Chapter-1

D.C GENERATOR

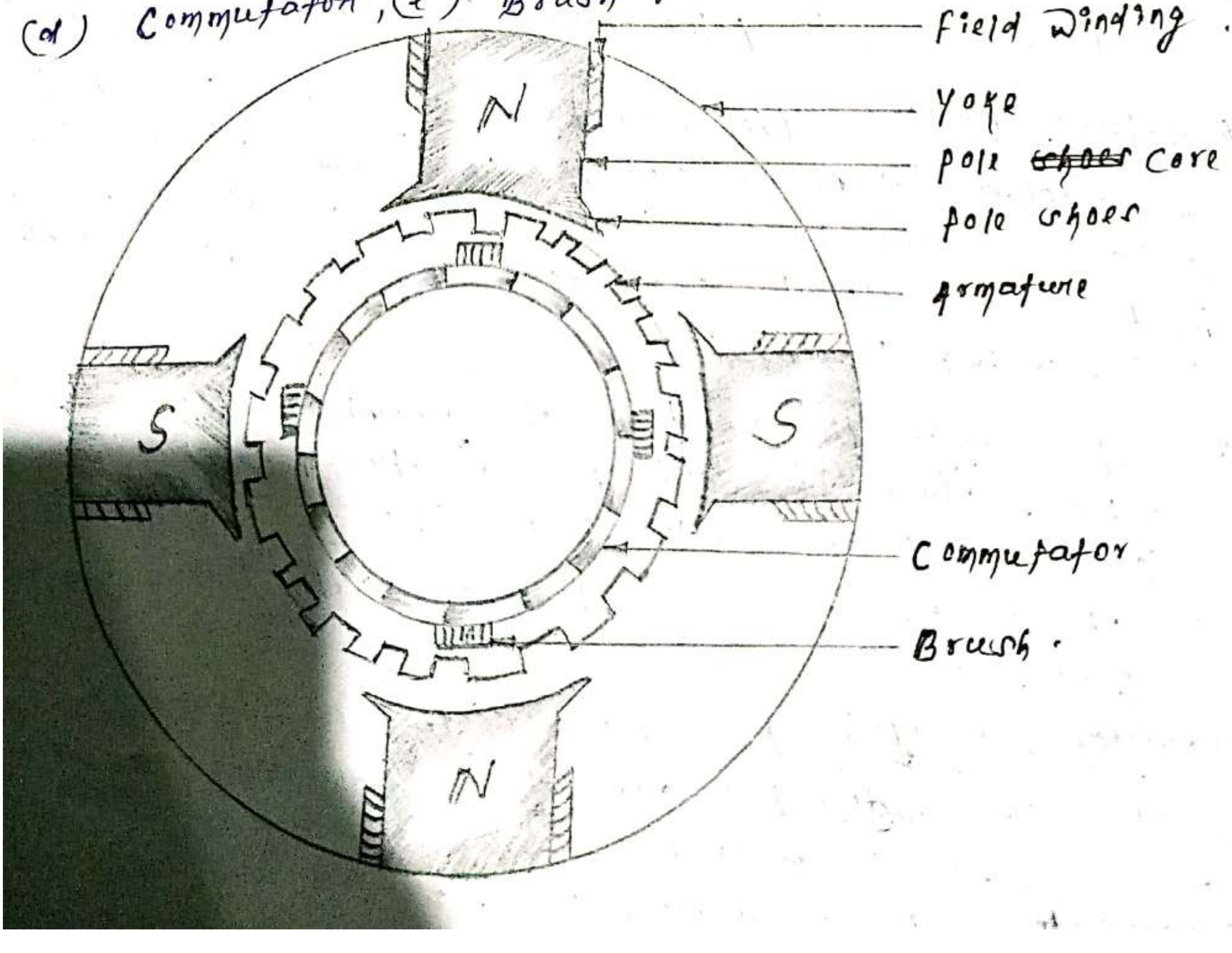
* The device which convert mechanical energy into D.C electrical energy is called "D.C generator".

principle ÷ When a conductor rotate inside a magnetic field an emf will induced into the conductor, according to Faradays law of electromagnetic induction which will cause a current flow in the circuit if the circuit is closed.

The direction of induced emf or current is given by "Fleming right hand rule".

Fleming right hand rule ÷ stretch the thumb, fore & middle finger of the right hand mutually perpendicular to each-other such that the thumb finger gives the direction of motion of the conductor, fore finger gives the dirn of magnetic field & middle finger gives the dirn of induced emf or current.

Construction of D.C generator ÷ It is consisting of (a) Field winding, (b) Armature, (c) Armature winding, (d) Commutator, (e) Brush.



Yoke : It forms the outer part of the machine & serve the following purpose :

* It provide mechanical protection for the pole & as a protecting cover for the whole machine.
* It carries the magnetic flux produced by yoke.
* yoke is generally made up of caste steel or rolled steel.

Pole : The field magnet consist of pole core & pole shoe. The pole shoes spreadout the magnetic flux in the air gap & reduced the reluctance by increasing the area of crossection.

* pole core may be made up of caste iron or caste steel but the pole shoes are always laminated.
* The field coils are connected in such a way that adjacent poles have opposite polarity.

Armature Core : The armature core is fixed to the machine shaft & rotate betn the field poles. slots are cut on the periphery of armature which hold the insulated conductor. The armature perform the following functions :

(i) It permit the rotation of mechanical generation action. Since it hold the armature conductor so an emf is induced in it.

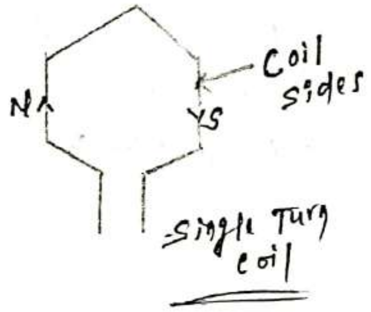
(ii) It provide a low reluctance path for magnetic flux.

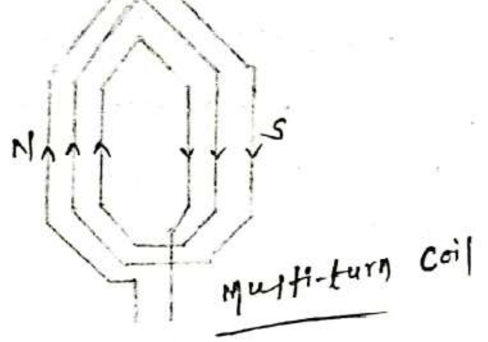
Armature Winding : The slots of the armature core holds the insulated conductor which are connected in a suitable manner to form the armature winding.

Commutator : It is a mechanical rectifier which convert the AC voltage generated in armature winding into D.C voltage across the brushes. It is made of copper segment insulated from each other by mica sheets.

Brush : It provides an electrical connection betn the rotating commutator & external load-circuit. The function of brush is to collect current from commutator segments & deliver it to load circuit. Brushes are generally made of carbon or graphite.

(a) **Armature Winding** : The armature conductors are connected to form coil & basic components of armature winding is the armature coil.





(b) **Coil** : when one or more turns are connected in series & the two ends of it are connected to adjascent segment of commutator.

(c) **Pole pitch** : It is defined as the no. of armature conductor per pole.

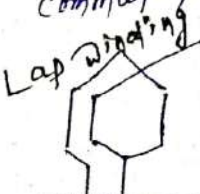
Z = No. of armature conductor
P = No. of pole.

$$\boxed{\text{pole pitch} = \frac{Z}{P}}$$

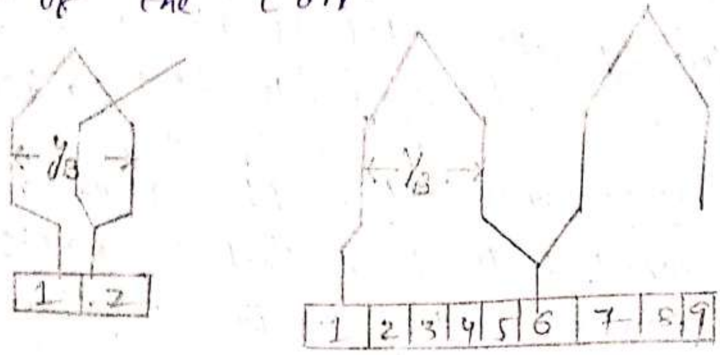
(d) **Coil pitch** or **Coil span** $[Y_s]$: It is defined as the distance measured in terms of no. of armature conductor betn two side of a coil.

* If coil pitch = pole pitch ← called fully pitched coil.
* If coil pitch < pole " ← called fractionally pitched coil.

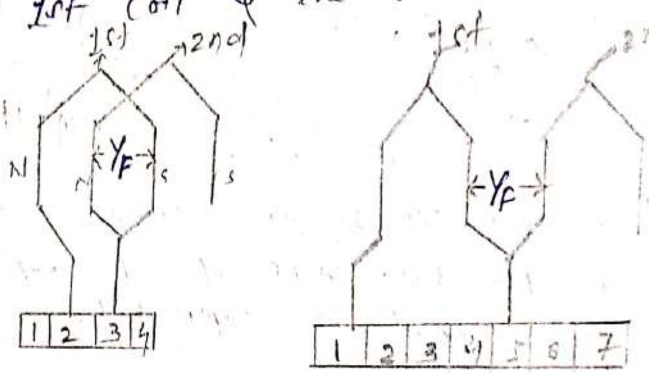
(e) **Commutator pitch** : (Y_c) - It is defined as the no. of commutator segment spanned by each coil of winding.



(f) **Back pitch (Y_B)** ÷ It is defined as in term of armature conductor betn the last & first conductor of the coil.



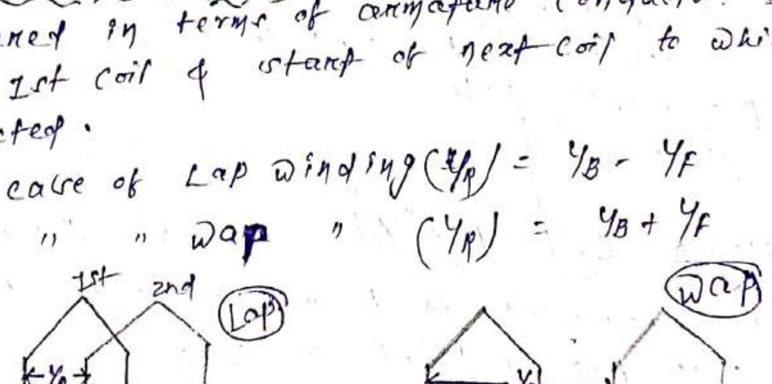
(g) **Front pitch (Y_F)** ÷ It is defined as the distance in term of armature conductor betn the 2nd conductor of 1st coil & the 1st conductor of 2nd coil.



(h) **Resultant pitch ÷ (Y_R)** It is defined as the distance measured in terms of armature conductor betn start of 1st coil & start of next coil to which it is connected.

* In case of Lap winding (Y_R) = $Y_B - Y_F$

* " " " wap " (Y_R) = $Y_B + Y_F$



Lap & wave winding ÷ Two types of winding mostly used in armature are known as Lap & wave winding. The difference betn the two is due to different arrangement of end connection at the front end or commutator end of the armature

Progressive winding ÷ A progressive winding is one in which one moves through the winding connection to the commutator will progress around the armature in the same dirn as being traced along the path of individual coil.

$$Y_B > Y_F$$

$$Y_C = +1$$

Retrogressive winding ÷ The winding in which as one traces through the winding the connections through commutator segment will progress around the machine in opposite dirn as being traced along the path of individual coil.

$$Y_B < Y_F \quad . \quad Y_C = -1$$

Design of Lap Winding ÷ In lap winding the finishing end of one coil is connected to a commutator segment and to the starting end of the adjacent coil situated under the same pole & so until all the coils are connected.

Important points ÷

(1) Both the Y_B & Y_F are odd.

$$Y_B = Y_F \pm 2,$$

(2) $Y_{avg} = \frac{Y_B + Y_F}{2} = \frac{Z}{P}$

(3) $Y_C = \pm 1$.

(4) $Y_A = Y_B - Y_F$

(5) The no. of slots of a two layer winding is equals to the no. of coil. The no. of commutator segment is also the same.

question Draw a winding diagram of a simple two layer lap winding for a 4-pole generator with 16 coil.

Soln - No. of conductor $(Z) = 16 \times 2 = 32$.

No. of pole $= 4$

pole pitch $(Y_P) = \frac{32}{4} = 8$

$$Y_{Avg} = \frac{Y_B + Y_F}{2} = \frac{Z}{P} = 8$$

$$y_B + y_F = 16 \quad \text{---(i)}$$

We know that $y_B = y_F + 2$

put the value of 'y_B' in eqn (i)

$$y_F + 2 + y_F = 16$$
$$2y_F = 14$$
$$y_F = \frac{14}{2} = 7$$
$$\therefore y_B = y_F + 2 = 7 + 2 = 9$$

$\therefore y_B = 9$

$\therefore y_F = 7$

Short-cut
For progressive $y_B = \frac{Z}{P} + 1$ $y_F = \frac{Z}{P} - 1$

Back connection (9)

$1 + 9 = 10$,
$3 + 9 = 12$,
$5 + 9 = 14$,
$7 + 9 = 16$,
$9 + 9 = 18$,
$11 + 9 = 20$,
$13 + 9 = 22$,

Front connection (7)

$10 - 7 = 3$
$12 - 7 = 5$
$14 - 7 = 7$
$16 - 7 = 9$
$18 - 7 = 11$
$20 - 7 = 13$
$22 - 7 = 15$

15 + 9 = 24,   24 - 7 = 17

17 + 9 = 26,   26 - 7 = 19

19 + 9 = 28,   28 - 7 = 21

21 + 9 = 30,   30 - 7 = 23

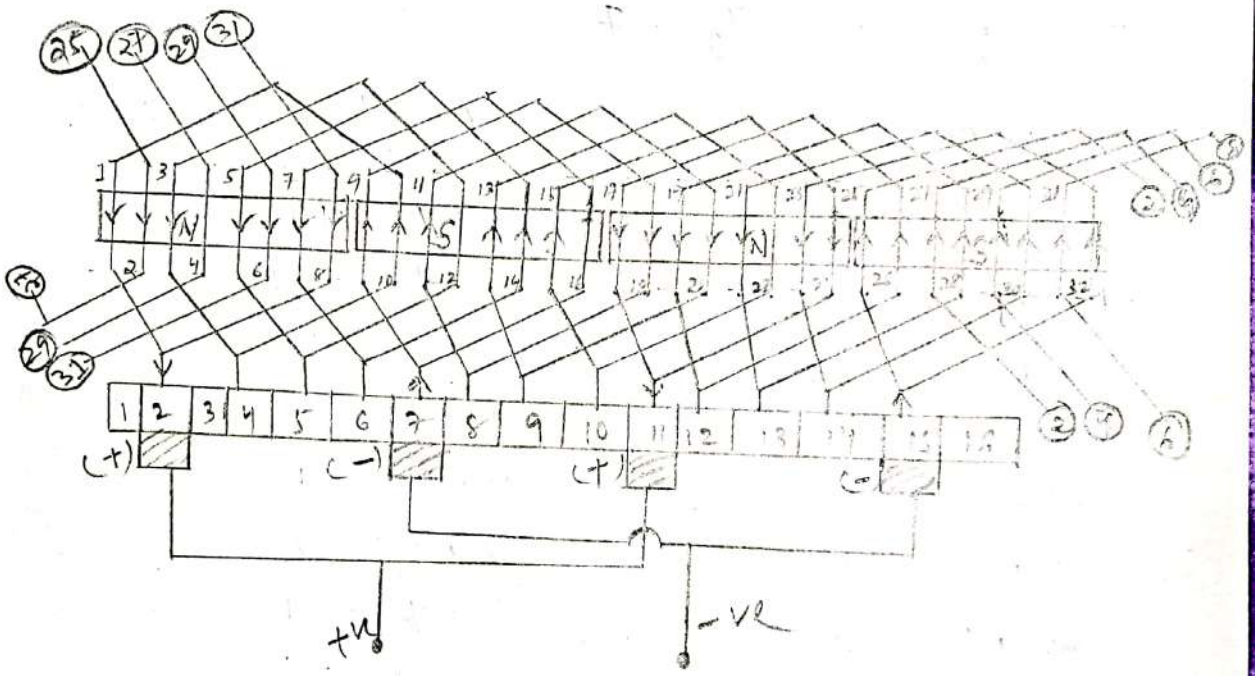
23 + 9 = 32,   32 - 7 = 25

25 + 9 = 34 - 32 = 2,   34 - 7 = 27 — (2)

27 + 9 = 36 - 32 = 4,   36 - 7 = 29 — (4)

29 + 9 = 38 - 32 = 6,   38 - 7 = 31, — (6)

31 + 9 = 40 - 32 = 8,   40 - 7 = 33 - 32 = (1) — (8)



2. Design of wave winding :-

Importants points :-

(1). Both Y_B & Y_F are odd number.

(2) Y_B & Y_F must be equals to pole pitch & may be equals or differ by 2.

(3). Commutator pitch Y_C = Average pitch.

(4) $Y_{Avg} = \frac{Y_B + Y_F}{2} = \frac{Z \pm 2}{P}$

(5) $Y_R = Y_B + Y_F$

EMF equation of DC generator :-

Let ϕ = Flux / pole in wb.

Z = Total no. of armature conductor = No. of slot × No. of conductor/slot

P = No. of pole.

A = No. of parallel paths in armature.

N = Armature revolution per minute (R.P.M)

E_g = EMF induced in the generator.

Flux cut by one conductor during one revolution

$$d\phi = P\phi \quad \text{----- (i)}$$

'N' no. of revolution = 60 sec.

Time taken to complete in one revolution

$$dt = \frac{60}{N} \text{ sec} \quad \text{--- (ii)}$$

EMF generated per conductor.

$$EMF = \frac{d\phi}{dt} = \frac{P\phi}{\frac{60}{N}} = \frac{P\phi \times N}{60}$$

Total emf generated per parallel path (E) $= \frac{P\phi N}{60} \times \frac{Z}{A} =$

$$\boxed{E_g = \frac{P\phi Z N}{60 \times A}} \quad \text{---}$$

* In case Lap winding, $A = P$

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

* In case wave winding, $A = 2$

$$E_g = \frac{P\phi Z N}{120 A}$$

Q.1 A 4 pole DC generator having wave wound armature winding has 51 slots & each slots contain 20 conductors, calculate the voltage generated when driven at 1500 r.p.m assuming flux per pole is 7 mWb.

Soln $P = 4$, $A = 2$, $Z = 51 \times 20 = 1020$, $N = 1500$ rpm

$\phi = 7 \times 10^{-3}$ wb.

$$E_g = \frac{P\phi Z N}{60 \times A} = \frac{4 \times 7 \times 10^{-3} \times 1020 \times 1500}{60 \times 2}$$

$$= 357 \text{ volt}$$

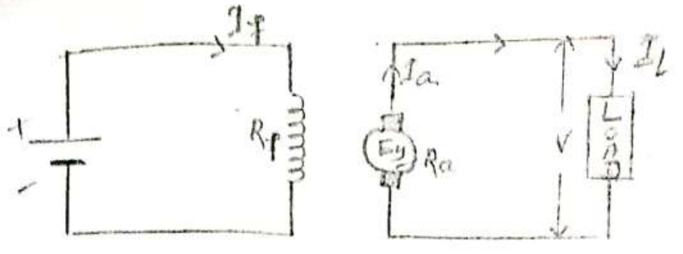
* Classification of DC generator :-

According to excitation of field winding

- Separately excited D.C generator
- Self-excited D.C generator
  - Series
  - Shunt
  - Compound
    - Short shunt
    - Long shunt

* Separately excited D.C generator :-

In this type of DC generator the field winding is excited from an external DC source.



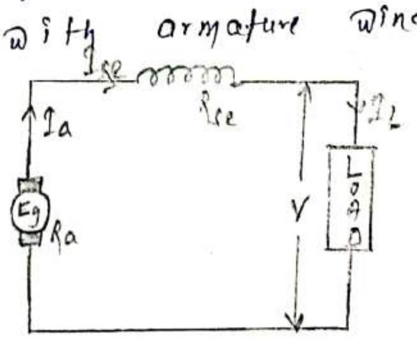
* $I_a = I_L$
* $E_g = V + I_a R_a$
* power of Armature = $E_g \times I_a$
* power delivered to Load = $E_g \times I_a - I_a^2 R_a$

  $= I_a [E_g - I_a R_a]$

  $= V \times I_L$

* **Self-excited DC generator** :- It is a type of DC generator in which the field winding is excited from the output of the generator itself.

(i) **Series DC generator** :- In this type of DC generator field winding is connected in series with armature winding.



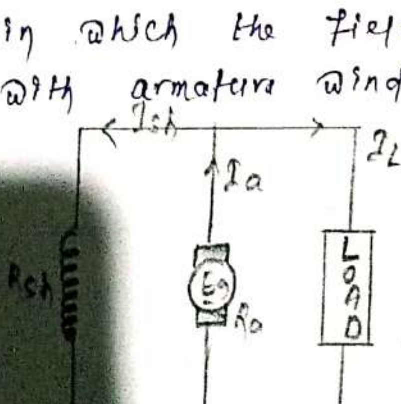
* $I_a = I_{se} = I_L$
* $E_g = V + I_a R_a + I_{se} R_{se}$

  $\Rightarrow E_g = V + I_a [R_a + R_{se}]$
* power of Armature = $E_g \times I_a$
* power to Load $= E_g I_a - I_a^2 R_a - I_a^2 R_{se}$

  $= I_a (E_g - I_a R_a - I_a R_{se})$

  $= V \times I_L$

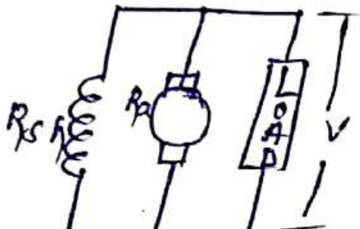
(ii) **Shunt DC generator** :- It is a type of DC generator in which the field winding is connected in parallel with armature winding.



* $I_a = I_{sh} + I_L$
* $E_g = V + I_a R_a$
* $I_{sh} = \frac{V}{R_{sh}} = \frac{E_g - I_a R_a}{R_{sh}}$
* power in Armature = $E_g \times I_a$
* power to Load = $V \times I_L$

$= 502 + 52 \times \frac{8}{100} = 502 + 4.16 = 506.16\,V$

Q A 30 kW, 300 V DC shunt generator has 'R_a' of 0.05 Ω & 'R_{sh}' is 100 Ω, calculate the total power developed by the armature where it delivered full load out-put.



