(CHAPTER-05) (Instrument Transformers)

→ Explain current transformer & potential transformer.

Definition of Instrument Transformer :→

→ Instrument transformers means Current transformer and voltage transformer are used in electrical power system for stepping down Currents and voltages of the system.

Current Transformer :→

→ It Can be treated as Series transformer under virtual short ckt conditions.

→ Secondary must be always shorted.

→ A small voltage exists across its terminals as Connected in series.

→ The winding Carries full line current.

→ The primary Current and excitation varies over a wide range.

→ The primary current is independent of the secondary circuit conditions.

→ Needs only one bushing as the two ends of primary winding are brought out through the same insulator Hence there is saving in cost.

→ The secondary of a C.T can not be open circuited on any circumstance when it is under service.

→ A current transformer may be considered as a Series transformer.

→ The primary winding of the current transformer is connected in series with the line carring the current to be measured. Hence it carries of the full line current.

→ With the help of current Transformer, a 5A ammeter can be used measure a high current like 200A

Potential Transformer :→

→ It Can be treated as parallel transformer under open circuit secondary.

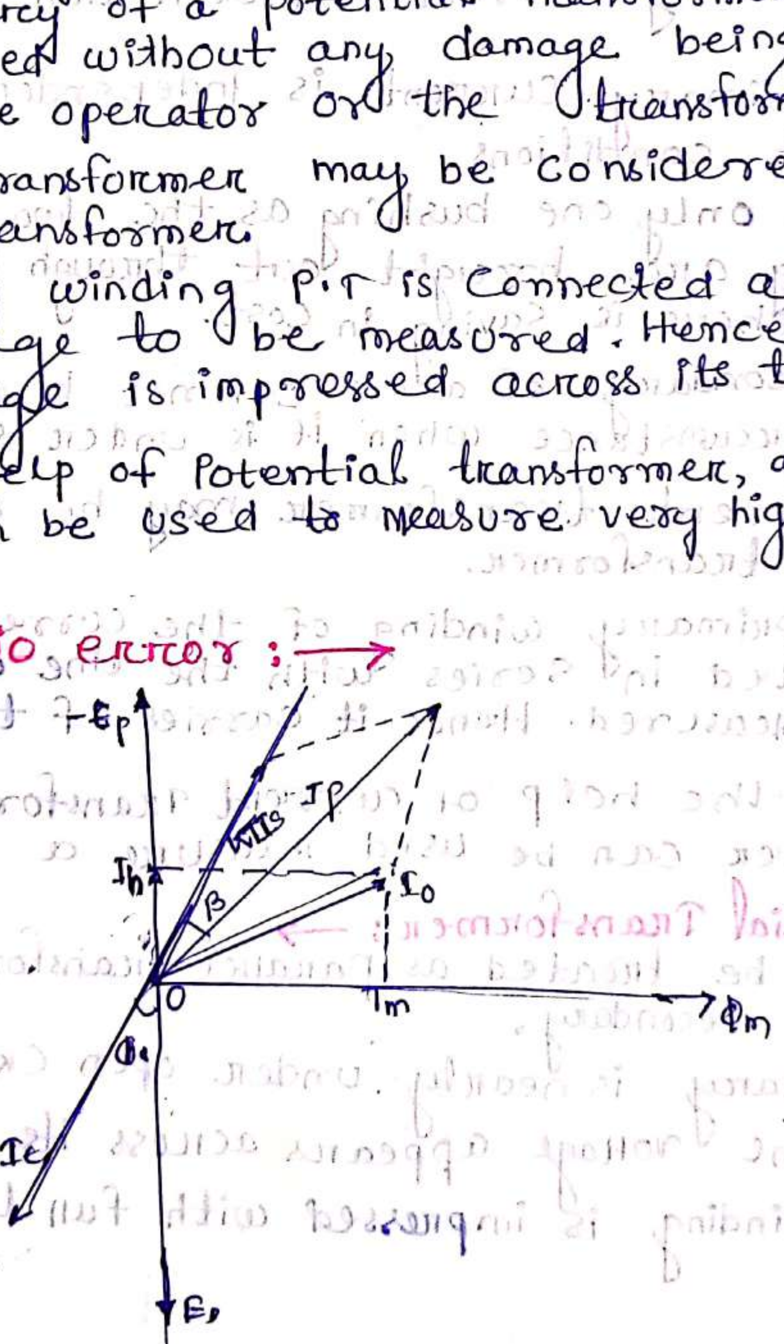
→ Secondary is nearly under open ckt conditions.

→ Full line voltage appears across its terminals.

→ The winding is impressed with full line voltage.

- The line voltage is almost constant hence exciting current and flux density varies over a limited range.
- The primary current depends on the secondary circuit conditions.
- Full line voltage appears across it terminals.
- The winding is impressed with full line voltage.
- The line voltage is almost Constant hence exciting Current and flux density varies over a limited range.
- The primary current depends on the secondary ckt conditions.
- Two bushings are required when neither side of the line is at ground potential.
- The secondary of a potential Transformer can be open circuited without any damage being caused either to the operator or the transformer.
- potential Transformer may be considered as a parallel transformer.
- The primary winding P.T is connected across the line of voltage to be measured. Hence The full line voltage is impressed across its terminals.
- With the help of potential transformer, a 120 v voltmeter can be used to measure very high voltages like 11kv.

Define Ratio error :→



> That primary Current I_P is not exactly equal to the secondary Current multiplied by turns ratio. i.e $K_T I_S$

> This difference is due to the primary Current is contributed by the core excitation Current.

> The error in current transformer introduced due to this difference is called current error of current transformer

The percentage current error = $\frac{|I_P| - |K_T I_S|}{I_P} \times 100\%$.

Phase angle error :→

> phase angle error is defind as the angular differexe between the secondary current phasor reversed and the primary Current phasor.

> If the reversed current phasor leads the primary current phasor then the phase angle error is defind as positive otherwise it is taken as negative.

> ~~The ph~~

> The phase angle error is due to the no load current or exciting current. this is the angle by which the secondary current, when reversed, differs in phase from the primary Current.

> In case of current Transformers, current ratio is more important, while phase angle error is of little importance. so long it is connected with an ammeter

Uses of current Transformer : →

> Measuring such magnitude of current that the meter or instrument cannot convenienty be measured.

> Measure the current of another circuit.

> Worldwide to monitor high-voltage lines across national power grids.

> used to Reduce or multiply on alternating current.

> Uses of ceramic capacitors is as follows:

>

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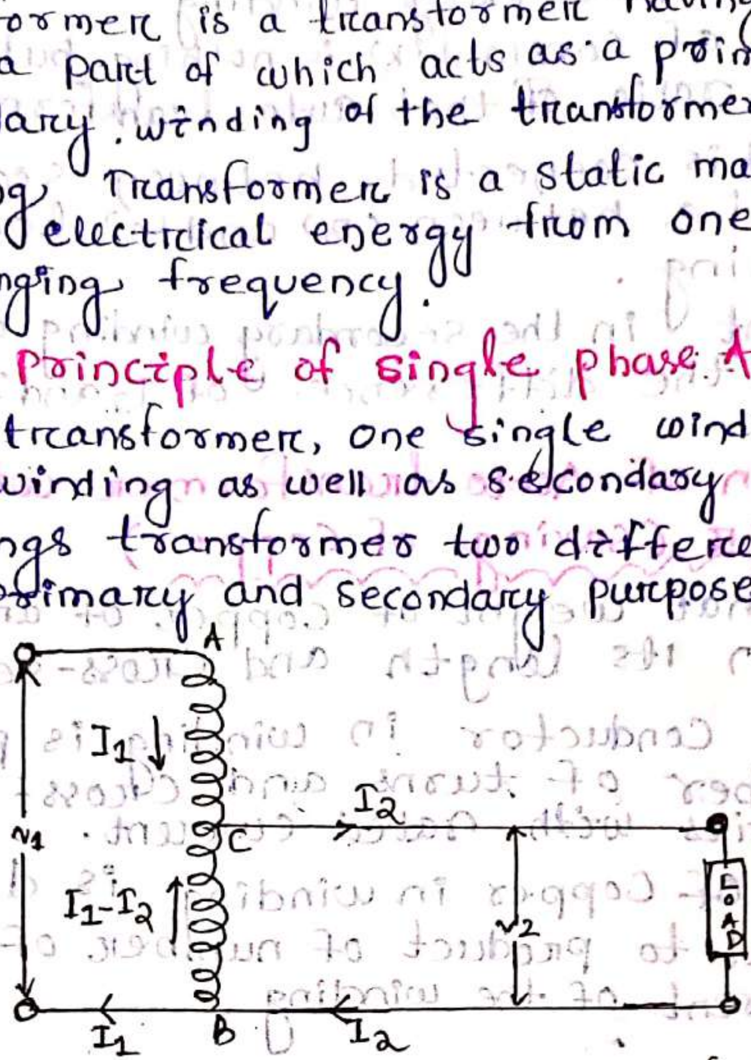
Auto- Transformer: (CHAPTER-4)

- Autotransformer is a transformer having only one winding, a part of which acts as a primary and other as a secondary winding of the transformer are interrelated.
- Two winding Transformer is a static machine which transfers electrical energy from one end to another without changing frequency.

Working principle of single phase AutoTransformer:

- In an autotransformer, one single winding is used as primary winding as well as secondary winding.
- Two windings transformer two different windings are used for primary and secondary purpose.



(Diagram of auto Transformer) →

- The winding AB of total turns N_1 is considered as Primary winding.
- This winding is tapped from point 'C' and portion BC is considered as secondary.
- The number of turns in between points 'B' and 'C' is N_2
- V_1 voltage is applied across the winding in between 'A' & 'C'

so voltage per turn in this winding is $\frac{V_1}{N_1}$

- The voltage across the portion BC of the winding will be

$\frac{V_1}{N_1} \times N_2$ and from the figure above, this voltage is V_2

$$\text{Hence } \frac{V_1}{N_1} \times N_2 = V_2$$

$$\Rightarrow \frac{V_2}{V_1} = \frac{N_2}{N_1} \quad \text{Constant} = K$$

BC portion is secondary winding.

→ That value of constant (K) is nothing but turns ratio or voltage ratio of that auto transformer.

→ When load is connected between secondary terminals i.e between (B) and (C) load current I_2 starts flowing.

→ The current in the secondary winding or common winding is the difference of I_2 and I_1.

Comparison of Auto transformer with an two winding transformer (saving of copper)

→ We know that weight of copper of any winding depends upon its length and cross-sectional area.

→ Length of conductor in winding is proportional to its number of turns and cross-sectional area varies with rated current.

→ So weight of copper in winding is directly proportional to product of number of turns and rated current of the winding.

Therefore, weight of copper in the section AC proportional to

$$(N_1 - N_2) I_1$$

and similarly,

weight of copper in the section BC proportional to $N_2 (I_2 - I_1)$

Hence,
Total weight of copper in the winding of auto transformer proportional to,

$$(N_1 - N_2) I_1 + N_2 (I_2 - I_1)$$

$$\Rightarrow N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1$$

$$\Rightarrow N_1 I_1 + N_2 I_2 - 2 N_2 I_1$$

$$\Rightarrow 2 N_1 I_1 - 2 N_2 I_1 \quad (\text{since, } N_1 I_1 = N_2 I_2)$$

$$\Rightarrow 2 (N_1 I_1 - N_2 I_1)$$

→ ~~Proved that~~

→ Proved that, the weight of copper in 2 winding transformer is proportional to ~~$N_1 I_1 + N_2 I_2$~~ ~~$= 2N_1I_1$~~

$= \cancel{2N_1I_1 (\text{so } N_1I_1 = N_2I_2)}$

$\Rightarrow 2\, N_1 I_1 = N_1 I_1 - N_2 I_2 \quad (\because N_2 I_1 = N_2 I_2)$

$\Rightarrow 2\, N_1 I_1 = \cancel{N_2} I_2 - \cancel{N_2} I_2$

$\Rightarrow 2\, N_1 I_1$

W_a & W_{tw} are weight of copper in auto transformer and two winding transformer respectively,

Hence $\dfrac{W_a}{W_{tw}} = \dfrac{2(N_1 I_1 - N_2 I_1)}{2(N_1 I_1)}$

$= \dfrac{N_1 I_1 - N_2 I_1}{N_1 I_1} = 1 - \dfrac{N_2 \cancel{I_1}}{N_1 \cancel{I_1}}$

$\Rightarrow 1 - \dfrac{N_2}{N_1} = 1 - K$

$\therefore W_a = W_{tw}(1-K)$

$\Rightarrow W_a = W_{tw} - K W_{tw}$

→ ∴ Saving copper in auto transformer compared two winding transformer,

$\Rightarrow W_{tw} - W_a = K W_{tw}$

Advantages of using Auto Transformers :→

→ The saving in cost of the material is of course not in the material is of course not in the same ~~poo~~ proportion.

→ The saving of cost is appreciable when the ratio of transformer is low, that is lower than 2.

→ Auto transformer is smaller in size and cheaper.

→ Auto transformer has higher efficiency than two winding transformer.

→ Less ohmic loss and core loss due to reduction of transformer material.

→ Auto transformer has better voltage regulation as voltage drop in resistance and reactance of the single winding is less.

Disadvantages of using Auto transformer :→

→ Electrical Conductivity of the primary and secondary windings the lower voltage ckt is liable to be impressed upon by higher voltage.

→ To avoid breakdown in the lower voltage circuit.

→ The leakage flux between the primary and secondary windings is small and hence the impedance is low. This results into server short ckt current under fault conditions.

→ Common natural in a star connected auto transformer it is not possible. to earth neutral of one side only.

→ Range of tapping is very large, the advantages gained ~~to~~ in initial cost is lost to great event.

Uses of Autotransformers :→

→ Compensating voltage drops by boosting supply voltage in distribution systems.

→ Auto transformers with a number of tapping are used for starting induction and synchronous motors.

→ Auto transformer is used as variac in laboratory or where continuous variable over broad ranges are required.

Tap-changing Transformers :→

→ The change of voltage is affected by changing the numbers of turns of the transformer provided with taps,

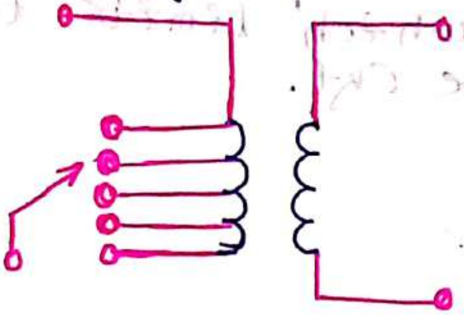
→ For sufficiently close control of voltage, taps are usually provided on the high voltage windings of the transformer.

→ There are two types of tap-changing transformers:

1. Off-load tap-changing transformer
2. On-load tap-changing transformer

Off-Load tap-changing Transformer: →

→ The transformer is disconnected from the main supply when the tap setting is to be changed. The tap selling is usually done manually.

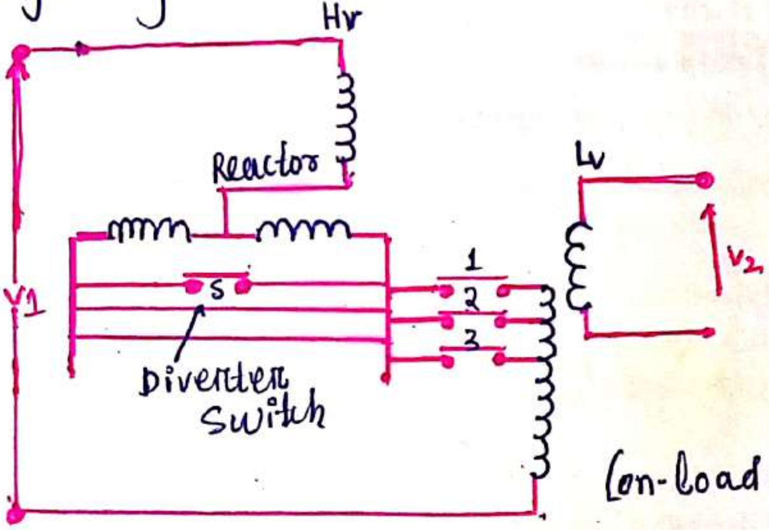


On-Load-tap-Changing Transformer: →

→ On-Load tap changing transformer are sued. such a transformer is known as a tap-changing under load transformer.

→ While tapping, two essential conditions are to be fulfilled.

1. The load ckt should not be broken to avoid arcing and prevent the damage of contacts.
2. No parts of the windings should be short circuited while adjusting the tap.



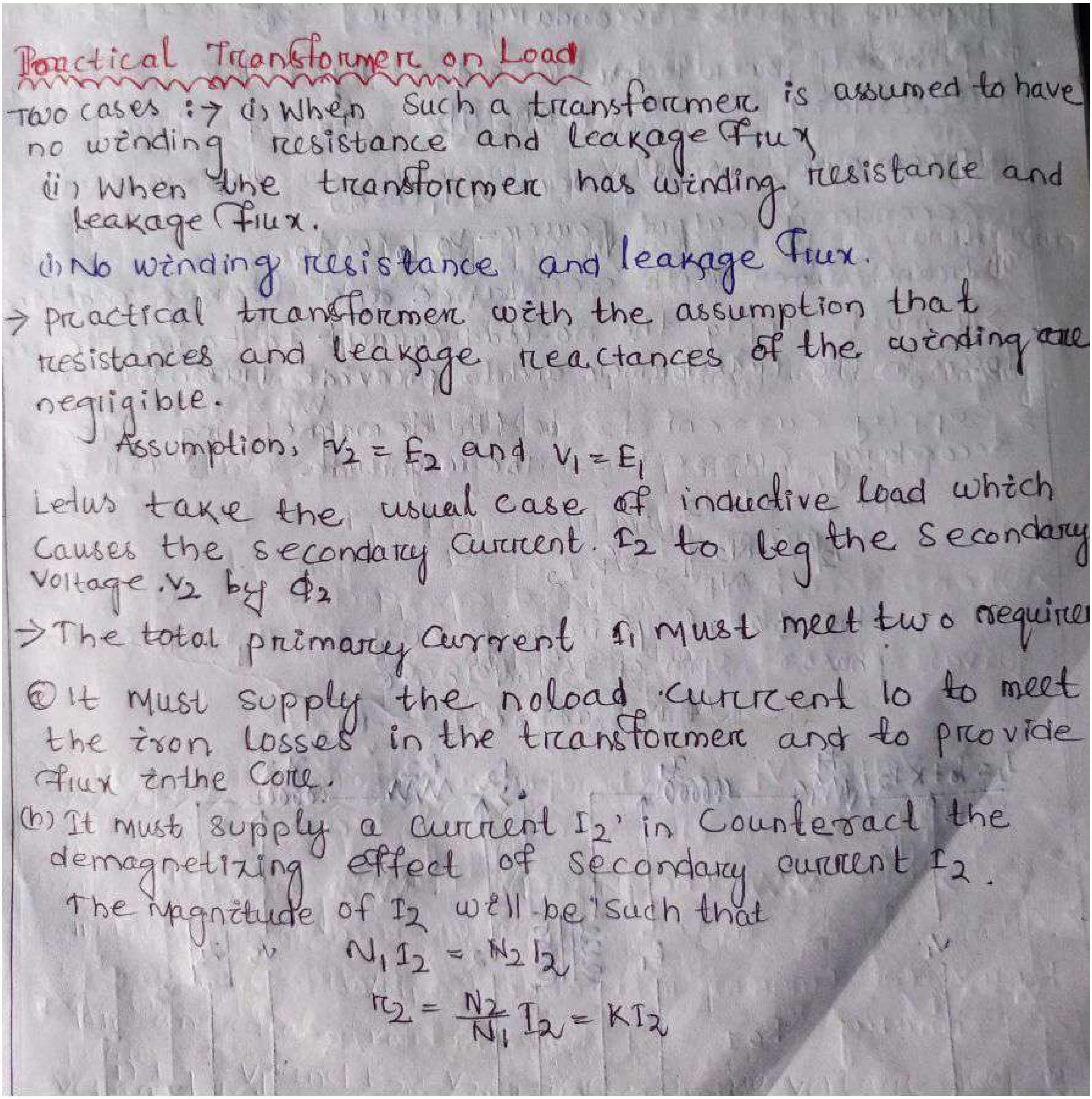
(on-load tap changing using a reactor)

R → Center tapped Reactor.
S → Diverter switch
1, 2, 3 → selector switch.

→ The transformer is in operation with switches 1 and S closed. to change to tap 2, switch S is opened, and 2 is closed, switch 1 is then opend, and S closed to complete the tap change.

→ It is to be noted that the diverter switch operates on load, and no-current flows in the selector switches during tap changing.

~~→ Durir~~ → During the ~~o~~ tap change, only half of the reactance which limits the current is connected in the ckt.



Practical Transformer on Load

Two cases :→ (i) When such a transformer is assumed to have no winding resistance and leakage flux

(ii) When the transformer has winding resistance and leakage flux.

(i) No winding resistance and leakage flux.

→ practical transformer with the assumption that resistances and leakage reactances of the winding are negligible.

Assumption, $V_2 = E_2$ and $V_1 = E_1$

Letus take the usual case of inductive load which causes the secondary current I_2 to leg the secondary voltage V_2 by ϕ_2

→ The total primary current I_1 must meet two requirer

(a) It must supply the noload current I_0 to meet the iron losses in the transformer and to provide flux inthe core.

(b) It must supply a current I_2' in counteract the demagnetizing effect of secondary current I_2.

