising amp-turn / pole} = Z I \left(\frac{1}{2P} - \frac{\theta_m}{360} \right)$$

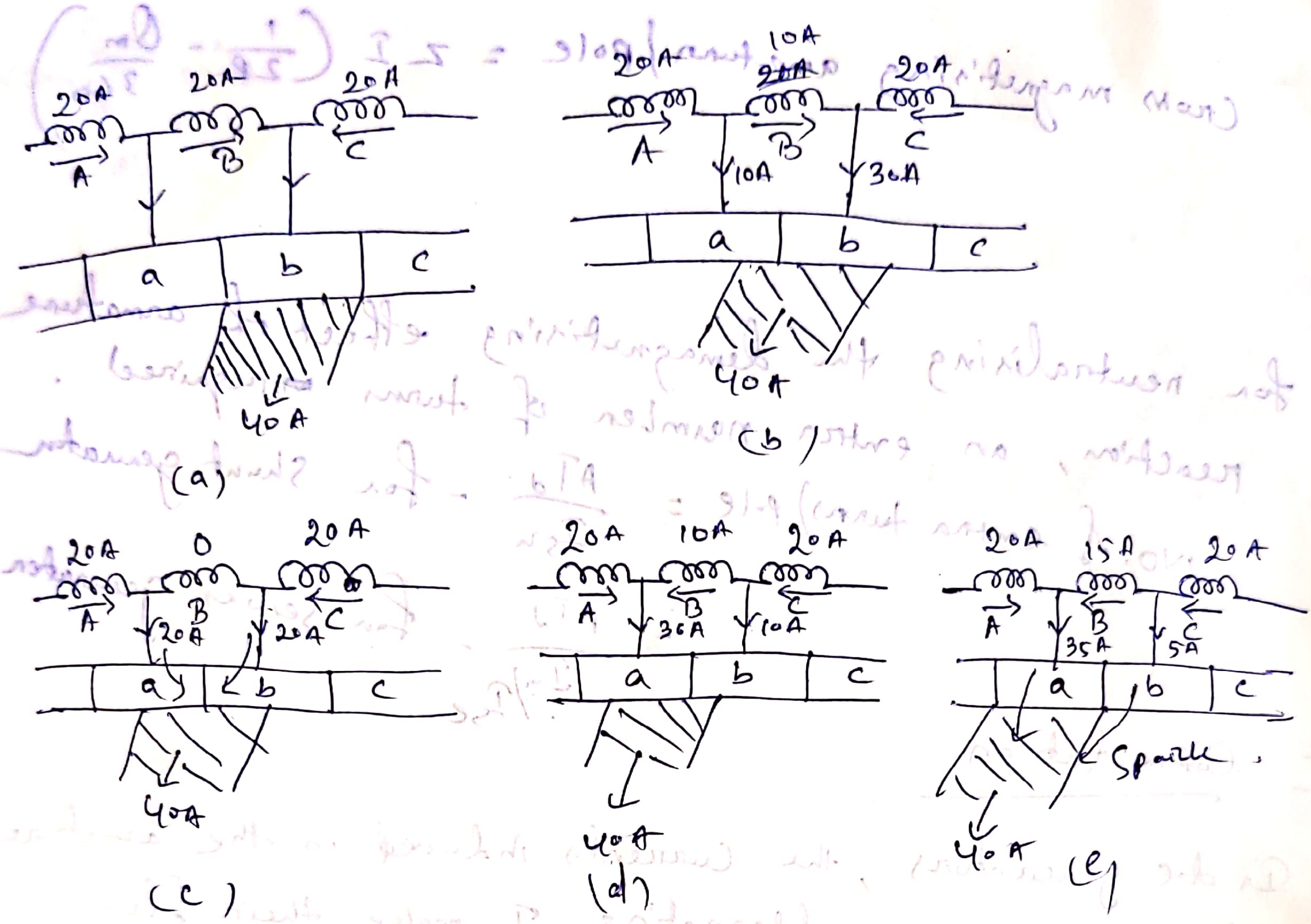
- for neutralising the demagnetising effect of armature reaction, an extra number of turns required.