Useful power $= V \times I_L$

$= 30 \times 10^3\,W$

$I_L = \frac{30 \times 10^3}{300} = 100\,A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{300}{100} = 3\,A$

$I_a = I_L + I_{sh} = 100 + 3 = 103\,A$

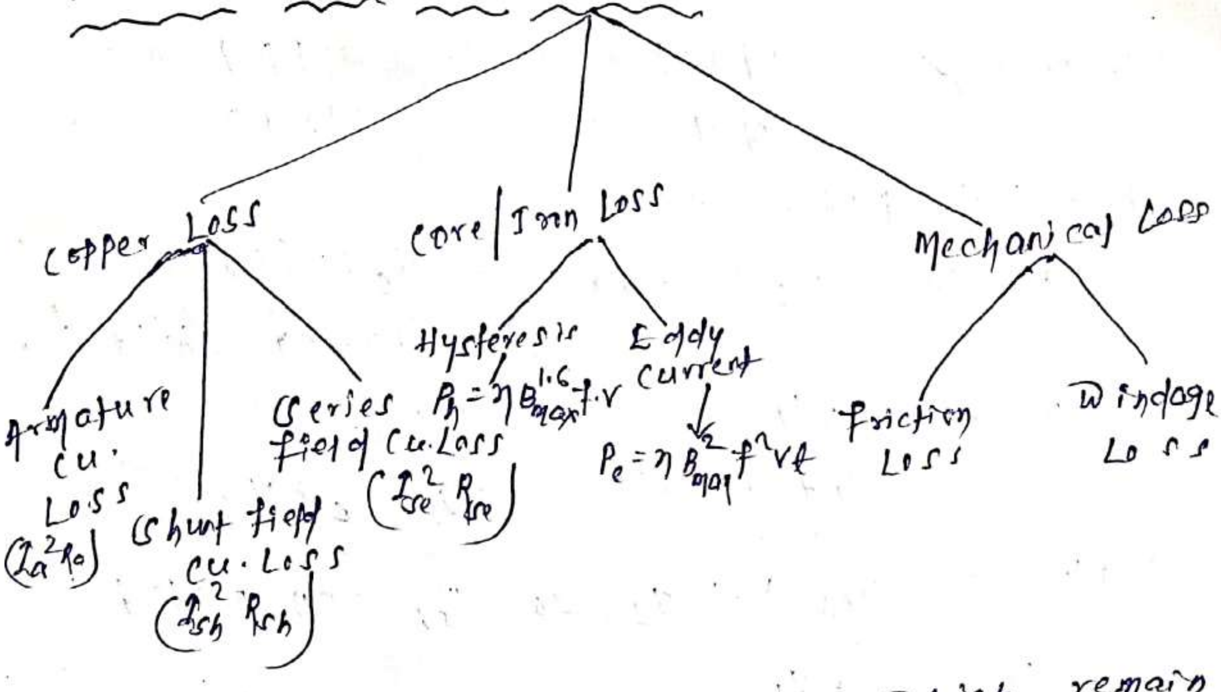
$E_g = V + I_a R_a = 300 + 103 \times \frac{5}{100} = 305.15\,V$

Power developed by armature $= E_g \times I_a$

$= 305.15 \times 103$

$= 31430.45$ watt

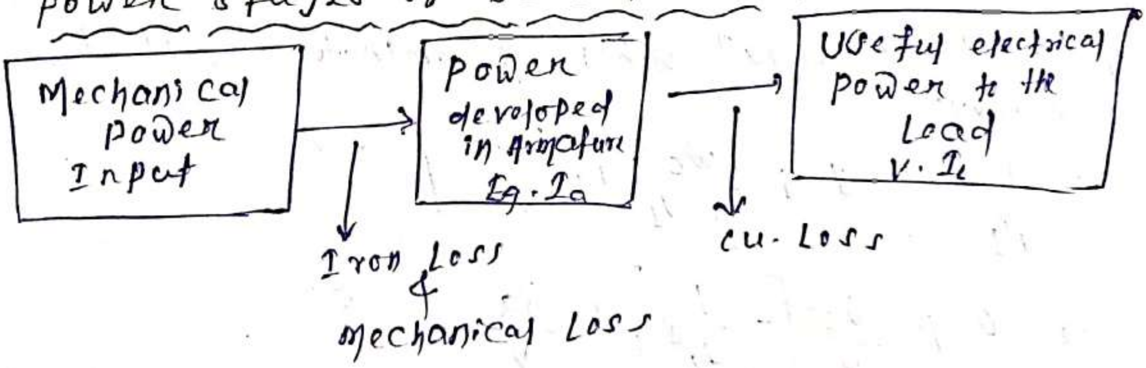
Losses in DC machine :-



* The losses of DC machine which remain constant at all Load are known as constant Loss.

* The Losses of a DC machine which are varies with load called variable Loss.

power stages of DC generator :-



* Mechanical efficiency $(\eta_m) = \dfrac{E_g I_a}{\text{mechanical input power}}$

* Electrical efficiency $(\eta_E) = \dfrac{V \cdot I_L}{E_g \cdot I_a}$

* Overall efficiency $(\eta_o) = \dfrac{V \cdot I_L}{\text{mech. input}}$

$$\boxed{\eta_{overall} = \eta_{elec} \times \eta_{mech}}$$

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Iron Loss :- The iron Losses occur in the armature of the DC machine & are due to the rotation of the armature in the magnetic field of the poles.

* It is are of 2 - types.

(a) Hysteresis Loss.

(b) Eddy current Loss.

(a) Hysteresis Loss :- It occurs in the armature of the DC machine since any given part of the armature is subjected to magnetic field reversal as it passes under successive poles.

* When a piece of armature a-b is under the influence of N-pole magnetic line pass from a to B. Half a revolution later when the same piece a-b under influence of S-pole the magnetic lines pass from b to a. In order to reverse continuously the magnet in the armature core some amount of power has to be spent called hysteresis loss & the value is given by $P_h = \eta B_{max}^{1.6} f \cdot V$

η = Hysteresis Loss Constant

$P_h \propto f$

(b) Eddy current loss :- When voltage is induced in the armature conductor there is some amount of voltage also get induced in the armature core.

This small amount of voltage in the armature core will gives rise to a small current called eddy-current & the losses is called eddy current loss.
& this is given by $P_e = \eta B_{max}^2 f^2 t^2 V$

$$\therefore P_e \propto f^2$$

V = volume of core
t = thickness of core.

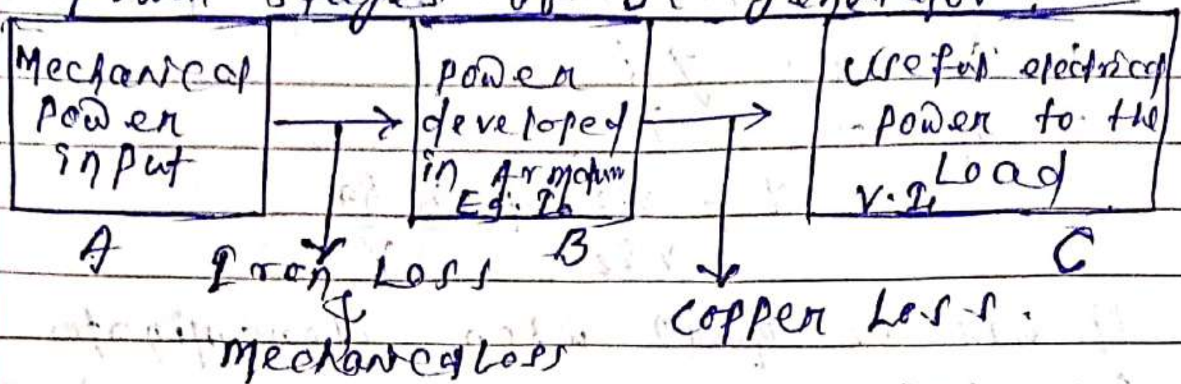
* Eddy current loss can be reduced by constructing the core of thin round iron sheets called lamination.

Classification of losses :-

- Constant Loss (W_c)
  - Iron loss (W_i)
  - Shunt field cu-loss ($I_{sh}^2 R_{sh}$)
  - Mechanical losses (W_m)
- Variable loss.
  - Armature Cu-loss
  - Series field Cu-loss.

* The losses of DC machines which remain constant at all load are known as constant losses.
* The losses of DC machine which varies with load called variable loss.

Power stages of DC Generator :-



Mechanical efficiency $(\eta_m) = \dfrac{E_g I_a}{\text{mech-input power}}$

Electrical " $(\eta_{electrical}) = \dfrac{V \times I_L}{E_g I_a}$

Overall Efficiency $(\eta_o) = \dfrac{C}{A} = \dfrac{V I_L}{\text{mech-input}}$

$$\eta_{overall} = \eta_{elect} \times \eta_{mech}$$

Condition for maxm efficiency in DC generator

Efficiency $= \dfrac{\text{output power}}{\text{input "}} = \dfrac{\text{output power}}{\text{output power} + \text{loss}}$

Electrical Power $= V I_L$

Losses $= W_C + W_{variable}$ $\quad (I_a = I_{sh} + I_L)$

$= W_C + I_a^2 R_a$ (Taking shunt DC generator)

$$\eta = \frac{V I_L}{V I_L + W_C + I_a^2 R_a} = \frac{V I_L}{V I_L + W_C + (I_{sh} + I_L)^2 R_a}$$

Value of $I_{sh} << I_L$, so I_{sh} can be neglected.

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

Dividing both numerator & denominator by $V I_L$, we get

$$\Rightarrow \eta = \frac{1}{1 + \frac{W_c}{V I_L} + \frac{I_L R_a}{V}}$$

η will be max when denominator will be minium

$$\frac{d}{dI_L}\left[1 + \frac{W_C}{V I_L} + \frac{I_L R_a}{V}\right] = 0$$

$$\Rightarrow 0 + \frac{W_C}{V}\left[\frac{-1}{I_L^2}\right] + \frac{R_a}{V} = 0$$

$$\Rightarrow \frac{-W_c}{V I_L^2} = \frac{-R_a}{V}$$

$$\Rightarrow \boxed{W_c = I_L^2 R_a}$$

$$\Rightarrow W_c \approx I_a^2 R_a$$

Constant Loss = Cu. Loss

Iron Loss = Cu. Loss

Armature Reaction :-

* GNA :- Geometric Neutral axis is a axis that bisect the angle betn centre line of adjacent pole.

* MNA :- magnetic Neutral axis is a axis which is drawn perpendicular to the flux passing through the armature.

* When a very less amount of current or no current flows through the armature conductor then the MNA & GNA will coincide each-other.

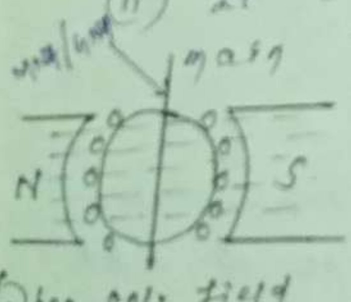
* When current flows through the armature conductor the combined effect of main flux & armature flux shifts the MNA from the GNA.

* In generator the MNA is shifted in the dirn of rotation of the machine & brush have to be shifted along the MNA to get sparkless commutation.

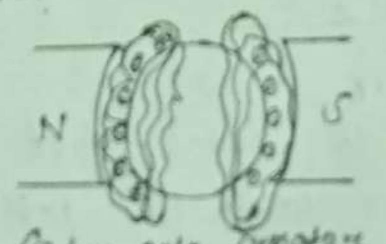
* The armature reaction produces the following effects-

(i) It demagnetises or weakens the main flux.

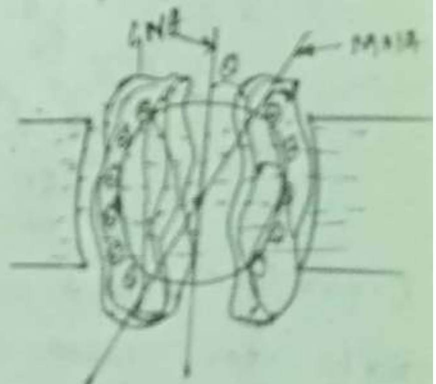
(ii) It cross magnetises or distorted the main flux.

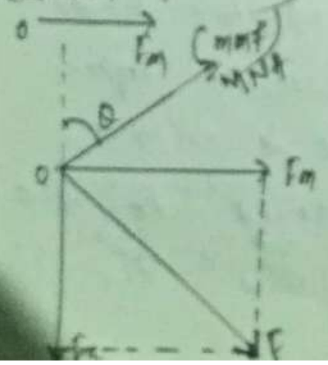


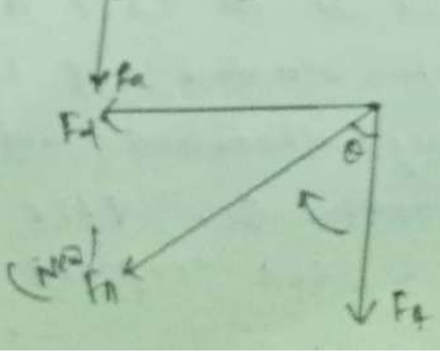
(When only field current present)



(When only armature flux is present)



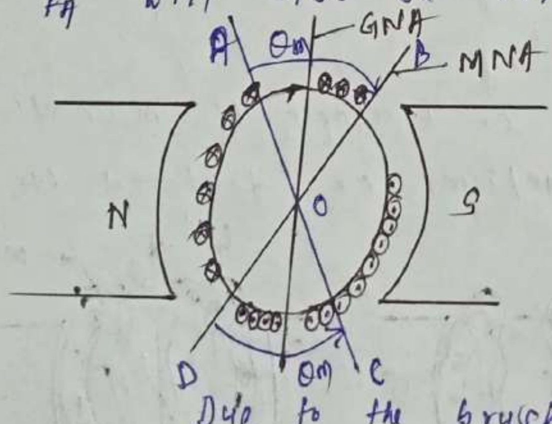




Case-1 : When only the main flux is present the dirn of main MMF $\vec{OF_m}$ will be horizontal.

Case-2 : When only the armature flux is present the current flowing through the conductor under the influence of N-pole will be inward where as current through conductor under the influence of S-pole will be outward. The dirn of mmf $\vec{OF_A}$ will be vertically downward.

Case-3 : But practically under load condition both armature MMF & main mmf will be present. The resultant mmf $\vec{OF}$ is the vector sum of $\vec{OF_m}$ & $\vec{OF_A}$. Now the MNA will always be perpendicular to the net mmf i.e. $\vec{OF}$. So MNA will be shifted by an angle 'θ' from its initial position. Now to get sparkless commutation brush will also be shifted along the dirn of MNA. Due to the brush shift F_A will also be rotated by an angle θ'.



Due to the brush shift some of the conductors which are under the influence of N-pole will now come under the influence of S-pole & same will be the case for conductors under S-pole. The armature mmf $\vec{OF_A}$ will no longer be vertically downward but will be rotated by an angle θ. This component $(\vec{OF_A})$ will results into two component i.e. $\vec{OF_d}$ & $\vec{OF_c}$.

$\vec{OF_d}$ is known as demagnetising component which weakens the main flux & $\vec{OF_c}$ is known as crossmagnetising component & it destroyed the main flux.

* ∠AOB & ∠COD are demagnetising conductors.
* ∠AOD & ∠BOC " crossmagnetising conductor

Demagnetising conductor,

$$\boxed{A.T_d/pole = \frac{Z \cdot I \cdot \theta_m}{360^\circ}}$$

Crossmagnetising conductor,

$$\boxed{AT_c/pole = Z \cdot I \frac{1}{2P} - \frac{\theta_m}{360}}$$

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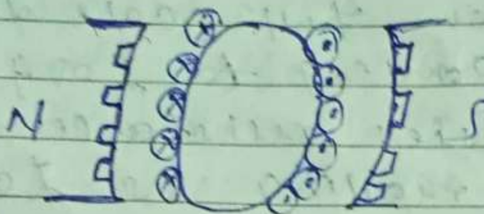
Compensating winding :

These windings are used to neutralized the crossmagnetising effect in the armature of a DC machine.



Current through compensating conductor (I_c) = I_a

" " " armature " (I_a) = $\frac{I_a}{A}$

Total no. of armature conductor/pole = Z_a

Total no. of compensating condu/pole = Z_c

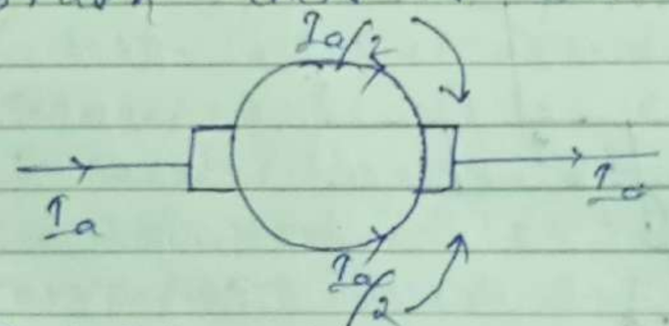
$$Z_c \cdot I_a = Z_a \cdot \frac{I_a}{A}$$

$$\boxed{Z_c = \frac{Z_a}{A}}$$

These windings are embeded into slot in the pole shoes & are connected in series with armature & in such a way that current through them flow in opposite to that of current flow through armature conductor directly below the pole shoes.

Commutation :-

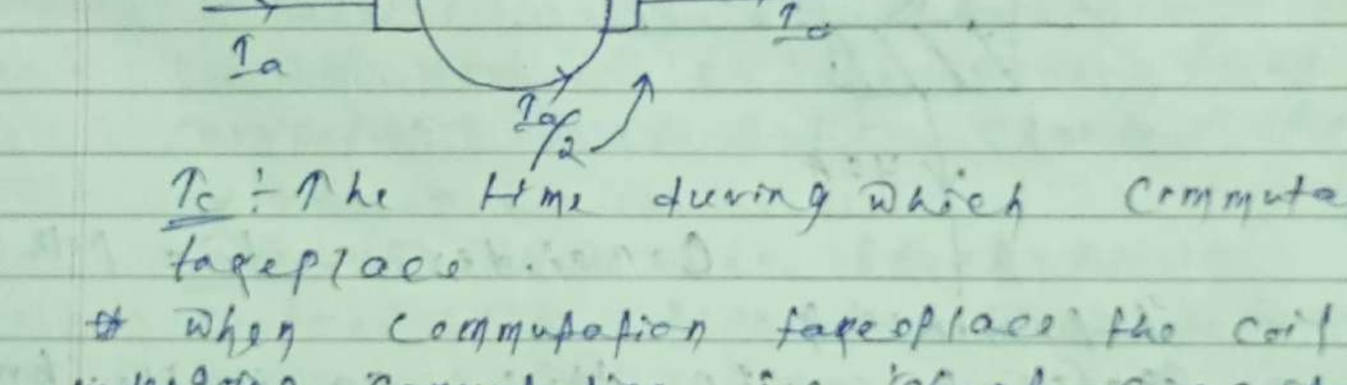
The process of reversal of current in a coil as it passes through the brush axis is called "commutation".

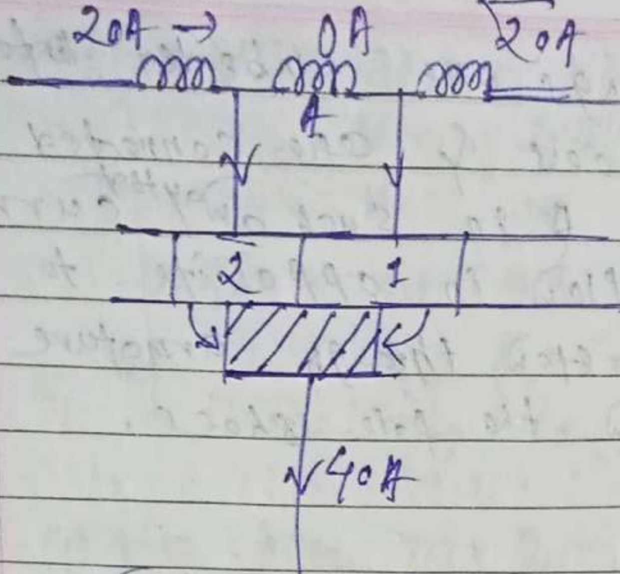


T_c = Commutation period

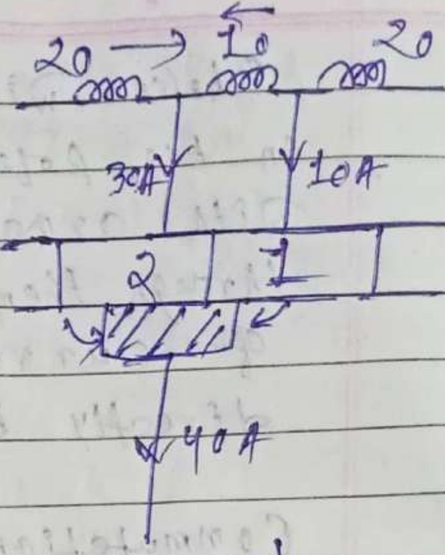
T_c :- The time during which commutation takeplace.

\# When commutation takeplace the coil undergoing commutation is short circuited by brush & the time period called T_c. So the current reversal is completed within the T_c is called ideal commutation.

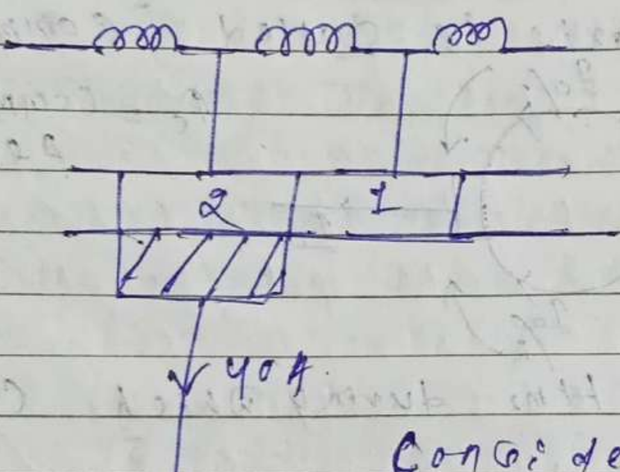




(Case-3)



(Case-4)



Consider a two pole Lap Winding.

Case-1 - In this case the brush is contact with segment '1' & the commutator segment '1' conduct 40 A i.e. 20A from coil side A & the adjacent coil. When the commutation process start the brush will make contact with segment '2'.

Case-2 - Here brush is in contact with 1/4 on segment 2 & 3/4 of segment '1'. So 10 A current flows through segment 2 & 30 A current through segment 1 making it 40 A current to the brush.

So it is observe that current in the coil A is reduced from 20A to 10 A.

Case-3 : In this case brush is ½ of segment 1 & ½ on segment 2. So 20 A current flows both from segment 1 & 2 making it 40 A through the brush. Here it is observe that current through coil-A is zero.

Case-4 : Here brush is in contact with ¾ on segment-2 & ¼ on segment 1. So 30A current flows through segment-2 & 10 A current flows thr segment-1 making it 40 A through the brush. So it is observe that current in coil-A is changed its direction

Case-5 - Here the brush is in contact with segment-2 completely. So 20A current flows from coil-A & 20 A from adjacent coil making it 40A to the brush, but it is observe that the current through coil-A is 20A but it totally in opposite dirn ~~when the brush is compared to~~ as compared to, when the brush is in contact with segment-1. This complete process of current reversal when ~~atom~~ the coil passes through brush axis is called commutation.

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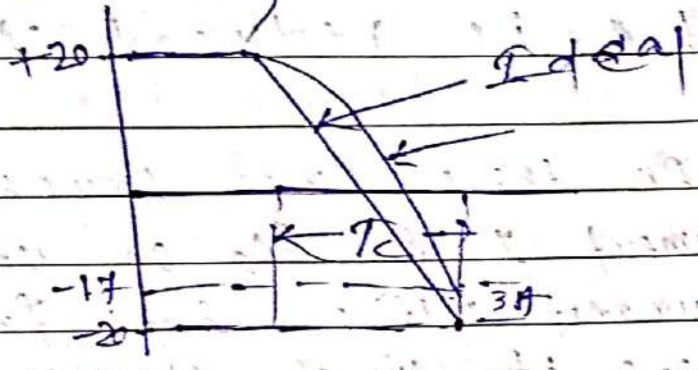
Ideal & practical commutation :-



If during commutation current changes at a uniform rate i.e. from +20A to -20A within the commutation period Tc then it is called ideal commutation. So in case of ideal commutation there will be no sparking betn commutator & brush. But in practical commutation the armature coil has got its own inductance, when current in coil undergoing commutation changes self induced emf is produced called reactance voltage. This reactance voltage will oppose the change in the value of current & current changes at a slower rate, than ideal commutation. At the end of commutation period the current in the coil is suppose to 17A, so 3A current flows from commutator segment 1 to the brush causing spark betn the commutator segment 1 & brush.

Reactance voltage $(V_R) = L \cdot \frac{dI}{dt}$

$= L \cdot \left[\frac{I - (-I)}{T_c} \right]$

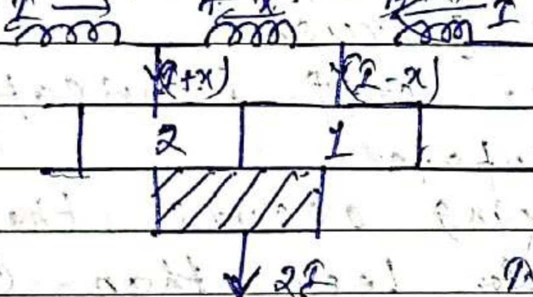
$$V_R = L \cdot \frac{2I}{T_c}$$

$$T_c = \frac{W_b - W_m}{v}$$

W_b = width of brush
W_m = " " mica insulation
v = velocity of movement of commutator segment

Methods for improving commutation:-
(i) Resistance Commutation.
(ii) Emf commutation.