The magnitude of I_2 will be such that

$$N_1 I_2 = N_2 I_2$$

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

Phasor diagram :→

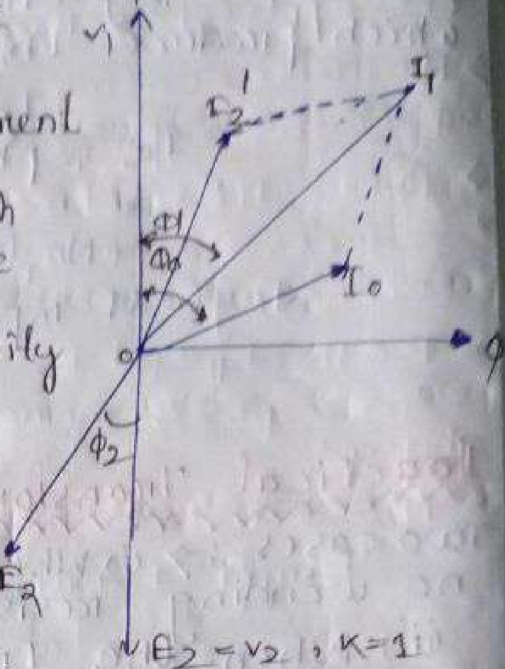
E_1, E_2 → lagbehind the mutual flux Φ by 90°.

I_2' & I_2 → primary & secondary Current

$I_2 = K I_2$ and it antiphase with E_2, I_0 → No load Current of the transformer.

The value K is assumed to be unity Sothat,

Primary phasors = Secondaryphasor.



Primary power factor = $\cos\phi_1$

Secondary " " = $\cos\phi_2$

Primary input power = $V_1 I_1 \cos\phi_2$

Secondary output power = $V_2 I_2 \cos\phi_2$

(ii) Transformer with resistance and leakage reactance

> It must Supply the no-load Current I_0 to meet the Iron Losses in the transformer and to provide flux in the core.

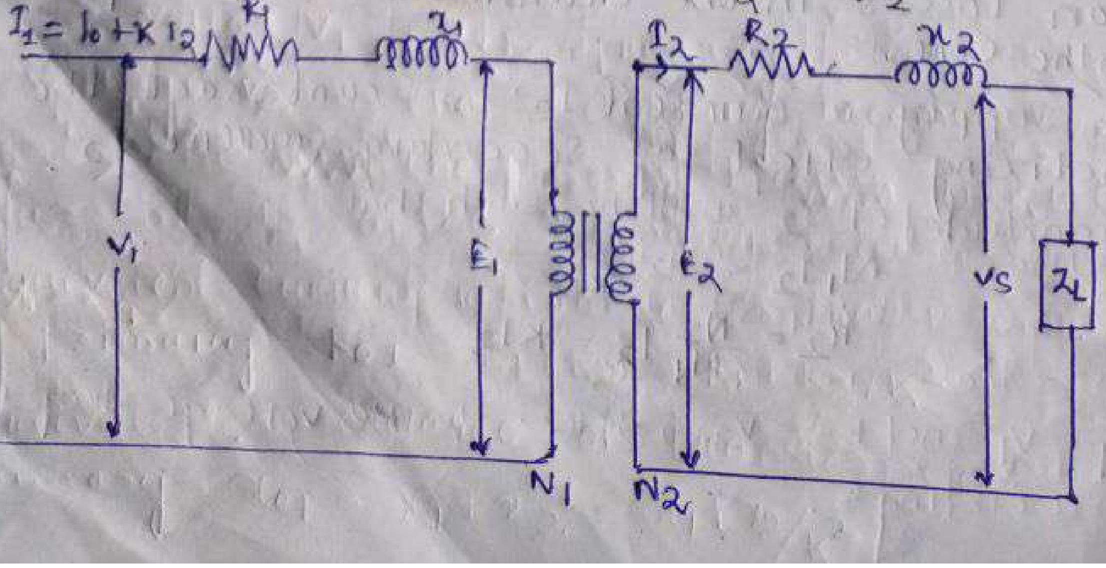
→ Supply Current I_2' to the demagnetising effect of Secondary Current I_2 The magnitude of I_2' will be

$$N_1 I_2' = N_2 I_2$$

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

The total primary current I_1 will be the phasor sum of I_2' and I_0 i.e

$$I_1 = I_2' + I_0 \quad \text{where } I_2' = -K I_2$$



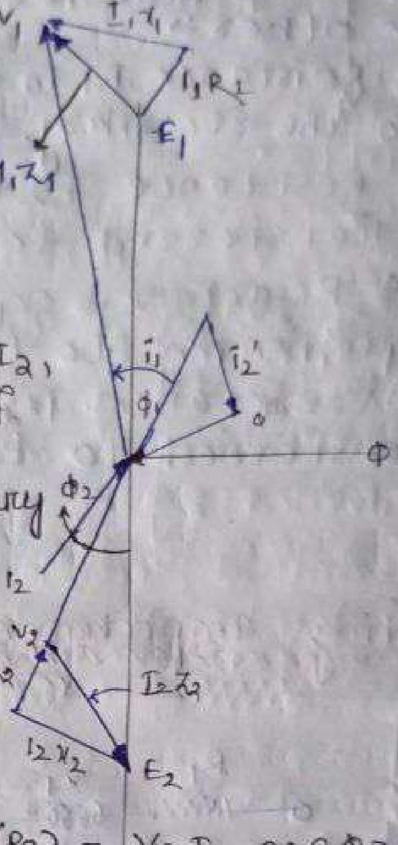
$v_1 = -E_1 + I_1(R_1 + jx_1)$ where $I_1 = I_0 + (-KI_2)$

$= -E_1 + I_1 Z_1$

$v_2 = E_2 - I_2(R_2 + jx_2)$

$= E_2 - I_2 Z_2$

Phasor diagram :→



Both E_1 & E_2 lag the mutual flux Φ by 90°

I_2' & I_2 → primary & secondary current.

$I_2' = KI_2$ and is opposite to I_2, Also I_0 is the no-load current of the transformer.

→ I_2 & I_0 gives the total primary current I_1.

→ Load power factor $= \cos\phi_2$

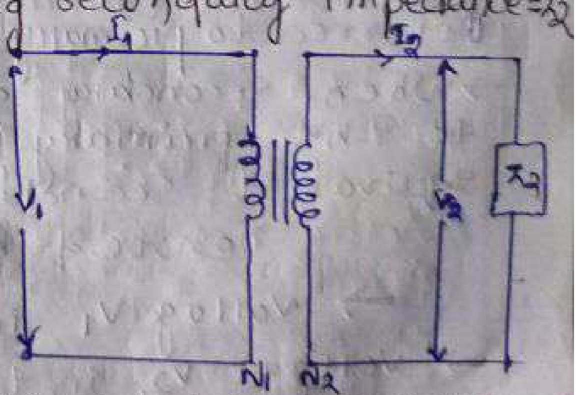
→ Primary power factor $= \cos\phi_1$

→ Input power to transformer, $(P_1) = V_1 I_1 \cos\phi_1$.

→ Output power of transformer $(P_2) = V_2 I_2 \cos\phi_2$

Impedance Ratio

Consider a transformer having secondary impedance $= Z_2$



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

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

$$\frac{Z_2}{Z_1} = \left(\frac{V_2}{V_1}\right) \times \left(\frac{I_1}{I_2}\right)$$

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

i.e Impedance ratio (Z_2/Z_1) is equal to the square of voltage transformation ratio.

→ Impedance Z_2 in secondary becomes Z_2/K^2 when transferred to primary.

→ Impedance Z_1 in primary becomes $K^2 Z_1$ when transferred to the secondary

Similarly, $\frac{R_2}{R_1} = K^2$

$\frac{x_2}{x_1} = K^2$

We can transfer the parameters from one winding to the other :-

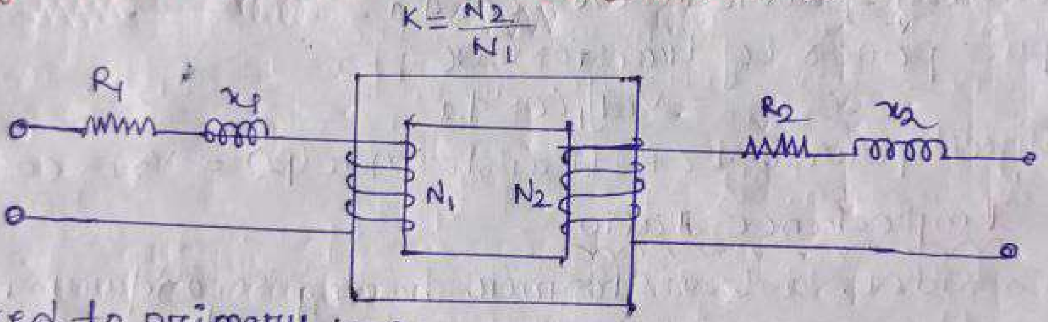
(i) A Resistance R_1 in the primary becomes $K^2 R_1$ when transfer to the secondary.

(ii) A Resistance R_2 in the secondary becomes R_2/K^2 when transferred to the primary.

(iii) A Reactance x_1 in the primary becomes $K^2 x_1$ when transferred to the secondary.

(iv) A reactance x_2 in the secondary becomes x_2/K^2 whe transferred to the primary.

Shifting Impedances in a Transformer :→



Referred to primary :→

→ When secondary resistance or reactance is transferred to the primary it is divided by K^2. It is then Calle equivalent secondary reactance.

Denoted by R_2 or x_2

→ Voltage V_1 in the primary becomes KV_1 in the Secon

→ voltage V_2 in the secondary becomes V_2/K in the prim

→ Current I_1 in the primary becomes I_1/K in the Secondary

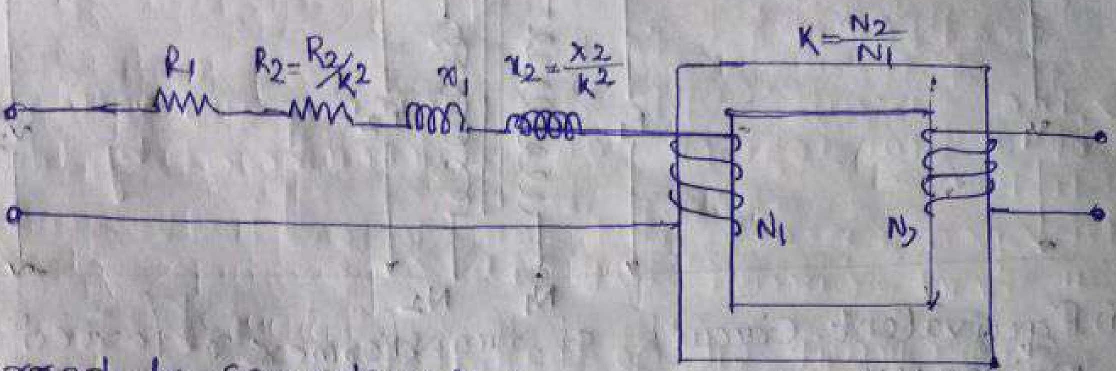
→ current I_2 in the secondary becomes KI_2 in the primary.

Equivalent ~~Current~~ resistance of transformer referred to primary $R_{01} = R_1 + R_2' = R_1 + R_2/K^2$

Equivalent reactance of transformer referred to Primary $x_{01} = x_1 + x_2' = x_1 + x_2/K^2$

Equivalent impedance of transformer referred to Primary

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



Referred to secondary :→

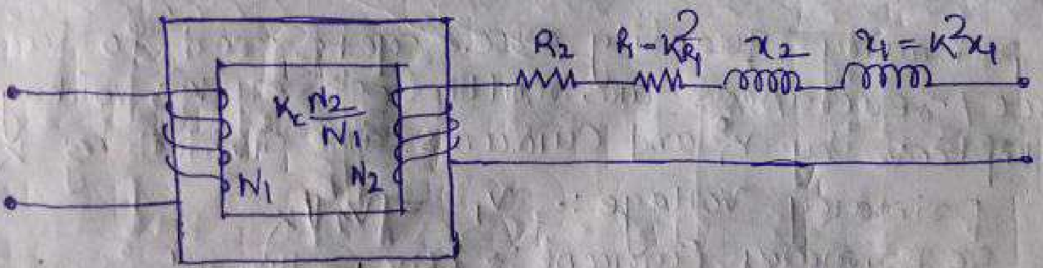
→ When Primary resistance or reactance is transferred to the Secondary. It is multiplied by K^2. It is called equivalent primary resistance or reactance

→ It is donoted by R_1' or X_1'

→ Equivalent resistance of transformer referred to secondary :- $R_{02} = R_2 + R_1' = R_2 + K^2 R_1$

→ Equivalent reactance of transformer referred to secondary :- $X_{02} = X_2 + X_1' = X_2 + K^2 X_1$

→ Equivalent impedance of transformer referred to secondary $Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}$

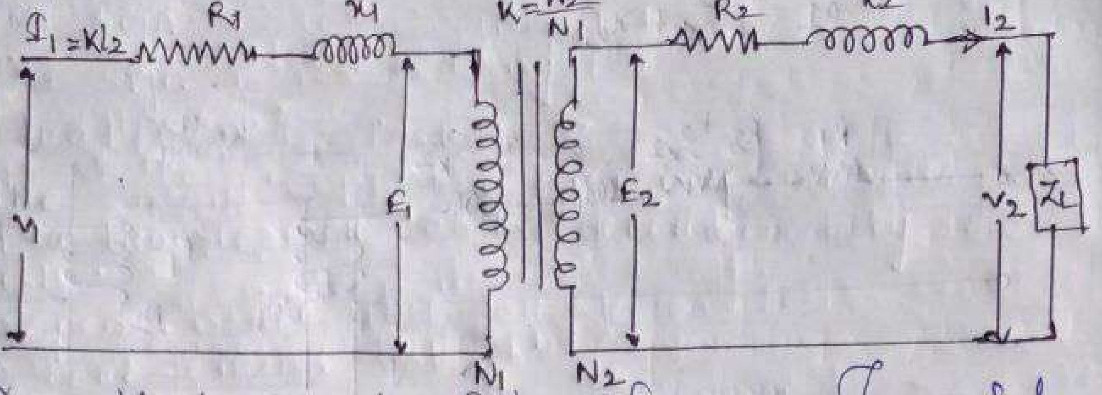


Approximate Equivalent Circuit of a Transformer :→

→ The no-load Current I_0 in a transformer is only 1-3% of the rated primary Current and may be neglected without any serious error.

→ This is an approximate representation because no-load current has been neglected.

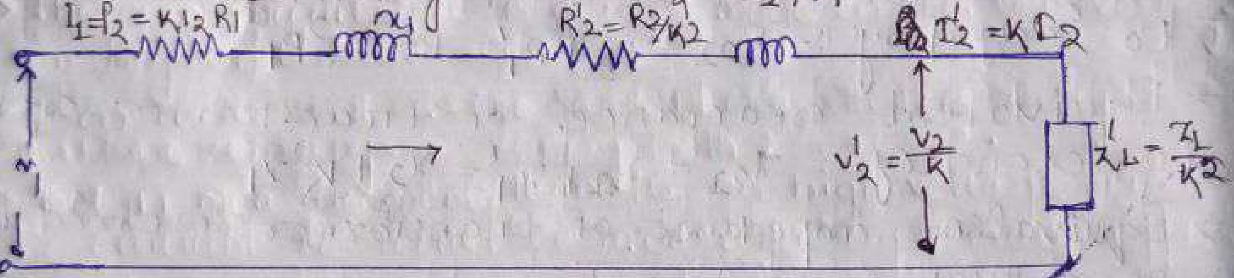
Ideal Transformer



(i) Equivalent circuit of transformer referred to primary :→

→ When secondary quantities are referred to primary resistances/reactances are divided by K^2. voltage are divided by K and currents are multiplied by K.

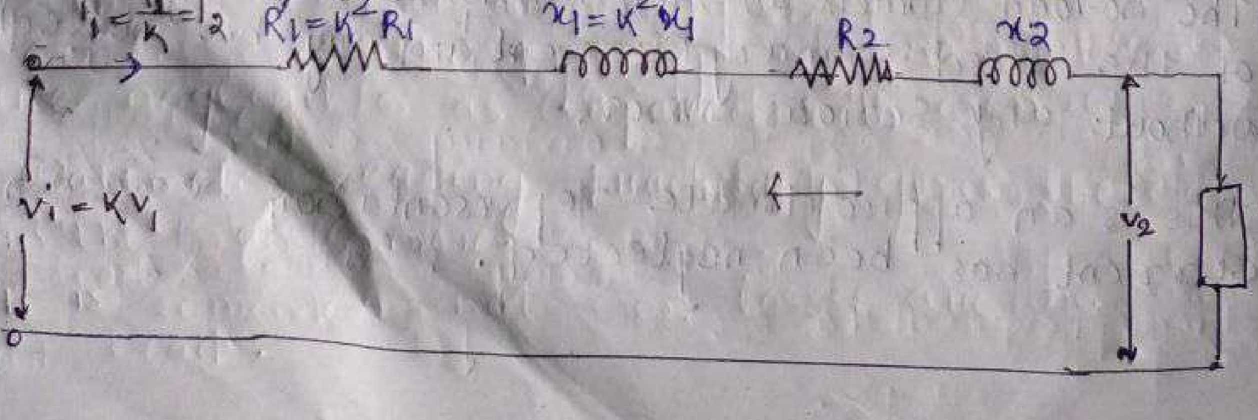
Actual secondary voltage $V_2 = K V_2'$
Actual secondary current $I_2 = I_2'/K$



(ii) Equivalent circuit of transformer referred to Secondary

→ When primary quantity are referred to Secondary resistance/reactances are multiplied by K^2, voltage are multiplied by K and currents are divided by K

Actual primary voltage :- $V_1 = V_1'/K$
Actual ~~se~~ primary Current :→ $I_1 = K I_1'$



Approximate Voltage Drop in a Transformer :→

→ The approximate equivalent circuit of transformer referred to secondary.

→ No-load, secondary voltage is KV_1, when a load having a lagging powerfactor p.f $\cos\phi_2$ is applied.

→ The secondary carries a current I_2 and voltage drops occur in $(R_2 + K^2R_1)$ and $(x_2 + K^2x_1)$

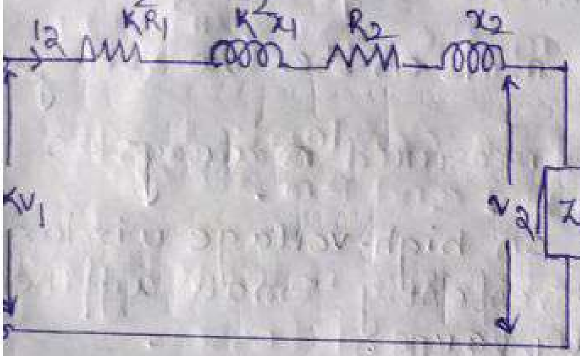
The secondary voltage falls from KV_1 to V_2

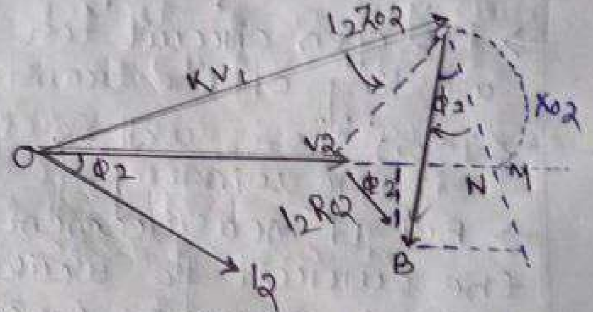
$$V_2 = KV_1 - I_2 (R_2 + K^2R_1) + j(x_2 + K^2x_1)]$$

$$= KV_1 - I_2 (R_{02} + jx_{02})$$

$$= KV_1 - I_2 Z_{02}$$

$= KV_1 + V_2 = I_2 Z_{02}$ (Drop in secondary voltage)





Approximate drop in secondary voltage.

$$= AN = AD + DN$$

$$= AD + BL$$

$$= I_2R_{02}\cos\phi_2 + I_2x_{02}\sin\phi_2$$

for a load having a leading p.f $\cos\phi_2$

Approximate voltage drop $= I_2R_{02}\cos\phi_2 - I_2x_{02}\sin\phi_2$

Voltage Regulation :→

The voltage Regulation of a transformer is the arithmetic difference between the no-load secondary voltage $({}_0V_2)$ and the secondary voltage V_2 on load expressed as percentage of no load voltage.

$$\%\text{age voltage regulation} = \frac{{}_0V_2 - V_2}{{}_0V_2} \times 100$$

${}_0V_2$ = No-load Secondary voltage $= KV_1$

V_2 = Secondary voltage on load.

$^{0}V_2 - V_2 = I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2$

+ve sign is for lagging p.f

−ve sign is for leading p.f

Transformer Tests :⟶

→ The circuit Constants, efficiency and voltage regulation of a transformer can be determined by two simple tests.

(i) open-circuit test or No-load test.

(ii) short-circuit test

Open-circuit or no load Test :⟶

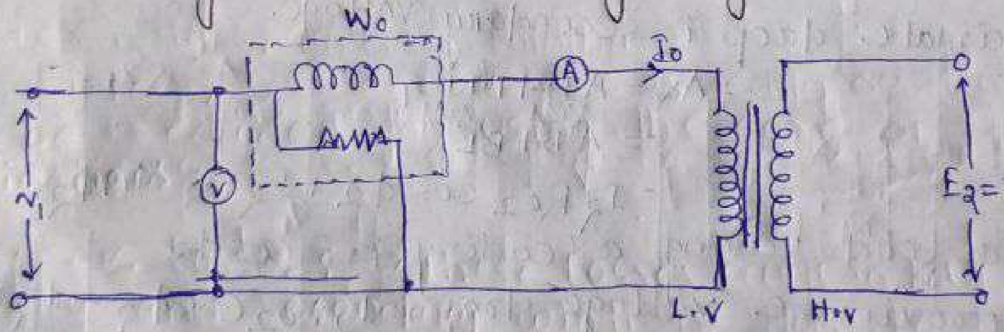
→ In this test, the rated voltage is applied to the primary while the secondary is left open-circuited.