$$\text{No. of extra turns / pole} = \frac{AT_d}{I_{sh}} \text{ - for shunt generator}$$

$$= \frac{AT_d}{I_{L}/I_{se}} \text{ - for series generator.}$$

1.7 Commutation

- In d.c generators, the currents induced in the armature conductors are alternating. To make their flow unidirectional in the external circuit, we need a commutator.
- ~~When~~ The induced currents flow in one direction when armature conductors are under N-pole and in the opposite direction when they are under S-pole.
- As conductors pass out of the influence of a N-pole and enters that S-pole, the current in them is reversed. The reversal of current takes place along magnetic neutral axis.
- This process by which current in short circuited coil is reversed while it crosses the M.N.A is called commutation.



- The Period during which Coil remains Short Circuited is known as Commutation Period T_c.
- If the Current reversal i.e the Change from $+I$ to Zero and then to $-I$ is Completed by end of short Circuit Period, then Commutation is ideal.
- If Current reversal is not Completed by that time, then Sparking is Produced between brush and Commutator.
- The main Cause which delays the quick reversal of is the Production of self induced emf in the Coil undergoing Commutation. That self induced emf is known as Reactance Voltage.

Value of Reactance Voltage $= L \times \frac{2I}{T_c}$ (Linear Commutation)

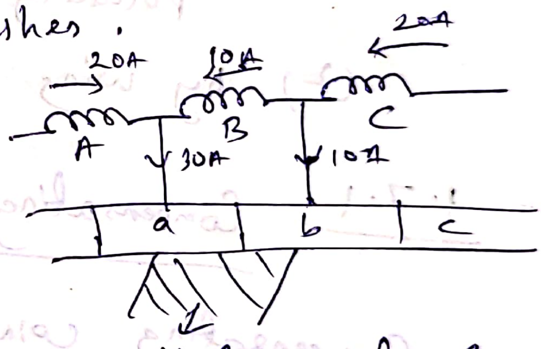
I = Current through the Conductor
T_c = Commutation Period.
L = Self-inductance of coil.

Methods of Improving Commutation.

- There are two ways to improve commutation.
  (1) Resistance Commutation
  (2) Emf Commutation.

(1) Resistance Commutation

- In this method, Low resistance cu. brushes are replaced by high resistance Carbon brushes.



- In this fig., 10A from Coil C enter in to the segment b and 10A from coil C enter into the segment b.
- If cu. brushes is used, then the most current from C will flow through the segment b, because of low resistance of cu. brushes.
- If Carbon brush ~~resistance~~ of high resistance is used, limited current will then through segment b, flow and rest of the current from coil C will flow through segment a.
- This way we can improve Commutation.

(2) Emf commutation

- In this method, an arrangement is made to neutralize the reactance voltage by producing a reversing emf in the short circuited coil under commutation.

- The reversing emf produced by two ways.

(1) giving the brushes a forward lead sufficient to bring the short-circuited coil under the influence of next pole of opposite polarity

(2) by using Interpoles.

1.7.1 Compensating windings

- Compensating windings are used to neutralize the Crossmagnetisation effect of armature reaction

- These windings are embedded in slots in the poleshoes and are connected in series with the armature in such a way that the current in them flows in opposite direction to that flowing in armature conductors.

Interpoles

- These are small poles fixed to the yoke and spaced in between main poles.
- These are connected in series with the armature so that they carry full armature current.

- The polarity of the interpoles is same as that of the main pole ahead in the direction of rotation.

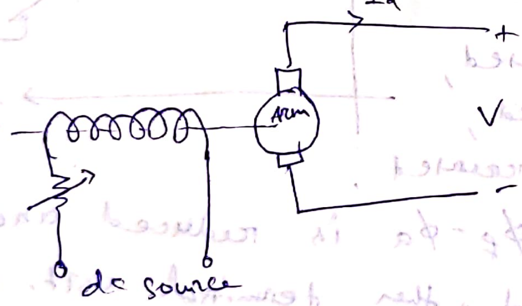
- Interpoles are used to neutralise the cross magnetisation effect in the interpolar region.