(i) Resistance Commutation:-



This method of improving the commutation consist of replacing low resistance 'Cu' brushes with high resist. carbon brushes. The current from coil 'B' reaches commutator segment 2 & in brush two path first is straight from commutator segment 1 to brush (I-x) & the other via short circuited path coil 'A' & commutator segment '2' to the brush. If low resistance 'Cu' brushes are used then the current will preferable follow the 1st path i.e. through segment 1 to brush due to low contact resistance of high resistance. carbon brushes are used the current will preferably follow the 2nd path i.e. through coil-A & segment 2 & then brush because the resist. R_1 of the 1st path will increase of diminishing area of contact of the bar with the brush and due to increase in contact area of brush with segment 2' resistance R' of the 2nd path will decrease and most of the current will flow through that path. Hence carbon brushes have almost replace Cu-brushes in DC machine.

Advantage of C-brush :-

They are self lubricating & polished the commutator.

If sparking occurs they would damage the commutator less than Cu-brushes.

Disadvantage :-

Due to high contact resistance a voltage drop about 2V will happened.

Because of high loss the commutator has to be made somewhat larger than Cu-brush.

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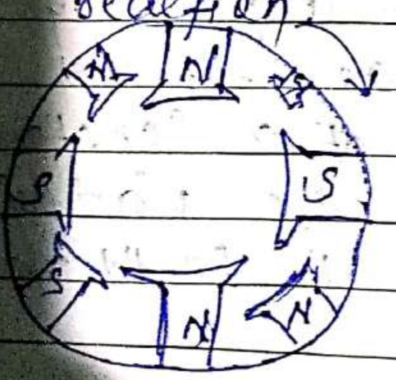
EMF Commutation :- (Interpole/Compole)

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

* The reversing emf will oppose the reactance voltage there by producing quick reversal of current in the short-circuited coil which will cause sparkless commutation.
* EMF commutation can be done by using interpoles or compoles.
* Interpoles are small poles wound with small number of turn placed infront the main pole. They are connected in series with the armature to carry full armature current.
* Their polarity in case of generator is same as that of the main pole ahead in the dirn of rotation.
* The function of interpole is to produced a reversing emf which will oppose the reactance voltage & leads to sparkless commutation.
* The MMF of the interpole also neutralises cross magnetising effect of armature reaction.



Characteristic of DC generator :-

1. Open circuit characteristic [O.C.C.]

It is the graph betn generated emf on no load 'Eo' and field current I_f at a constant speed. This is also called magnetic characteristics.

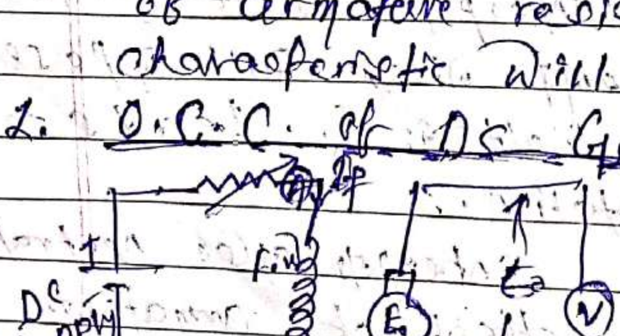
2. Internal characteristic :-

It is the graph betn generated emf at load 'Eg' & field current 'I_f'. The value of 'Eg' is always less than 'Eo' due to armature reaction drop, so internal characteristic is lie below O.C.C.

3. External characteristic :-

It is the graph betn voltage across the load 'V' & load current 'I_L'. The value of 'V' will be less than 'Eg' because of armature resistance drop. So external characteristic will lie below I.C.

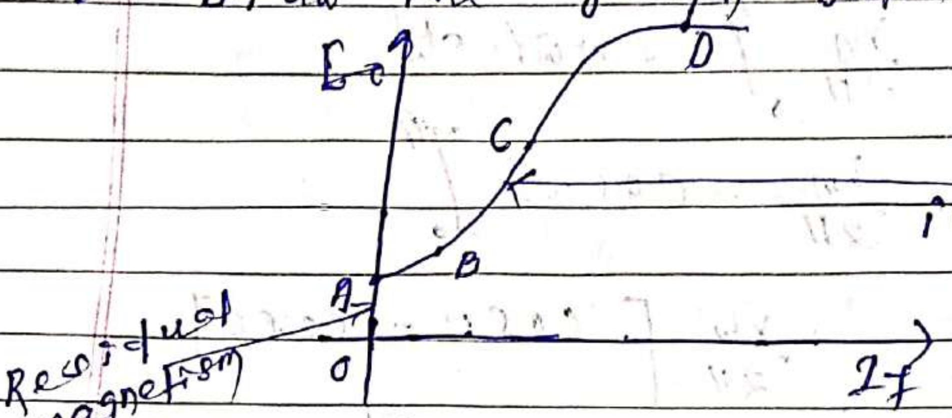
1. O.C.C. of DC Generator :- ($E_o \sim I_f$)



The field winding of DC generator is disconn from the machine & it separately excited from an external DC source.

* The machine is run at a constant speed.
* The value of 'I_f' is varied by varying the value of field resistance.

* For each value of field current note down the value of E_0 by the voltmeter.
* Draw the graph bet^n E_0 & I_f.



* When 'I_f' is zero there is presence of some generated emf represented by 'OA' this is due to residual magnetism in the field pole.
* upto point 'C' the curve is linear because at low flux density the reluctance of iron is neglisible as compared to air gap..
* After point 'C' reluctance of iron will comes to existance due to higher value of flux density & the curve will not linear.
* After point 'D' saturation of the poles, begins & the curve will level off. This is called O.C.C.

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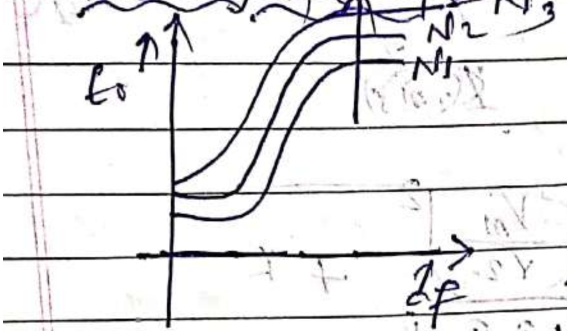
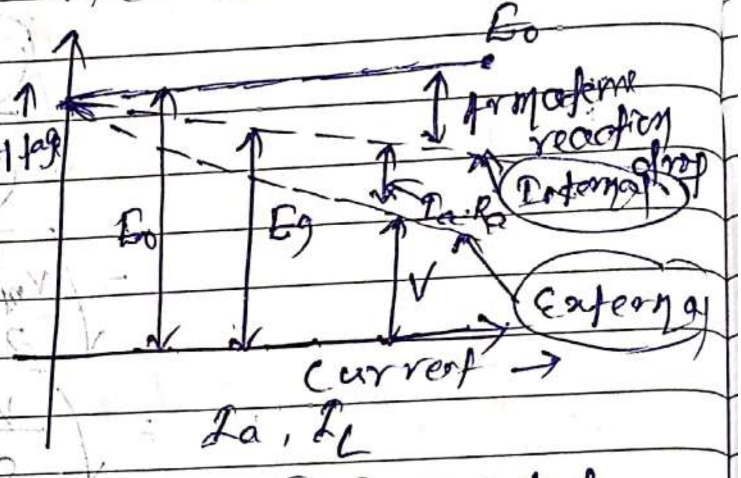
Characteristics of separately excited DC generator

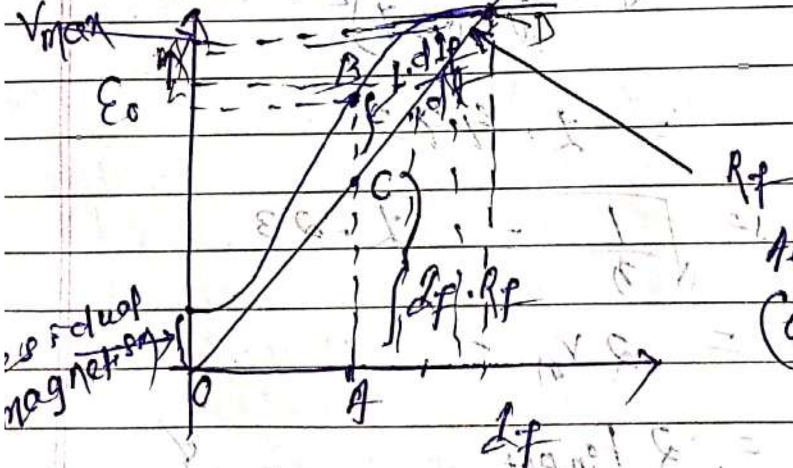


O.C.C

With increase in speed steepness of O.C.C curve increases.



Voltage Build-up in a self-excited DC Generator:-



AB = AC + CB

(ohmic drop in field resistance)

* When the generator is run at a constant speed some emf will always be generated due to residual magnetism. This emf will circulate a small current in the field winding which will increase the flux.
* This increase in flux will result in increase in generated emf & hence

field current will increase which will again result in increase in emf & the process goes on. The

* Thus 'Eg' in the armature has to supply - (i) The ohmic drop in the field resistance.

(ii) Has to overcome the opposing self induced emf in the coil.

* At any given instant of field current 'OA' the total emf generated is 'AB'. So, AB = AB + BC. The part 'AC' ($I_f \cdot R_f$) will be all absorb the ohmic drop & part 'BC' will be available for overcoming $L \cdot \frac{dI_f}{dt}$.

* If the field current is increase further at point 'D' the available voltage will be 'OM' & it all absorb by the ohmic drop and that will indicate the maxm voltage build-up by a DC generator.

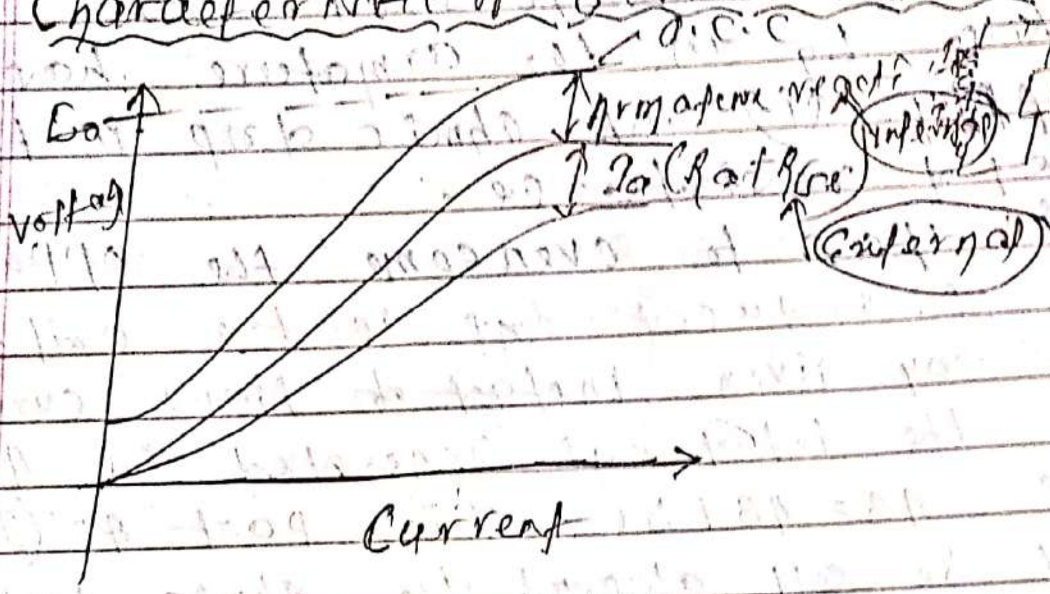
* The total voltage build up by the DC generator can be found by the intersection of the O.C.C. with the field resistance line.

Critical field Resistance(R_c): Voltage build up in a generator depends on the field resistance. For field resistance 'R_1' the voltage build-up is OM, if the field resistance is increase to R_2 voltage buildup become less i.e. OL

* When the field resistance become tangent to O.C.C the generator will just excite

and that represent the critical value of field resistance.

Characteristic of Series Generator :-



Shunt generator :- Same as separately excited DC generator.

Voltage regulation :-

$$\% V_{reg} = \frac{V_{No.Load} - V_{Full.Load}}{V_{Full\,Load}} \times 100$$

The full load voltage of a DC generator is less than the no load terminal voltage. The difference in the terminal voltage betn the condition of no load & full load expressed as a %age of full load V_T is called voltage regulation.

Need for parallel operation:-

(1) Continuity of Service:-

(a) Several small units are more releable that one large unit because if one unit ~~phase~~ fail then the continuity of supply can be maintain by the remaining unit. On the other hand if one large unit is used in the event of break-down there will be completely shut-down.

(2) Efficiency:- The load on the power station fluctuates usually having its peak value during the day & minim value during night.

So when the Load decreases one or more unit can be shut-down and the reamaing unit can be load at efficiently increasing the efficiency of operation.

(3.) Maintenance & Repair :-
Generators generally require routin maintenance & repair. If generator are operated in parallel the maintenance operation can be perform by isolating the affected generator while the Load can be supply by the reamaining generators.

(4.) Need for increasing plant capacity:-
When the Load on the power station increases additional unit can be installed in parallel with the existing one to withstand the Load.

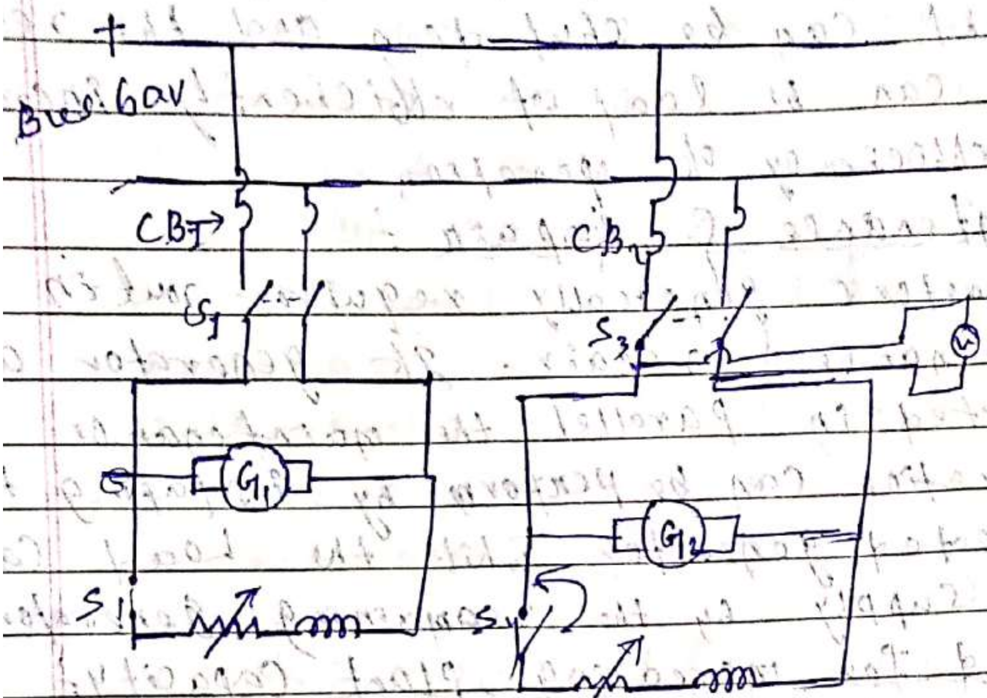
Condition for parallel operation:-

(1.) The terminal voltage of all the generators to be connected in parallel must be same.

(2.) The polarities of all the generators to be connected in parallel must be same.

(3.) Frequency of all generator connecting parallel must be same.

Shunt-generator in parallel :



Generators in power plants are connected in parallel through bus bar.

* Bus bar are heavy thick copper bar which supply equal amount of voltage at all point & act as +ve & -ve terminal.

+ve side of the generator are connected to +ve bus bar & -ve side connected to -ve bus bar.

proof

Generator G_2 is rotated & brought to rated speed and switch S_2 is closed. CB_2 is closed and generator G_2 is excited at a voltage equal to bus bar voltage. This is indicated by voltmeter.

Now generator G_2 is ready for parallel with generator G_1.

* When generated emf of G_2 is equal to bus bar voltage it is not supplying any load & generator is said to be floating on the bus bar.
* If generator G_2 has to supply some load then the generated voltage should be greater than the bus-bar voltage. That is $E > V$

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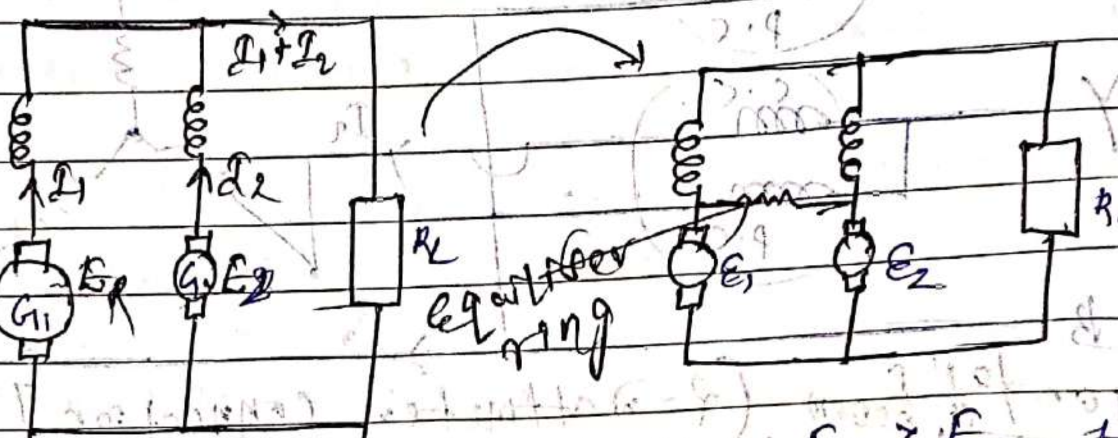
Series generator in parallel :-



* If due to any reason $E_1 > E_2$ then $I_1 > I_2$. So field of generator-1 is strengthen & further E_1 will increase.
* While field of G_2 is weakend & E_2 will decrease further. At a stage will come when generator-1 will be supplying the whole load current and it is attempting to operate generator to as a motor.
* At this point two generators will form a short-circuited loop & current will be high. So that C.B will triped and disconnect the generator from the load.
* So this method of parallel operation will lead to unstable operation.
* This problem can be solve by connect a equilizer bar across the two machine.

Ch-2 **D.C motor**

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

$T = F \times r$

principle :- whenever a current carrying conductor is placed inside a uniform magnetic field, force will act on the conductor and the dirn of force is given by "Fleming Left hand Rule".

* According to Fleming Left hand rule the force will try to rotate the conductor in anticlockwise dirn producing a torque

* Similarly torque will also be produce in all the conductors and gives a resultant torque. This resultant torque will try to rotate the armature in the anticlockwise dirn producing rotation.

Back EMF :- when the armature conductor rotates under the influence of ~~magnetic field~~ torque, it will cut the magnetic lines of force & hence an emf is induced into the conductor.

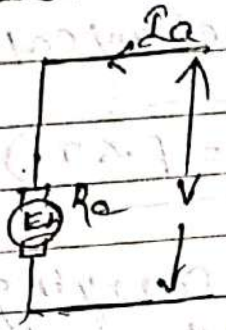
* The emf induced will oppose the supply voltage due to LENZ's Law & that why it is called back emf or counter emf.

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

$E_g \cdot I_a$

$V \cdot I_L$

Voltage Eqn of DC motor :



$$V = E_b + I_a R_a + \text{Brush contact drop}$$

Power Eqn : we know that

$$V = E_b + I_a R_a \quad \text{----(i)}$$

multiply both side I_a

$$V \cdot I_a = E_b I_a + I_a^2 R_a$$

($V I_a$ → Elect. power input; $E_b I_a$ → Mech. power of armature; $I_a^2 R_a$ → Armature Cu. Loss)

$$\boxed{P_m = V I_a - I_a^2 R_a}$$

Cond^n for Max^m power :

We know, $P_m = V I_a - I_a^2 R_a$

For P_m to be max^m, $\frac{dP_m}{dI_a} = 0$

$$\frac{d}{dI_a}\left[V I_a - I_a^2 R_a\right] = 0$$

$$V - R_a (2 I_a) = 0$$

$$V = 2 I_a R_a$$

so $I_a R_a = \frac{V}{2}$

Also, we know $V = E_b + I_a R_a$

putting value $I_a R_a = \frac{V}{2}$

$$V = E_b + \frac{V}{2}$$

$$E_b = V - \frac{V}{2} = \frac{V}{2}$$

$$\boxed{E_b = \frac{V}{2}}$$

Hence mech. power developed by motor will max^m, when E_b will be equal to $\frac{1}{2}$ of supply voltage.

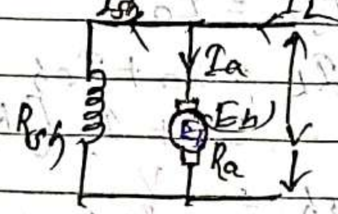
EC-1

Types of DC motor :-

- Shunt
- Series
- Compound
  - Short-shunt
  - Long-shunt

(i) **Shunt DC motor** :-

Here the field winding is connected with armature winding.



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

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

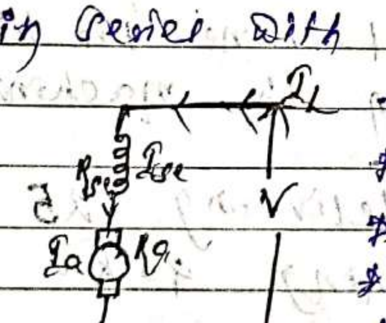
$$V = E_b + I_a R_a = I_{sh} \cdot R_{sh}$$

* Electrical power supply to motor = $V \times I_L$

* Mechanical power developed in Armature = $E_b \times I_a$

(ii) **Series DC motor** :-

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



* $I_L = I_{se} = I_a$

* $V = E_b + I_a R_a + I_{se} R_{se}$

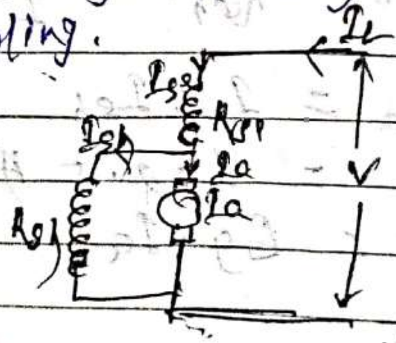
* $V = E_b + I_a(R_a + R_{se})$

* electrical power supply = $V \times I_L$

* mech. " developed = $E_b \times I_a$

(iii) **Compound DC motor** :- In case of compound DC motor both series field as well as shunt field are present.

(a) **Short-shunt** :- In this case shunt field winding is only parallel with the armature winding.



$$I_L = I_{se}$$

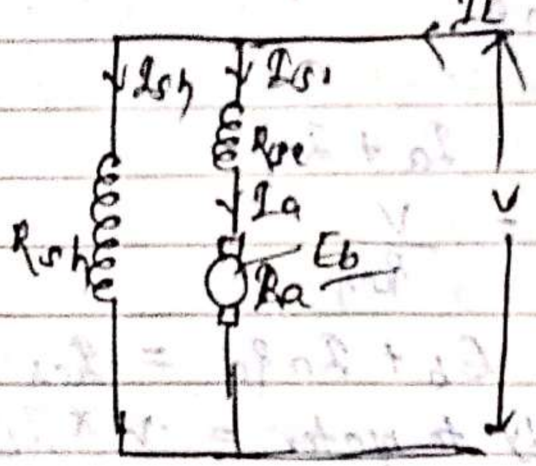
$$I_L = I_a + I_{sh}$$

$$V = E_b + I_a R_a + I_{se} R_{se}$$

$$I_{sh} = \frac{E_b + I_a R_a}{R_{sh}} = \frac{V - I_{se} R_{se}}{R_{sh}}$$

* Electrical power supply = $V \times I_L$
* Mechanical " developed = $E_b \times I_a$.