→ The applied primary voltage V_1 is measured by the voltmeter, the no-load current I_0 by ammeter and no-load input power W_0

→ The open circuit test is always made on the low-voltage winding of the transformer.

→ Iron losses will be the same if measured ~~is always~~ on either winding.

→ But if measurement it made on high-voltage winding the current I_0 would be inconveniently small and the applied voltage inconveniently large.



→ wattmeter will record the iron losses and small Copper loss in the primary.

→ Cu losses in the primary under no load Condition are negligible as compared with iron losses.

→ Wattmeter reading practically gives the iron losses in the transformer.

→ It is reminded that iron losses are the same at all loads.

Iron losses, P_1 = wattmeter reading = W_0

No load current = Ammeter reading = I_0

Applied voltage = Voltmeter reading = V_1

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

No-load p.f $\cos\phi_0 = W_0 / V_1 I_0$ ~~$\cos\phi_0$~~

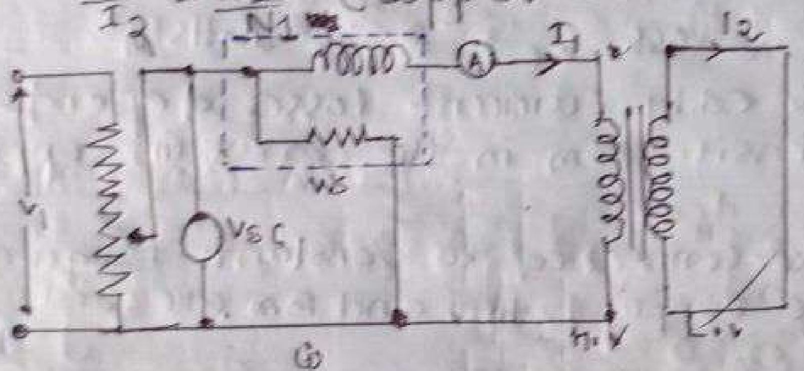
$I_w = I_0 \cos\phi_0$; $I_m = I_0 \sin\phi_0$

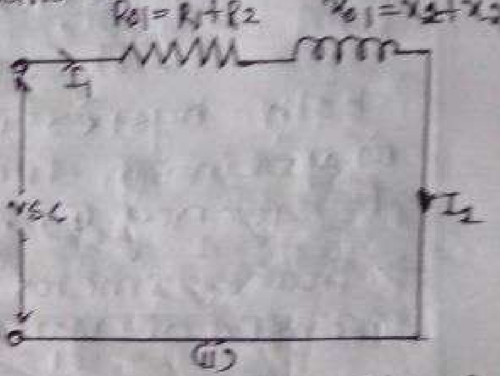
(ii) short-circuit or impedance test :→

→ The secondary in short-ckt by a thick conductor and variable low voltage is applied to the primary.

→ The low input voltage is gradually raised till at voltage V_{sc} full load current I_1 flows in the primary.

$\frac{I_1}{I_2} = \frac{N_2}{N_1}$ (Copper loss is the same as that on full load)





→ Short circuit test :→ Low voltage winding is always short circuited and measurements are make on the high voltage winding.

→ If measurements are make on the low-voltage winding the voltage will be inconveniently low.

full load cu loss. P_c = wattmeter reading = W_s

Applied voltage = voltmeter reading = V_{sc}

Primary current = Ammeter reading = I_1

$$P_c = I_1^2 R_1 + I_1^2 R_2' = I_1^2 R_{01}$$

$$R_{01} = P_c / I_1^2$$

Real impedance referred to primary $Z_{01} = V_{sc}/I_1$

Total leakage reactance referred to primary

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

short-ckt p.f $\cos\phi_s = P_c / V_{sc} I_1$

Short ckt test gives full-load cu loss, R_{01}, X_{01}

→ Short ckt test will give full-load cu loss

Losses In a Transformer :→

The power losses in a transformer are 2 types

1. Core or Iron losses
2. Copper losses.

These losses appear in the form of heat and Produce (i) an increase in temperature

(ii) a drop in efficiency.

(1) Core or Iron losses :(P_1) →

These consist of hysteresis and eddy current losses and occur in transformer core due to the alternating flux.

$$\text{Hysteresis loss} = K_h f B_m^{1.6} \text{ watts/m}^3$$

$$\text{Eddy Current loss} = K_e f^2 B_m^2 t^2 \text{ watts/m}^3$$

Both hysteresis & eddy current losses depend upon (i) maximum flux density B_m in the core & (ii) supply frequency (f).

→ Transformers are connected to constant frequency, constant voltage supply both f and B_m are constant.

$$\text{Iron or core losses}, P_1 = \text{Hysteresis loss} + \text{eddy current loss}$$
$$= \text{constant losses.}$$

→ hysteresis loss can be minimised by using steel of high silicon content where as eddy current loss can be reduced by using the core of thin laminations.

2. Copper losses :→

These losses occur in both the primary and secondary windings due to their ohmic resistance.

→ These can be determined by short-circuit test

$$\text{Total cu losses} = P_C = I_1^2 R_1 + I_2^2 R_2$$
$$= I_1^2 R_{01} \text{ or } I_2^2 R_{02} \quad \text{(variable losses)}$$

→ It is clear that copper losses very as the sq of load current.

Total losses in a transformer = $p_i + p_c$
= constant losses + variable losses

→ Transformer, copper losses account for about 90% of the total losses.

Efficiency of a Transformer :→

→ The efficiency of a transformer is defind as the ratio of output power to input power (watt or kW)

$$\text{Efficiency} = \frac{\text{o/p power}}{\text{i/p power}}$$

→ Efficiency can be determined by directly loading the transformer and measuring input & output power.

→ method :- (i) Since efficiency of a transformer is very high, even 1% error in each wattmeter may give ridiculous results.

→ Since the test is performed with transformer on load, considerable amount of power is wasted for large transformer. → The cost of power alone would be considerable

→ It is generally difficult to have a device that is capable of absorbing all of the output power.

→ The test gives no information about the proportion of various losses.

→ open ckt & short ckt tests are carried out to find the efficiency.

$$\text{Efficiency} = \frac{\text{Output}}{\text{input}} = \frac{\text{output}}{\text{Output} + \text{Losses}}$$

→ Efficiency from Transformer test :→

F.L Iron loss = P_i (open-ckt)
F.L Cu loss = P_c (Short ckt)
Total F.L losses = $P_i + P_c$

→ find full load efficiency of the transformer at any p.f without actually loading the transformer

$$\text{F.L efficiency } \eta_{FL} = \frac{\text{full-load VA} \times \text{p.f}}{(\text{full-load VA} \times \text{p.f}) + P_i + P_c}$$

$$\eta_x = \frac{(x \times \text{full load VA}) \times \text{p.f}}{(x \times \text{full Load VA} \times \text{pf}) + P_i + x^2 P_c}$$

Condition for maximum efficiency :→

output power = $V_2 I_2 \cos\phi_2$

If R_{o2} is the total resistance of the transformer refer to secondary,

Total Cu loss, $(P_c) = I_2^2 R_{o2}$

Total loss = $P_i + P_c$

∴ Transformer efficiency $\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2}$

$$\boxed{= \frac{V_2 I_2 \cos\phi_2}{V_2 \cos\phi_2 + P_i / I_2 + I_2 R_{o2}}}$$

→ for normal transformer V_2 is constant.

→ for a load of given P.f efficiency depends upon load current.

→

$$\frac{d\eta}{dI_2} = 0$$

$$\text{or } \frac{d}{dI_2}\left(V_2 \cos\phi_2 + P_i / I_2 + I_2 R_{o2}\right) = 0$$

$$\text{or } 0 - \frac{P_i}{I_2^2} + R_{o2} = 0$$

$$\boxed{P_i = I_2^2 R_{o2}}$$

Iron Losses = copper losses

→ Hence efficiency of transformer will be maxim when copper losses are equal to constant or Iron loss.

$$\boxed{I_2 = \sqrt{\frac{P_i}{R_{o2}}}}$$

→ In a transformer, iron losses are constant where as copper losses are variable.

→ load current should be that total Cu losses equal to iron losses.

output KVA Corresponding to maximum efficiency :-

P_c = Copper losses a full-Load KVA

P_i = Iron losses

x = Friction of full-load KVA at which efficiency is Maximum

$= x^2 p_c$ (→ Total cu loss)

$$x^2 p_c = p_i$$

$$x = \sqrt{\frac{p_i}{p_c}} = \sqrt{\frac{\text{Ironloss}}{\text{f.L Cu loss}}}$$

∴ output KVA corresponding to maximum efficiency

$$= x \times \text{full Load KVA}$$

$$\boxed{= \text{full load KVA} \times \sqrt{\frac{\text{Ironloss}}{\text{f.L Cu loss}}}}$$

All day (Or energy) efficiency :→

$$\text{commercial efficiency} = \frac{\text{outputpower}}{\text{inputpower}}$$

→ The Performance of such transformers is judged on the basis of energy consumption during the whole day. This is known as all-day or energy efficiency.

→ The ratio of output in kwh to the input in kwh of a transformer over a 24-hour period is known as all-day efficiency.

$$\eta_{\text{all-day}} = \frac{\text{Kwhoutput in 24 hours}}{\text{Kwh input in 24 hours}}.$$

→ All day efficieny is of special importance for those transformers whose primaries are never ope-cut but the secondaries carry little or no load much of the time during the day.

Construction of a Transformer :→

→ (i) The core is made of silicon steel which has low hysteresis Loss and high permeability.

→ further core is laminated in order to reduce eddy current Loss & Iron Losses and no-load current.

(ii) Instead a placing primary on one limb and seconda
On the other.
→ This ensures tight coupling between the two windings. consequently leakage flux is Considerably reduced.

(iii) The winding resistance R_1 and R_2 are minimised to reduce i^2R loss and resulting rise in temp and to ensure high efficiency.

Cooling of Transformers :→

→ Heat is produce in a transformer by the iron loss in the Core and I^2R loss in the windings.

(i) Small transformers, natural air Cooling is employed i.e the heat produced is carried away by the surrou air.

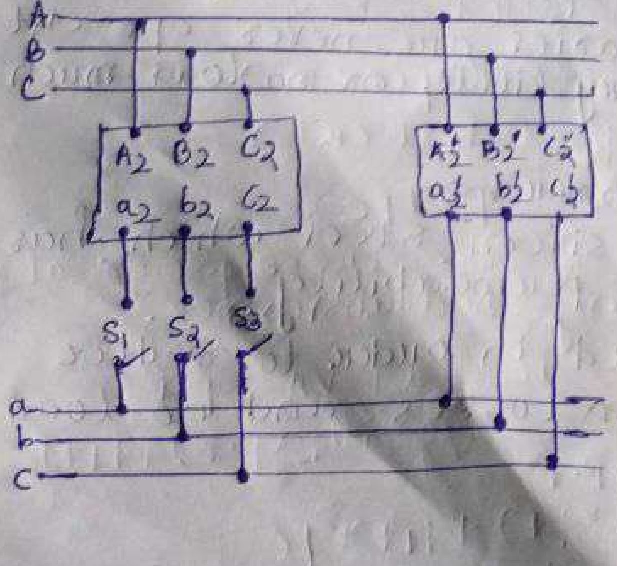
(ii) Medium size power or distribution transformers are generally cooled by housing them in tank filled with

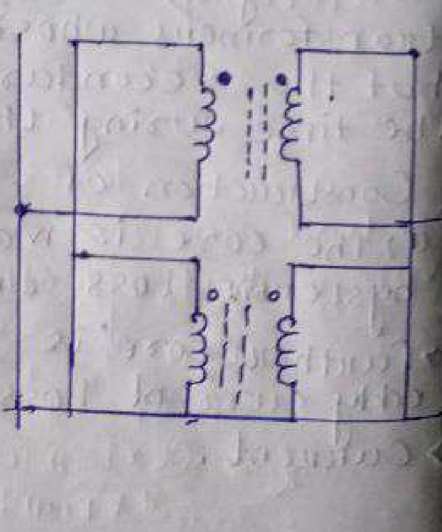
*The oil serves a double purpose, carrying the heat from the windings to the surface of the tank and insulating the primary from the secondary.

(iii) For Large transformers, external radiators are added to increase the Cooling surface of the oil filled tank.

* The air circulates around the transformer and moves through the radiators where the heat is relased to surrounding air.

What is parallel operation of Transformers ?





Why parallel operation of transformer is required?

→ It is economical to installe numbers of smaller rated transformers in parallel than installing a bigger rated electrical power transformers.

Advantages :→

1. To maximize electrical power system efficiency. generally electrical power transformer gives the maximum efficiency at full load.

→ If we run numbers of transformers in parallel, we can switch on only those transformers which will give the total demand by running nearer to its full rating for that time.

→ When load increases. we can switch none by one other transformer connected in parallel to fulfill the total demand.

→ In this way we can run the system with maximum efficiency.

2. To maximize electrical power system availability

→ If numbers of transformers run in parallel, we can shutdown any one of them for maintenance purpose.

→ Other parallel transformers in system will serve the load without total interuption of power.

3. To maximize power system reliability

→ If any one of the transformers run in parallel, is tripped due to fault of other parallel transformers in the system will share the load, hence power supply may not be interrupted if the shared loads donot make other transformers over loaded.

4. To maximize electrical power system flexibility:-

→ There is always a chance of increasing or decreasing future demand of power system.

→ It is predicted that power demand will be increased in future.

→ It is not economical from business point of view to install a bigger rated single transformer by forecasting the increased future demand as it is unnecessary investment of money.

→ Again if future demand is decreased transformers running in parallel can be removed from system to balance the capital investment and its return.

Conditions for parallel operation of Transformers :→

→ When two or more transformers run in parallel, they must satisfy the following Conditions for satisfactory performance.

→ These are the conditions for parallel operation of transformers.

1. Same voltage ratio of transformer.
2. Same percentage impedance
3. Same polarity
4. Same phase sequence.

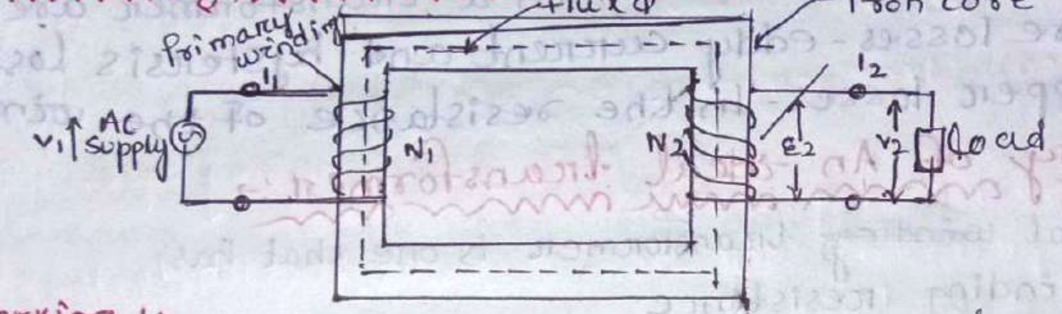
(CHAPTER-3) (Single phase Transformer)

Transformer :→ The transformer is a static devich which transfor electric power from one circuit to another circuit without any change in frequency.

Transformer are performed the following imp tasks :→

* To step up the voltage for transmission and other Purpose.
* To step down the voltage for distribution puropse in Rectifiers and other electronic equipment.

Working principle of single phase Transformer :-



Working :→

When an alternating voltage V_1 is applied the primary an alternating flux ϕ is set up in the core.

→ This alternating flux links both the windings and induces emf s E_1 & E_2 in then according to faraday's laws of electromagnetic induction

→ The emf E_1 is termed as primary e.m.f and e.m.f E_2 is termed as secondary e.m.f.

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

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

$$\frac{E_2}{E_1} = \frac{+N_2 \cancel{d\phi/dt}}{+N_1 \cancel{d\phi/dt}} = \frac{N_2}{N_1}$$

→ that magnitudes of E_2 and E_1 depends upon the number of turns of the secondary and primary respectively.

→ A step-down transformer, If load is Connected across the secondary winding, the secondary emf E_2 will cause a current I_2 to flow through the load.

→ A transformer enables us to transfer ac power from one circuit to another with a change in voltage level.

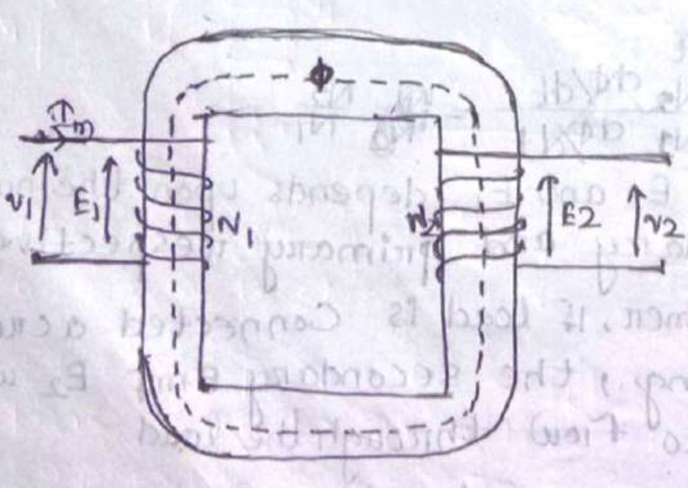
(i) The transformer action is based on the laws of electromagnetic induction.
(ii) There is no electrical connection between the primary and secondary.
(iii) The a.c power is transferred from primary to secondary through magnetic flux.
(iv) There is no change in frequency i.e. output power has the same frequency as the inputpower.
(v) The losses that occur in a transformer are.
a) core losses - eddy current and hystersis losses.
b) copper losses - In the resistance of the winding.

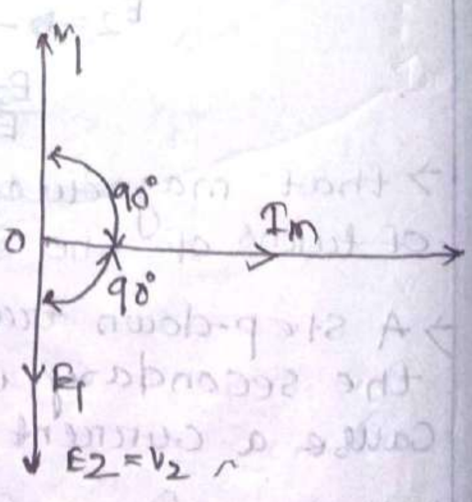
Theory of An ideal transformer :→

An ideal ~~winding~~ transformer is one that has
1. No winding resistance
2. No leakage flux (i.e the same flux links both the windings)
3. No iron losses (i.e eddy current and hystersis losses) in the core.

→ Pratical transformers have properties that approach very close to an ideal transformer.

→ Consider, the ideal transformer on no load i.e secondary is open-circuited.





- When the alternating voltage 'v_1' is applied to the primary. It draws a small magnetic current I_m which lags behind the applied voltage by 90°.
- The alternating current I_m produces an alternating flux ϕ which is proportional to and in phase with it.
- The alternating flux ϕ links both the windings and induces e.m.f E_1 in the primary and e.m.f E_2 in the secondary.
- Both E_1 and E_2 lag behind flux ϕ by 90°
- In a pure inductive ckt, current lags behind the voltage by 90°.
- there are no iron losses, flux ϕ is in phase with I_m.

E.m.f Equation of a Transformer

Consider than an alternating voltage v_1 of frequency f is applied.

(i) The sinusoidal flux ϕ produced by the primary can be represented as

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

The instantaneous e.m.f e_1 induced in the primary.

$$E_{m1} = 2\pi f N_1 \phi_m$$

The r.m.s value of the primary e.m.f is

$$E_1 = \frac{E_{m1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_m}{\sqrt{2}}$$

$$E_1 = 4.44 f N_1 \phi_m$$

$$E_2 = 4.44 f N_2 \phi m$$

$E_1 = V_1$ and $E_2 = V_2$ (an ideal transformer)

Voltage Transformation Ratio (K)

(i) Induced EMF $= \frac{E_2}{E_1} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K$

(ii) the constant K is called voltage transformation ratio, $K=5$ (i.e $N_2/N_1=5$) then $E_2 = 5E_1$

For an ideal transformer:-

(i) $E_1 = V_1$ and $E_2 = V_2$, there is no voltage drop in the windings.

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

(ii) There are no losses,

therefore, volt-amperes input to the primary are equal to the output volt-amperes i.e.

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

$$\frac{I_2}{I_1} = \frac{V_1}{V_2} = \frac{1}{K}$$

Hence, currents are in the inverse ratio of voltage transformation ratio.

Pratical Transformer on No load :→

→ Transformer on no load i.e. secondary open circuit as shown in fig.