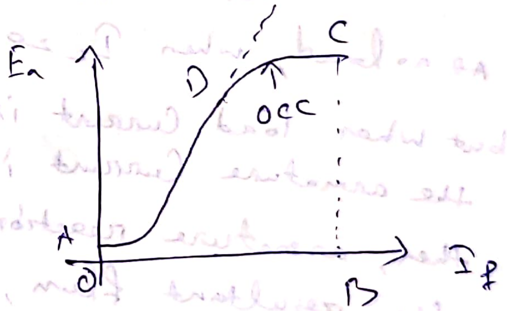
1.8 Characteristics of D.C Generator

Separately excited DC generator

No load characteristics (E_o vs I_f)

- This characteristics gives the variation of armature generated emf E_a with field current I_f, for zero armature current and constant speed.





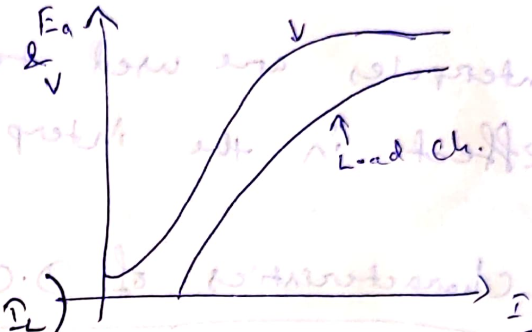
- From fig. OA represent the residual voltage (2 to 6 volts) due to the presence of residual flux in the main poles.

- When field winding is energised and exciting current I_f is increased then E_a is also increased, it shown in graph AC. where DC is found by saturation.

- In dc machine, field winding is excited by d.c current. So there will be no hysteresis loss in field winding (stator core)

Load characteristics (V vs I_f)

It is the graph between terminal voltage and field current for const. I_a and speed.

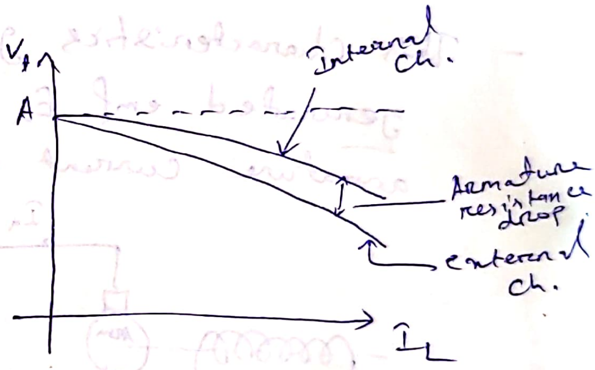


External characteristics (V vs I_L)

- It is the graph between armature terminal voltage and load current (I_L) for const. speed and fixed field current.

$V = E - I_a R_a$

$I_a = I_L$



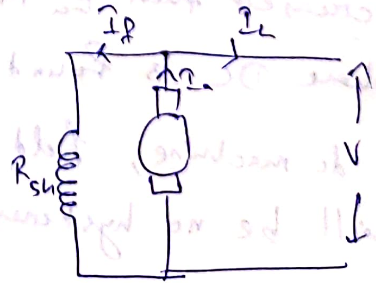
- At no load, when $I_L = 0$, $V = E$
- but when load current is increased, the armature current increased, then, armature reaction is increased, the resultant flux, $\phi = \phi_f - \phi_a$ is reduced and the induced emf is reduced, then terminal volt. is reduced and voltage drop occurs across armature resistance.

Shunt generators

- Shunt generators are self excited generators.