(b) Long shunt :- In this case the shunt field is in parallel with both armature as well as series field winding.

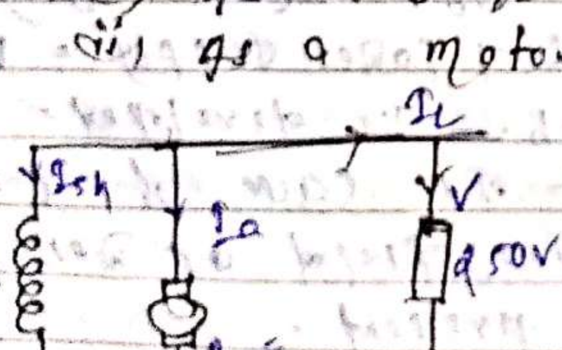


* $I_{se} = I_a$
* $I_L = I_a + I_{sh}$
* $V = E_b + I_a [R_a + R_{se}]$
* $I_{sh} = \frac{V}{R_{sh}}$
* $P_{elec} = V \times I_L$.
* $P_{mech} = E_b \times I_a$

Q- A 25 kW, 250 V, DC shunt generator has armature resistance of 0.06 Ω & shunt field resistance of 100 Ω. Determine the total armature power developed when the machine is working -

(i) As a generator delivering 25 kW.

(ii) As a motor taking 25 kW input.



$V = 250\ V$

$V I_L = 25\ kW = 25 \times 10^3\ W$

$I_L = \frac{25 \times 10^3}{250} = 100\ A$

$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5\ A$

$I_a = I_L + I_{sh}$

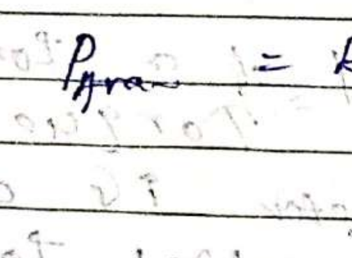
$= 102.5\ A$

Armature power $= E_g \cdot I_a$

$E_g = V + I_a R_a$
$= 250 + 102.5 \times 0.06$
$= 256.15\ V$

$P_{gross} = E_g \cdot I_a = 256.15 \times 102.5$
$= 26255.375\ W$
$= 26.255375\ kW$

iii)



$R_a = 0.06$
$R_{sh} = 100\ \Omega$
$V = 250\ V$

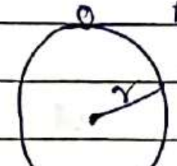
$V I_L = 25000\ W$
$I_L = 100\ A$
$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{100} = 2.5$
$I_a = I_L - I_{sh} = 100 - 2.5 = 97.5\ A$
$E_b = V - I_a R_a = 250 - 97.5 \times 0.06$
power developed in Armature $= 244.15$
$E_b \times I_a = 244.15 \times 97.5$
$= 23804.625$ Watt

E.C.-1

Torque:

Work done by force:
$W = F \times 2\pi r$.

* The twisting movement of a force about an axis called "Torque".
* Every armature conductor is acting upon by a circumferential force from the centre of the armature.



n = speed in rps, $n = \frac{N}{60}$
N = " " RPM

→ work done by force, $W = F \times 2\pi r$
→ work done by armature conductor in 1 revolution $= F \times 2\pi r$.
→ workdone by a.c. in 1 sec/power develop $= F \times 2\pi r \times n$.

$$\text{power} = T \times 2\pi n \quad (T = F \times r)$$

Expression for Armature Torque: (T_a)

Let 'T_a' be the armature torque of a DC motor rotating at 'n' rps.
∴ power developed $= T_a \times 2\pi n$ --(i)

power developed in armature $= E_b \times I_a$ --(ii)

$T_a \times 2\pi n = E_b I_a$ --(iii)

putting the value of 'E_b' in eqn (3)

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

$$T_a = \frac{P \phi Z I_a}{2\pi A} = 0.159 \times Z \phi I_a \times \frac{P}{A}$$

$$T_a = 0.159 \times Z\phi I_a \times \frac{P}{A}$$

If speed 'N' in RPM from eqn (iii),

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

$$T_a = 9.55 \times \frac{E_b I_a}{N}$$

$$T_a \propto \phi I_a$$

$\because$ Z, P, & A are constant.

- In case of shunt motor, ϕ = constant
  $T_a \propto I_a$.
- In series motor, $\phi \propto I_a$
  So, $T_a \propto I_a^2$

Shaft Torque (T_{sh}) :-

$$T_{sh} = 9.55 \times \frac{\text{motor output power}}{N}$$

- The whole 'T_a' developed is not available for doing useful work, because some %age is required for supplying iron & friction losses.
- The torque available for doing useful work called 'T_{sh}'.

$$T_{sh} = 9.55 \times \frac{\text{motor out power}}{N}$$

$T_a > T_{sh}$

$T_a - T_{sh}$ = Loss of torque

T_a - Loss = T_{sh} → Load

EC-L

Q- A 250V 4 pole wave wound DC series motor has 782 no. of conductor on it armature & series field resistance is 0.75Ω, of load current is 40A & flux is 25mWb, find speed & armature torque?

Sol^n $V = 250V, \quad P = 4, \quad A = 2, \quad Z = 782$

$R_a + R_{se} = 0.75\Omega, \quad I_L = 40A, \quad \phi = 25 \times 10^{-3} Wb$

$I_a = I_{se}$

$N = ? \quad T_a = ?$

$V = E_b + I_a [R_a + R_{se}]$

$E_b = 250 - 40 \times 0.75 = 220V$

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

$$N = \frac{E_b \times 60 \times A}{Z \phi P} = \frac{220 \times 60 \times 2}{782 \times 25 \times 10^{-3} \times 4}$$

$$= 337.59 \text{ rpm}$$

$$T_a = \frac{9.55 \times 220 \times 40}{337.59}$$

$V I_L$ — out, $E_b I_a$ — input

$$= 248 \text{ Nm}$$

Q. Determine the armature torque & shaft torque of a 220V, 4-pole DC series motor, with 800 no. of conductors, wave connected supplying a load of 8.2 kW by taking 45A from the main; the flux per pole is 25mWb & armature resistance is 0.6Ω

$T_a = ?$, $T_{sh} = ?$, $V = 220V$, $P = 4$, $Z = 800$

$A = 2$, motor output $= 8.2$ kW, $I_L = I_a = I_{se} = 45A$

$\phi = 25 \times 10^{-3}$ wb, $R_a = 0.6\,\Omega$

$$T_a = 0.159 \times Z \times \phi \times I_a \times \frac{P}{A}$$

$$= 286.2 \text{ N·m}$$

$$T_{sh} = 9.55 \times \frac{\text{motor output}}{N}$$

$$E_b = 220 - 45 \times 0.6 = 193 \text{ V}$$

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

$$N = \frac{E_b \times 60 \cdot A}{P \phi Z} = \frac{193 \times 60 \times 2}{800 \times 25 \times 10^{-3} \times 4}$$

$$= 289.5 \text{ rpm}$$

$$T_{sh} = \frac{9.55 \times 8.2 \times 10^3}{289.5}$$

$$= 270.5$$

Loss torque $= T_a - T_{sh}$

$= 296.2 - 270.5$

$= 25.7$ N·m.

<u>Speed of DC Motor:</u>

We know that, $E_b = V - I_a R_a$

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

$$\frac{P \phi Z N}{60 \times A} = V - I_a R_a$$

$$N = \frac{V - I_a R_a}{\phi} \left(\frac{60 \times A}{Z P} \right)$$

A, Z, P, 60 = constant

So, $\frac{60 \times A}{Z P} = K$

$$N = K \cdot \frac{E_b}{\phi}$$

$$\boxed{N \propto \frac{E_b}{\phi}}$$

\# At initial speed is N_1 at a flux of ϕ_1 & back emf of E_{b1}

$$N_1 \propto \frac{E_{b1}}{\phi_1} \quad \text{---------- (1)}$$

\# At final speed is N_2 at flux of ϕ_2 & E_b is E_{b2}

$$\Rightarrow N_2 \propto \frac{E_{b2}}{\phi_2} \quad \text{------- (2)}$$

From eqn (1) & (2)

$$\frac{N_2}{N_1} = \frac{E_{b2}}{\phi_2} \times \frac{\phi_1}{E_{b1}} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}.$$

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}}$$

\# For series motor $\phi \propto I_a$

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}}$$

\# For shunt motor, ϕ = constant

So,

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}}$$

A 220V, DC shunt motor runs at 500 rpm, when the I_a is 50 A, calculate the speed when the torque is double. The R_a is of the motor is 0.2 Ω.

$V = 220V$, $N_1 = 500$ rpm, $I_{a1} = 50A$

$N_2 = ?$, T = double

$R_a = 0.2\,\Omega$.

Sol^n $E_{b1} = V - I_{a1} \cdot R_a$

$= 220 - 50 \times \frac{2}{10}$

$= \boxed{210\,V}$

$E_{b2} = V - I_{a2} R_a$

$= 220 - 100 \times \frac{2}{10}$

$= \boxed{200}$

$T \propto I_a \phi$

For shunt motor, ϕ = constant, $T \propto I_a$

If torque is double, the armature current, $I_{a2} = 2 \times I_{a1}$

$= 2 \times 50 = 100$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

$$\frac{N_2}{500} = \frac{200}{210}$$

$N_2 = 476$ rpm

Input → $V \cdot I_L$ → Mechanical power
Eat

EC-I Dt - 27/01/20

Losses in DC motor :-

# Cu Loss	# Iron Loss / Core Loss	# Mechanical
i) Armature Cu loss	i) Hysteresis	i) friction
ii) Field Cu loss	ii) Eddy current	ii) Windage
iii) Cu loss winding compensating and interpole.		

Constant Loss :-
Iron loss, Mech. Loss, Shunt field Cu. loss

Variable Loss :-
Armature Cu. loss, Series field Cu. loss

Efficiency of DC motor :-

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

$$=$$

$I = I_a + I_{sh}$

Input to DC motor $= V I_L$

losses $= W_C + I_a^2 R_a$

Cond^n for Max^m efficiency :-

$$\eta = \frac{\text{Input} - \text{Losses}}{\text{Input}} = \frac{V I_L - [W_C + I_a^2 R_a]}{V I_L}$$

$$= \frac{V I_L - W_C - I_a^2 R_a}{V I_L}$$

consider a shunt motor

$I_L = I_a + I_{sh}$

$I_{sh} << I_a$, so $I_L \approx I_a$

$$\eta = \frac{V I_L - W_c - I_L^2 R_a}{V I_L}$$

$$\eta = 1 - \frac{W_c}{V I_L} - \frac{I_L R_a}{V}$$

For η is max^m $\frac{d\eta}{dI_L} = 0$

$$\frac{d\eta}{dI_L} = 0 - \frac{W_c}{V}\left(\frac{-1}{I_L^2}\right) - \frac{R_a}{V} = 0$$

$$\frac{W_c}{V I_L^2} = \frac{R_a}{V}$$

$$W_c = I_L^2 R_a$$

Constant loss = variable loss

Power stages in motor :-

A		B		C
Electrical Input power $V I_L$	→ Cu-Loss	Mech. power developed in Armature ($E_b I_a$)	→ Iron & Friction Loss	Output useful power

$$\eta_{elec} = \frac{B}{A} = \frac{E_b I_a}{V I_L}, \quad \eta_{mech} = \frac{C}{B} \rightarrow \eta_{overall}$$

$$\eta_{overall} = \eta_{mech} \times \eta_{elec}$$

Q- A 220V, DC shunt motor at no Load takes a current of 2.5 A, the armature resistance is 0.8 Ω & shunt field resistance is 200 Ω, Estimate the efficiency of the motor when the input current is 32 A

Sol) At no. Load

$V = 220V$, $R_a = 0.8\Omega$, $R_{sh} = 200\Omega$

$I_L = 2.5A$

Input power $= V \cdot I_L = 220 \times 2.5$
$= 550$ W

Since the motor is operating at no load condⁿ, so the whole input power is utilised in supply the constant losses & 'Cu' loss.

i.e. $550 = W_C + I_a^2 R_a$

$I_a = I_L - I_{sh}$

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

$I_a = 2.5 - 1.1$
$= 1.4A$

$I_a^2 R_a = (1.4)^2 \times 0.8 = 1.56$ W

$W_C = 550 - 1.56 = 548.4$ W

At Load condⁿ :-

$V = 220V$, $I_L = 32A$

Input power $= V I_L = 220 \times 32 = 7040$

Losses $= W_C + I_a^2 R_a$

$I_a = I_L - I_{sh} = 32 - 1.1$
$= 30.9A$

$I_a^2 R_a = (30.9)^2 \times 0.8 = 763.8$ W

Loss $= 548.4 + 763.8$
$= 1312.2$

$\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{Input} - \text{Loss}}{\text{Input}}$

$$= \frac{7040 - 1312}{7040} \times 100 = 81.36\ \%$$

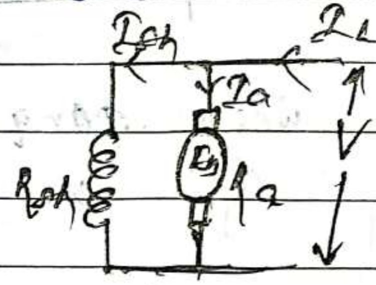
EC-1

Characteristic's of DC motor :

1. Torque Vs Armature Current [T Vs I_a]
2. Speed Vs I_a
3. Torque Vs N / Mechanical characteristic.

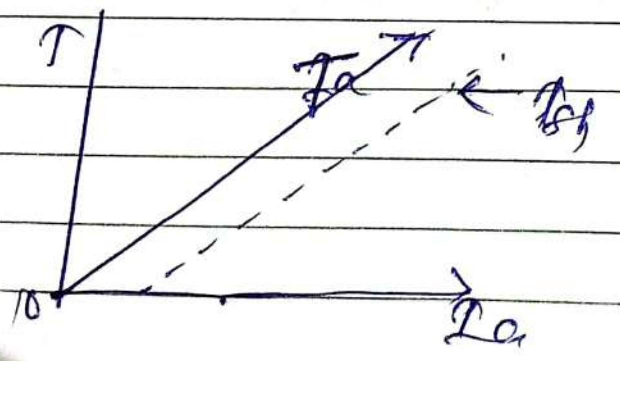
1. DC Shunt Motor :

(a) $T \propto I_a$:



We know, $T \propto I_a \phi$

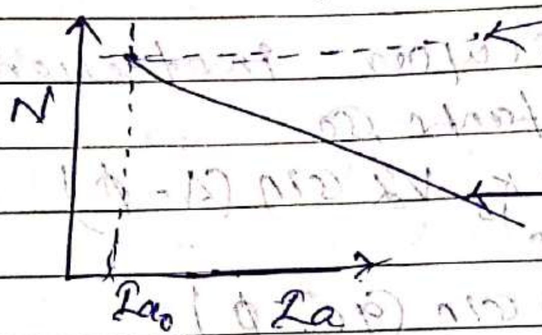
But, ϕ = const, $T \propto I_a$



(b) N Vs I_a :-

$$N \propto \frac{E_b}{\phi} = \frac{V - I_a R_a}{\phi}$$

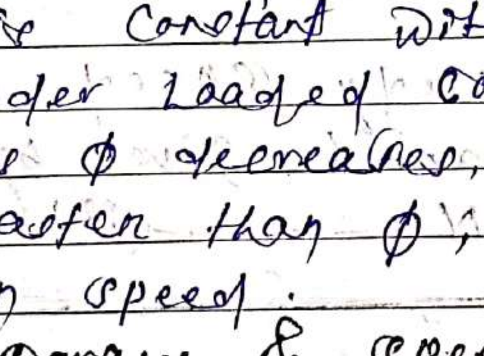
Normal working condition: ϕ & E_b is constant



\# Under normal working cond^n, flux(ϕ) is constant & E_b is constant, so speed (N) is constant with respect to I_a.

\# Under Loaded cond^n E_b decreases as well as ϕ decreases, but decrease in E_b is faster than ϕ, so there is some decrease in speed.

(c) Torque & speed :-



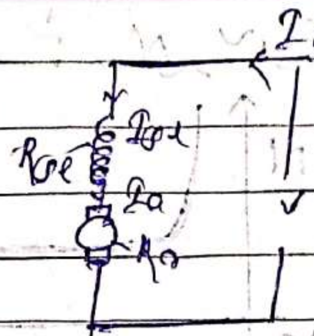
$T \uparrow I_a \uparrow$

$\downarrow N$

When torque increases speed decreases & vice-versa.

(2) <u>DC series motor</u>:

(a) $T \sim I_a$:

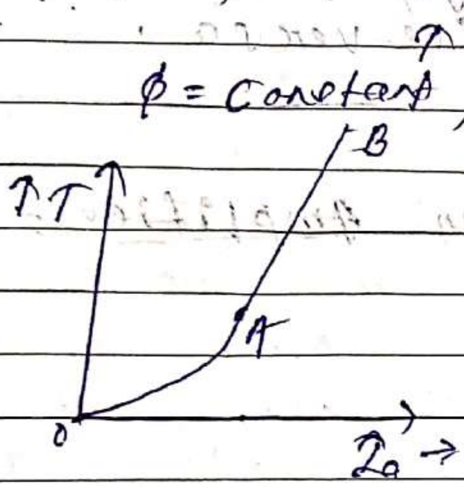


$$T \propto I_a \cdot \phi$$

but $\phi \propto I_a$, so $T \propto I_a I_a$

$T \propto I_a^2$ ← upto saturation point.

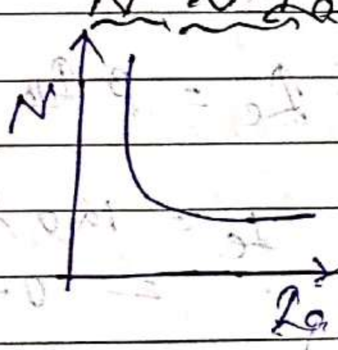
ϕ = constant, $T \propto I_a$ ← After " ".



OA = upto saturation

AB = After "

(b) $N \sim I_a$:



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

* $I_a \uparrow$, $I_{se} \uparrow$, $\phi \uparrow$,

* $\downarrow E_b$ ← Neglected

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

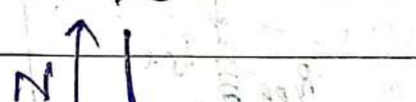
* When I_a increases, I_{se} increases, so ϕ increases, But with increase in I_a, E_b decreases. However change in E_b is very small as compared ϕ. And hence neglected, so $N \propto \frac{1}{I_a}$.

With increase in I_a, speed (N) decreases & vice-versa.

.67

2.4

I ~ N :



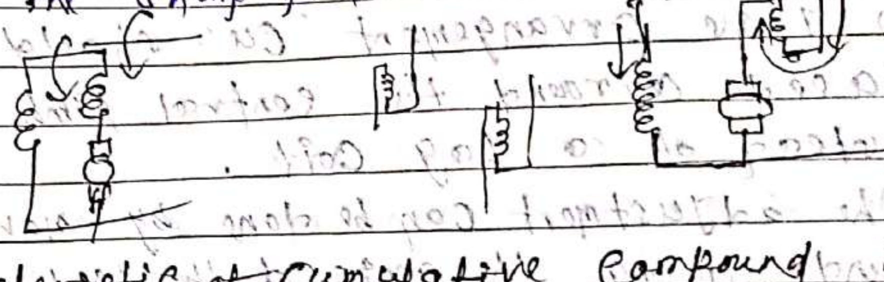
From the above two characteristic it is found that, when 'N' will be high 'I' will be low, & vice-versa.

EC-1

Compound motor

Cumulative compound — Series field add the shunt field

Differential — Series field oppose shunt field.

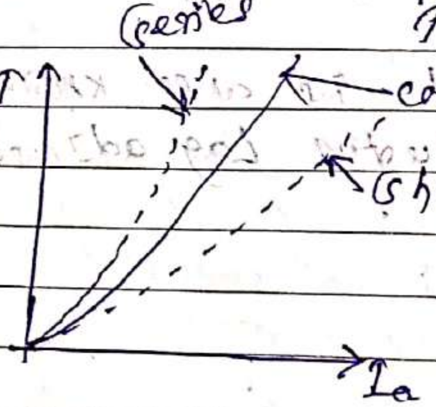


Characteristic of Cumulative Compound Motor:

i) T ~ Ia : Load is increased, field strength of series field increases but shunt field strength will remain constant.

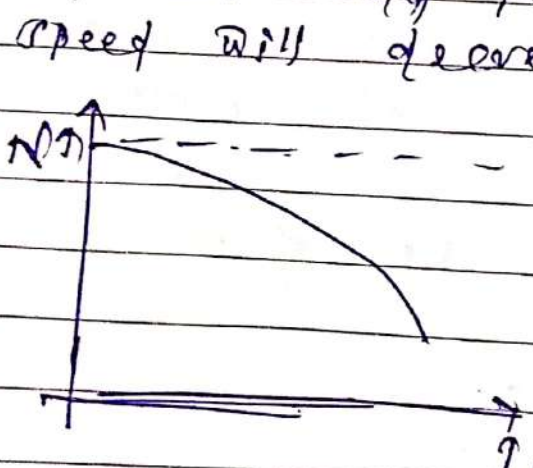
$\phi \rightarrow$ increases

$T \propto I_a \phi$, T increases.

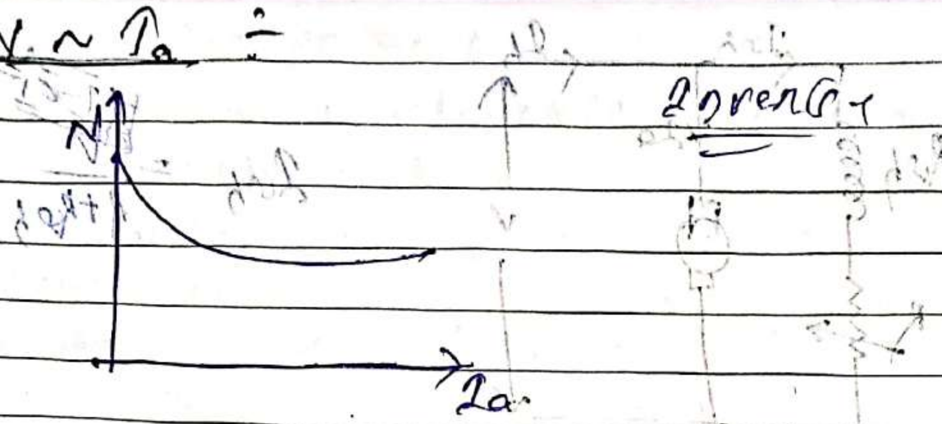


ii) N ~ Ia : → Ia increases due to load increase and finally ϕ increases, so speed will decrease.

$$N \propto \frac{E_b}{\phi}$$



(iii) $N \sim I_a$:-



Application of DC motor :-

(i) Shunt motor :- (constant speed motor)
* Lathe machine
* Drill
* Shapers
* Boring mills
* Spinning mills etc

(ii) Series motor :- (variable speed ")
* Cranes, Elevators, Air compressor, Hair drier, vaccume cleaner.