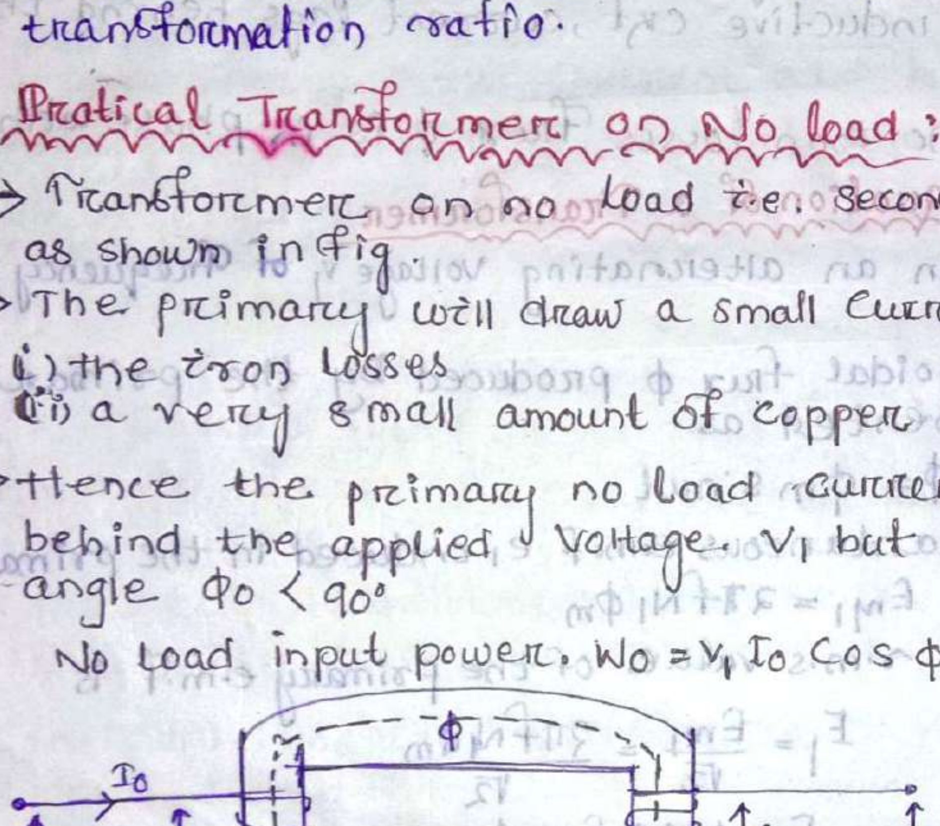
→ The primary will draw a small current I_0 to suppy

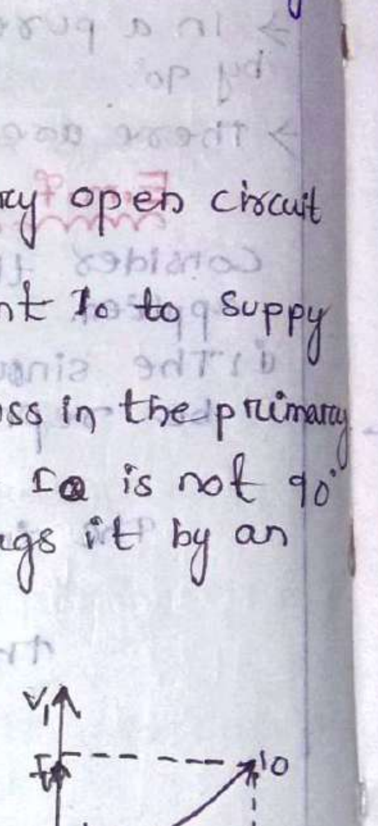
(i) the iron losses

(ii) a very small amount of copper loss in the primary

→ Hence the primary no load current I_0 is not 90° behind the applied voltage. V_1 but lags it by an angle $\phi_0 < 90°$

No load input power, $W_0 = V_1 I_0 \cos \phi_0$





The no-load primary current I_0 can be resolved into two rectangular components viz.

(i) The component I_w in phase with the applied voltage V_1. This is known as active or working or iron loss component and supplies the iron loss and a very small primary copperloss

$$I_w - I_0 \cos \phi_0$$

(ii) The Component I_m lagging behind V_1 by 90° and is known as magnetising Component. It is this Componet which produces the Mutual flux ϕ in the Core.

$$I_m = I_0 \sin\phi_0$$

I_a is phasor sum of I_m and I_w

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

No load p.f $\cos\phi_0 = I_w / I_0$

No load input power :→ W_0 = Iron loss

Practical Transformer on Load

Two cases :→ (i) When such a transformer is assumed to have no winding resistance and leakage flux

(ii) When the transformer has winding resistance and leakage flux.

(i) No winding resistance and leakage flux.

→ Practical transformer with the assumption that resistances and leakage reactances of the winding are negligible.

Assumption, $V_2 = E_2$ and $V_1 = E_1$

Letus take the usual case of inductive load which causes the secondary current I_2 to leg the secondary voltage V_2 by ϕ_2

→ The total primary current I_1 must meet two requirement

(a) It must supply the noload current I_0 to meet the iron losses in the transformer and to provide flux inthe Core.

(b) It must supply a current I_2' in Counteract the demagnetizing effect of secondary current I_2.

The magnitude of I_2 will be such that

$$N_1 I_2 = N_2 I_2$$

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

CHAPTER-2

(D.C. MOTORS) Dt :- 13-05-2021

Deffination

→ A DC motor is an electrical machine that converts electrical energy into mechanical energy.

→ Special applications such as in steel mills, mines and electric trains it is advantages. to Convert altenating current into Direct current in orde to use DC Motor.

→ The reasons is that speed/torque characteristics of dc motors are much more superior to that ac motor.

→ D.c Motors are three types :-

1. series-wound D.c Motor
2. shunt-wound D.c Motor.
3. Compound-wound D.c Motor.

Working Principle of D.c Motor

→ operation of Dc Motor based on the principle when a current carrying conductor is placed in a Magnetic field. the Conductor experience a Mechanical force.

→ Direction of the D.c Moter working in Fleming's left hand rule.

Feming's left hand rule:- When a current-carrying Conductor is placed in an magnetic field, the conductor experience a force perpendicular to both the field. and to the direction of the current flow.

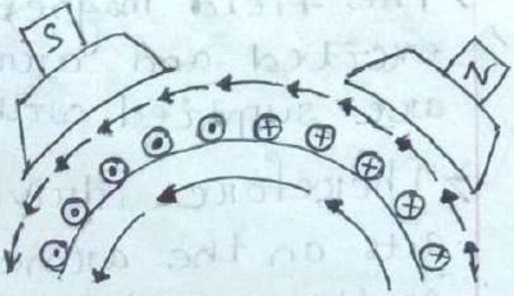
→ If the fore finger indicates the direction of the Magnetic field.

→ The Middle finger indicates the direction of the current and the thumb represents the direction of the motion.

→ When the terminals of the motor are connected to an external source of dc supply.

1. The field magnets are excited developing alternate N and S pole.

2. The armature conductors carry currents. All conductors under N-pole carry current in one direction while all conductors under S-pole carry currents in the opposite direction.



→ Suppose the conductors under N-pole carry currents into the plane of the paper and those under S-pole carry currents out of the plane of the paper.

→ Since each armature conductor is carrying current and is placed in the magnetic field, a mechanical force acts on it.

→ That force on each conductor is tending to rotate the armature anticlockwise direction.

→ All these forces add together to produce a torque which sets the armature rotating.

→ When the conductor moves from one side of a brush to the other, the current in that conductor is reversed and at the same time it comes the influence of next pole which is opposite polarity.

→ Consequently, the direction of force on the conductor remains the same.

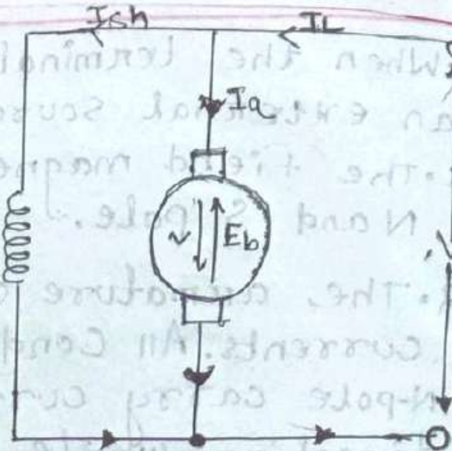
Back or counter E.M.F

→ The armature conductors move through the magnetic field and hence e.m.f is induced in them as in a generator. The induced emf act as a opposite direction to the applied voltage(V) and is knowns. as back or counter e.m.f. (E_b).

→ The back e.m.f $\boxed{E_b = \frac{P\phi Z N}{60A}}$

P - Number of poles., ϕ - flux per pole

N - speed , Z - Total number of conductor in the armature



→ Consider a shunt wound moter. when dc voltage v is applied across the motor terminals.

→ The field magnets are excited and armature conductors are supplied with current.

→ Therefore, driving torque acts on the armature which begins to rotate. As the armature rotates, back emf E_b is induced which opposes the applied voltage V.

→ The applied voltage V ~~is~~ has to force current through the armature against the back emf.

→ The electric work done in overcoming and causing the current to flow again E_b is convert in to mechanical energy developed in a d.c motor.

→ Therefore, that energy conversion in a d.c motor is only possible due to the production of back emf(E_b)

Net voltage across armature ckt $\boxed{= V - E_b}$

Ra is the armature circuit resistance,

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

where, I_a - Armature current

V = applied voltage.

E_b - back emf

R_a - Resistance of Armature

Since, V and Ra are usually fixed.

E_b - will determine the current drawn by the motor.

→ If the speed of the motor is high, the back emf $E_b = (P\phi ZN/60A)$ is Large.

Significance of Back emf

The presence of back e.m.f makes the dc Motor a Self-regulating machine.

→ It Makes the Motor to draw as armature current as is devlop the torque required by the load.

Armature current $\boxed{I_a = \frac{V - E_b}{R_a}}$

①→ When the motor is running at no-load, small torque is required by the motor to overcome friction and windage losses. Therefore, a small current is drawn by the motor armature and the back emf is almost equal to the supply voltage.

②→ If the motor is suddenly loaded, the load torque becomes greater than the armature torque and the motor starts to slow down.

③→ As Motor speed decreases, back emf decreases and therefore, armature current starts increasing.

④→ Armature torque increases and at some point it becomes equal to the load torque.

⑤. At that moment, motor stops slowing down and keeps running at this new speed.

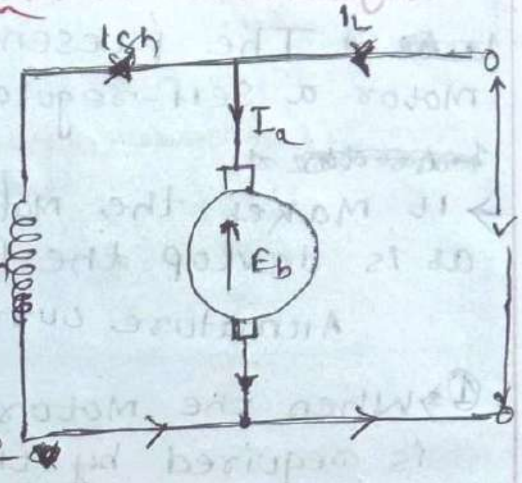
⑥. If the load on the motor is decreased, the driving torque is momentarily in excess of the requirement so that armature is accelerated.

⑦. The armature speed increases; the back emf E_b also increases and causes the armature current to decrease.

⑧. The Motor will stop accelerating will start rotating uniformly at this new slightly increased speed.

Therefore the back emf of dc Motor regulates the flow of armature current. i.e. automatically change the armature current to need the load requirement

Voltage Equation of D.C Motor.



Let in a dc. motor

V = applied voltage

E_b – Back e.m.f

R_a – Armature resistance

I_a – Armature current

since back emf (E_b) acts in opposition to the applied voltage (V)

→ the net voltage across the armature circuit is $V - E_B$.

∴ Armature current $(I_a) = \frac{V - E_B}{R_a}$

voltage equation of DC Motor $\boxed{V = E_B + I_a R_a}$

Power Equation of DC Motor

→ Multiplied current in voltage equation.

$$V = E_b + I_a R_a \qquad (\because P = VI)$$

$$\boxed{\Rightarrow VI_a = E_b I_a + I_a^2 R_a}$$

this is power equation of DC Motor.

where VI_a = electric power supplied to armature (armature input)

$E_b I_a$ = power developed by armature (armature output)

$I_a^2 R_a$ = electric power wasted in armature (armature cu loss)

Condition ~~o~~For Maximum Power

The Mechanical power developed by the motor is

$$\boxed{P_m = E_b I_a}$$

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

Since V and Ra fixed,

power developed by the motor depends upon armature current. for maximum power dP_m/dI_a should be zero

i.e, $\frac{dP_m}{dI_a} = 0$

$\Rightarrow V - 2I_aR_a = 0$

$\Rightarrow V = 2I_aR_a \Rightarrow \boxed{I_aR_a = \frac{V}{2}}$

then, voltage eq^n of DC motor = $V = E_b + I_aR_a$

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

~~[illegible]~~ $\boxed{E_b = V/2}$

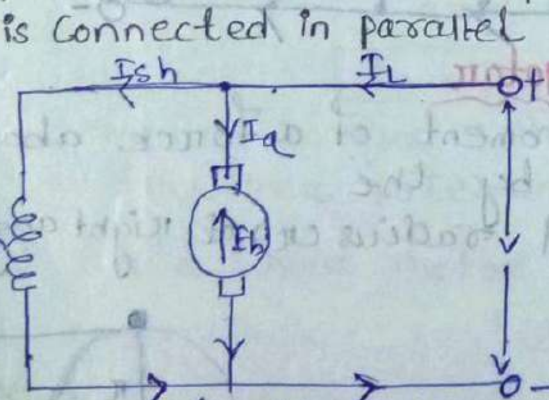
Hence mechanical power developed by the motor is maximum when back e.m.f is equal to half the applied voltage.

Types of D.C Motor

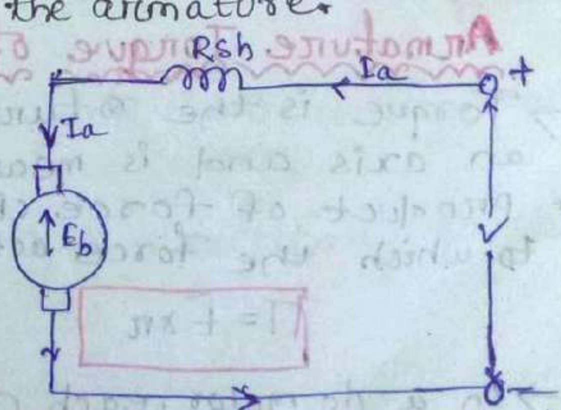
These are three types ~~to~~

(i) Shunt-wound Motor

→ ~~[illegible]~~ Shunt-wound motor in which the field winding is connected in parallel with the armature.



(Shunt-wound Motor)



(Series wound Motor)

Series-Wound Motor:-

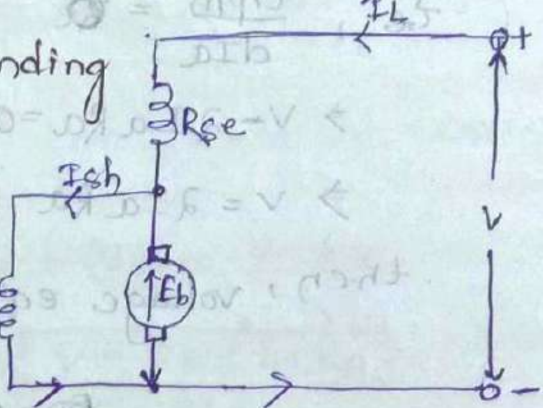
→ series wound motor in which the field winding is connected in series with the armature.

(iii) Compound Wound Motor

→ Compound wound Moter has two field windings.
1. one connected parallel with armature
2. other connected series with armature

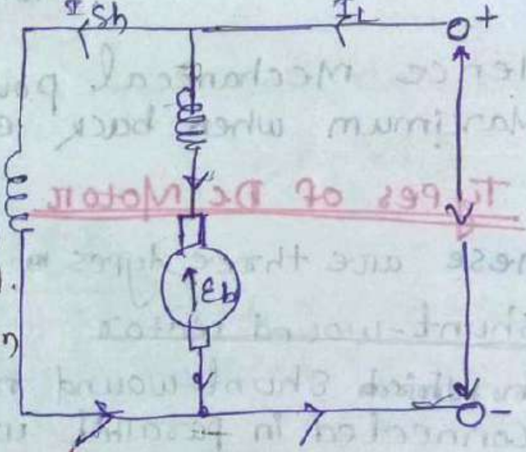
Compound wond motor are 2 types connection.
1. Short-shunt Connection.
2. Long-shunt Connection.

Short-shunt Connection



→ When the shunt field winding is directly connected across the armature terminals.. is called Short-shunt Connection.

Long-shunt Connection

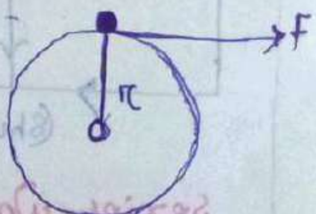


→ When the sunt field winding is so connected that it shunts the series combination of armature and series field. is called long-shunt Connection

Armature Torque of DC motor

→ Torque is the turning moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts i.e

$$\boxed{T = F \times r}$$



→ In a dc Motor, each Conductor is acted by a circumferential force (F) at a distance r, the radious of the armature.

→ The sum of the torques due to all armature conductors is known as gross or armatore torque (T_a)

let in a d.c Motor. r - average radius of armature.

l - effective length of each conductor

Z - Total Number of armature Conductors

A = Number of parallel path.

i - Current in each conductor = I_a/A

B = average flux density in wb/m^2

ϕ - flux per pole wb

P - Number of poles.

Force on each conductor, $F = Bil$ newtons.

Torque due to one conductor = $F \times r$ newton metre

Total armature torque, $T_a = ZFr$ newton-metre.

$$\boxed{= ZBilr}$$

Now $i = I_a/A$, $B = \phi/a$ where a is the x-sectional area of flux path/pole at radius r.

$$a = \frac{2\pi r l}{P}$$

$$T_a = Z \times \left(\frac{\phi}{a}\right) \times \left(I_a/A\right) \times l \times r$$

$$= Z \times \frac{\phi}{\frac{2\pi \cancel{r}\cancel{l}}{P}} \times \frac{I_a}{A} \times \cancel{l} \times \cancel{r}$$

$$= \frac{Z\phi I_a P}{2\pi A} \qquad \boxed{T_a = 0.159\, Z\phi\, I_a\, (P/A)} \text{ Newton-met}$$

Since Z, P and A are fixed for a given machine

$$\boxed{T_a \propto \phi I_a}$$

Hence torque in a d.c motor is directly proportional to flux per pole and armature current.

(i) For a shunt motor. flux ϕ is practically constant

$$\boxed{T_a \propto I_a}$$

(ii) For a series motor, flux ϕ is directly proportional to armature current I_a provided magnetic saturation does not take place.

$$\boxed{T_a \propto I_a^2}$$

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

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

for eq (i), we get the expression of Ta as

$$T_a = 0.159 \times \left(\frac{60 \times E_b}{N}\right) \times I_a$$

$$\boxed{T_a = 9.55 \times \frac{E_b I_a}{N} \text{ N-m}}$$

Shaft Torque :

→ The Torque which is available at the motor shaft for doing useful work is known as shaft torque.

Shaft torque T_{sh} is somewhat less than the total armature torque T_a. The difference $T_a - T_{sh}$ is known as lost torque.

$$T_{sh} = 9.55 \times \frac{\text{output}}{N} \text{ n-m}$$

$$\text{Lost torque} = 9.55 \times \frac{\text{Iron and friction loss}}{N}$$

Sppeed of A D.C Motor

$$E_b = V - I_a R_a \text{ —— (i)}$$

$$E_b = P\phi Z N / 60A \text{ —— (ii)}$$

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

$$N = \frac{(V - I_a R_a)}{\phi} \cdot \frac{60A}{PZ}$$

$$N = K \frac{(V - I_a R_a)}{\phi} \quad \text{where } K = \frac{60A}{PZ}$$

$$V - I_a R_a = E_b$$

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

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

Therefore in a d.c motor speed is directly proportional to back emf E_b and inversely proportional to flux per pole ϕ.

Speed Relations

If a d.c motor has initial values of speed, flux per pole and back emf. ~~Eb~~ as N_1, Φ_1 and E_1

$$N_1 \propto \frac{E_{b1}}{\phi_1} \quad \text{and} \quad N_2 \propto \frac{E_{b2}}{\Phi_2}$$

$$\frac{N_1}{N_2} = \frac{E_{b1}}{E_{b2}} \times \frac{\Phi_2}{\Phi_1}$$

(i) For a shunt motor flux practically remains Constant so that $\Phi_1 = \Phi_2$

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

(ii) For a series motor $\phi \propto I_a$ prior to saturation

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

I_{a1} = Initial armature current

I_{a2} = final armature current

Speed Regulation

→ The speed regulation of a motor is the change in speed from full-load to no-load

$$\% \text{ speed regulation} = \boxed{\frac{\text{N-L speed} - \text{F.L speed}}{\text{F.L speed}}} \times 100$$

$$= \frac{N_0 - N}{N} \times 100$$

N_0 = No load speed

N = full load speed.

Losses in a D.C motor

The losses occurring a d.c motor are the same as in d.c generator.

(i) Copper losses
(ii) Mechanical losses
(iii) iron losses.

As in a generator these losses cause.

1. an increase of temperature.
2. Reduction in efficiency of the D.c Motor.

Efficiency of D.c Motor

A dc generator, the efficiency of a d.c motor is the ratio of output power to the input power:-

$$\boxed{\text{Efficieny, } \eta = \frac{\text{Output}}{\text{Input}} \times 100}$$

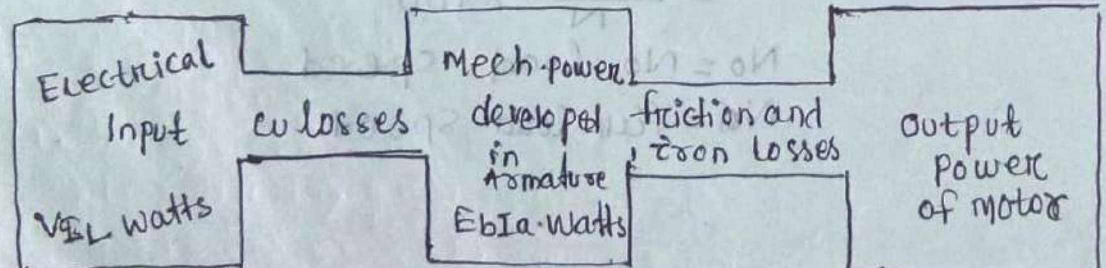
$$= \frac{\text{Output}}{\text{Output+losses}} \times 100$$

for a generator, the efficiency of a d.c Motor will be Maximum when:-

variable losses = Constant losses.