No-load characteristics

$V = E - I_a R_a$



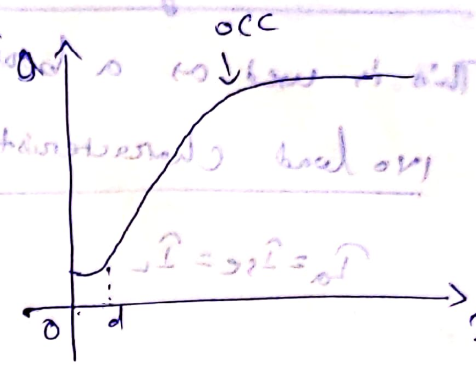
at no load, $I_L = 0$, $I_a = I_f = 0$

then, $V = E$, initially I_f is zero

- $I_f = \frac{E_{res.}}{R_f}$

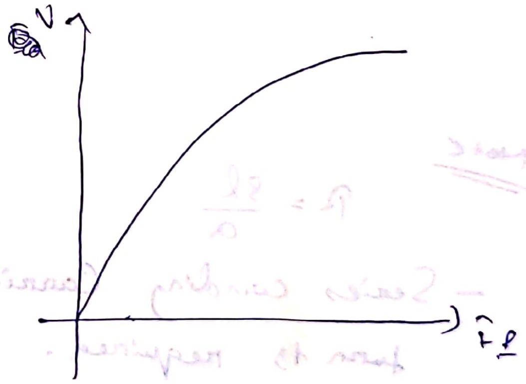
- But due to residual flux, some induced voltage is induced.

- In shunt generator, initially field current is zero due to residual flux, residual voltage is generated and field current increases to I_{f_0} (od). Due to this increase field current, flux increases, and induced emf increases and this emf again increases field current and flux also increased. Hence, as a result of this cumulative process the induced volt. (E) build up.



Load characteristics

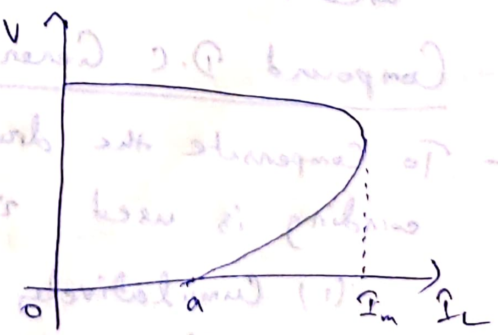
- It is the graph between terminal volt. (V) and field current (I_f).



External characteristics

- It is the graph betn terminal voltage (V) and Load current (I_L)

- If load is gradually increased by reducing load resistance and load voltage is decreasing. After reaching a max. value of load current, the load resistance further decreases, terminal volt. reduces largely.

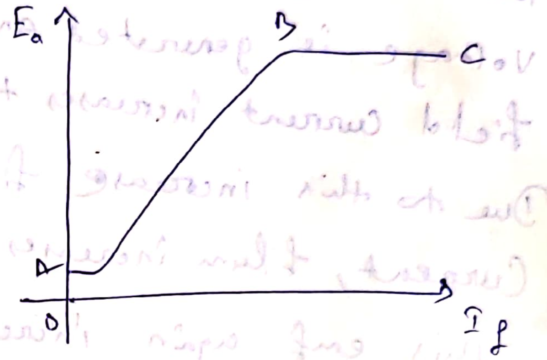


Series d.c generator

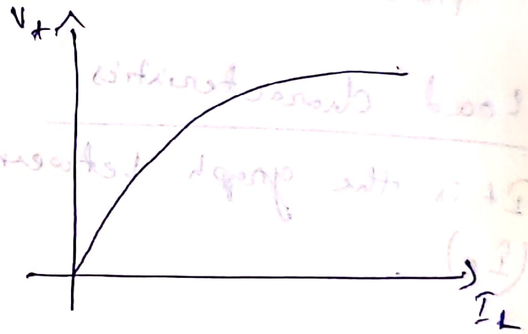
- This is used as a boosters.

No load characteristics

$I_a = I_{se} = I_L$



- Load Ch. is identical with Separately excited generator.
- External characteristics



Note

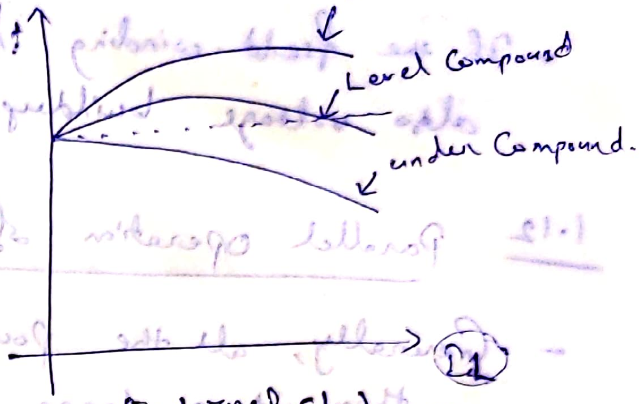
$R = \frac{\rho l}{a}$

- Series winding carries large current, so thick wire few turn is required.
- In shunt winding d.c generator, shunt winding carries low current, so, large resistance, thin wire, large length is used.