(iii) Compound motor :-
* printing press, Receprocating machine

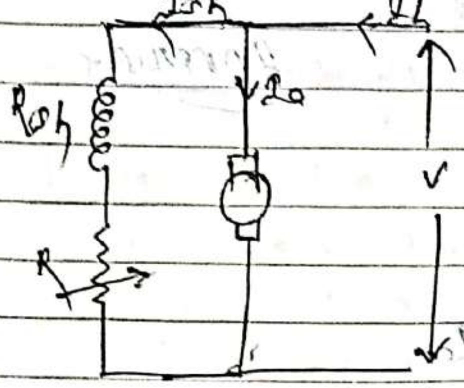
Speed Control of DC motor :

(i) Flux Control methode :- (ϕ = change)
(ii) Armature " " : (R_a = " ")
(iii) Voltage " "

(a) ~~Flux Control method~~ :

1) Speed Control of shunt DC motor by flux control method :-

$$N \propto \frac{V - I_a R_a}{\phi} = \frac{E_b}{\phi}$$



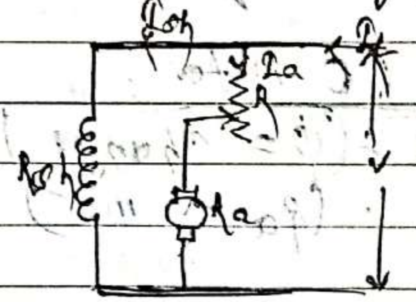
$$I_{sh} = \frac{V}{R + R_{sh}}$$

* In this method of speed control a variable rheostat is connected in series with the shunt field.
* So the total field resistance increases and shunt field current I_{sh} decreases, due to the decrease in I_{sh}, flux ϕ decreases and hence speed increases, because

$$N \propto \frac{1}{\phi}$$

* In this method speed above the normal speed can be achieved.

(b) Shunt motor by Armature Control method :-



$$E_b = V - I_a(R_a + R)$$

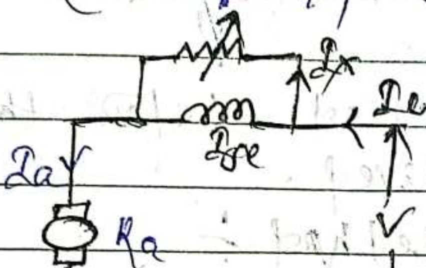
In this method a variable resistor is connected in series with armature. Due to increase in resistance $(R_a + R)$, E_b decrease due to decrease in E_b, speed decrease because $N \propto \frac{E_b}{\phi}$

* In this method of speed control, speed below the normal speed can be achieved

* Speed Control of DC Series Motor :

(i) Flux Control Method :

(a) Field diverter



$I_L = I_a + I_{se}$ (with diverter)

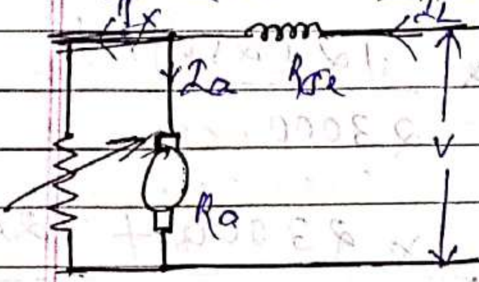
$I_L = I_{se}$ (without diverter)

In this method of speed control a variable resistance called diverter is connected in parallel with series field winding.

* Due to this diverter the series field current decreases and hence flux reduce.
* As $N \propto \frac{1}{\phi}$, so speed increases.

* By using this method of speed control speed above normal speed can be achieved.

(ii) Armature Diverter Method :-



$$I_a = I_L - I_x$$

$$T \propto I_a \cdot \phi$$

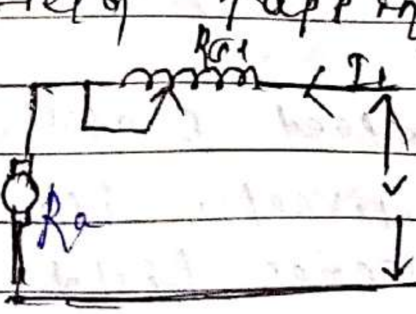
$$I_a \downarrow, \quad \phi \uparrow$$

$$\downarrow N \propto \frac{1}{\phi \uparrow}$$

* In this method a variable resistance called diverter, is connected in parallel with armature winding.
* As some part of the current will go through the diverter, so I_a decrease.
* For a given load, if I_a decreases flux must be increase to maintain the torque, as flux increases speed will automatically decrease. because $N \propto \frac{1}{\phi}$.

* In this method speed below the normal speed can be achived.

(iii) Field Tapping method :-



No. of Turn $\downarrow$

Flux $\rightarrow \phi \downarrow$

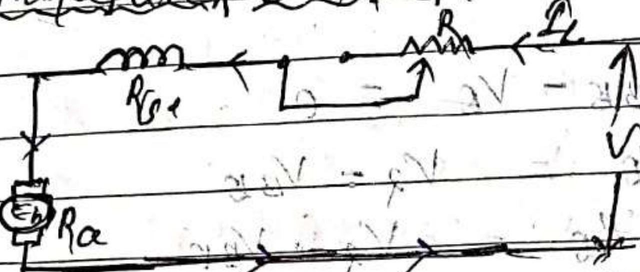
$N \uparrow$

In this method of speed control no. of turns in the field winding, decreases due to tapping, As no. of turns decreases, so flux decreases.

As we know $N \propto \frac{1}{\phi}$, so speed will increase. & speed above normal speed can be achived.

DT - 6/02/22 E.C.

(2) Armature Resistance Control of DC series motor:-



$\downarrow N \propto \frac{E_b \downarrow}{\phi} = \frac{\downarrow V - I_a(R_a+R)}{\phi}$

In this method a variable resistance is connected in series with the supply, so due to the voltage drop across the resistance net voltage available across the armature terminal decreases & hence speed decreases.

* By using this method speed below normal speed can be obtained.

Q- A 200V, DC series motor runs at 800 rpm when taking a line current of 15 A. The R_a is 0.6 Ω & R_{se} is 0.4 Ω. Find the speed at which the motor will run when connected in series with a 5 Ω resistance taking the same current & voltage.

$V = 200\,V$, $N_1 = 800\,rpm$, $I_a = 15\,A$

$R_a = 0.6\,\Omega$, $R_{se} = 0.4\,\Omega$

$N_2 = ?$, $R_{ext} = 5\,\Omega$, $I_a = 15\,A$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2} = \frac{E_{b2}}{E_{b1}} \times \frac{I_{a1}}{I_{a2}}$$

$$I_{a1} = I_{a2}$$

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}$$

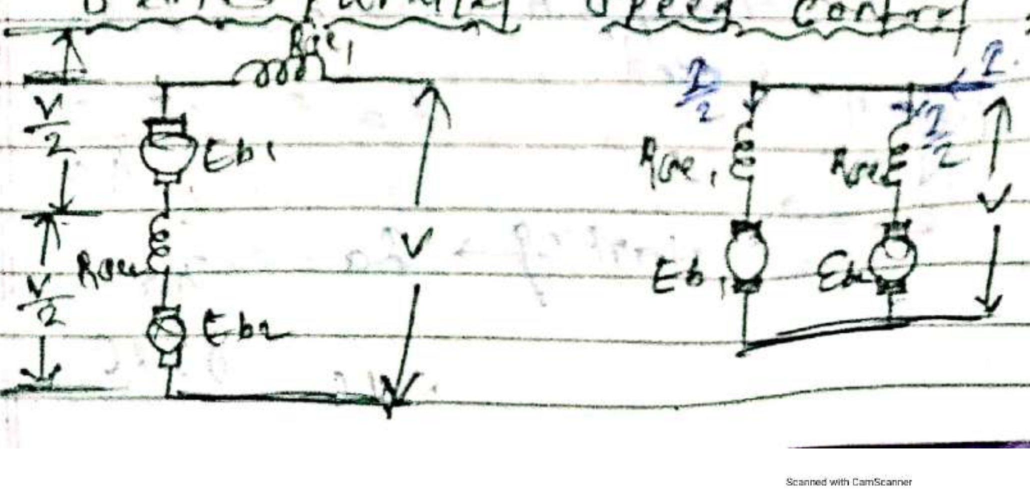
$$E_{b1} = V - I_a(R_a + R_{se}) = 200 - 15(1)$$
$$= 185\,V$$

$$E_{b2} = V - I_a(R_a + R_{se} + R_{ext})$$
$$= 200 - 15(0.6 + 0.4 + 5)$$
$$= 200 - 15 \times 6$$
$$= 200 - 90 = 110\,V$$

$$N_2 = \frac{E_{b2}}{E_{b1}} \times N_1 = \frac{110}{185} \times 800$$

$$= 475\,rpm$$

(3) Series-parallel speed control :



$N \propto \frac{V/2}{I}$ $N \propto \frac{V}{I/2}$

$N \propto \frac{V}{2I}$ $N \propto \frac{2V}{I}$

* Here two or more similar DC series motor are mechanically coupled to same load. When they are connected in series each motor will receive half of supply volt i.e. $V/2$ & current will remain same i.e. I, so $N \propto \frac{V}{2I}$

* When the same two motors are connected in parallel, each motor will receive the normal voltage, but current received by each motor will be $I/2$.

So $N \propto \frac{2V}{I}$

So, it is observe that when connected in parallel approximately four times the speed, when they are connected in series.

Use → Traction system.

Starting of DC series motor:-

$V = E_b + I_a R_a$

Stationary cond^n

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

$N = 0$

$E_b = 0$

starting → $I_a = \frac{V}{R_a}$

NVC, OLRC

Date
Page

Starter

2-point	3-point	4-point
L, A	L, F, A	L, L, F, A

Use → Series motor

Shunt / Compound Motor.

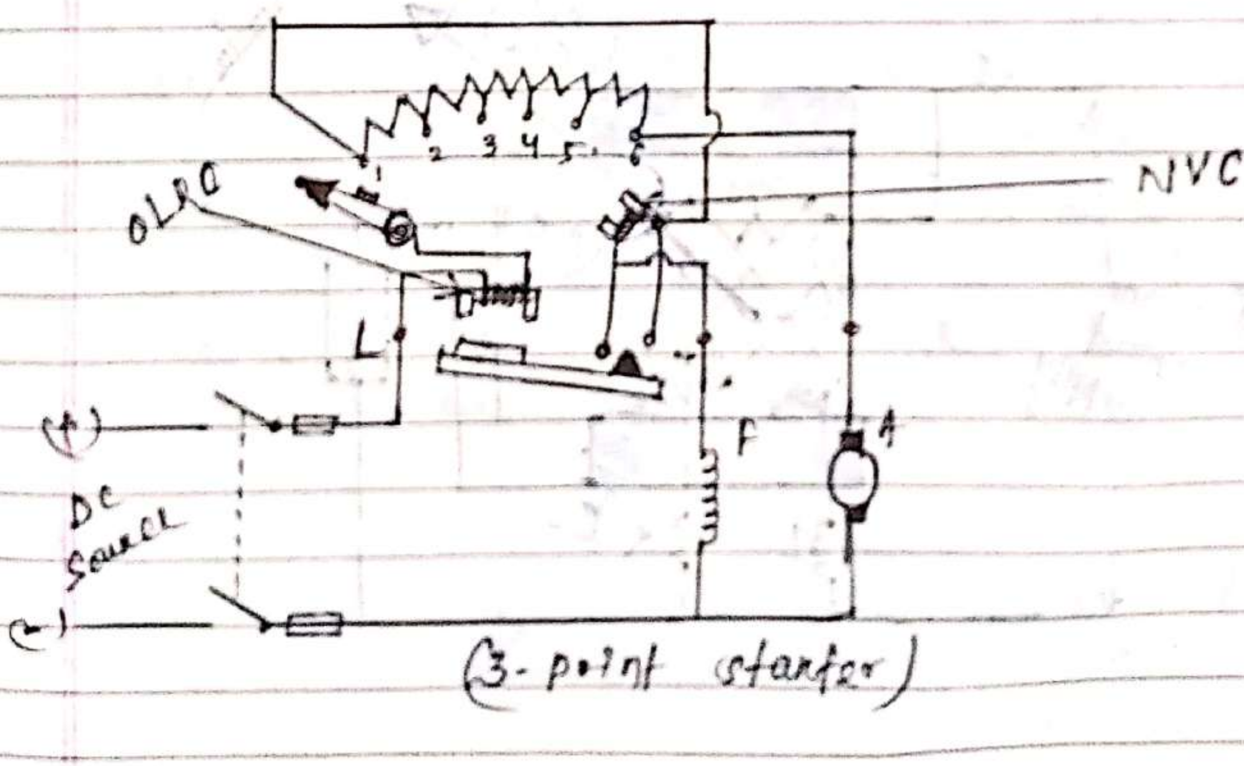
1. 3-point starter :- A 3-point starter mainly includes 3-terminals namely L, F & A. Here, 'L' is connected to the positive supply, 'F' is the shunt field coil & 'A' is the armature coil. The direct current supply is connected to the starter, the motor is connected through a double pole switch & circuit through a suitable fuses. The starter has an insulated handle or knob for the operator's use.

By moving the starter handle from the off position to the first brass contact of the starter, the armature is connected across the line through the starting resistance. Note that the armature is in series with the total starting resistance. The shunt field, in series with the NVC, is also connected across the line. In this mode of operation the initial current to the armature is limited by the resistance. At the same time, the field current is at max^m value to provide a good starting torque.

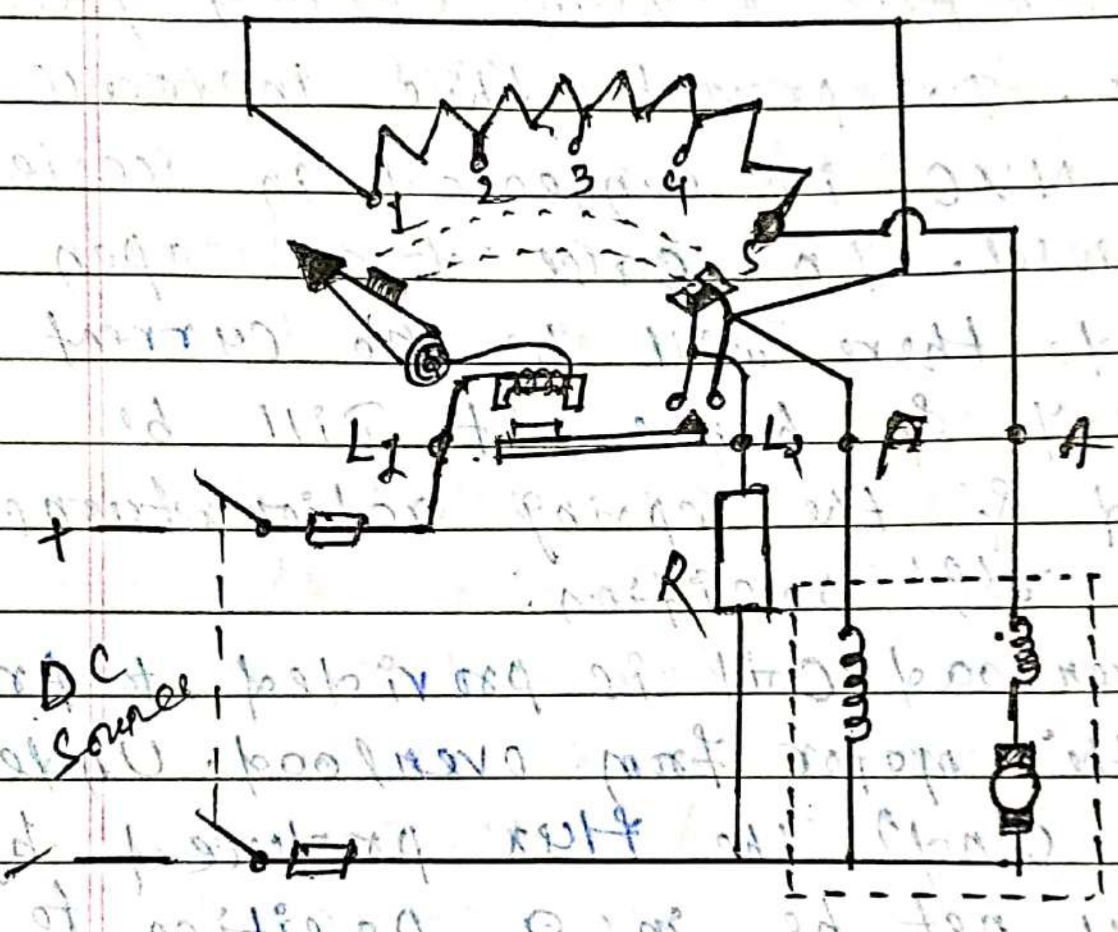
As the handle arm is moved to the right the starting resistances is reduced & the motor gradually accelerates. When the last contact is reached, the armature is connected directly across the supply; thus the motor is at full speed.

NVC The NVC is connected in series with the shunt field to provide 'no-field release'. If the field circuit opens by accident the motor speed will become excessive should the armature remain connected across the the line. To prevent this increase in speed, the NVC is connected in series with the field. In case of an open circuit in the field, there will be no current through the NVRC coil & hence, it will be demagnetized & the spring action returns the arm to the 'off' position.

OLRC An overload coil is provided to prevent damage to the motor from overload. Under normal load condⁿ, the flux produced by the O/L coil will not be in a position to attract the metal piece, this metal piece short-circuit the ~~handle~~ holding/NVC & demagnetized it. As a results the handle come to the 'OFF' position due to the tension of the spring.

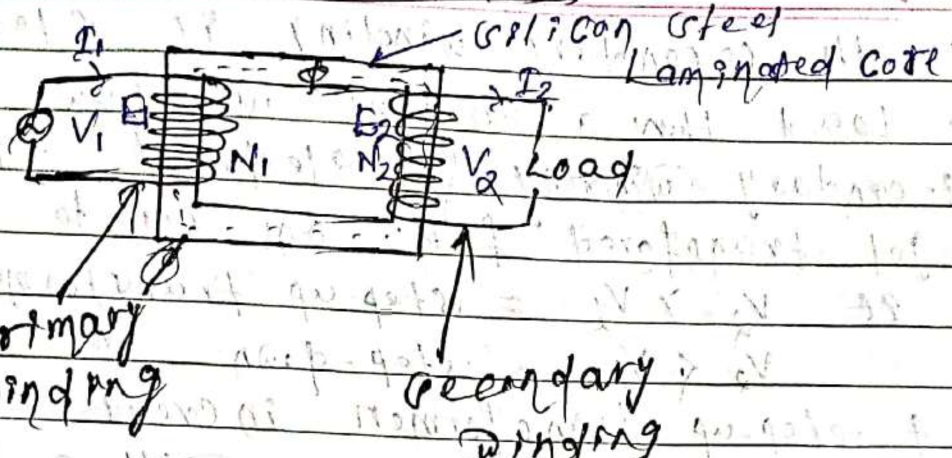


(3-point starter)



(4-point starter)

EC-1 Transformer



* A transformer is a static device which transform electrical energy from one coil to another coil by the principle of electromagnetic induction & maintaining the constant frequency.
* A transformer consist of two winding wound on a common laminated magnetic core. The core is made of silicon steel to reduced hysteresis loss. And core is laminated to reduce eddy current loss.
* The winding to which supply is given is called primary winding & the winding to which load is connected is called secondary winding.
* The primary & secondary winding are connected by only magnetically.
*

If the primary winding is connected to a AC-voltage & alternating flux will be set-up in the laminated core which will link both the coil. And this flux will induced emf E_1 & E_2, according to Faraday's law of electromagnetic induction in both the winding & value is given by, $E_1 = -N_1 \cdot \frac{d\phi}{dt}$

$$E_2 = -N_2 \cdot \frac{d\phi}{dt}$$

If the secondary winding is closed through a load then a current will flow in the secondary winding & electrical energy got transfered from one coil to other coil.

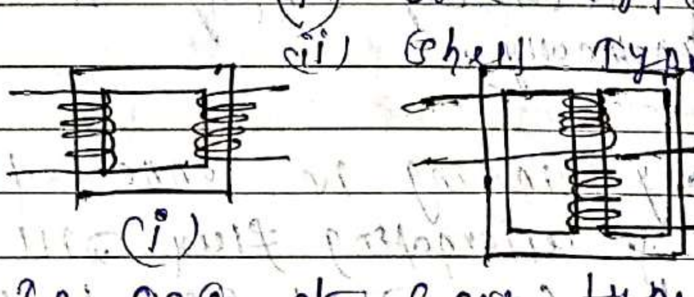
* If $V_2 > V_1$ = Step-up transformer.
  $V_2 < V_1$ = Step-down

* A step-up transformer increases the voltage in the secondary winding with a corresponding decreasing in current

* A step-down transformer decreases the voltage in the secondary winding with a corresponding increase in the value of current.

Construction :- The simple construction of a transformer consist of a laminated silicon steel core & ~~laminated core~~ two coil having mutual inductance.

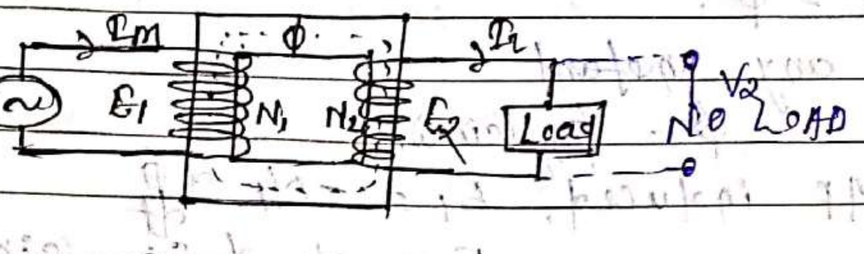
* Depending on the manner in which the primary & secondary coils are placed around the laminated core transformer are classified into two types.
  (i) Core Type (High voltage Application)
  (ii) Shell Type (Low " ")

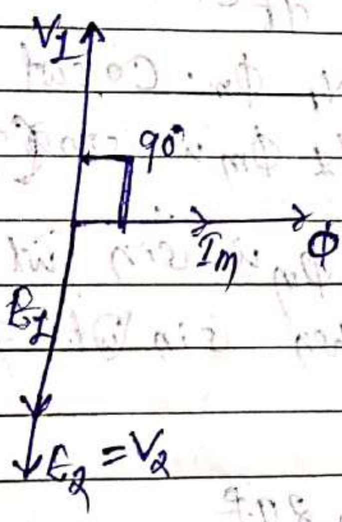


In case of core type winding surround a considerable part of the core but in shell type core surrounds a considerable part of the winding

EC-1 **Transformer**

Ideal Transformer :- A transformer is said to be ideal when, (i) It has no winding resistance (ii) No Iron Loss, (iii) No Leakage flux, i.e flux is same in both the winding.





* When an alternating voltage V_1 is applied to the primary side of an ideal transformer under no Load cond^n a very small magnetising current I_m will flow through the primary winding & Lag behind V_1 by 90°, because of purely inductive circuit.

* Due to absence of core Loss the flux will Lie in the same line with I_m, this I_m will set-up flux ϕ which Link both the coil & induced emf E_1 & E_2 in primary & secondary winding respectively.
* EMF E_1 will oppose the very cause produced by it V_1 due to lenz's Law, so E_1 will be out of phase 180° with V_1. E_1 & E_2 will lie on same phase due to common flux ϕ but magnetude are vary depending on the no. of turns.

EMF eqn of Transformer :- Let

V_1 = be the alternating voltage applied to the primary of a transformer having frequency 'F' Hz. Let flux set-up by the voltage $V_1 = \phi$.

* At any instant

$$\phi = \phi_m \sin\omega t$$

EMF induced, $E_1 = -N_1 \frac{d\phi}{dt}$

$$E_1 = -N_1 \frac{d}{dt}[\phi_m \sin\omega t]$$

$$= -N_1 \phi_m \cos\omega t \cdot \omega$$

$$= -N_1 \phi_m \omega \sin(90° - \omega t)$$

$$= N_1 \phi_m \omega \sin(\omega t - 90°)$$

E_1 will be max^n when $\sin(\omega t - 90°) = 1$

$$E_{1max} = N_1 \phi \omega$$

$$E_{1max} = N_1 \phi_m 2\pi f$$

RMS value of E_1

$$E_{1rms} = \frac{E_{1max}}{\sqrt{2}} = \frac{2\pi f \phi_m N_1}{\sqrt{2}}$$

$$E_1 = 4.44 \phi_m N_1 f \quad \text{---(i)}$$

Similarly in secondary side

$$E_2 = 4.44 \phi_m N_2 f \quad \text{---(ii)}$$

In general, EMF eqn

$$\boxed{E_{rms} = 4.44 \phi_m N F}$$

Voltage Tranformation Ratio :- (K)

from eqn (i) & (ii)

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

Also, $\frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$

If $N_2 > N_1$,

$V_2 > V_1$ (step-up transformer)

If $N_2 < N_1$

$V_2 < V_1$ (step-down ")

In a ideal transformer input VA = output VA

$$\Rightarrow V_1 I_1 = V_2 I_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{I_1}{I_2} = K$$

$$\boxed{\frac{N_2}{N_1} = \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{I_1}{I_2} = K}$$

$$\boxed{\text{Turn ratio} = \frac{N_1}{N_2}}$$

E.C - 1

An ideal 25KVA transformer has 500 no. of turns on primary winding & 40 no. of turns on the secondary winding. The primary is connected to 3000V, 50Hz supply. Calculate - i) primary & secondary current
ii) secondary emf ?
iii) ϕ_m = ?