Power stages

A-B = Copper losses
B-C = Iron and friction losses



Overall efficieny $\eta_c = C/A$
Electrical efficiency $\eta_e = B/A$
Mechanical efficiency $\eta_m = C/B$

D.C Motor Characteristics

> The performance of a d.c motor can be judged from its characteristic curves known as motor characteristics.

D.C Motor Characteristics is three types :→

1. Torque and Armature Current characteristic →

> The curve between armature Torque & armature Current Ia of a dc Motor. It is also known as electrical characteristic of the motor.

2. Speed and armature current characteristic :>

> If the curve between speed (N) and armature Current Ia of a d.c motor.

> It is very important characteristic.

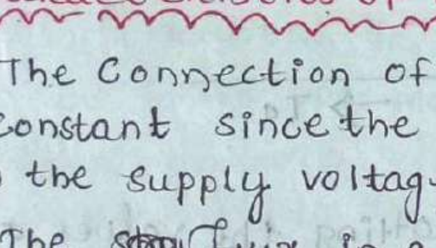
3. Speed and torque characteristic :>

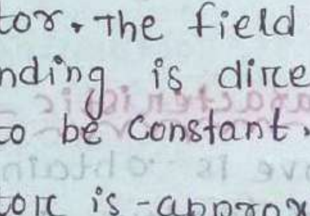
> It is the curve between Speed (N) and armature torque Ta of a d.c motor. It is also known as mechanical characteristic.

Characteristics of D.C shunt Motors

> The Connection of a d.c Motor. The field current Ish is constant since the field winding is directly Connected to the supply voltage V. is to be constant.

> The ~~stoo~~ flux in a shunt motor is approximately Constant.





(i) T_a/I_a Characteristic :- $T_a \propto \phi I_a$

> Motor ~~foo~~ is oprating from a constant supply voltage. flux ϕ is constant.

> T_a/I_a characterstic is a straight line passing through the origin.

> Shaft torque is less than T_a (as dotted line)

→ Shunt Motor should not be started on heavy load.

→ The curve that a very large current is required to start a heavy load.

(ii) N/Ia Characteristic :→

The speed N of a Motor given

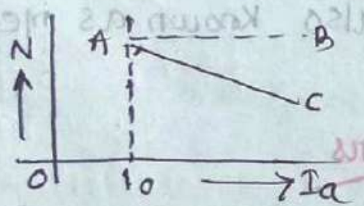
$$N \propto \frac{E_b}{\phi}$$

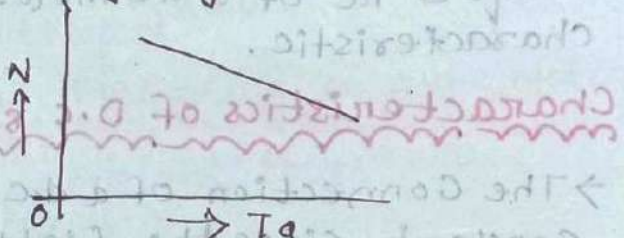
→ The flux (φ) and back emf (E_b) in a shunt Motor are almost constant. under normal condition.

→ Speed of a shunt motor will remain constant as the armature current varies.

→ When load is increase, E_b & φ decrease due to the armature resistance drop and armature reaction respectively.

→ E_b decreases slightly more than φ so that the speed of the motor decreases slightly with load.





(iii) N/Ta Characteristic →

→ This curve is obtained by plotting the values of N and Ta for various armature currents.

→ speed falls somewhat as the load torque increases.

Conclusion →

1. There is slight change in the speed of a shunt motor from no load to full load.

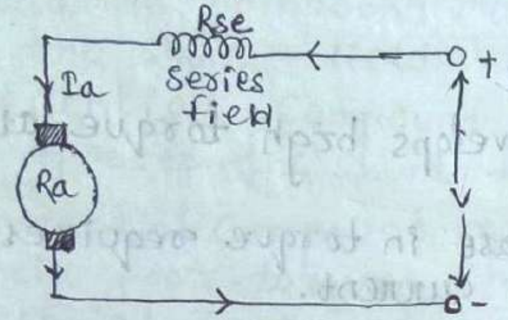
→ It is a essentically Constant-speed motor.

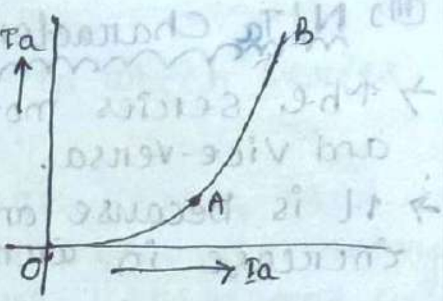
2→ The starting torque is not high because $T_a \propto I_a$

Characteristics of D.C Series Motors. :→

→ The Connection of a d.c series motor. if the mechanical load on the motor increase, the armature current also increases.

→ The flux in a series motor increase with the increase in armature Current and vice-versa.





(i) Ta / Ia characteristic :→

We know $T_a \propto \phi I_a$

magnetic saturation - $\phi \propto I_a$ so that $T_a \propto I_a^2$

After magnetic saturation ϕ is Constant so that $T_a \propto I_a$

→ Thus upto magnetic saturation, the armature torque is directly proportional to the square of armature current. Ia is doubled, Ta is almost quadrupled.

→ Ta / Ia Curve upto magnetic saturation is a parabola.

→ After magnetic saturation, torque is directly Proportional to the armature current.

→ Therfore Ta/Ia Curve after magnetic saturation is a straight line.

→ The starting Torque of a dc series motor will be very high as compared to a shunt motor.

(ii) N/Ia Characteristic →

$$\text{speed } N \propto \frac{E_b}{\phi} \cdot \text{where } E_b = V - I_a(R_a + R_{sh})$$

→ when armature current increases, the back emf (E_b) Decreases. due to $I_a(R_a + R_{se})$ drop while flux ϕ increases

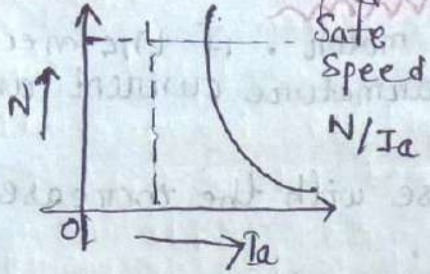
→ $N \propto \frac{1}{\phi}$

$\propto \frac{1}{I_a}$ upto magnetic saturation.

→ upto magnetic saturation, the N / Ia curve follows the hyperbolic path.

→ After saturation, the flux becomes Constant and so does the

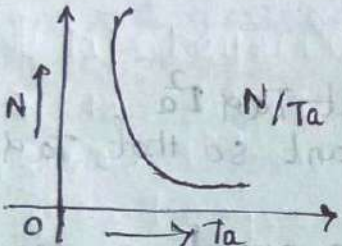
Speed.



(iii) N/Ta Characteristic →

→ The series motor develops high torque at low speed and vice-versa.

→ It is because an increase in torque requires an increase in armature current.



Conclusion →

(i) It has a high starting torque because initially $T_a \propto T_a^2$.

(ii) It is variable speed motor.

(iii) Thus if the load decreases, its speed is automatically raised and vice-versa.

(iv) At no load, the armature current is very small and so is the flux.

(v) The speed rises to an excessive high value.

(vi) This is dangerous for the machine which may be destroyed due to centrifugal forces.

(vii) A series motor should never be started on no load.

→ However, to start a series motor, mechanical load is first put and then the motor is started.

Compound Motors :→

⇒ A compound motor has both series field and shunt field.

⇒ The shunt field is always stronger than the series field.

⇒ compound are two types :-

(i) Cumulative-compound motors in which series field aids the shunt field.

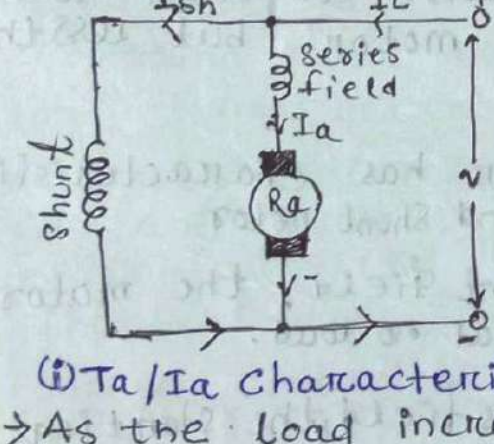
(ii) Differential compound motors in which series field opposes the shunt field.

→ Differential Compound motors are rarely used due to their poor torque characteristics at heavy.

→ Differential-compound motors are rarely ~~and~~ used to their poor torque characteristics at heavy loads.

Characteristics of cumulative compound motors :→

→ Each pole carries a series as well as shunt field winding

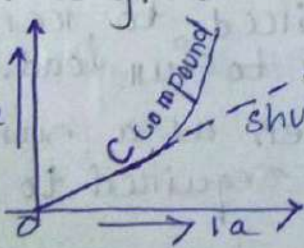


(i) Ta / Ia Characteristic :-

→ As the load increase, the series field increases but shunt field strength remains constant.

⇒ Total flux increased and hence the armature torque.

⇒ It may be noted that torque of a cumulative compound motor is greater than that of shunt motor for a given armature current due to series field.

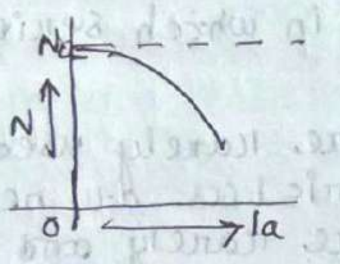


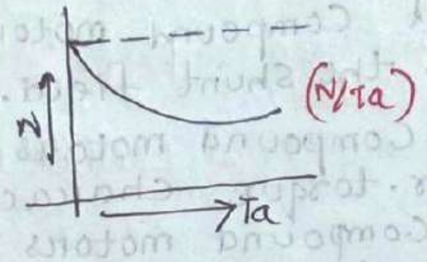
(ii) N/Ia Characteristic :→

→ The load increases, the flux per pole also increase

→ The speed of the motor falls as the load increases

→ It may be noted that torque of Cumulative-compound motor is greater than that of Shunt motor for a given armature current due to series.





(iii) N/Ta Characteristic :→

→ N/Ta characteristic of a Cumulative Compound Motor.

→ The torque of Cumulative compound motor is more than that of a shunt motor but less than that of a Series Motor.

Conclusion →
A cummulative compound motor has characteristics intermediate between series and Shunt motor.

(i) Due to the presence of shunt field, the motor is Prevented from running away at no load.

(ii) Due to the presence of Series field, the starting torque is increased.

→ Application of D.C Motor

Shunt Motor ⇒ ~~App~~ characteristics of a shunt motor reveal that it is an approximately constant speed Motor.

→ used :→ (i) Where the speed is required to remain almost constant from no load to full load.

(ii) Where the load has to be driven at a number of speeds and any one of which is required to remain nearly Constant.

Industrial use :→ Laths, drills, boring mills, shapers, Spinning and Weaving Machine.

(ii) Series Motor :→

→ It is variable speed motor.

→ Speed is low at high torque and vice-versa.

→ However at light or no load, the motor tends to attain dangerously high speed.

→ The Motor has a high starting torque.

Used →

(i) Where large starting torque is required in elevators and electric traction.

(ii) Where the load is subjected to heavy fluctuations. and the speed is automatically required to reduce at high torques and vice-versa.

Industrial use :→

Electric traction, cranes, elevators, air compressors, vacuum cleaners, hair dryer, sewing machines.

(iii) Compound Motor :→

→ Compound motor are rarely used because of their poor torque characteristics.

→ Cumulative-Compound motors are used where a fairly constant speed is required with irregular loads or suddenly applied heavy loads.

Industrial use :→ presses, shears, reciprocating machines.

Speed control of D.C Motors :→

The speed of a d.c motor is given by.

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

$$N = K \frac{(V - I_a R)}{\phi} \text{ r.p.m}$$

$R = R_a$ -- (for shunt motor)

$R_a + R_{se}$ (for series motor)

Two main methods of controlling the speed of a d.c motor ~~is~~.

(1) By varying the flux per pole (ϕ). This is known as Flux Control Method.

(ii) By varying the resistance in the armature circuit. This is known as armature control method.

Speed Control of D.C Shunt Motors :→

→ The speed of a shunt motor can be changed by

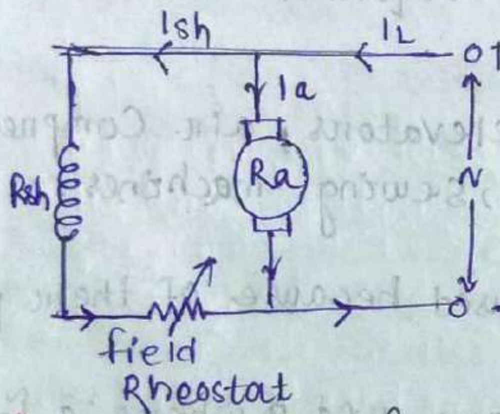
(i) flux control method.

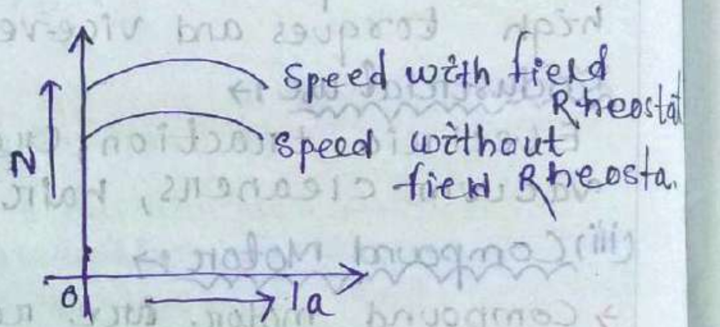
ii) Armature control Method.

Flux-Control Method :→

→ It is based on the fact that by varying the flux φ, the motor speed ($N \propto 1/\phi$) can be changed and hence that name flux control method.

- In this method, a variable resistance known as shunt field rheostat.





→ The shunt field rheostat reduces the shunt field current Ish and flux φ.

→ Therefore, we can only raise the speed of the motor above the normal speed.

→ Generally this method permits to increase the speed in the ratio 3 : 1.

Advantages :→

(i) This is an easy and convenient method.

(ii) It is an inexpensive method since very little power is wasted in the shunt field rheostat due to relatively small value of Ish.

(iii) The speed control exercised by this method is independent of load on the machine.

Disadvantages :→

(i) only speeds higher than the normal speed Can be obtained since the total field circuit resistance cannot be reduced below Rsh - the shunt field winding resistance.

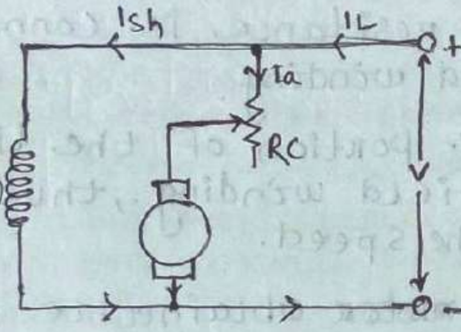
(ii) There is a limit to the maximum speed can be obtained by this method.

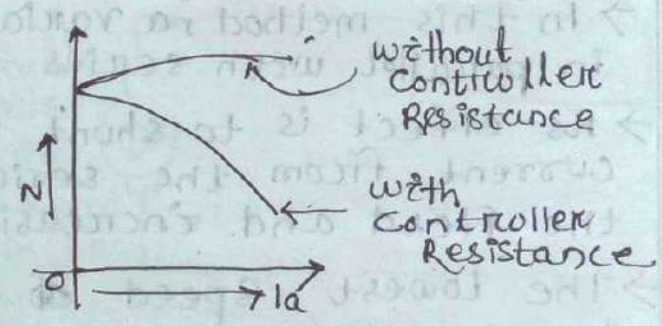
(ii) Armature control Method :→

→ This method is based on the fact that by varying the voltage available across the armature.

→ The back e.m.f and hence the speed of the motor can be changed.

→ This is done by inserting a variable resistance Rc in Series with the armature.





$$N \propto V - I_a(R_a + R_c)$$

RC = Controller resistance.

→ Due to voltage drop in the Controller resistance, the back emf is decreased. since $N \propto E_b$,
The speed of the motor is reduced.

→ The highest speed obtainable is that corresponding to RC = 0.- (Normal speed)

→ This method can only provides Speeds below the normal speed.

Disadvantages :→

→ A large amount of power is wasted in the Controller resistance since it Carries full armature current Ia.

→ The output and efficiency of the motor are reduced.

→ This Method results in poor speed regulation

- The speed varies widely with load since the speed depends upon the voltage drop.

~~Speed control of D.C~~

- This method is seldom used to control the speed of shunt motors.

Speed control of D.C Series motors :→

- The speed control of dc series motors can be obtaine by (i) flux control method.
  ii) Armature-resistance control method.

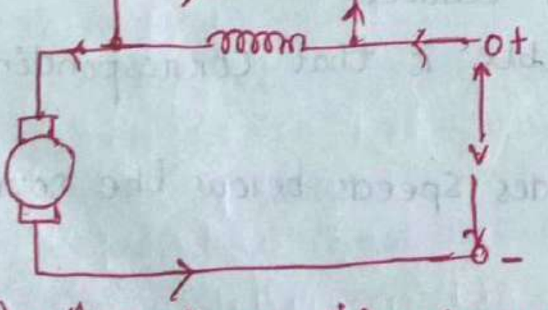
(i) Flux-control method :→

- This method, flux produced by the series motor is varied and hence the speed.

The variation of flux can be achieved - 2 ways.

1. Field Diverters :→

- In this method, a variable resistance is connected in parallel with series field winding.
- Its effect is to shunt some portion of the line current from the series field winding., thus weaking the field and increasing the speed.
- The lowest speed ~~of the motor~~ obtainable is that corresponding to zero current is the diverter.
- The lowest speed obtainable is the normal speed of the motor, consequently, this method can only provide speeds above the normal speed.



2. Armature diverter :→

- A variable resistance is connected in parallel with the armature.
- The diverter shunts some of the line current, the reducing the armature current.

→ If I_a is decreased, the flux ϕ must increase.

→ Since $N \propto 1/\phi$, the motor speed is decreased, By adjusting the armature diverter,

→ Any speed lower than the normal speed can be obtained.

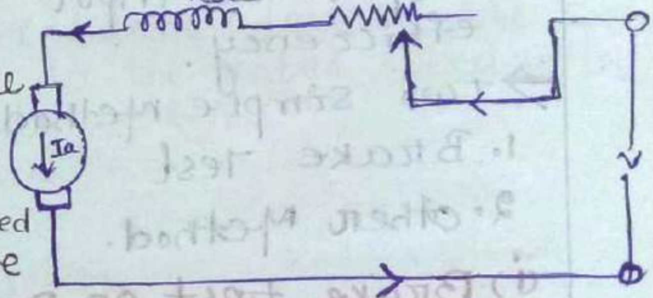
Tapped field Control :→

→ The flux is reduced by decreasing the number of turns of the series field winding.

→ full turns of the field winding, the motor runs at normal speed and as the field turns are cut-out. Speeds higher than normal speed are achieved.

(ii) Armature-resistance control :→

→ In this method, a variable resistance is directly connected in series with the supply to the complete motor.



→ This reduces the voltage available across the armature and hence the speed falls.

→ By changing the value of variable resistance, any speed below the normal speed can be obtained.

→ This is the most common method employed to control the speed of D.C series motors.

→

Calculation of Efficiency when the Machine is generating on Load:

Power input = VI

Armature copper loss,

$$P_{cu} = I_2 R_a = (I + I_{sh})^2 R_a$$

Constant losses

$$W_c = VI_0 - (I_0 - I_{sh})^2 R_a$$

Total losses = $p_{cu} + W_c$

∴ Efficiency of the generator.

$$n = \frac{Output}{Input} = \frac{Input - losses}{Input} = \frac{VI - (p_{cu} + W_c)}{VI}$$

Efficiency By Direct Loading method :→

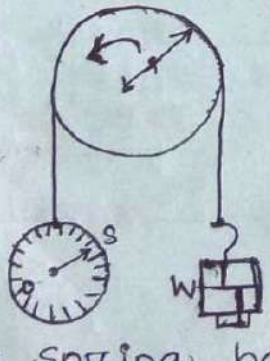
→ In this method, the DC Machine is loaded and output and input are measured to find the efficiency.

→ Two simple methods can be used.

1. Brake Test
2. other Method.

(i) Brake test on DC Machines.

→ In this brake test on D.C Machines a brake is applied to a water-cooled pulley mounted on the motor shaft.



→ One end of the rope is fixed to the floor via a spring balance S and a known mass is suspended at the other end.