Compound D.C Generator

- To compensate the drop of shunt generator, series field winding is used i.e. Compound generator.
  (1) Cumulatively Compound d.c generator, $\phi_c = \phi_{sh} + \phi_{se}$
  (2) Differentially " " " , $\phi_d = \phi_{sh} - \phi_{se}$

- In Differential Compound generator, with the increase in load, series field flux opposes the Shunt field flux and consequently terminal voltage falls more rapidly.

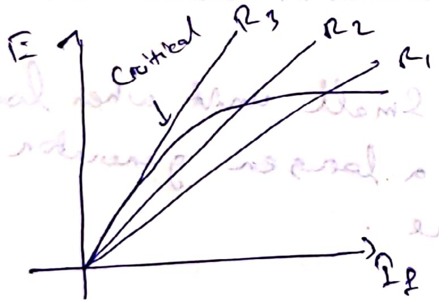


(External ch.) ~~(No-load ch.)~~ for Cumulative Compound generator.

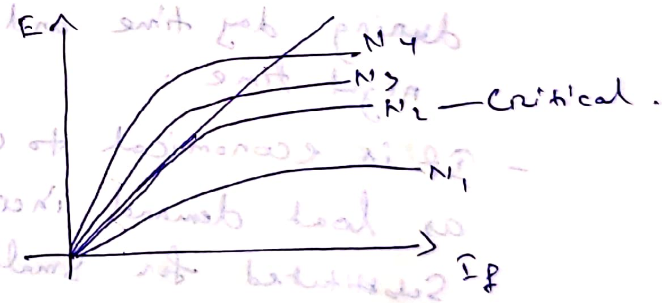
-

1.10 Concept of Critical resistance and Critical speed of DC generator

- Critical resistance is the resistance above which the dc generator failed to build up the voltage.
- Critical speed is the speed below which the dc generator failed to build up the voltage.



$(R_3 > R_2 > R_1)$



$(N_4 > N_3 > N_2 > N_1)$

1.11 Conditions of voltage Build up in d.c generator

- If no residual magnetism is present in main poles.
- If the field Resistance at a particular speed is greater than critical field resistance
- If the speed of generator is less than the critical speed of the generator.

- If the field winding is not properly connected, then also voltage buildup will failed.

1.12 Parallel operation of DC generator

- Generally, all the power plants are running in parallel rather than large single units capable of supplying max. peak load.
- Some advantages are

(1) Continuity of Service.

- In the event of breakdown of prime mover or the generator itself, the supply can be maintained.

(2) Efficiency:

- usually the load fluctuates between its peak value during day time and its minimum value during night time.
- It is economical to use a small unit when load is light, as load demand increases, a larger generator can be substituted for smaller one.

(3) Maintainance and repair

- When the maintainance of the generator requires, the other generators can be ~~maintained~~ continue to supply

(4) Addition to plant

- In future, when load increases, power plants can be added to the existing plant.

1.13 Uses of dc generators.

Shunt Generators ~~motors~~: These are used for Charging batteries and for ordinary lighting and Power supply.

Series Generators. These are used as boosters line in railway Service.

Compound generators:

- Cumulative Compound generators are used for motor driving which require d.c supply at Const. Voltage, for lamp loads and for heavy power Service such as electrical ~~railw~~ railways.
- Differentially Compound generators are used in arc welding..

Dummy coils

- Dummy Coils are used in wave winding:
- It is used to Mechanically balanced the armature winding in armature Conductor in dc generator.

1.11 Conditions for Voltage build up in a dc generator

(1) There must be residual magnetism in main poles.

(2) The field resistance Should be less than critical field resistance.

(3) The speed of dc generator should be more than critical speed in a dc generator.

(4) The field winding Should be properly Connected.