Input VA = output VA = 25 KVA

$V_1 I_1 = V_2 I_2 = 25$ KVA

$N_2 = 40$,

$N_1 = 500$, $V_1 = 3000$ V, $F = 50$ Hz, $\phi_m = ?$

$I_1 = ?$, $I_2 = ?$

$$I_1 = \frac{25 \times 10^3 \text{ VA}}{3000} = 8.33 \text{ A}$$

$$K = \frac{N_2}{N_1} = \frac{40}{500} = \frac{4}{50} = 0.08$$

$$\frac{I_1}{I_2} = K \quad I_2 = \frac{I_1}{K} = \frac{8.33}{0.08} = 104.12 \text{ A}$$

$$K = \frac{E_2}{E_1}, \Rightarrow E_2 = K \cdot E_1 = K \cdot V_1$$
$$= 0.08 \times 3000$$
$$= 240 \text{ V}$$

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

$$\phi_m = \frac{E_1}{4.44 \times N_1 \times f} = 0.027\ wb$$

$$= \frac{3000}{4.44 \times 500 \times 50}$$

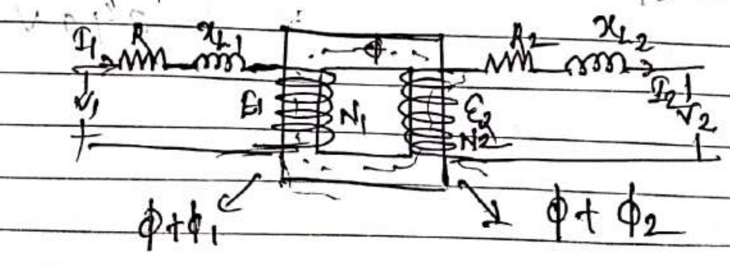
Practical Transformer :-

A practical transformer in which there is existance of core loss, winding resistance & also presence of leakage flux which results in leakage reactance.

i) Core Loss :- Since the primary winding of the transformer is always subjected to A.C voltage so there is production of hysteresis & eddy current Loss in the core and these two losses always form core loss or iron loss.

ii) Winding resistance :- Since the winding is constructed by taking cu wire & the cu wire got resistance so each winding has got winding resistance.

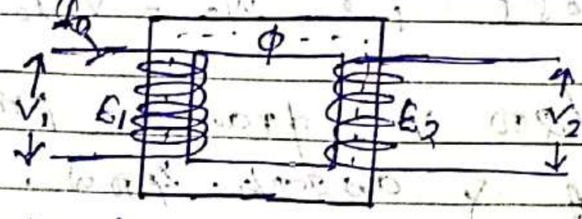
→ Due to winding resistance there will be power loss as well as voltage drop & that's why $E_1 < V_1$ & similarly $V_2 < E_2$



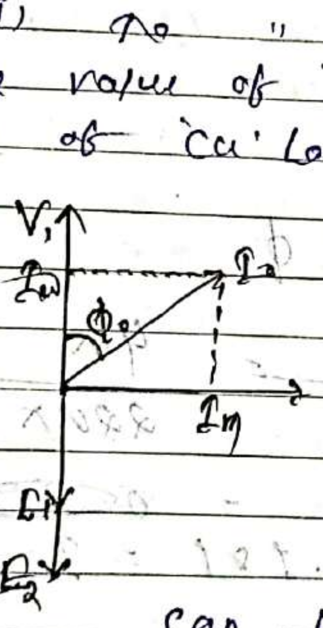
ϕ_1 & ϕ_2 = Leakage flux

(iii) Leakage flux / reactance :- x_{L_1}, x_{L_2} =

Practical Transformer on No Load Cond? :-



I_0 = No Load primary Current.
(i) To supply Iron Loss in core.
(ii) To " small amount of Cu Loss.
∴ The value of I_0 is very less, so in the primary value of Cu Loss $I_0^2 R_1$ is neglected.



Here the no Load current I_0 will be Lagging behind V_1 by an angle ϕ_0 Less than 90° & this no Load input Current I_0 can be resolve into two component.

(i) $I_w = I_0 \cos\phi_0$ known as working / Iron Loss component and it will always lie inphase with V_1.

(ii) $I_m = I_0 \sin\phi_0$ known as magnetising component & useful for maintaining the mutual flux. I_m will alway Lag behind V_1 by 90°.

$$I_0 = \sqrt{I_w^2 + I_m^2}$$

* At no Load condⁿ the core loss is very small, so practically whole of the input power will be converted into core loss, i.e. $W_0 = V_1 I_0 \cos\phi_0$.

Q. A 220/200 V draw a primary current of 0.6 A & absorb 400 W. Find out $I_m = ?$ $I_w = ?$

Solⁿ. $V_1 = 220$

$I_0 = 0.6$

$W_0 = 400 W$

$W_0 = V_1 I_0 \cos\phi_0$

$I_0 \cos\phi_0 = \frac{W_0}{V_1} = \frac{400}{220} = 0.181$

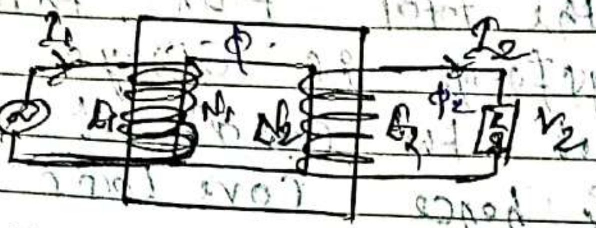
(i) $I_0 \cos\phi_0 = 0.181 = I_w$

(ii) $I_m = \sqrt{I_0^2 - I_w^2}$

$= \sqrt{(0.6)^2 - (0.18)^2} = 0.57 A$

DT - 17/02/18 E.C.L

Practical Transformer under Load :-



When the secondary of a transformer is Loaded a secondary current I_2 will set-up. The secondary current will set-up its own mmf ($N_2 I_2$) & its own flux (ϕ_2) which is in opposition to main flux (ϕ). The secondary ampere turn ($N_2 I_2$) is known demagnetising ampere turn. The property of ϕ_2 is to weakens the main flux (ϕ) momentarily & hence primary emf (E_1) tends to decrease for a movement $V_1 >> E_1$ & hence causes a current in the primary winding. Let this additional amount of current is I_2' called Load component of primary current. I_2' will oppose I_2. The I_2' will also set-up its own mmf $N_1 I_2'$ in the primary winding & sets up flux ϕ_2' which is in opposition to ϕ_2. ϕ_2' & ϕ_2 are equal in magnitude but opposite in direction so they cancelled each-other. Hence the net flux passing through the core is approximately the same as at the condⁿ of no-Load. So the magnetising effect of secondary current is completely neutralise by I_2'.

from the above discussion it is found that the total flux through the core of transformer is always constant irrespective of the condn of no-Load or Load & hence core loss is always constant.

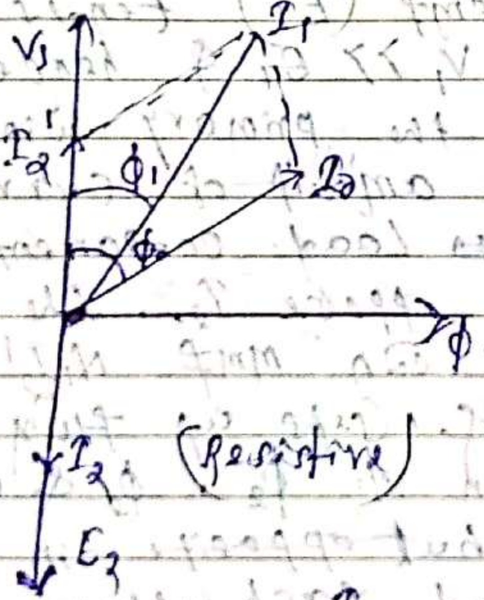
$$\phi_2 = \phi_2'$$

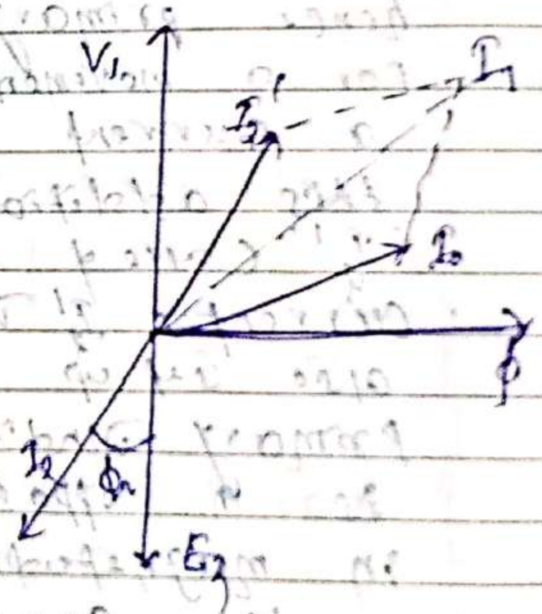
$$N_2 I_2 = N_1 I_2'$$

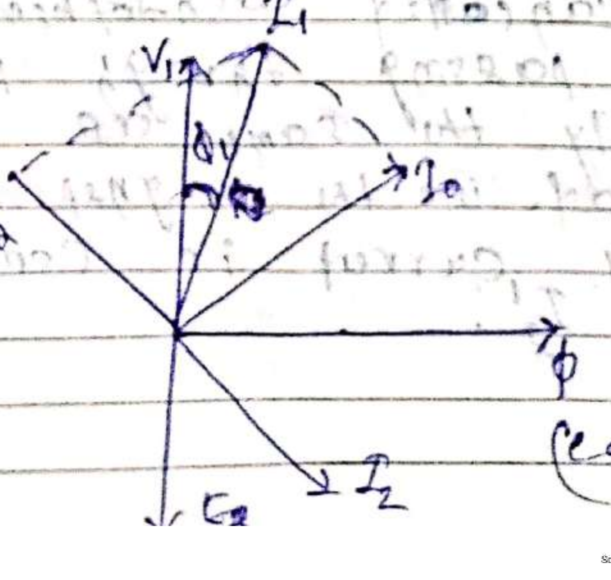
$$I_2' = \frac{N_2}{N_1} \cdot I_2 = K \cdot I_2$$

$$I_1 = I_0 + I_2'$$

$$= I_0 + K \cdot I_2$$







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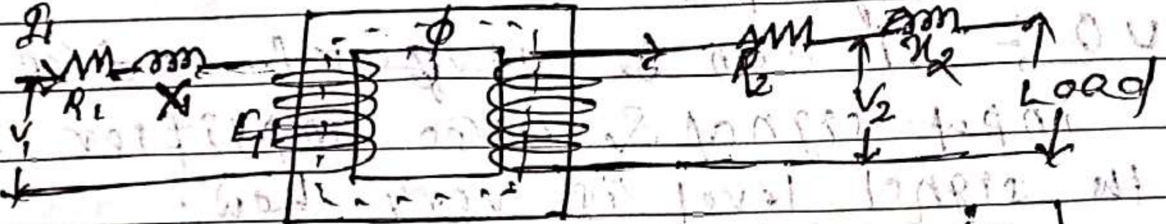
Dt-10-02-20 E.C-I

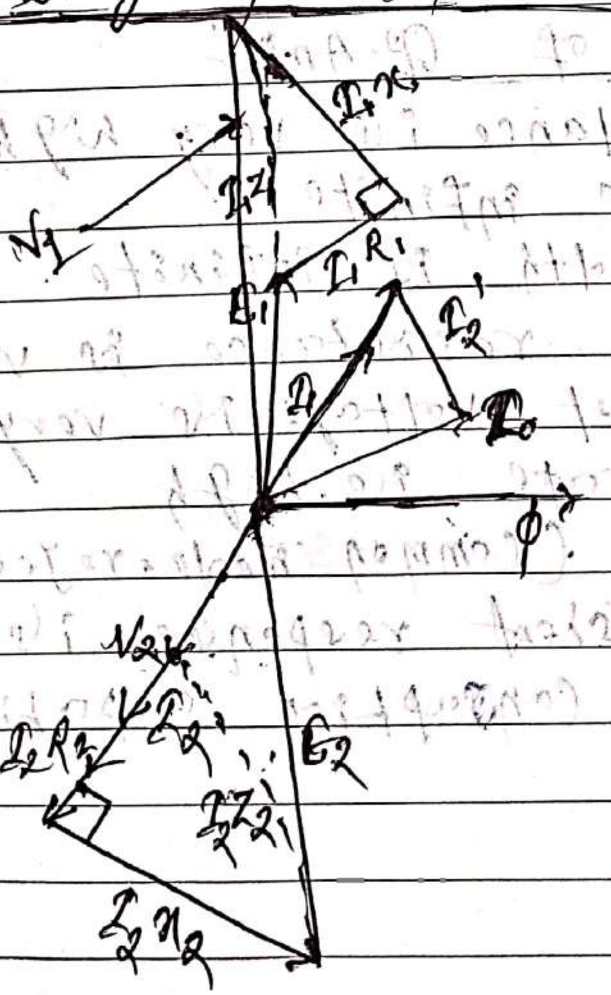
practical Transformer with winding resis & Leakage reactance :-



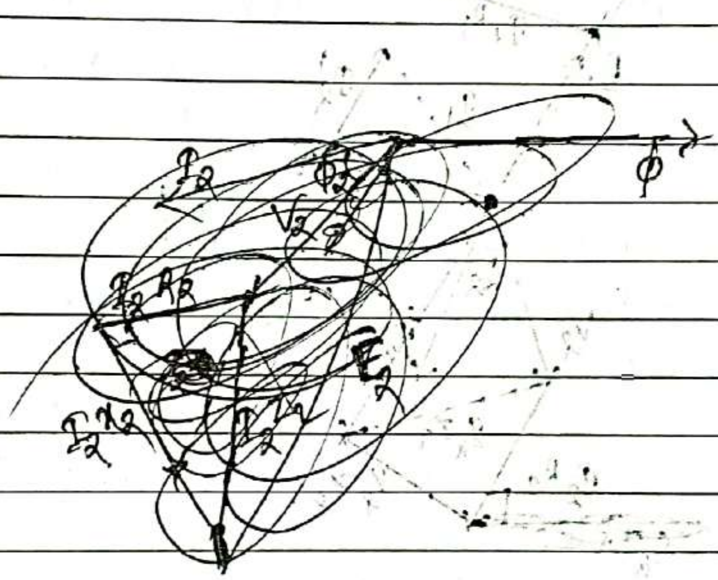
$E_1 < V_1$, $V_1 = E_1 + I_1(R_1 + jX_1)$
$= E_1 + I_1 Z_1$

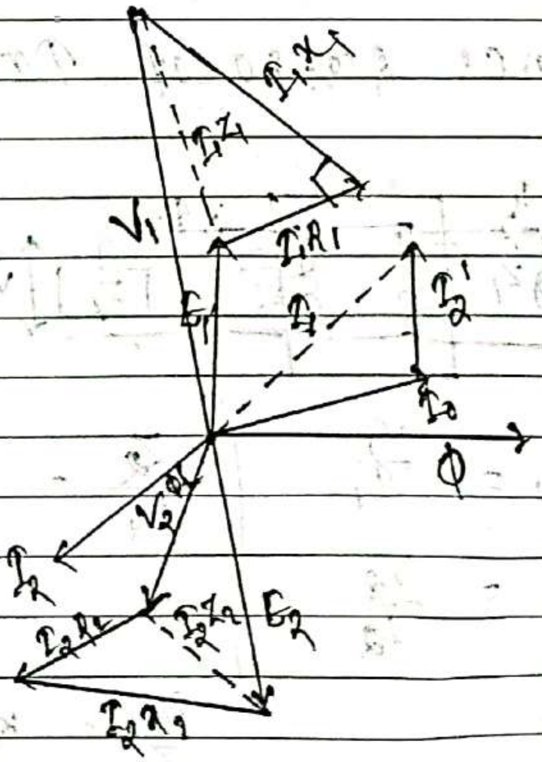
$E_2 > V_2$, $E_2 = V_2 + I_2(R_2 + jX_2)$
$= V_2 + I_2 . Z_2$

Phasor Diagram when Load is resistive/unity pf

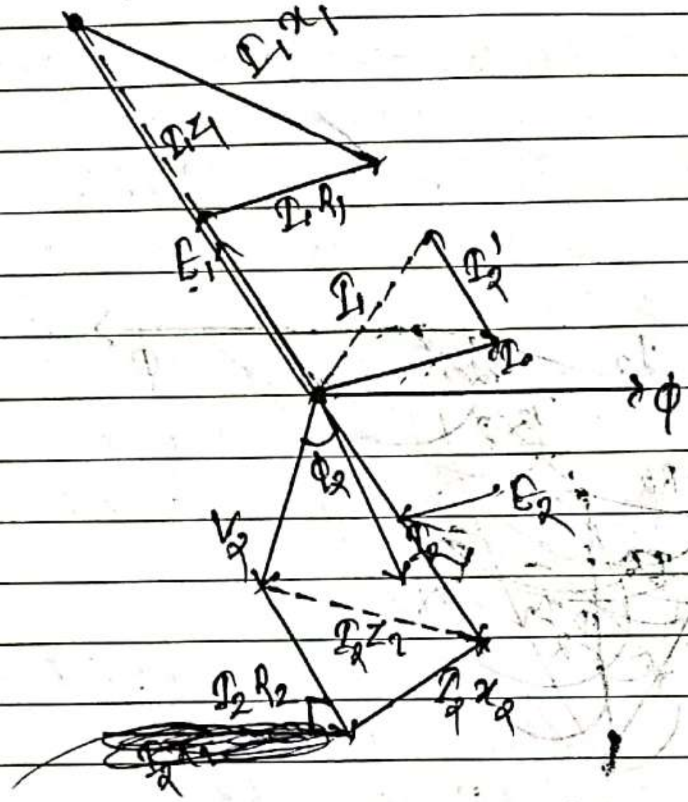


2. Phasor diagram for Inductive Load :- (Lagging p.f)





3. Phasor diagram when Load is capacitive :-



Impedance Ratio of Transformer :-

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

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

$$\frac{Z_2}{Z_1} = \frac{V_2}{I_2} \div \frac{V_1}{I_1}$$

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

$$\frac{Z_2}{Z_1} = K \times K = K$$

$$\boxed{\frac{Z_2}{Z_1} = K^2}$$

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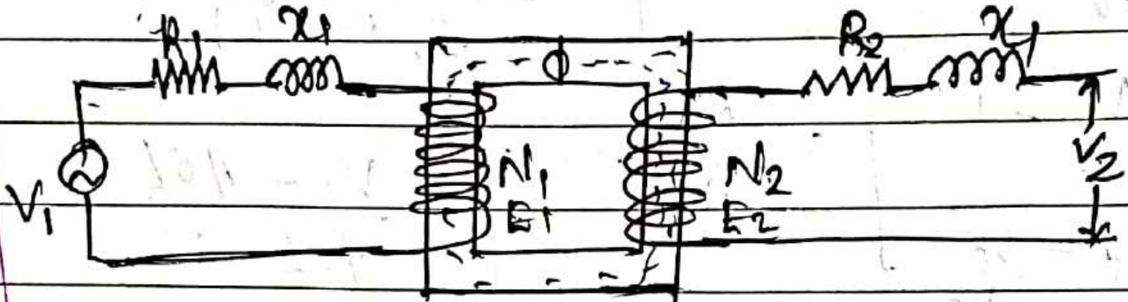
* The secondary impedance Z_2' becomes $\frac{Z_2}{K^2}$ when refer to primary side.
* When primary impedance Z_1' will becomes $Z_1 \times K^2$, when refer to secondary side.
* Secondary Resistance R_2' becomes $\left(\frac{R_2}{K^2}\right)$ when refer to primary side.
* primary resistance R_1 becomes $(R_1 \times K^2)$ when refers to secondary side.
* primary side voltage V_1' will become $V_1 \times K$ when refers to secondary side.
* primary side current I_1' will become $\left(\frac{I_1}{K}\right)$ when refers to secondary side.
* Secondary side current I_2' will becomes $(I_2 \times K)$ when refers to primary side.

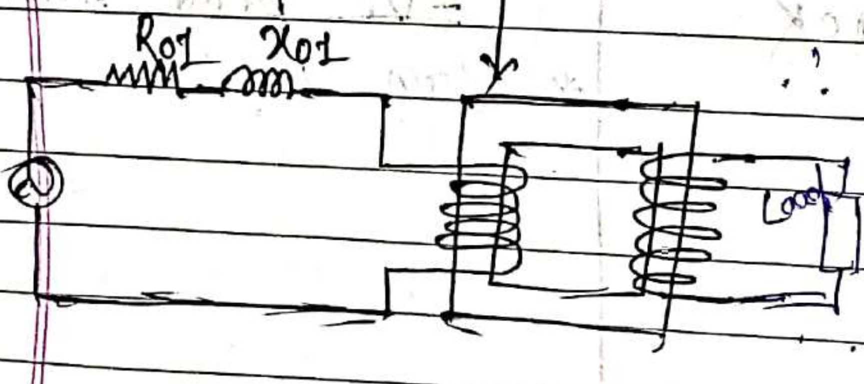
E.C-1

Shifting impedance of Transformer :

$R_2' = K^2 . R$



(i) Refer to primary side :



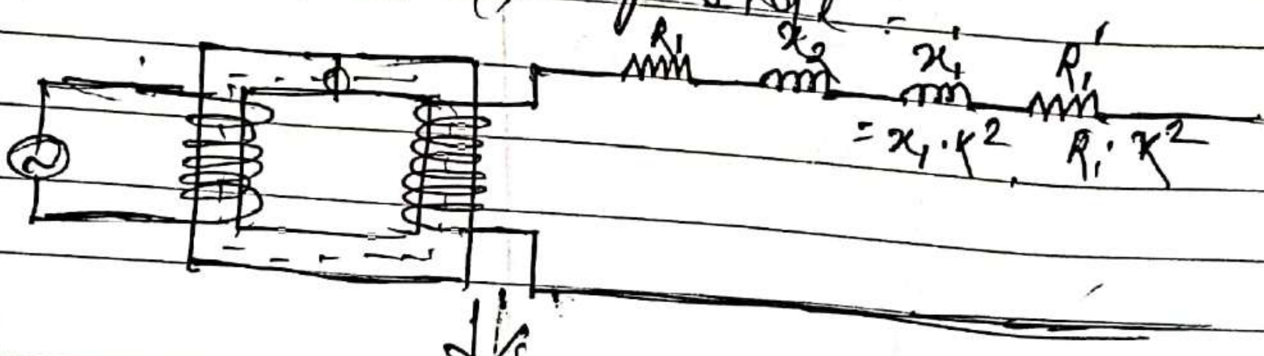
$\therefore R_{01} = R_1 + R_2'$

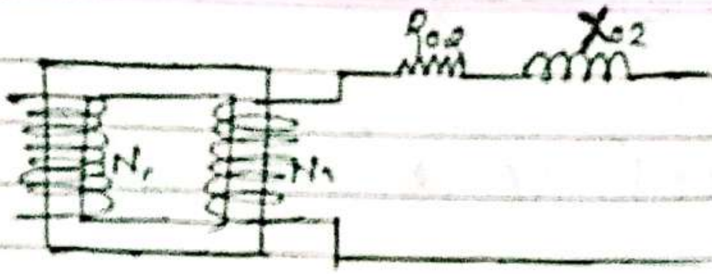
$$R_{01} = R_1 + \frac{R_2}{K^2}$$

$x_{01} = x_1 + x_2'$

$$x_{01} = x_1 + \frac{x_2}{K^2}$$

(ii) Refer to secondary side :





$$R_{02} = R_2 + R_1'$$
$$= R_2 + R_1 \times K^2$$

$$X_{02} = x_2 + x_1'$$
$$= x_2 + x_1 \times K^2$$

$$Z_{02} = \sqrt{(R_{02})^2 + (X_{02})^2}$$

Q- A 100 kVA, 2200/440 V transformer has primary resistance R_1 0.3 Ω, x_1 = 1.1 Ω, R_2 = 0.01 Ω, x_2 = 0.035 Ω. Calculate
(i) Equivalent impedance of transformer refer to primary side.
(ii) Total Cu Loss.