→ If the spring balance reading is Kg-wt and the suspended mass has a weight of W Kg-wt

Net pull on the rope = (W-S)

Kg.wt = (W-S)* 9.81 Newtons

If r is the radius of the pully in meters, then the shaft torque T_{sh} developed by the motor is

$$T_{sh} = (W-S) * 9.81\, r \text{ N-m}$$

If the speed of the pulley is N r.p.m then,

$$\text{Output power} = 2 * 3.14\, N\, T_{sh}/60$$

$$= \frac{2\, 3.14\, N \times (W-S)\, 9.81\, r}{60}$$

Swinburne's Test method :→

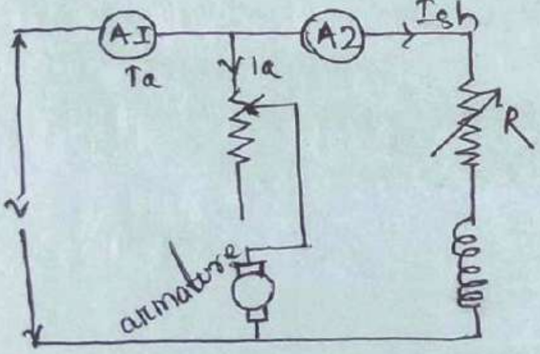
→ This method is an indirect method of testing a DC machine.

→ Swinburne's Test is the most commonly used and simplest method of testing of shunt and compound wound DC Machines.

→ In this test the efficiency of the machine at any load is pre-determined.

→ In this method of testing no load losses are measured separately and eventually we can determine the efficiency.

→ The ckt connection for swinburne's test is the speed of the machine is adjusted to the rated speed with the help of the shunt regulator R.



→ The swinburne's test no load power input is only required to supply the losses.

→ The losses occur in the machine mainly are:-
1. Iron losses in the core
2. Friction and windings losses
3. Armature copper loss.

→ No load mechanical output of the machine is zero in Swinburne's test, the no load input power is only used to supply the losses.

Disadvantages of swinburne's Test

1. Iron loss in neglected through there is change in iron loss from no load to full load due to armature reaction.
2. We cannot be sure about the satisfactory commutation on loaded condition because the test in done on no-load.
3. We can't measure the temperature rise when the machine is loaded. power losses can very with the temperature
4. In DC series motors, the swinburne's cannot be done to find its efficiecy as it is a no load test.

CHAPTER-01 D.C. GENERATOR

1.1. Operating principle of generator.

An electric generator is a machine that Converts. mechanical energy into electrical energy.

- Whenever flux is cut by a conductor. an emf is induced ~~will~~ which will cause a current to flow if the conductor circuit is closed.
- The Direction of induced e.m.f. is given by 'Fleming' right hand rule'.
- essential Components of a generator are,
  - (i) a magnetic field.
  - (ii) Conductor or a group of Conductor.
  - (iii) Motion of conductor with respect to magnetic field.

Fleming's right hand rule. :-

- Stretch the thumb, fore-fingure and middle finger and middle finger of your right hand so that they are at right angles to each other.
- If the fore-finger Points in the direction of field, thumb in the direction of motion of the conductor, then middle fingure will point in the direction of induced emf.

1.2 Construction of D.C generator :-

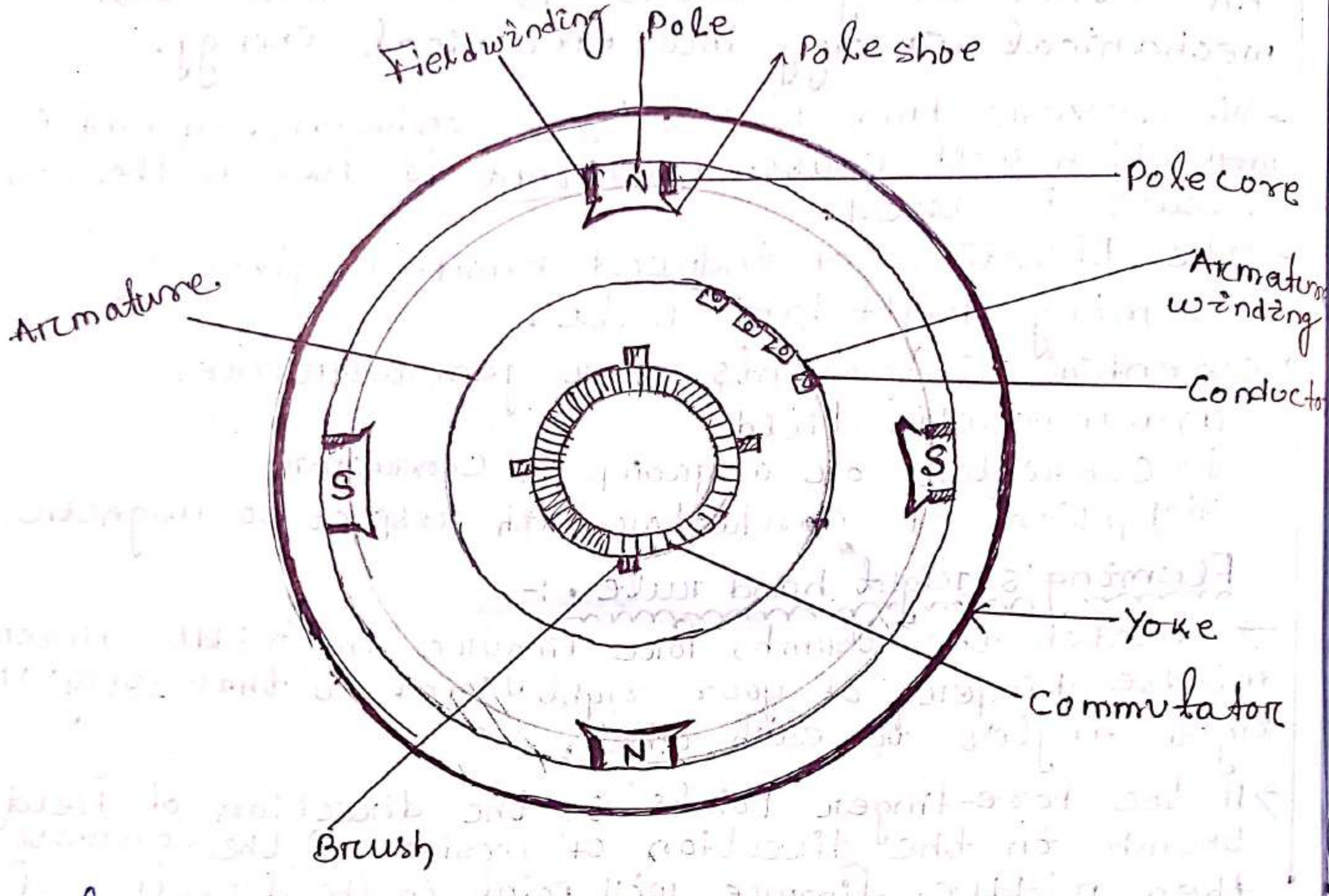
- The d.c generator and d.c motor have the same general construction.
- All d.c machines have principal components are :- (i) field system (ii) armature core (iii) armature winding (iv) commutator (v) brushes.

(i) Field system :-

- The function of the field system is to produce uniform magnetic field within which the armature rotates.
- Number of salient poles boiled to the inside of circular frame. (generally called YOKE)
- The yoke is usually made of solid cast steel where-as. the pole pieces are composed of stacked laminations.
- Field coils are mounted on the poles and carry the d.c exciting current.

(ii) Armature core :-

→ The armature core is keyed to the machine shaft and rotates between the field poles.



(iii) Armature winding Conductors :-

> The slots of the armature core hold Insulated Conductors that are Connected in a suited manner. This is known as armature winding.

> This is the winding which is working emf is Induce

> The armature Conductors are Conducted in Series so as increase the voltage, in parallel path So as to increases the current.

(iv) Commutator :-

→ A Commutator is a mechanical rectifire which Convert The alternating voltage generated in the armature winding in-to direct voltage across the ~~bustoo~~ brushes.

> The Commutator is made up copper segments insulated from each other by mica sheets.

(V) Brushes.

→ The propose of brushes is to insure electrical connections between the rotating Commutator and stationary external load Circuit.

→ The brushes are made of carbon and rest on the Commutator The brushes pressure is adjusted by means of adjustable springs.

Types of Armature winding:-

There are two types of simple drum winding.

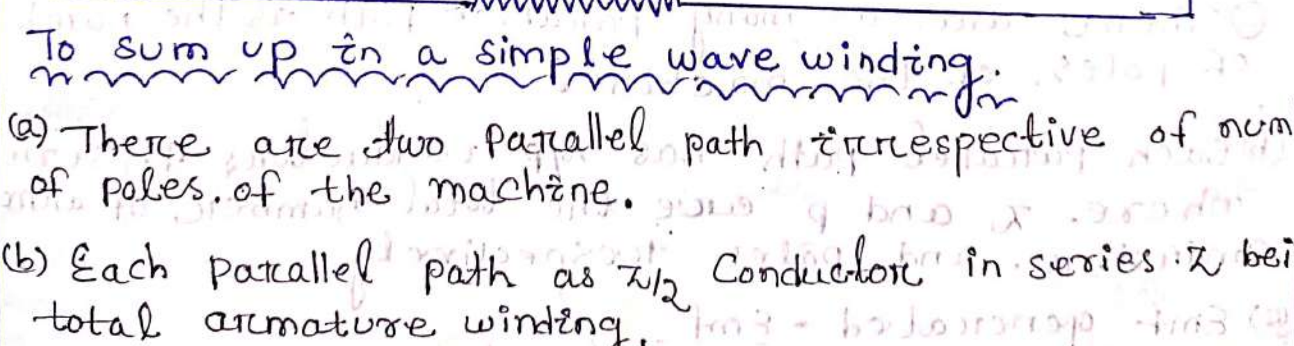
1. simple wave winding
2. simple lap winding.

1.2.3 Simple Wave Winding

→ In the arrangement the armature coil are Connected in series through commutator segments in such a way that the armature winding is divided into two parallel Paths.

→ If there are Z Armature conductor then $Z/2$ Conductor will be in series in each Parallel path.

→ Each parallel path will carry a Current $I_a/2$ where I_a is the total armature current.



To sum up in a simple wave winding.

(a) There are two parallel path irrespective of number of poles of the machine.

(b) Each parallel path as $Z/2$ Conductor in series Z being total armature winding.

(c) EMF Generated = $\frac{\text{EMF}}{\text{Parallel path}}$

(d) Total armature current $I_a = 2 \times \text{Current/parallel path}$

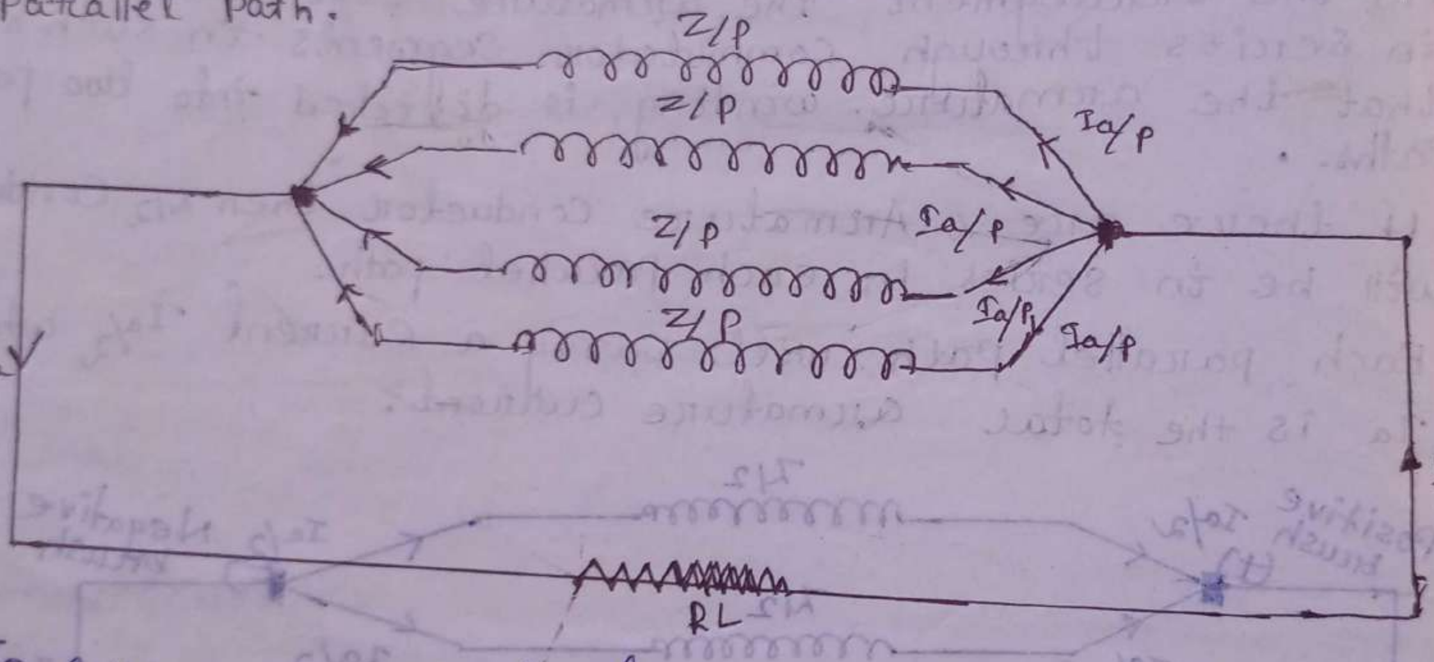
Simple lap winding.

> In this arrangment coils are Connected in Series through Commutator segments in such a wa that the armature winding is divided into as many Parallel path as the number of poles of the machine.

> If the Z Conductors and P-poles than there wi be parallel path. each containg Z/P Conductors in Series.

> Each path will carry a current of I_a/P where I_a is the total armature current.

> Here it is assumed that P=4 so that there are 4 Parallel path.



To sum up in a simple lap winding:-

(a) There are as many parallel path as the number of poles. of the machine.

(b) each parallel path has Z/P conductors in series where Z and P are the total number of armature conductors. and poles respectively.

c) Emf generated = $\frac{\text{Emf}}{\text{Parallel path}}$

d) Total current I_a = P × current / parallel path.

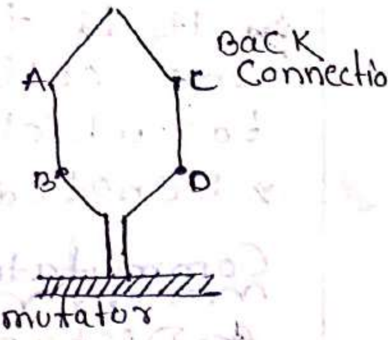
~~Choice of Armature windings~~ 1.2.2

Pole pitch :-

1. pole pitch is the peripherical distance between two adjusent pores. It is Measurred in terms of armature slots or conductor.

2. It can be also defind as the number of armature conductores per pole.

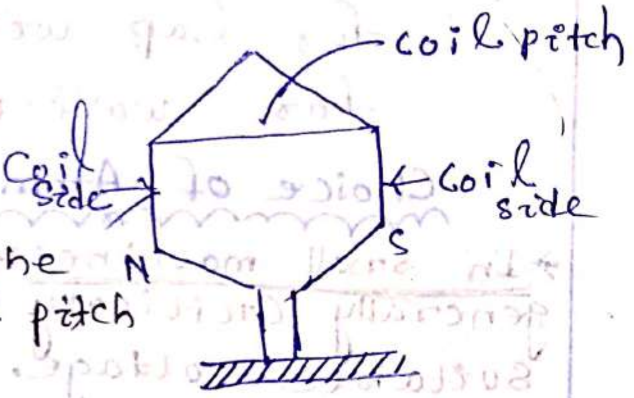
E.x = Conductor = 48
pole = 4
Pole pitch = $\frac{48}{4} = 12$



Coil pitch

1. It is the ~~mean~~ angular distance between 2 sides of coil, Measured in the term of armature slots per poll.

E.x = Slots = 36
pole = 4
Coil pitch = $\frac{36}{4} = 9$



2. If the coil pitch is equal to the pole pitch then is called full pitch coil.

3. For fall pitch coil each coil side lies under the opposite pole, i.e. the coil span is 180° electrical.

4. If the coil pitch less than the pole pitch than it is sad to be short pitch coil or fractional pitch coil.

Winding pitch :-

> It is defind as the distance between two succesive conductor which as directly connect together around the armature.

> It is the beginning of two successive Coil side & is denoted by y.

Back pitch

1> Denoted by y_b & defind as the distance between the 1st & last Conductors of a coil.

Frontpitch

> It is the distance between the 2nd Conductor of one coil & the first Conductor of the next coil.

> Both the coil should be Connected to the Same commutator segment & on the front denot by y_f.

Resultant pitch :-

> It is the distance between the beginning of one coil & the beginning of the next coil to which is connected.

> Denoted by y_r

Commutator pitch :-

- Distance between the commutator segments to which the two ends of coil are connected.

for lap winding $y_c = y_b - y_f$

for wave winding $y_c = y_b + y_f$

Choice of Armature winding

> In small machines:- the Current carrying is not generally critically Therefore in order to obtain suitable voltage.

> wave winding are often used.

In large Machines: suitable voltage are easily obtained because of the relativly large numbe of armature. Conductors available.

> Current capacity is More critical.

> large Machines generally used lap winding.

- In some cases, neither simple lap winding nor simple wave winding Provides a satisfactory solution in such cases. we use more complicated type of armature winding.

E.M.F Equation of a D.C generator

We shall now derive on expression for the emf generated in a dc generator.

ϕ = flux/pole wb / flux per pole.
Z = total number of armature conductor
P = Number of poles
A = number of parallel paths for wave winding & for lap winding
N = speed of armature in r.p.m
E_g = Emf of the generator = $\frac{\text{emf}}{\text{parallel path}}$.

flux cut by one conductor in one revelotion of the armature $d\phi = P\phi$ webers.

Time taken to complete one revolution $dt = 60/N$ second.

E.m.f generated/conductor = $\frac{d\phi}{dt} = \frac{P\phi}{60/N} = \frac{P\phi N}{60}$ Volt

emf of generator E_g = Emf per parallel path
= (emf/conductor) x no of conductor in series in parallel path

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

$$E_g = \frac{P\phi Z N}{60A}$$ (for wave winding)

where A = (For lap winding)

Armature Resistance:-

→ The resistance affered by the armature circuit is known as armature resistance (R_a) and includes

(1) Resistance of armature winding.
(2) Resistance of Brushes.

→ The Armature Resistance depends upon the construction of the Machine. Except for small Machines. It value is generally less than 1Ω.

Question-01

An 8 Pole 250 V wave wound generator has 400 conductor if the generator is to be lap wound the number of Conductor is ?

Sol^n given that

Number of pole(P) = 8 , for wave wound ⇒ A = 2

Number of conductor (Z) = 400

The wave wound generator (Emf) = 250 V

$$\text{Emf} = \frac{P\Phi ZN}{60A} = \cancel{8000}\ \frac{8\times\Phi\times400\times N}{60\times2} \text{ ——— (i) (for wave wound)}$$

$$\text{Emf} = \frac{P\Phi ZN}{60A} = \frac{8\times\Phi\times Z\times N}{60\times8} \text{ ——— (ii) (for lap wound)}$$

By equating eq (i) & (ii),

$$\Rightarrow \frac{400\times8\times\cancel{\Phi N}}{\cancel{60}\times2} = \frac{8\times Z\times\cancel{\Phi\times N}}{\cancel{60}\times8}$$

$$\Rightarrow \frac{400\times8}{2} = \frac{8Z}{8} \Rightarrow \frac{400\times8\times8}{8\times2} = 1600$$

∴ The lapwound generator the number of Conductor is 1600.

Question-02

A 6 pole lap wound generator has 300 conductors. The emf induced per Conductor being 5 V then the generated voltage of generator ?

Sol^n given that

~~Noto~~ A lap wound generator.

Number of conductors (Z) = 300

EMF induced per conductor = 5V

No of Poles (P) = 6

Total emf = 300 × 5 = 1500 V

then generated emf = $E_g = \dfrac{\text{total emf}}{\text{Parallel path / poles}}$ (for lapwound)

$$E_g = \frac{1500}{6} = 250\text{ V (Ans)}$$

∴ So that the output voltage of generator is 250 V.

Q.3 A. 4 pole generator having wave wound armature winding has 51 slots each slot containing 20 conductors what will be the voltage generated in the machine when driven 1500 rpm, assuming flux per pole to be 7.0mwb.

Solution Given that

No of poles(P) = 4

slot = 51 & per slot conductor = 20

Wave wound armature winding (A) = 2

(Z) Total conductor = 51 × 20 = 1020

N = 1500 rpm

$Q = 7.0 \text{ mwb} = 7.0 \times 10^{-3} = 0.007 \text{ wb}$

Then $\text{Emf} = \frac{PQN}{60} \times \frac{Z}{A}$

$$= \frac{4 \times 0.007 \times 1500 \times 1020}{60 \times 2} = \frac{42840}{120} = 357 \text{ v}$$

∴ The generated voltage of the machine 357 v

Types of DC generators.

> The magnetic field in d.c generator is normally produced by electromagnets rather than permanent magnet.

> ~~generators~~ D.c generator are divided into 2 types.

1. Separately excited d.c generator
2. self-excited d.c generator.

> The behaviour of a d.c generator on load ~~ro~~ depends upon the method of field excitation adopted.

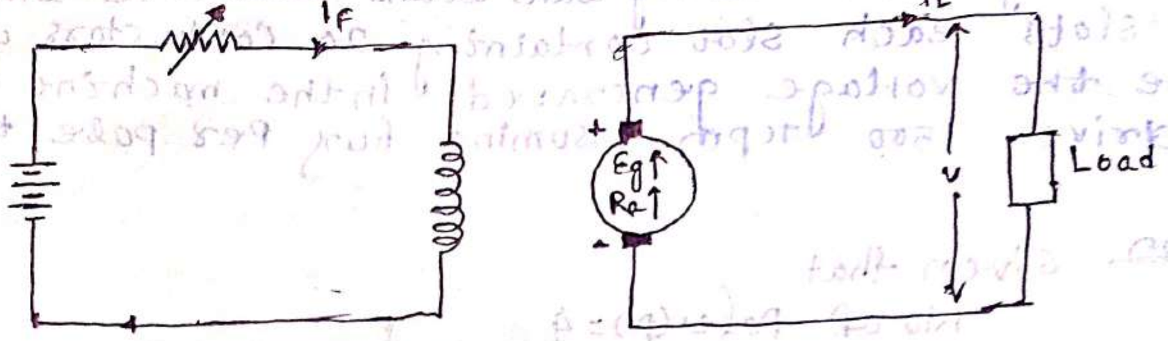
Separately excited generator.