Ans:

Rating = 100 kVA

$V_1 = 2200\,V, \quad V_2 = 440\,V$

$R_1 = 0.3\,\Omega, \quad R_2 = 0.01$

$x_1 = 1.1\,\Omega, \quad x_2 = 0.035\,\Omega$

$$K = \frac{V_2}{V_1} = \frac{440}{2200} = 0.2$$

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 0.3 + \frac{0.01}{(0.2)^2} = 0.55$$

$$X_{01} = x_1 + x_2' = x_1 + \frac{x_2}{K^2} = 1.1 + \frac{0.035}{(0.2)^2} = 1.98$$

i) $Z_{01} = \sqrt{(R_{01})^2 + (X_{01})^2}$

$= \sqrt{(0.55)^2 + (1.98)^2}$

$= 2.054 \ \Omega$

ii) Cu Loss $= I_1^2 R_{01}$

$I_1 = \frac{100 \times 10^3}{22} = 45.45$

$I_1^2 R_{01} = (45.45)^2 \times 0.55$

$= 1136.13$ W

i) Calculate the impedance refer to secondary (0.2)

$R_{02} = R_2 + R_1' = R_2 + R_1 \cdot K^2$

$= (0.01) + (0.3) \times (0.2)^2$

$= 0.022$

$X_{02} = X_2 + X_1' = X_2 + X_1 \cdot K^2$

$= (0.035) + (1.1) \times (0.2)^2$

$= 0.079$

$Z_{02} = \sqrt{(0.022)^2 + (0.079)^2}$

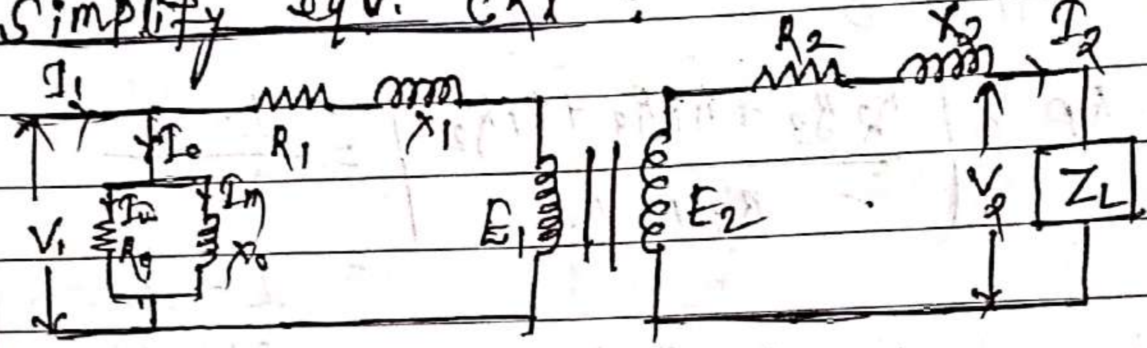
$= 0.082$

Cu Loss $= I_2^2 R_{02}$ $\qquad I_2 = \frac{100 \times 10^3}{440} = 227.27$ A

$= (227.27)^2 \times (0.022)$

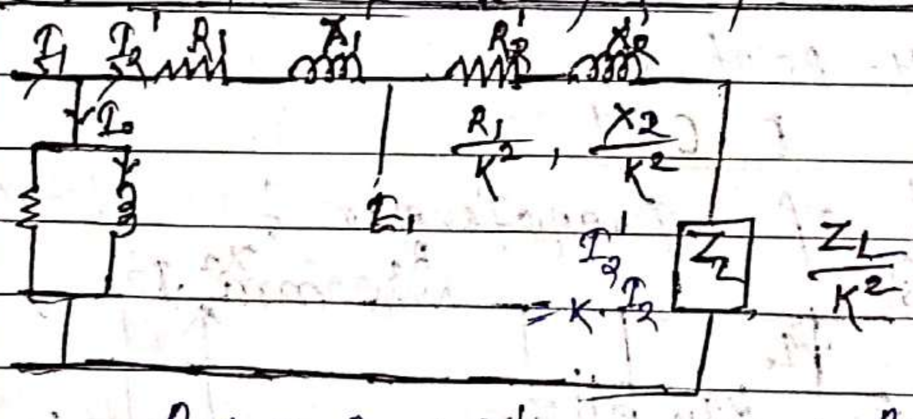
$= 1136$ W

Simplify eqv. ckt :-



The no load current 'I_0' of a transformer is very small as compared to rated primary current 'I_1', so voltage drop in R_1 & X_1 due to I_0 is negligible, so R_0, X_0 shunt circuit can be shifted nearer to the input terminal.

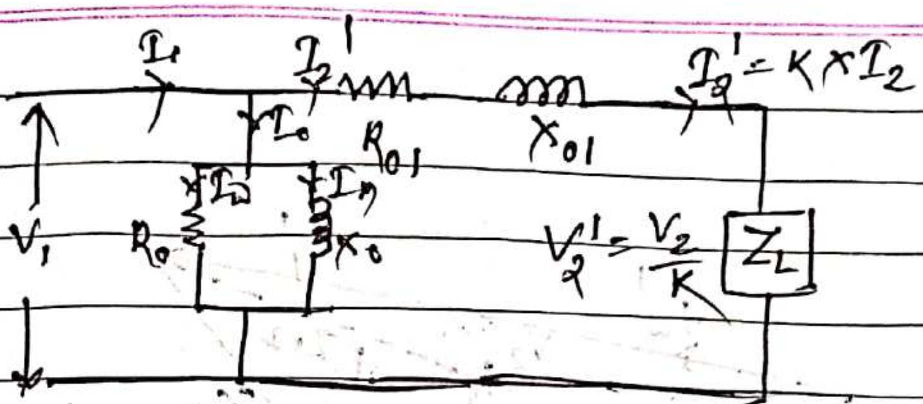
Eqv. ckt of Transformer referred to primary

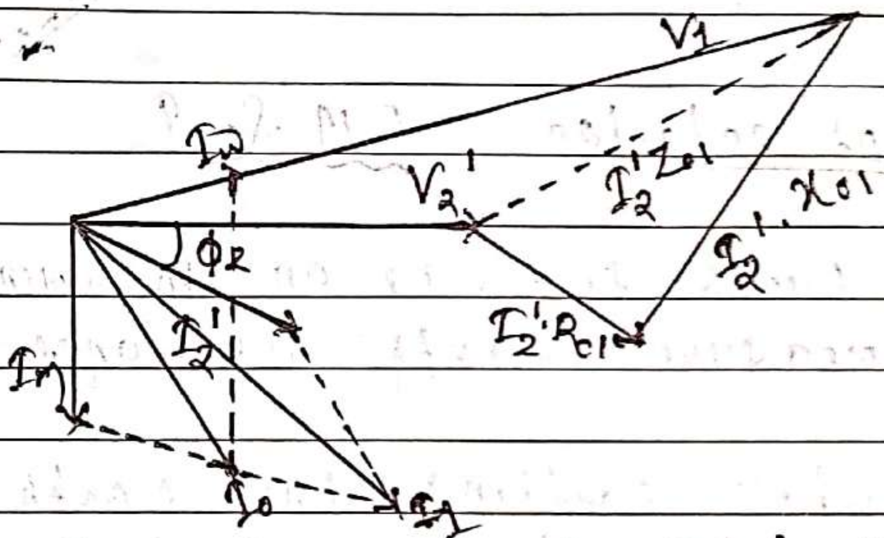


$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

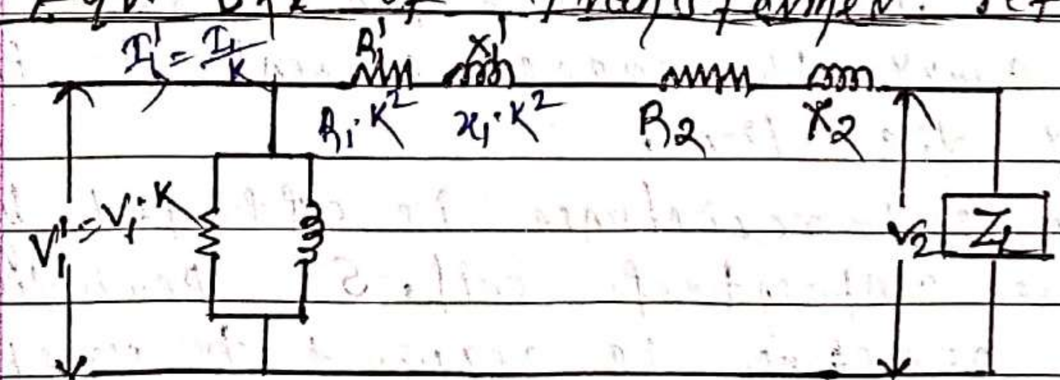
$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$$

$$V_2' = \frac{V_2}{K}, \quad I_2' = K \times I_2, \quad Z_L' = \frac{Z_L}{K^2}$$



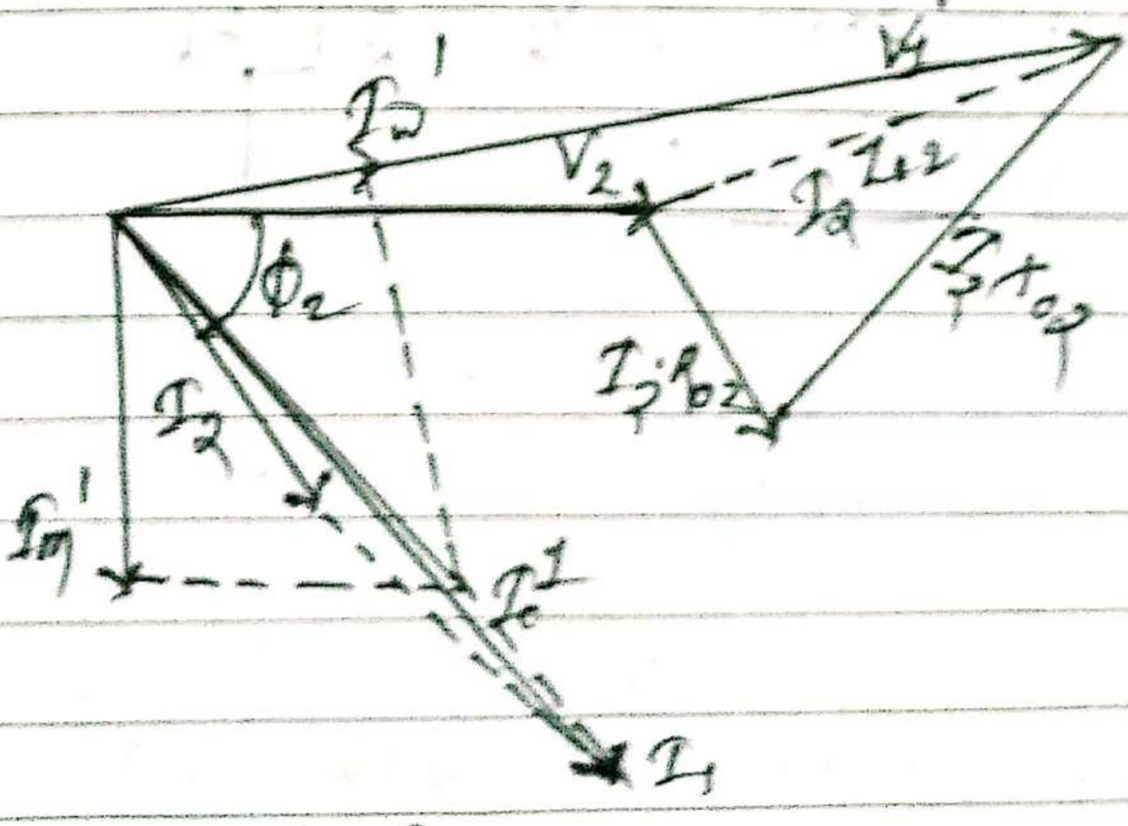


Eqv. ckt of Transformer referred to secondary



$$R_{02} = R_2 + R_1' = R_2 + R_1 \cdot K^2$$

$$X_{02} = x_2 + x_1' = x_2 + x_1 \cdot K^2$$



V_1'
I_w'
V_2
$I_2 Z_{e2}$
I_2
Φ_2
$I_2 X_{o2}$
$I_2 R_{o2}$
I_2
I_m'
I_o'
I_1

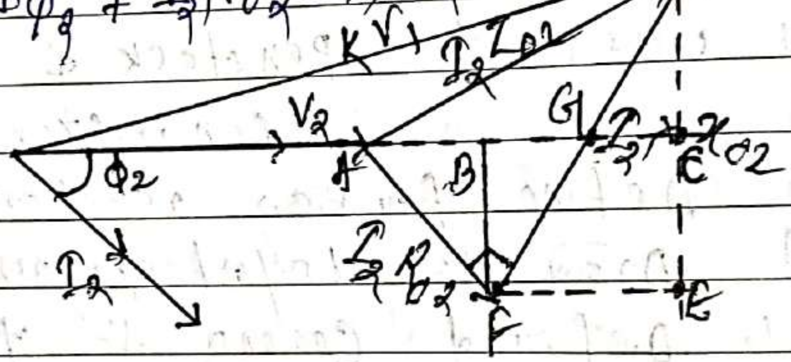
Phasor diagram taking a Lagging P.F. Load:

Approximate drop = $I_2 Z_{02}$ = $AD \simeq AC$

$\approx AB + BC$

$\approx AB + EF$

* $I_2 Z_{02} \approx I_2 R_{02} \cos\phi_2 + I_2 X_{02} \sin\phi_2$



* For Leading P.F Load the app. drop will become = $I_2 R_{02} \cos\phi_2 - I_2 X_{02} \sin\phi_2$.

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Voltage Regulation of Transformer :-

$$\% \, V.R = \frac{{}_0V_2 - V_2}{{}_0V_2} \times 100$$

It is defined as the arithmetic difference betn no load secondary voltage & secondary voltage at load expressed as a percentage of no load secondary voltage i.e. '${}_0V_2$'.

$$\% \, VR = \frac{I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2}{{}_0V_2} \times 100$$

+ = Lag
− = Lead

Q- A 230/460 V, transformer has primary resistance of 0.2 Ω & reactance of 0.5 Ω and the corresponding values for the secondary are 0.75 Ω & 1.8 Ω. Find the secondary terminal voltage when supplying 10 A at 0.8 p.f lagging.

Sol

$K = \frac{460}{230} = 2$, $V_1 = 230\,V$

$V_2 = 460$

$I_2 = 10\,A$ $R_1 = 0.2\,\Omega$

$\cos\phi_2 = 0.8$ $X_1 = 0.5$

$R_2 = 0.75\,\Omega$

$R_{02} = R_2 + R_2' = 0.75 + R_1 . K^2$ $X_2 = 1.8\,\Omega$

$= 0.75 + 0.2 \times 4 = 1.55\,\Omega$

$X_{02} = x_2 + x_1 . K^2$

$= 1.8 + 0.5 \times 4 = 3.8\,\Omega$

Approximate drop $= I_2 \left[R_{02} \cos\phi_2 + X_{02} \sin\phi_2 \right]$

EC-1

The primary & secondary winding of 40 KVA, 6600/250 V, single phase transf. have resistance of 10 Ω & 0.02 Ω respectively. The leakage reactance of transformer referred to primary side is 35 Ω, calculate the % V.R of transformer while supplying full-load current at a p.f of 0.8 lag.

$K = \frac{250}{6600} = 0.037$ $\quad V_1 = 6600$

$V_2 = 250$

$\cos\phi_2 = 0.8$ $\quad R_1 = 10\Omega, R_2 = 0.02\Omega$

$0V_2 =$ $\quad x_{01} = 35$

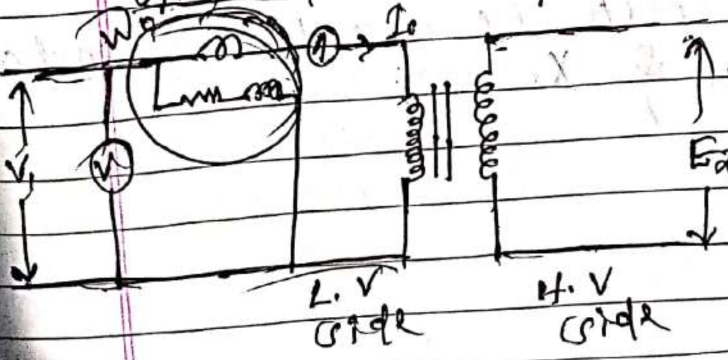
$R_{01} = R_1 + \frac{R_2}{K^2} = 10 + \frac{0.02}{(0.037)^2} = 24.6$

$I_1 = \frac{40 \times 10^3}{6600} = 6.06$

$\% V.R = \frac{6.06 \times 24.6 \times 0.8 + 6.06 \times 35 \times 0.6}{6600}$

$= 3.7\%$

Open ckt Test / No Load Test:



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Reading of Wattmeter

W_0 / Iron Loss $= V_1 \times I_0 \times \cos\phi_0$

$$W_0 = V_1 I_0 \cos\phi_0$$

$$\cos\phi = \frac{W_0}{V_1 I_0}$$

$I_w = I_0 \cos\phi_0$, $I_m = I_0 \sin\phi_0$

$$R_0 = \frac{V_1}{I_w}, \quad X_0 = \frac{V_1}{I_m}$$

* No Load test is used to find out the iron Loss or core Loss.
* In this test rated voltage is applied to the L.V. side and the H.V. side is kept open.
* The voltage 'V_1' is measured by the voltage, 'I_0' measured by ammeter & W_0 is measured by wattmeter.
* The value of no-Load current I_0 is very small, so the Cu-Loss is negligible hence all the no Load input power will be convert into iron Loss / core Loss.
* So W_0 = given above.
* open circuit test is used to find of core Loss, R_0, & X_0

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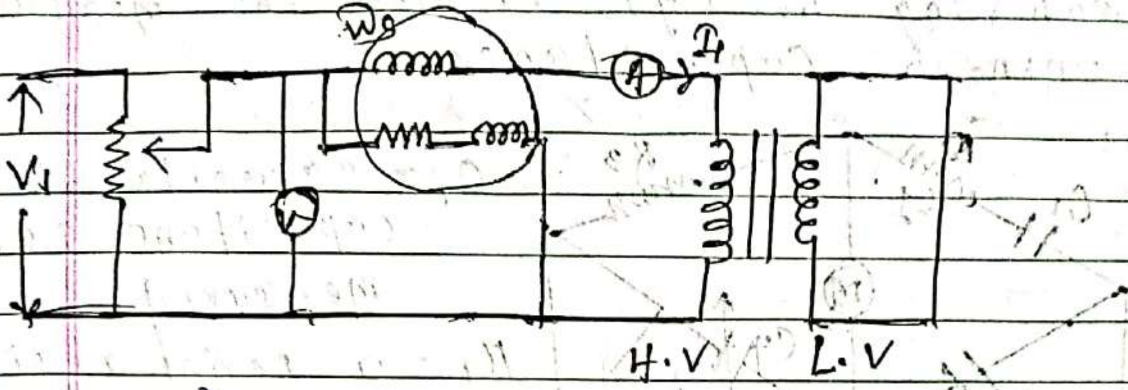
7. Short ckt Test / Impedance Test



W_s = Cu - Loss ,

$$W_s = I_1^2 \times R_{01}$$

$$R_{01} = \frac{W_s}{I_1^2}$$

$I_1 = I_0 + I_2'$

I_0 ↓ NoLoad ↓ neglect, I_2' ↓ Load

$$Z_{01} = \frac{V_1}{I_1}$$

$$X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}$$

* This test is used to determine Cu-loss
* In this test the L.V. side is short ckt & variable Low voltage is apply to H.V side.
* The Low voltage input is gradually increase till V_{sc} and Full Load Current I_1 flow in H.V. side.
* Under short ckt condn there will be no output from the transformer so the total input power is equal to total Cu- Loss.
* This test is used to find Cu Loss, R_{01} & X_{01}.

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Dt-29/02/20 EC-1 Saturday

Rating of Transformer :- (VA or KVA)

Iron Loss → Voltage
Cu Loss → Current
} VA → KVA

$KW = KVA \times \cos\phi$

* The rating of transformer depends on the value of iron Loss & Cu Loss.
* The value of iron Loss is dependent on voltage & the value of Cu-Loss is depends on current and that's why the rating of a transformer is in KVA.

Losses in Transformer :-

- Iron Loss
  - Hysteresis (P_h)
  - Eddy Current (P_e)
- Cu Loss

$$P_h = K_h B_{max}^{1.6} f . V \quad ---- (i)$$

$$P_e = K_e B_{max}^{2} f^2 t^2 . V \quad --- (ii)$$

From eqn (i) & (ii) the material is constant so, V, t & B - same, then

$P_h \propto f$ $\qquad$ $P_e \propto f^2$

$P_h = a . f \quad - (3)$ $\qquad$ $P_e = b . f^2 \quad -- (4)$

a, b = Constant

So, $\boxed{P_i = af + bf^2}$

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Cu - Loss :- When current flows through the Cu-winding there will be losses produce in primary as well as secondary winding and this as a whole is called Cu - Loss.

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2 = I_1^2 R_{01} = I_2^2 R_{02}$$

Total Loss $= P_i + P_{cu}$

P-1 The Iron Loss in a transformer core at normal flux density was measured at 30 Hz & 50 Hz, the result be 31 watt & 54 watt, respectively. Calculate the hysteresis & eddy current loss at 50 Hz.

Condn-1, $f = 30\,Hz$, $P_i = 31$ watt

We know that, $P_i = af + bf^2$

$31 = 30a + 900b$ --- (i)

Condn-2, $f = 50\,Hz$, $P_i = 54$ watt

$54 = 50a + 2500b$ --- (ii)

Solving eqn (i) & (ii),

$a = 0.96$

$b = 2.333 \times 10^{-3}$

$P_h \Big]_{at\ 50\,Hz} = a \times f = 0.96 \times 50 = 48\,W$

$P_e \Big]_{at\ 50\,Hz} = b \times f^2 = 2.333 \times 10^{-3} \times (50)^2 = 5.8325$

Efficiency :-

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{\text{output}}{\text{output} + \text{losses}} = \frac{o/p}{o/p + P_i + P_{cu}}$$

$$\Rightarrow \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_{02}}$$

Cond^n for max^m efficiency :-
Dividing numerator & denominator by I_2

$$\eta = \frac{V_2 \cos\phi_2}{V_2 \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}} \quad \text{---(i)}$$

For 'η' to be max^m, denominator has to be min^m. So from (i)

$$\frac{d}{dI_2}\left[V_2 \cdot \cos\phi_2 + \frac{P_i}{I_2} + I_2 R_{02}\right] = 0$$

$$\Rightarrow 0 + P_i\left(\frac{-1}{I_2^2}\right) + R_{02} = 0$$

$$\Rightarrow -\frac{P_i}{I_2^2} + R_{02} = 0$$

$$\Rightarrow R_{02} = \frac{P_i}{I_2^2}$$

$$\Rightarrow \boxed{P_i = I_2^2 \times R_{02}}$$

Iron Loss = Cu - Loss

: E.C-1

Q-1 In a 50 KVA transformer the Iron Loss is 500 W & full Load Cu Loss is 800 W. Find the efficiency at full-Load & half-Load at 0.8 p.f Lagging

Sol^n At full-Load at 0.8 p.f Lagging -

output = 50 KVA × 0.8
= 40 KW

Losses = $P_i + P_{cu}$ = 500 + 800 = $\frac{1300}{1000}$ = 1.3

η at full Load = $\frac{40}{40+1.3}$ = $\frac{40}{41.3}$
= 96.85%

At half-Load at 0.8 Lagging

output = 25 × 0.8 = 20 KW

Losses = $P_i + P_{cu}$
= 500 + 200 = 700 W
= 0.7 KW

%η at half Load
= $\frac{20}{20+0.7}$ × 100 = $\frac{20}{20.7}$ × 100
= 96.61 %

Q-2 A 440/110 V transformer has a primary resistance of 0.03 Ω & secondary resistance of 0.02 Ω, its iron loss at normal input is 150 W, Determine the secondary current at which max efficiency will occur?

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find the value of η_{max} at unity P.F Load.

Soln

$$K = \frac{V_2}{V_1} = \frac{110}{440} = \frac{1}{4}$$

$$R_{02} = R_2 + R_1 \cdot K^2$$
$$= 0.02 + 0.03 \times \left(\frac{1}{4}\right)^2$$
$$= 0.022\ \Omega$$

At condn of maxm η.

$$P_i = I_2^2 R_{02}$$
$$150 = I_2^2 \times 0.022$$
$$I_2 = \sqrt{\frac{150}{0.022}} = 82.57$$

$$\text{Output} = V_2 I_2 \cos\phi_2$$
$$= 110 \times 82.57 \times 1 = 9082.7$$

$$\text{Losses} = P_i + P_{cu} = 150 + 150 = 30\text{ W}$$

$$\%\eta = \frac{\text{output}}{\text{output} + \text{Loss}} = \frac{9082.7}{9082.7 + 300} \times 100$$
$$= 96.80\%\ \text{Ans}$$

V → Cu → I^2R → $I^2 \cdot R$

Full load voltage" V/2 → I_2 (I^2R) ($I^2/4$)

Half

*

*

*

E.C-1

All day Efficiency :- (Energy eff.)

$$\eta_{All-day} = \frac{\text{KWh output of transformer in 24 hrs of}}{\text{KWh Input " " " " "}}$$

* $\eta_{All-day} < \eta_{commercial}$

* The ratio of output in KWh to input in KWh of a transformer over a period of 24 hours is known as "All day efficiency".

A 5 KVA distribution transformer has a full Load efficiency of 95% at which the Cu loss equals to iron Loss. The trans. is Loaded for 24 hrs as follow
1) No Load for 10 hr
2) 1/4 full-Load for 7 hr → 8.75
3) 1/2 of " " for 5 hr → 12.5
4) full-Load for 2 hr. → 10
Calculate all-day-efficiency of the transformer ?

At unity P.F = $\cos\phi = 1$.

output = 5 KVA × 1 = 5 KW

$$\eta_{all-day} = \frac{Output}{Input}$$

$$0.95 = \frac{5\,KW}{Input}$$

$$Input = \frac{5\,KW}{0.95} = 5.26\ KW$$

Total Losses = Input − output
= 5.26 − 5 = 0.26 KW

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Iron Loss = Cu Loss = $\frac{0.26}{2}$ = 0.13 KW

We know Iron Loss occurs all the time

So Total iron loss = 0.13 KW × 24 hr
= 3.12 KWh

Total Cu Loss in KWh = $\left(0 + \frac{0.13}{16}\times 7 + \frac{0.13}{4}\times 5 + 0.13\times 2\right)$
= 0.47

Total Loss in KWh = Total Cu Loss in KWh + Total Iron KWh
= 0.47 + 3.12
= 3.59 KWh.

Total output in KWh = $0 + \left(\frac{1}{4}\times 5\times 7\right) + \left(\frac{1}{2}\times 5\times 5\right) + (5\times 2)$
= 31.25 KWh

$\eta_{all-day} = \frac{\text{output in KWh for 24 hr}}{\text{output '' + Losses}} \times 100$

$= \frac{31.25}{31.25 + 3.59} = 0.89 \times 100$

= 89 %

Parallel operation of transformer :-

Neccessity for parallel " :-

(a) Continuty of supply.
(b) Repair & maintenance.
(c) capability to withstand future Load demand.

Cond^n for parallel operation:

(i) polarities of all the transformer to be connected in parallel must be same and properly connected.

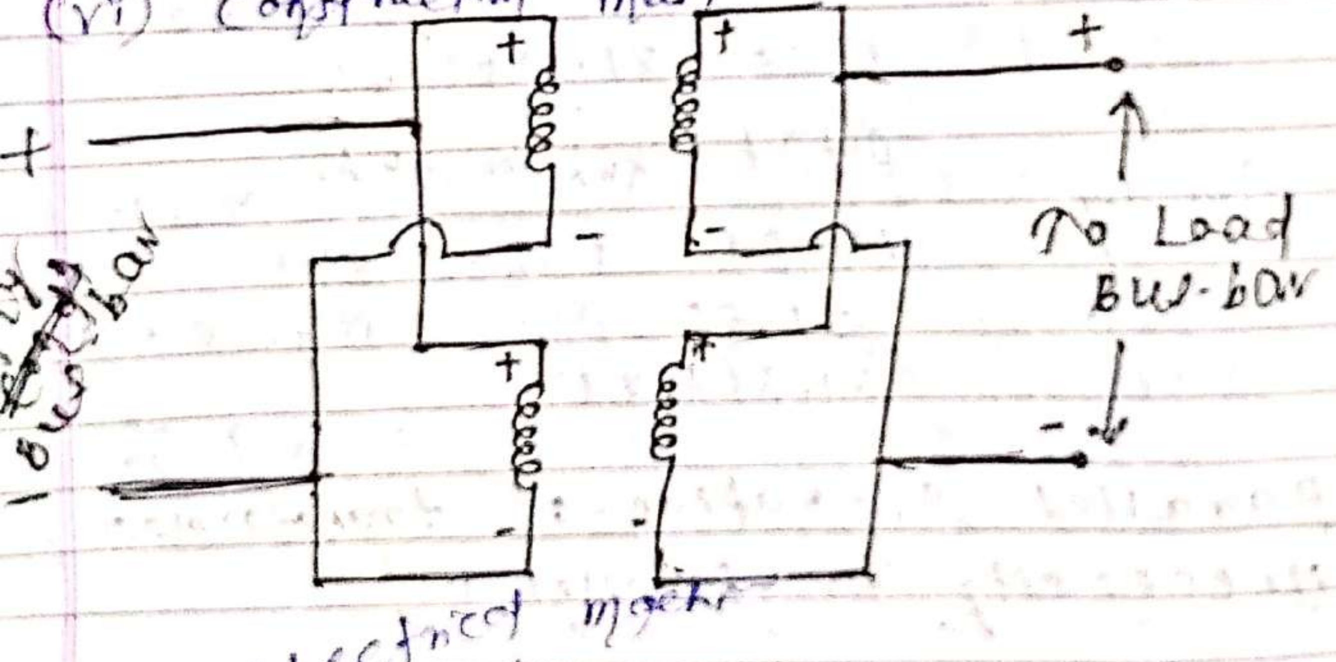
(ii) The voltage ratio & voltage ratio of all the transformer to be connected in parallel must be same.

(iii) The impedance ratio of all the transformer to be connected in parallel must be same.

(iv) The reactance to resistance ratio of all the transformer " " " must be same.

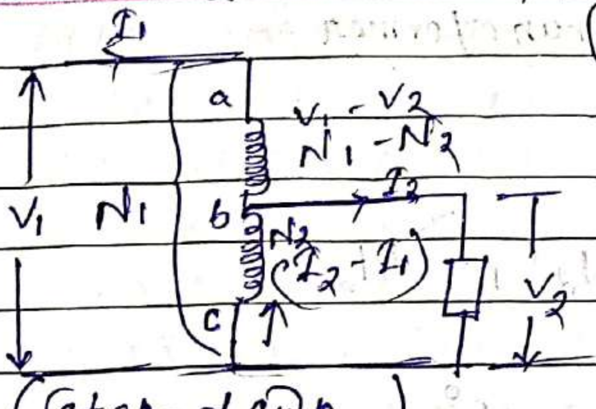
(v) Frequency must be same.

(vi) Construction must be same.



electrical machine
J. B. Gupta

Auto Transformer (1-ϕ-4T)

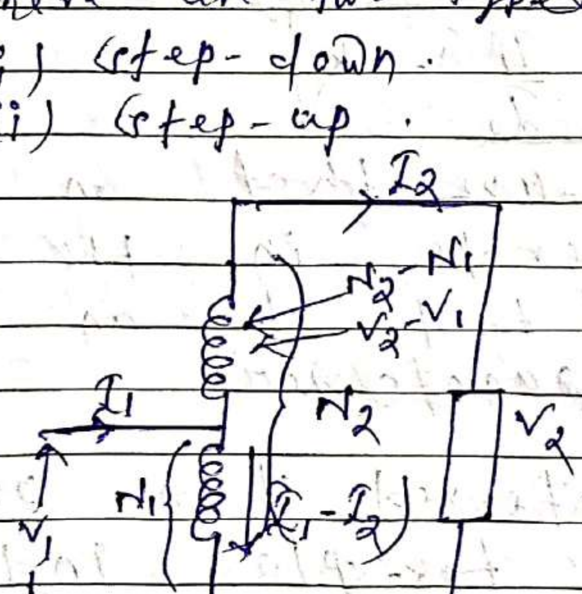


$V_1 > V_2$

$I_2 > I_1$

ac = primary
bc = Secondary.

* An auto-transformer is a single winding transformer on an iron core and part of the winding is common to both primary & secondary side.
* Here both the primary & secondary winding are connected electrically as well as magnetically.
* So power from primary is transferred to secondary inductively as well as conductively.
* There are two types of autotransformer.
  (i) step-down.
  (ii) step-up.



$V_2 > V_1$

$I_1 > I_2$

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Theory of Auto Transformer:-

$$\frac{V_2}{V_1 - V_2} = \frac{N_2}{N_1 - N_2}$$

$$V_2 N_1 - V_2 N_2 = N_2 V_1 - N_2 V_2$$

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} \text{ ——— (i)}$$

Consider ideal step down transform

VA of ab = VA of bc

$$(V_1 - V_2) \times I_1 = V_2 (I_2 - I_1)$$

$$V_1 I_1 - V_2 I_1 = V_2 I_2 - V_2 I_1$$

$$\frac{V_2}{V_1} = \frac{I_1}{I_2} \text{ ——— (ii)}$$

From eqn (i) & (ii) we get

$$\boxed{\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K}$$

So it is observe that an auto-transformer operate in the same principle as that of an ordinary two winding transformer.

Here power transferred from primary to secondary side takesplace inductively as well as conductively.

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* Input power = $V_1 I_1$

power transferred inductively

$= V_2 (I_2 - I_1)$ $\left[\because \frac{I_1}{I_2} = K\right]$

$= V_2 (I_2 - I_2 K)$

$= V_2 I_2 (1 - K)$

$= V_1 I_1 (1 - K)$

$=$ Input $(1 - K)$

* Total input = power transferred inductively + power trans conductively

⇒ power transferred conductively = Input − p.t. inductively

= Input − Input (1−K)

= ~~Input~~ − ~~Input~~ + Input × K

= Input × K

Main parts of Transformer :-

1. Laminated core.
2. Winding.
3. Oil tube.
4. Main tube.
5. Conservation tank.
6. Breather.
7. Buchholz relay.
8. Radiators.
9. Explosion vent.
10. Lightning arrester.

* Low rating transformer < 25 KVA → Air cool
* Medm " " → Oil "
* High " " → Radiators.

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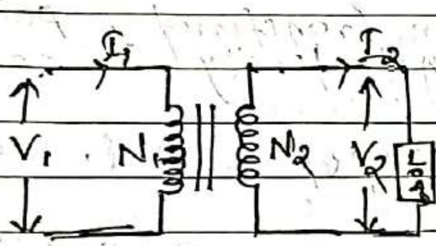
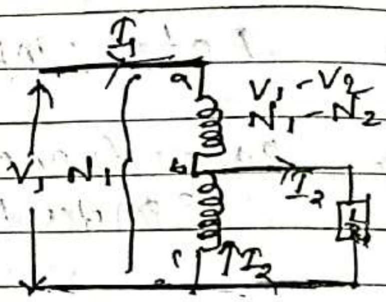
Saving of Cu in AT as compared to 2-winding transformer :-

* Due to a single winding is present in a AT the amount of Cu required in AT will be less than that of a 2-winding transformer of the same rating & same transformation ratio.





* volume of core / wt. of Cu required
 = length of winding × cross section area of core

Length ∝ No. of turn
Area ∝ current
So wt of Cu required
 = No. of turn × current — (1)

* For 2-winding, Cu required
 $= N_1 I_1 + N_2 I_2$ — (2)

For auto-transformer
 wt of Cu $\propto (N_1 - N_2) I_1 + N_2 (I_2 - I_1)$ — (3)

From eqn (2) & (3) wt. of Cu in 2-winding transformer

$\frac{W_a}{W_o} =$

$\frac{W_a}{W_o} =$

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$\frac{W_a}{W_o} = \frac{\text{wt of Cu in AT (~~2-winding~~) transformer}}{\text{wt of Cu in ~~auto~~ 2-winding}}$

$$\frac{W_a}{W_o} = \frac{(N_1 - N_2)I_1 + N_2(I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$= \frac{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}{N_1 I_1 + N_2 I_2}$$

$$= \frac{N_1 I_1 + N_2 I_2}{N_1 I_1 + N_2 I_2} - \frac{2 N_2 I_1}{N_1 I_1 + N_2 I_1}$$

$$= 1 - \frac{2 N_2 I_1}{N_1 I_1 + N_2 I_1}$$

As $N_1 I_1 = N_2 I_2$

$$\frac{W_a}{W_o} = 1 - \frac{2 N_2 I_1}{2 N_2 I_2} = 1 - \frac{I_1}{I_2} = 1 - K$$

$$W_a = W_o (1 - K)$$

Saving of Cu $= W_o - W_a$

$= W_o - W_o(1-K)$

$= W_o \times K$

Saving of Cu in AT $= K \times$ wt. of Cu required in ordinary transf

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- Advantage of AT as compared to 2-winding transformer :-
* The amount of cu' required will be less in AT as compared to a 2-winding transformer of same rating.
* Efficiency of AT transformer will be higher than that of two winding transformer.
* Size of AT transformer will be smaller than that of a 2-winding transformer of same rating.
* Voltage regulation of AT will be batter than that of a 2-winding transformer of same rating.

Application :-
* Use to compensate voltage drop in transmission & distribution line called as booster transfor.
* Use to starting ac motor.
* Use for contineous variable supply.

Transformer Accessories

→ For providing long service life to the transformer different transformer accessories get fitted to it.

BREATHER

→ When the temperature changes occur in transformer insulating oil, the oil expands or contracts and there is an exchange of air also occurs when transformer is fully loaded.

→ When transformer gets cooled, the oil level goes down and air gets absorbed within.

→ This process is called breathing and the apparatus that pass through the air is called breather.

→ Silica gel breathers controls the level of moisture, entering electrical equipment during the change in volume of the cooling medium and airspace caused by temp. increasing.

TANK

↙ Main tank

↘ Conservator tank

Main tank

→ It is also known as oil tank.

→ It protects the core and the windings from outer conditions like mechanical injuries, moisture, short ckt. etc.

→ It work as oil container.

Conservator tank

→ This is a cylindrical tank mounted on supporting structure on the roof of the transformer's main tank.

→ When transformer is loaded, the temp. of oil increases and consequently the volume of oil in the transformer gets increased.

→ The conservator tank of the transformer provides adequate space for expansion of oil.

Explosion Vent

→ It is used to prevent damage of the transformer tank be releasing any excessive pressure generated inside the transformer.

Radiators / Cooling tube

→ Radiators increases the surface area for dissipating heat of the oil.


Conservator
EXPLOSION VENT
BREATHER
Buchholz Relay
COOLING
TUBES

Cooling Methods of Transformer

- Cooling of a transformer is the process of dissipation of heat developed in the transformer to the surroundings.
- The main source of heat generation in transformer is its copper loss or I^2R loss.
- If this heat is not dissipated properly, the temp. of transformer will rise continually which may cause damage in insulation. So it is essential to control the temp. with in permissible limit to ensure long life of transformer.
- Different cooling methods are used depending upon their size and ratings of transformers:

i) In small transformer (below 50 KVA), natural air cooling is employed i.e. heat produced is carried away by the surrounding air.

ii) Medium size power or distribution transformer are generally cooled by housing them in tanks filled with oil. The oil carries the heat from the winding to the surface of the tank and also insulate the primary from the secondary.

iii) For large transformers, external radiators are used to increase the cooling surface of the oil filled tank. The oil circulates around the transformer and moves through the radiators where heat is released to the surrounding air.

7.49 Applications of Transformers

There are four principal applications of transformers viz.

(i) power transformers (ii) distribution transformers
(iii) autotransformers (iv) instrument transformers

(i) **Power Transformers**. They are designed to operate with an almost constant load which is equal to their rating. The maximum efficiency is designed to be at full-load. This means that full-load winding copper losses must be equal to the core losses.

(ii) **Distribution Transformers**. These transformers have variable load which is usually considerably less than the full-load rating. Therefore, these are designed to have their maximum efficiency at between 1/2 and 3/4 of full-load.

(iii) **Autotransformers**. An autotransformer has only one winding and is used in cases where the ratio of transformation (K), either step-up or step down, differs little from 1. For the same output and voltage ratio, an autotransformer requires less copper than an ordinary 2-winding transformer. Autotransformers are used for starting induction motors (reducing applied voltage during starting) and in boosters for raising the voltage of feeders.

(iv) **Instrument transformers**. Current and voltage transformers are used to extend the range of a.c. instruments.

(a) Current transformer

A current transformer is a device that is used to measure high alternating current in a conductor. Fig. (7.55) illustrates the principle of a current transformer. The conductor carrying large current passes through a circular laminated iron core. The conductor constitutes a one-turn primary winding. The secondary winding

consists of a large number of turns of much fine wire wrapped around the core as shown. Due to transformer action, the secondary current is transformed to a low value which can be measured by ordinary meters.

$$\text{Secondary current, } I_S = I_P \times \frac{N_P}{N_S}$$

For example, suppose that I_P = 100 A in Fig. (7.55) and the ammeter is capable of measuring a maximum of 1 A. Then,

$$N_S = N_P \times \frac{I_P}{I_S} = 1 \times \frac{100}{1} = 100$$

(b) Voltage transformer

It is a device that is used to measure high alternating voltage. It is essentially a step-down transformer having small number of secondary turns as shown in Fig. (7.56). The high alternating voltage to be measured is connected directly across the primary. The low voltage winding (secondary winding) is connected to the voltmeter. The power rating of a potential transformer is small (seldom exceeds 300 W) since voltmeter is the only load on the transformer.

$$V_P = V_S \times \frac{N_P}{N_S}$$

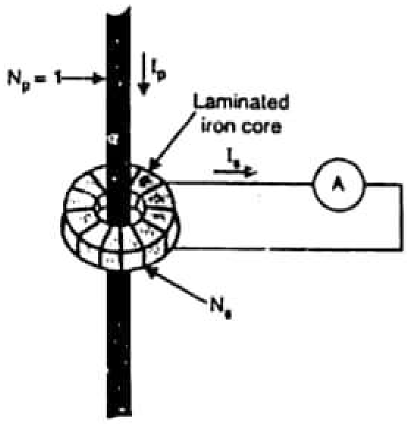

Fig.(7.55)

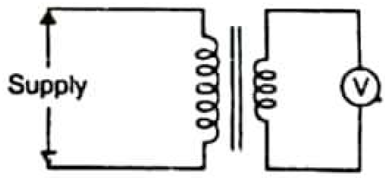

Fig.(7.56)

* Current Error / Ratio Error

→ In a C.T. I_p is not exactly equal to $I_s \cdot K$.

→ The difference is due to the primary current is contributed by the core excitation current.

→ The error introduced due to this difference is called current error / Ratio error of CT.

$$\% \text{ Ratio Error} = \frac{|I_p| - |K \cdot I_s|}{I_p} \times 100$$

* Phase Angle Error

→ In an ideal CT, the angle betn. I_p & I_s is zero

→ But in an actual CT, there is always a difference in phase due to fact that primary current has to supply component of exciting current

→ The angle betn. the above two phases is termed as phase angle error (β).

* Reduce Error in Current Transformer

→ For better performance, achieving minimum error is required.

i) Using a core of high permeability and low hysteresis loss magnetic material.

ii) Keeping the rated burden to nearer value of actual burden.

iii) Lowering secondary internal impedance.

iv) Ensuring minimum length of flux path and increasing cross-sectional area of core.

* Burden of CT

→ The burden of CT is the maximum load (in VA) that can be applied to the CT secondary.

→ It can be expressed in 2 ways.

→ It can be expressed as the total impedance in ohms of the circuit or the total VA and power factor at a specified value of current or voltage and frequency.

EC - I

D.C. Generator

2 Mark

1. Describe the basic principle of DC Generator.
2. State different parts of D.C. generator.
3. Define back pitch / Front pitch / Commutator pitch / Resultant pitch.
4. What is the function of commutator in DC Machine.
5. What is the function of pole shoes in DC Machine.
6. Difference betn. Lap winding & wave winding.
7. Classify DC generator according to their excitation.
8. State the condition of Maxm. efficiency of DC Generator
9. Define Armature reaction.
10. Define commutation.
11. Define critical resistance & critical speed of DC Generator.
12. Explain why parallel operation of DC generators is required.

Long type

1. Explain the construction and different parts of DC Machine with suitable diagram.
2. Derive E.M.F. eqn. of DC Generator.

3. Derive condition for maximum efficiency of DC. Generator.

4. Explain the process of armature reaction in a D.C. Generator

5. Explain briefly the process of commutation in a D.C. Generator and methods improving commutation.

6. Explain different characteristics of D.C. Generator.

7. Explain the necessity and conditions of parallel operations of DC. Generators.

8. Problems ⇒ Solve problems as discussed in class.

D.C. MOTOR

1. Explain the working principle of D.C. Motor.

2. What is back EMF.

3. State the voltage equation of DC Motor.

4. State the condition of Max^m. power output of D.C. Motor.

5. Define shaft torque of D.C. Motor.

6. Classify D.C. Motor.

7. Explain the necessity of starter in starting of D.C. Motor.

8. Write some applications of shunt DC motor / Series DC Motor / Compound DC Motor.

Long type

1. Derive an equn for Armature torque of a DC Motor.
2. Describe various characteristics of series DC Motor / Shunt DC Motor.
3. Describe the speed control of DC shunt Motor by flux control method and armature control method
4. Describe various methods of speed control of DC series motor.
5. Explain the construction and working of 3 point starter / 4-point starter with suitable diagram.
6. Problems related to Brake test / Swinburne's test.
7. Problems discussed in class.

TRANSFORMER

2 Mark

1. Define transformer.
2. Define transformation ratio of transformer.
3. Why rating of transformer in KVA ?
4. What is the function of breather in a transformer
5. Define voltage regulation of transformer

6. What are the different types of losses that occur in a transformer.

7. State the condition for maximum efficiency of transformer.

8. Define All-day efficiency of transformer.

Long type

1. Derive EMF equ^n. of transformer.

2. Explain the operation of transformer on load with suitable phasor diagram.

3. Explain briefly cooling methods of transformer.

4. Draw phasor diagram of a loaded transformer with winding resistance and leakage reactance at unit p.f. load, leading p.f. & lagging p.f.

5. Explain open ckt. & short ckt. of a transformer.

6. Explain the necessity, condition & principle of parallel operation of single phase transformer.

7. Derive a condition for max^m. efficiency of transformer.

* AUTO-TRANSFORMER

2 Mark

1. Define Autotransformer.

2. State applications of Autotransformer.

Long type

1. Explain how saving of Cu will takes place in an Autotransformer as compared to a 2-winding of transformer.

* Instrument Transformer

2 Mark

1. What is the function of C.T./P.T.
2. Define Ratio error of C.T.
3. Define phase Angle error of CT.

Long type

1. Explain the construction & working of a Current transformer.
2. Explain the construction & working of a potential transformer.