> A d.c generator whose field magnet winding ~~was~~ is supplied from an independent external d.c source is called a separately excited generator.

> The voltage output depends upon the speed of rotation of armature and the field current.

> The greater the speed and field current, greater is the generated emf. It may be noted that ~~sps~~ separately excited d.c generators are rarely used in practice

> D.c generators are normally self-excited type.



Armature current $I_a = I_L$

Terminal voltage $V = E_g - I_aR_a$

Electric power developed $= E_gI_a$

Power delivered to load $= E_gI_a - I_a^2R_a = I_a(E_g - I_aR_a) = VI$

Self-excited generators :-

A d.c generators whose field magnet winding is supplied current from the output of the generator is called self-excited generators.

> self-excited generators depending upon the manner in which the field winding is connected to armature.

> self-excited generators are three types.

1. series generator
2. shunt generator
3. Compound generator.

1. Series generator :-

> In series-wound generator the field winding is connected in series with armature winding.

> so that whole armature current flows through the field winding as well as load.

> Field winding carries the whole of load current. It has a few turns of thick wire having low resistance.

> Series generator are used in boosters.

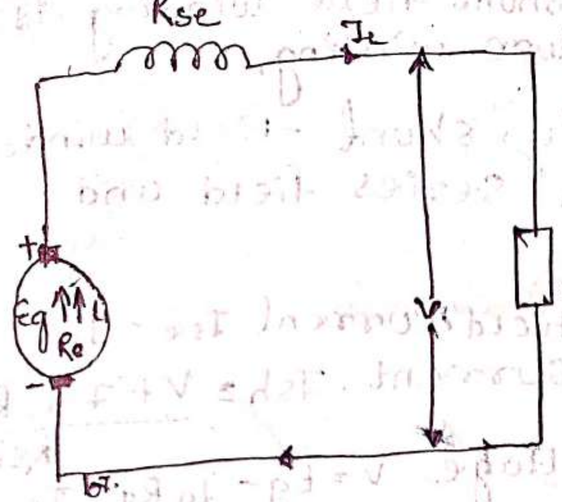
Armature current $I_a = I_{se} = I_L = I$

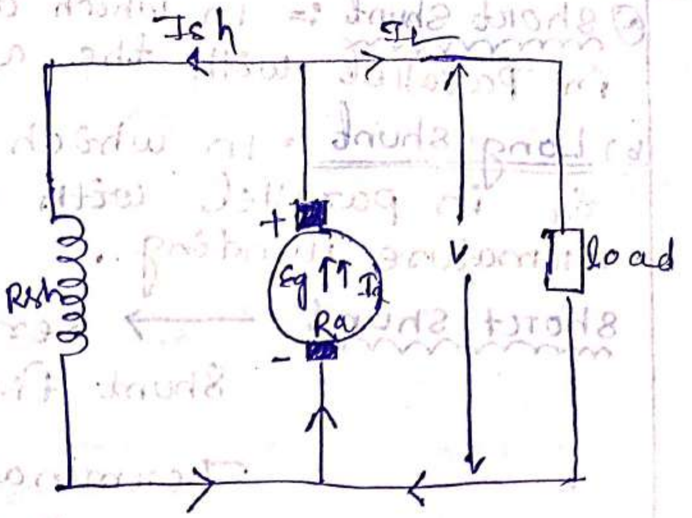
Terminal voltage $V = E_g - I(R_a + R_{se})$

power developed in armature $= E_gI_a$

Power delivered to load $= E_gI_a - I_a^2(R_a + R_{se})$

$= I_a[E_g - I_a(R_a + R_{se})] = VI_a$ or VI_L.





(ii) Shunt generator :-

> In a shunt generator, the field winding is connected in parallel with the armature winding, so that terminal voltage of the generator is applied across it.

⇒ The shunt winding has many turns of fine wire having high resistance.

⇒ The connection of a shunt-wound generator.

Shunt field current $I_{sh} = V/R_{sh}$

Armature current, $I_a = I_L + I_{sh}$

Terminal current, $V = E_g - I_{sh} R_a$

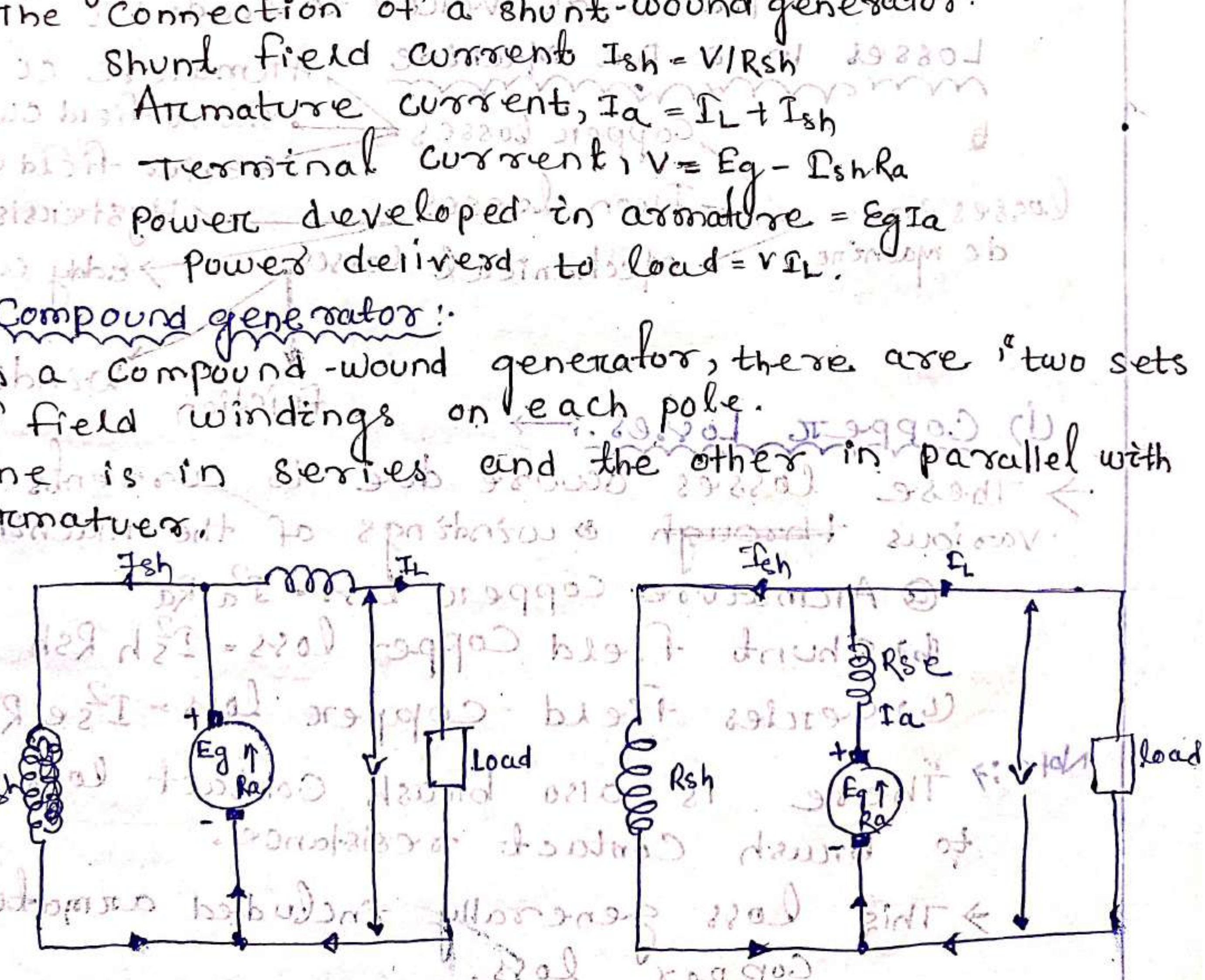
Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$.

(iii) Compound generator :-

> In a compound-wound generator, there are two sets of field windings on each pole.

* one is in series and the other in parallel with armature.



(Compound generator)

~~Eg = V + IaRa~~

ⓐ Short shunt :- In which only shunt field winding is in parallel with the armature winding.

(b) Long shunt :- In which only shunt field winding is in parallel with both series field and armature winding.

Short shunt ⟶ Series field current $I_{se} = I_L$

Shunt field current $I_{sh} = \frac{V + I_{se} R_{se}}{R_{sh}}$

Terminal voltage $V = E_g - I_a R_a - I_{se} R_{se}$

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$

Long shunt ⟶ Series field current, $I_{se} = I_a = I_L + I_{sh}$

Shunt field current, $I_{sh} = V / R_{sh}$

Terminal voltage :- $V = E_g - I_a (R_a + R_{se})$

Power developed in armature $= E_g I_a$

Power delivered to load $= V I_L$.

Losses In a D.C Machine

b.

- Losses in dc machine
  - Copper losses
    - Armature cu loss
    - Shunt field cu loss
    - Series field cu loss
  - Iron losses
    - Hysteresis loss
    - Eddy current loss
  - Mechanical losses
    - Friction
    - Windage.

(i) Copper Losses :⟶

→ These losses occure due to currents in the various ~~through~~ windings of the machine.

ⓐ Armature copper loss $= I_a^2 R_a$

(b) Shunt field Copper loss $= I_{sh}^2 R_{sh}$

(c) Series field copper loss $= I_{se}^2 R_{se}$.

Note :→ There is also brush contact loss due to brush contact resistance.

→ This loss generally included armature copper loss.

(ii) Iron Losses:-

→ These losses occure in the armature of a DC machine and are due to the rotation of armature in the magnetic field. of the ~~field~~ poles. → they are 2 types.

* Hystersis Loss

→ The phenomenon of lagging of magnetization or induction flux density behind the magnetizing force is known as hystersis.

→ The loss due to hystersis is called hysteresis loss.

→ Hystersis loss occure in the armature of the dc Machine

Hystersis loss ~~occur~~(P) = $P_h = \eta B_{max}^{1.6} f V$ watts.

B_{max} = Maximum flux density in armature

f = frequency of magnetic reversals.

= $NP/120$ where N is in r.p.m.

V = Volume of armature in m^3

η = Stometz hystersis coefficient.

Eddy Current Loss.

→ When armature rotates in the magnetic field of the pole an emf is induced in it which circulates eddy currents in the armature cores.

The power losses due to this eddycurrent called eddy current loss.

Eddy current loss $P_e = K_e B_{max}^2 f^2 t^2 V$ watt

K_e = Constant

B_{max} = Maximum flux density in the core.

f = frequency of magnetic reversal

t = Thickness of lamination.

V = Volume of Core in m^3.

Mechanical losses:-

> These losses are due to friction and windage.

(a) friction loss e.g bearing friction, brush friction.

(b) Windge loss e.g air friction of rotating armature. the losses depend open the speed of the Machine.

Constant and variable losses:-

Constant losses :- These losses in a dc generator which remain Constant at all loads are known as Constant losses.

The Constant losses in a dc generator

a) Iron Losses
b) Mechanical losses
c) shunt field losses.

Variable losses :- Those Losses in a dc generator which vary with load are called variable losses.

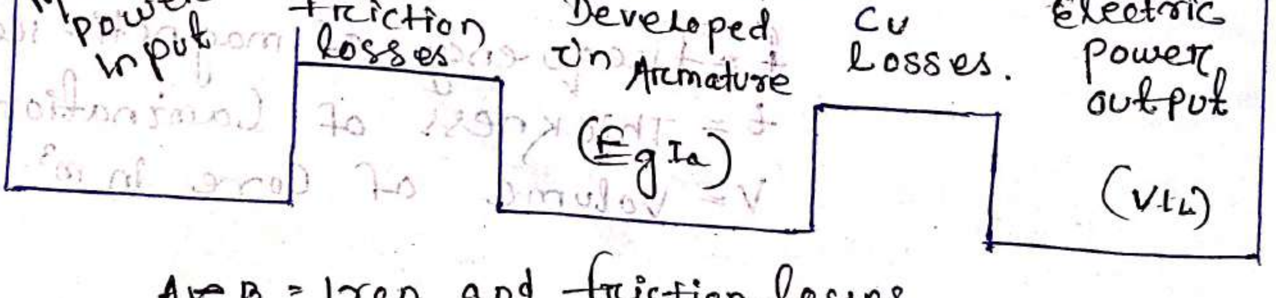
> The variable losses in a d.c generator

a) Copper loss in armature winding ($I_a^2 R_a$)
b) Copper loss in series field winding ($I_{se}^2 R_{se}$)

Total losses = Constant losses + Variable losses.

Power stages.

The various power stages in dc generator →



A-B = Iron and friction losses.
B-C = Copper losses.

(i) Mechanical efficiency :- $\eta_m = \frac{B}{A} = \frac{E_g I_a}{\text{Mechanical power Input}}$

(ii) Electrical efficiency :- $\eta_e = \frac{C}{B} = \frac{VI_L}{E_g I_a}$

(iii) Commercial or overall efficiency :-

$$\eta_c = \frac{C}{A} = \frac{VI_L}{\text{Mechanical power Input}}$$

$$\eta_c = \eta_m \times \eta_e$$

Clearly,

Unless otherwise stated, Commericial efficiency is always understood.

Now, Commercial efficiency, $\eta_c = \frac{C}{A} = \frac{\text{output}}{\text{input}}$

$$= \frac{\text{Input} - \text{Losses}}{\text{Input}}.$$

Conditions for Maximum efficiency

The efficiency of a DC generator is not constant but varies with load. Consider a shunt generator delivering a load current I_L at a terminal voltage (V)

General output :- VI_L

General Input :- output + losses.

$= VI_L +$ variable losses + constant losses

$= VI_L + I_a^2 R_a + W_C$

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

The shunt field current I_{sh} is generally small as compared to I_L and there force can be negleted. generator Input $= VI_L + I_L^2 R_a + W_C$

$$\eta = \frac{\text{output}}{\text{Input}} = \frac{VI_L}{VI_L + I_L^2 R_a + W_C} = \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right)}$$

$$\Rightarrow \frac{d}{dI_L}\left(\frac{I_L R_a}{V} + \frac{W_C}{VI_L}\right) = 0$$

$$\Rightarrow \frac{R_a}{V} - \frac{W_C}{VI_L^2} = 0 \Rightarrow \frac{R_a}{\cancel{V}} = \frac{W_C}{\cancel{V} I_L^2}$$

$I_L^2 R_a = W_C$ (variable loss = constant loss)

The load current corresponding to maximum efficien
is given by $I_L = \sqrt{\frac{W_C}{R_a}}$

Hence the efficiency of a dc generator will be maximum when the load current is such that the variable loss is equal to the constant loss.

Armature Reaction

Dt :- 29-4-2022

→ So far we have assumed that the only flux acting in a dc machine is that due to the Main poles called main flux.

⇒ However current flowing through the armature Conductor also creat a magnetic flux called armature flux that distorts and weakness the flux Coming from the Poles.

⇒ The action of armature flux on the mainflux know as armature Reaction.

⇒ When the generator is on no-load a small current flowing in the arm armature does. not applicable affect the main flux Ø₁

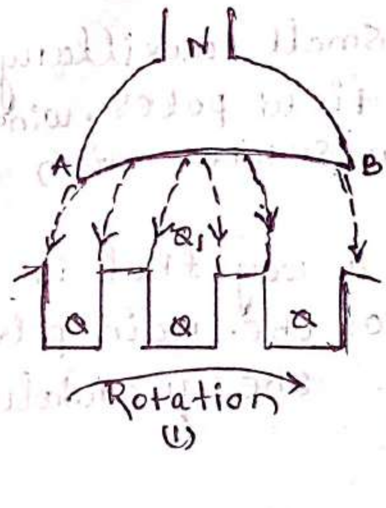
(i) Coming from the pole when the generator is loaded the Current flowing through armature conductor setup flux Ø₂. ~~Coming from the pole~~ ~~i) when the generator is loaded, the current flowing through armature~~

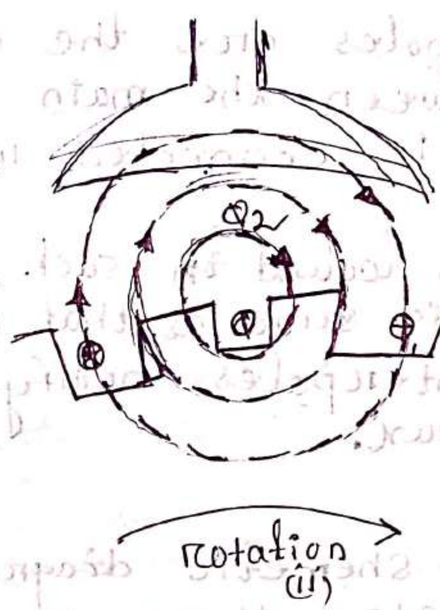
(ii) shows flux due to armature current alone by Superimposing Ø₁ and Ø₂, we obtain the resulting flux Ø₃ as shown in fig.

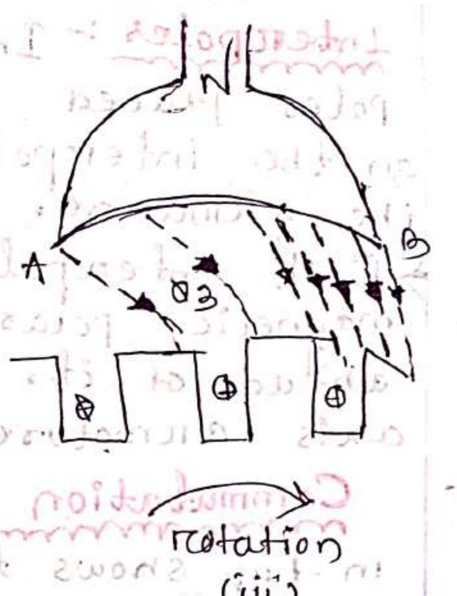
(iii) It is clear that flux density at the trailing pole tip (point-B) in increased.

while at the leading pole tip (point A). It is decreased. This unequal field distribution produces the following two effects :-

(i) The main flux is distorted.







- Due to Higher flux density at pole tip B, saturation sets in. Consequently, the increase in flux at pole tip B is less than the decrease in flux under pole tip A. flux ϕ_2 at full load is, therefore, less than flux ϕ_1 at no load.

How to Reduce Armature Reaction :-

- Usually no special efforts are taken for small. Machines to reduce the armature reaction. But for large DC Machines, Compensating winding and interpoles are used to get rid of the ill effects of armature reaction.
- Compensating winding :- Now we know that the armature reaction is due to the presence of armature flux. Armature flux is produced due to the current flowing in armature conductors. Now if we place another winding in close proximity of the armature winding and if it carries the same current but in opposite direction.
- That of the armature current (Ia) then this will nullify the armature field, such an additional winding is called as compensating winding

➢ It is placed on the pole faces. compensating winding is connected in series with the armature winding in such a way that it carries the current of the opposite direction.

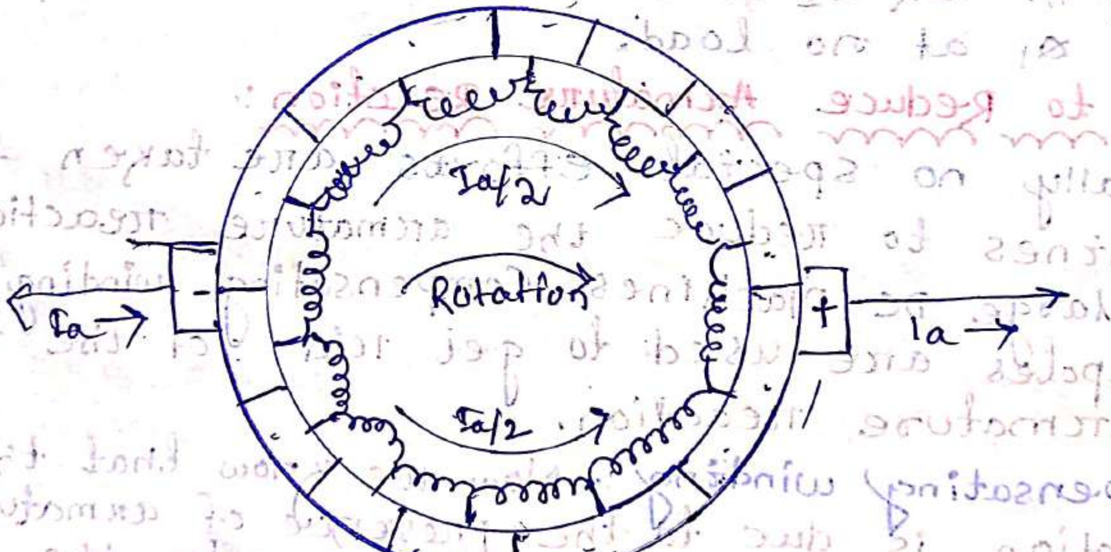
Interpoles :- Interpoles are the small auxillary poles placed between the main field poles. winding on the interpoles is connected in series with the armature.

➢ Each interpole is wound in such a way that is magnetic polarity is same as that of the main pole ahead of it. Interpoles nullify the quardature axis armature flux.

Commutation

In fig shows the shemetic diagram of a 2-pole lap wound generator. there are two parallel paths between the brushes.

➢ Therefore, each coil of the winding carries one-half of the total current (Ia) entering or leaving the armature circuit.



Note that the current in the coils connected to a brush are either all towards the brush or all directed away from the brush.

➢ Therefore, current in the coil will reverse as the coil passes a brush This reversal of current in the coil passes a brush is called commutation.

→ The complete reversal of current in a coil at a uniform rate as the coil passes the brush is called ideal commutation.

Illustration :→

→ Let us illustrate the phenomenon of commutation in one coil in the armature winding shown in fig. for this purpose, we consider the coil A. suppose the width of the brush is equal to the width of the commutator. Segment and total armature current is 40 A.

→ Since there are two parallel paths, each coil carries a current of 20A.

(i) In fig (i) the brush is in contact with only segment 1 of the commutator. The commutator segment 1 conducts a current 40 A to the brush, 20A from coil A and 20 A from the adjacent coil as shown. The coil A has yet to under go commutator.

(ii) As the armature rotates, the brush will make contact with segment 2 and thus short-circuits the coil A as shown in fig.

→ There are now two parallel paths into the brush as long as short circuit of coil A exists.

→ Shows the instant when the brush in one-furth on segment 2 and three-fourth on segment 1. for this condition, the resistance of the path through segment 2 is three times the resistance of the path through segment 1.

→ Resistance varies inversly as the area of contact of brush with the segment).

→ The brush again conducts a current of 40A; 30 A through segment 1 and 10 A through segment 2

→ Note that current is coil A (the coil undergoing commutation) is reduced from 20 A to 10A.

(iii) Shows the instant when the brush is one-half on Segment 2 and one-half on segment 1.

→ The brush again conducts 40 A. 20 A through segment 1 and 20 A through segment 2. (∵ now resistances of the two parallel paths are equal)

→ Note that current in coil A is zero.

(iv) The fig. shows the instant when the brush is three fourth on segment 2 and one-fourth on segment 1

→ The brush conducts a current of 40 A. 30 A through through segment 2 and 10 A through segment. 1.

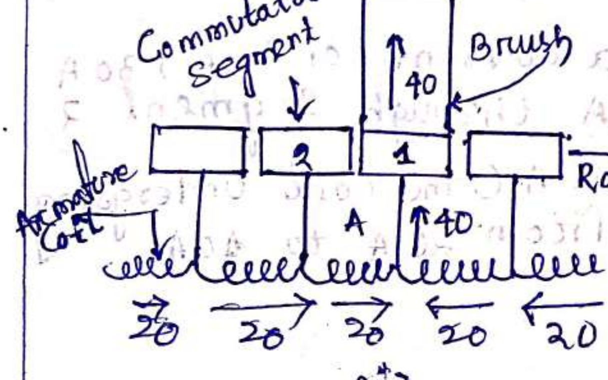
→ Note that current in coil A is 10 A but in the reverse direction to that before the start of commutation. The reader may not the action of commutator in reversing current in a coil as the coil passes a brush.

(v) The fig shows the instant when the brush is contact only with segment 2. The brush again conducts 40 A. 20 A from coil A and 20 A from the adjacent coil.

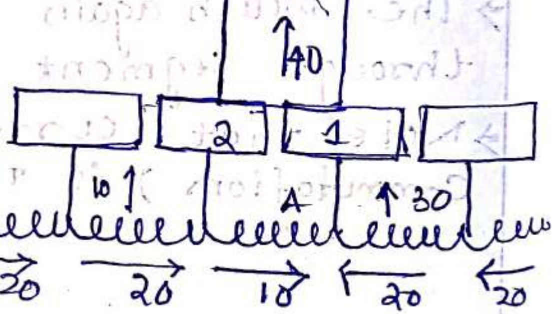
→ Note that now current in coil A is 20 A but in the reverse direction.

→ Thus the coil A has undegone commutation. Note that now current in coil A is 20 A but in the reverse direction. Thus the coil a has undergone commutation.

→ Note that during commutations, the coil under consideration remains short-circuited by the brush.

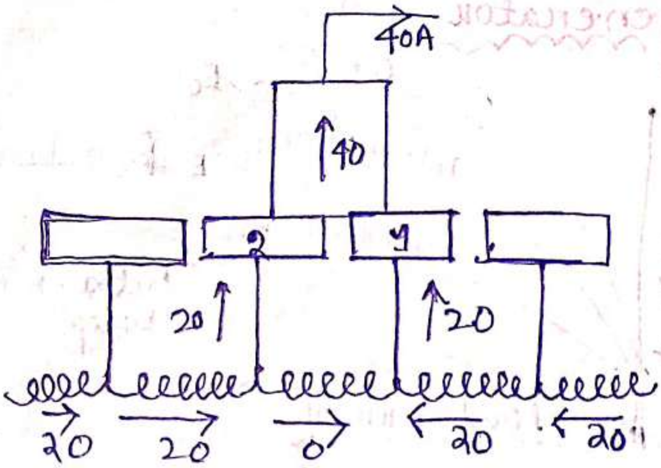


(i)

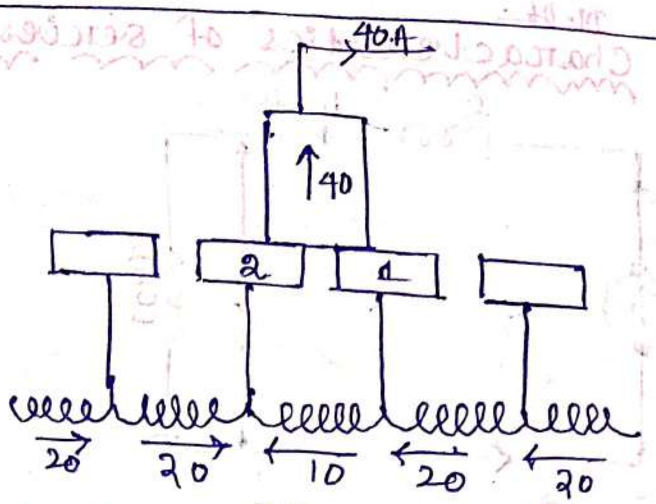


(iv)

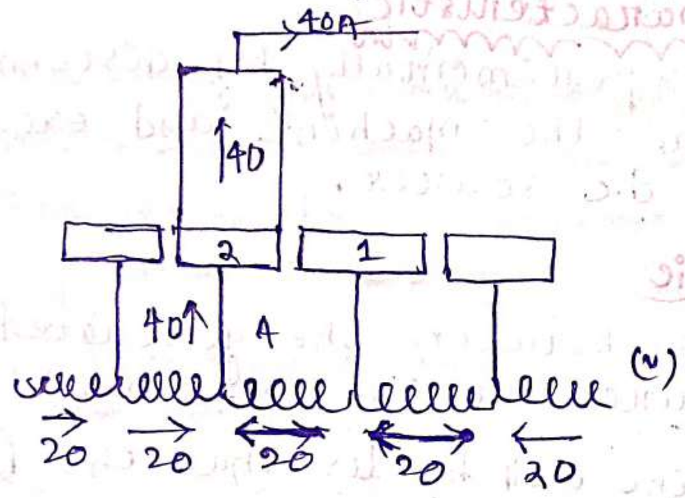
Charlie puth



(iii)

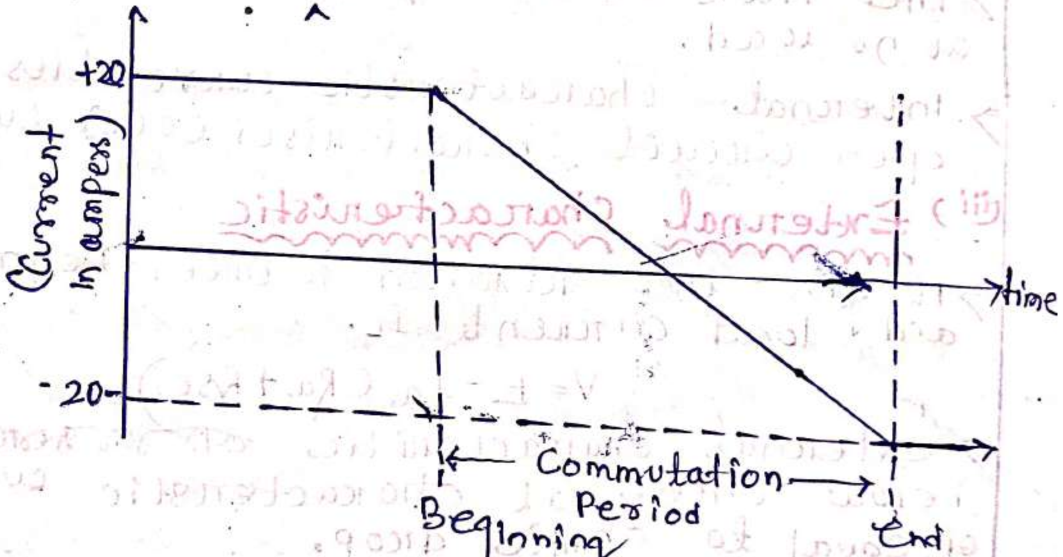


(iv)



(v)

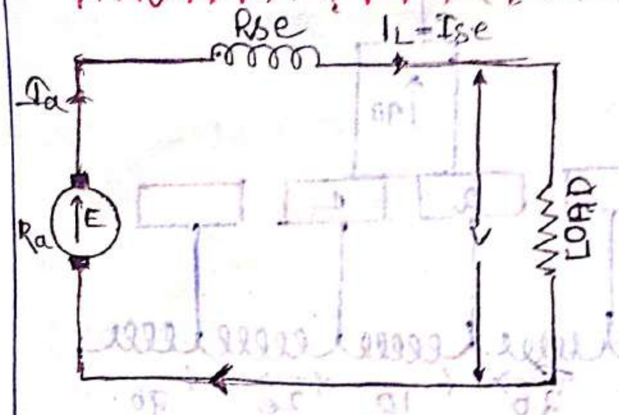
Attention

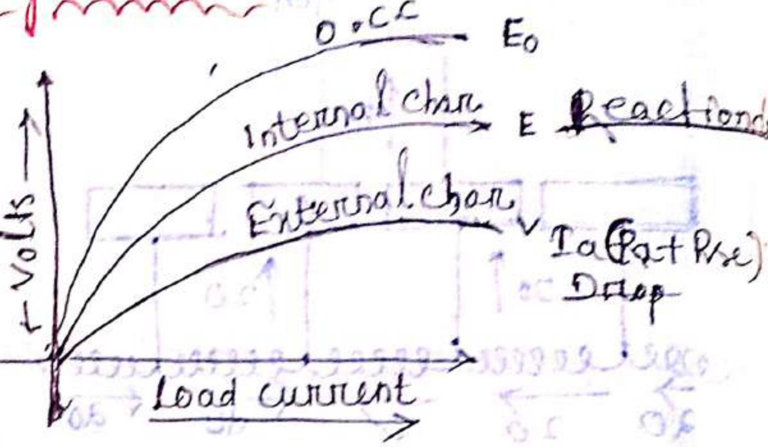


The fig shows the current-time graph for coil A during ideal commutation note that current reversal in coil A is uniform.

Dt-Dt

Characteristics of series generator





(i) O.C.C → open circuit characteristic

→ It can be obtained experimentally by disconnecti the field winding from the machine and exciting it from a separated d.c source.

(ii) Internal characteristic

→ It gives the relation between the generated em E on load and armature current. Due to armatur reaction.

→ The flux in the machine will be less than the flux at no load.

→ internal characterstic curve lies below the open circuit characteristi (OCC) curve.

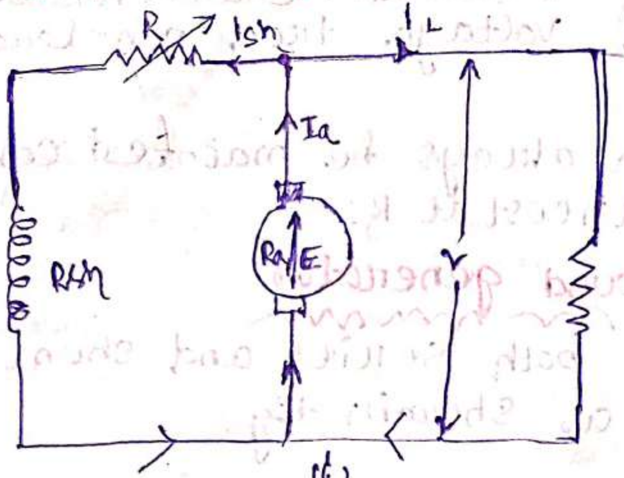
(iii) External characteristic

→ It gives the relation between terminal voltage V and load current I_L.

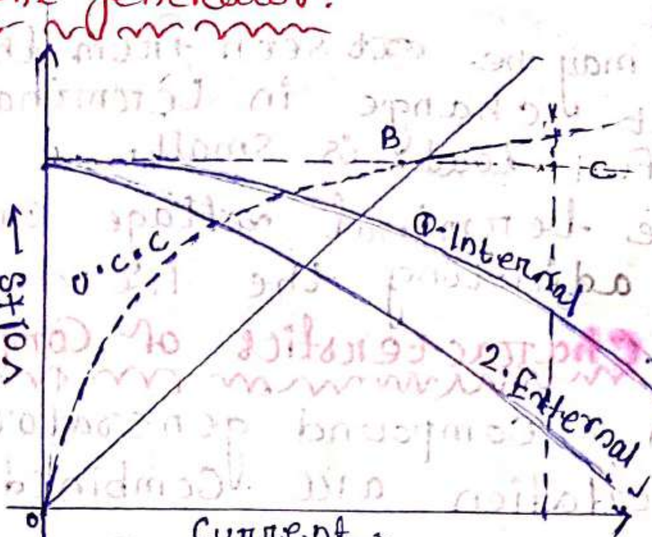
$$V = E - I_a(R_a + R_{se})$$

→ external characteristic ~~of a series~~ curve will li below internal characterstic curve by an amoun of equal to ohmic drop.

Characteristics of a shunt generator.



(i)



(ii)

O.c.c- Open Circuit Characteristics

> The O.C.C of a shunt generator is similar in shape to that of a series generator as shown in fig (ii)

> The line OA represents the shunt field circuit resistance. when the generator is run at normal speed. It will build up a voltage OM. At no-load.

> The terminal voltage of the generator will be constant (o
represented by the horizontal dotted line MC.

Internal Characteristics.

> When the generator is loaded flux per pole is reduce due to armature reaction.

> Therefore, emf E generated on load is less than the emf generated at no load As a result. the internal characteristic (E/Ia) drops down slightly as shown in fig(ii)

External Characteristics.

> Curve 2 shows the external characteristic of a shunt generator. It gives the relation between terminal voltage V and load current I_L.

$$V = E - I_a R_a$$

$$= E - (I_L + I_{sh}) R_a$$

> Therefore, external characteristic curve will lie below the internal characteristic curve by an amount equal to drop in the armature circuit.

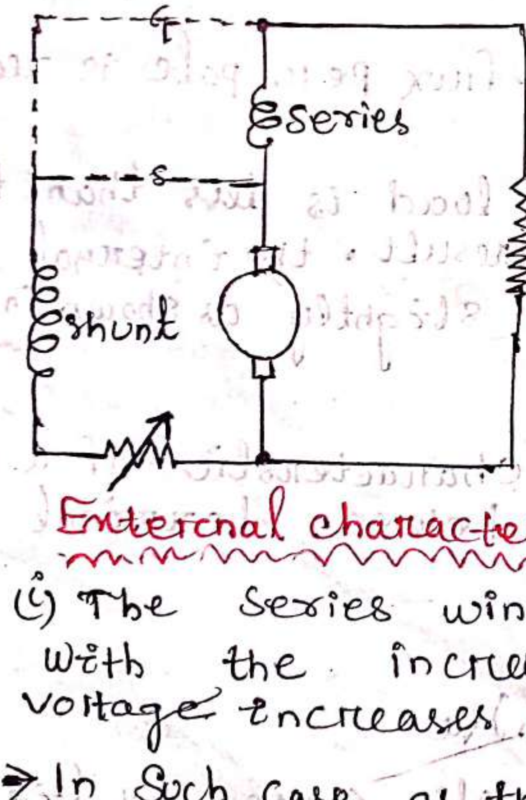
$[i.e\ (I_L + I_{sh}) R_a]$ as shown in fig (ii)

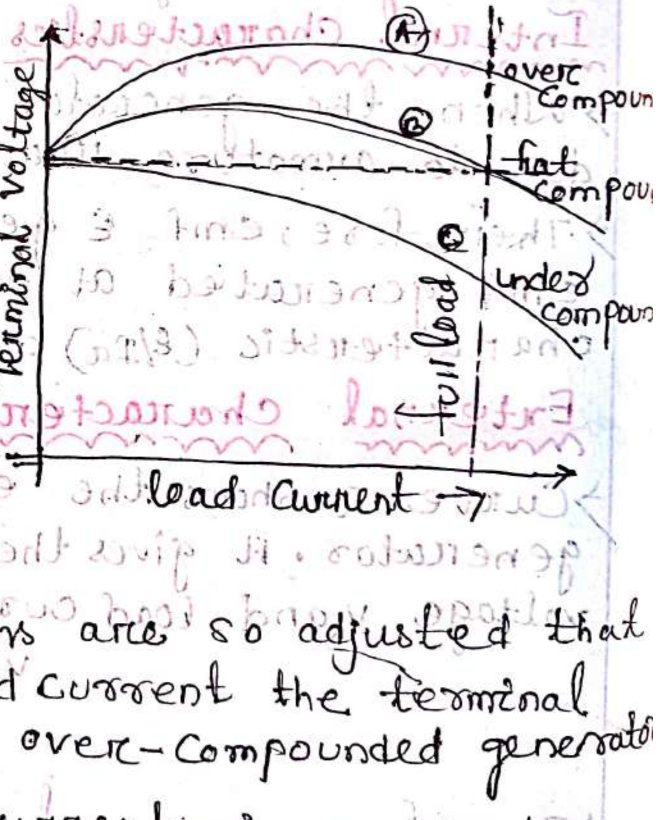
Note

- It may be seen from the external characteristic that change in terminal voltage from non-load to full load is small.
- The terminal voltage can always be mainted consta by adjusting the field rheostat R.

Characteristics of Compound generator

- In a compound generator both series and shunt excitation are combined as shown in fig.
- $I_a = I_L + I_{sh}$ As I_{sh} is small, $I_a \simeq I_L$
- Shunt winding can be connected either across the armature only (short-shunt connections) or across armature puls series (long-shunt connecti
- The compound generator can be comulatively compounded or differentially compounded generator.
- External characteristics of long and shunt compound generators are almost identical.





External characteristic

(i) The series winding turns are so adjusted that with the increase in load current the terminal voltage increases is called over-compounded generator

- In such case as the load current increases, the series field m.m.f increases and tends to increase the flux and hence the generated voltage.
- The increase in generated voltage is greater than the I_aR_a drop. so that instead of decreasing

> The terminal voltage increases as shown by curve 1 in fig.

(ii) The series winding turns are so adjusted that with the increase ~~to~~ in load current.. the terminal voltage remains constant. It is called flat-compound generator.

> The series winding of such a machine has lesser number of turns than the one in over-compounded machine. and does not increase the flux.

> The load current consiquently, the full load voltage is nearly equal to the ~~b~~ no-load voltage as indicated by curve B.

(iii) The terminal voltage winding has lesser number of turns than for a flat-compounded machine, the terminal voltage falls with increase in load current as indicated by curve C in fig.

> This machine is called under-compounded generator.

Applications of series wound DC generator.

> These types of generators are restricted for the use of power supply.

> They are used for supplying field excitation current in DC locomotives for regenerative breaking.

> This type of generators are used as boosters to compensate the voltage drop in the feeder in various types of distribution system such as railway service.

> In series are lightening this type of generators are mainly used.

Applications of shunt wound DC generator.

> They are used to supply power to apparatus situated very close to its position.

> This type of DC generator generally give constant terminal voltage for small distance operation with the help of field regulators from no load to full load.

> They are used for general lighting.

> They are used for charge battery because they can be made to give constant output voltage.

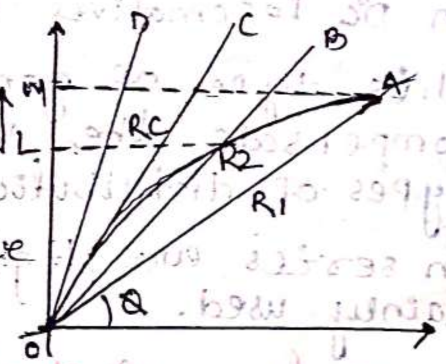
- They are used for giving the excitation to the alternat
- They are also used for small power supply.

Application of compound Wound DC generators.

- The compound wound DC generators are most widely used because of its Compensating property. Dependin upon number of series field turns.
- Cammlatively compound generators may be over compounded, fiat compounded, under compounded
- They are used for lighting, powe supply Purpos and for heavy power services.
- They are mainly made over compounded.
- Commulative compound wound generator also used fo driving a motor.
- Used for small distance operation. like power supply for hotels, offices, homes and lodges.

Critical field Resistance of a shunt-generator.

- The voltage build up in a shunt-generator depends upon field circuit resistance.



- field circuit resistance is R1 then generator will build up OM.
- If the field ckt resistance is increased to R2 (line OB) the generated will build up a voltage OL, slightly less than OM. & slop of resistance line also increased.
- The effect of residual magnetism has been neglected in drawing O.C.C

Resistance = slope of line = $\tan Q$

Here Q is the angle which the lines makes with x-axis, As Q increases.

- The maximum field circuit resistance with which the shunt-generator would just excite is known as critical field resistance