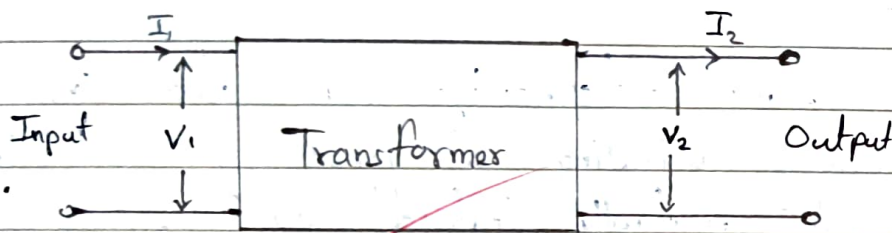


Unit - 4 Single phase transformer

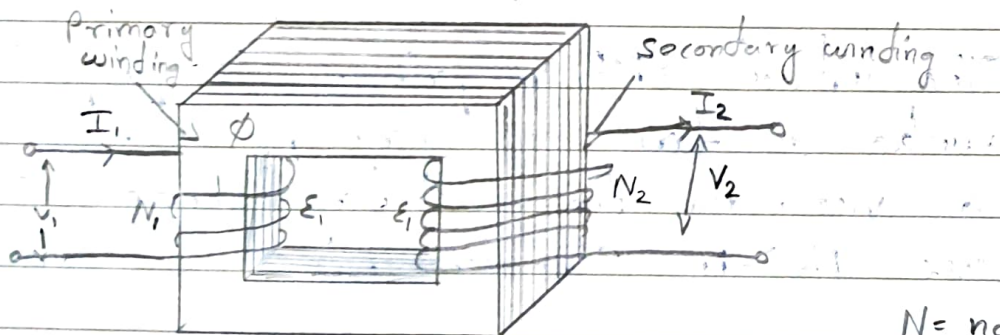
Transformer

A transformer is a static device which transfers AC ~~electron~~ electrical power from one circuit to the other at the same frequency but the voltage level is changed usually as shown in figure. When the voltage is raised on the output side ($V_2 > V_1$) the transformer is called a step-up transformer, whereas the transformer in which the voltage is lower on the output side ($V_2 < V_1$) is called a step-down transformer.



★ Working principle of a transformer

The basic principle of transformer is electro magnetic induction (EMI).



Step up.

N = no. of winding

E = Induced

EMF

Φ Magnetic flux

It essentially consist of two separate windings placed over the laminated silicon steel core. The winding to which the AC supply is connected is called primary winding & the windings to which load is connected is called a secondary winding.

When AC supply of voltage $[V_1]$ is connected to primary winding, an alternating flux is setup in the core. This alternating flux then links with secondary winding, and EMF is induced in it called mutually induced EMF. The direction of this induced EMF is opposite to the applied voltage V_1 . According to Lenz's law

The same alternating flux also link with the primary winding & produced self induced EMF $\mathcal{E}_1$ & mutually induced EMF $\mathcal{E}_2$.

The induced EMF in the primary & secondary winding depends upon the rate of change of flux linked

$$N \frac{d\phi}{dt} \quad (N = \text{no. of turns})$$

The induced EMF in primary is proportional to number of turns in primary winding $\mathcal{E}_1 \propto N_1$ & vice versa for secondary winding $\mathcal{E}_2 \propto N_2$, in case $N_2 > N_1$. The transformer is step-up.

If $N_2 < N_1$. Then the transformer is step down.

Turn Ratio: The ratio of primary to secondary is called turn ratio = $\frac{N_1}{N_2}$

5 Transformation Ratio: The ratio of secondary voltage to primary voltage is called voltage transformation ratio. It is represented by k .

10
$$k = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

Construction of a transformer:-

15 According to the core construction there are three types of transformer.

- 1) Simple core type
- 2) shell type
- 3) Berry type.

* Simple core type:-

25 In simple type the magnetic core is built of laminations to form rectangular frame. The laminations are cut in the form of L-shape strips. In order to avoid high reluctance at the joint where laminations are butted against each other.

30 while placing this windings.

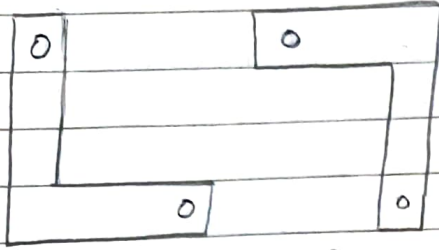
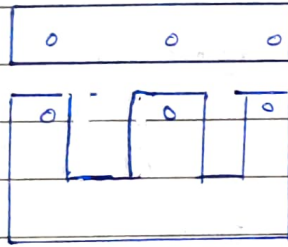
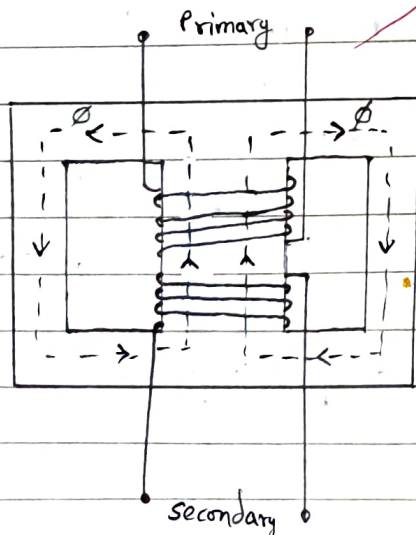


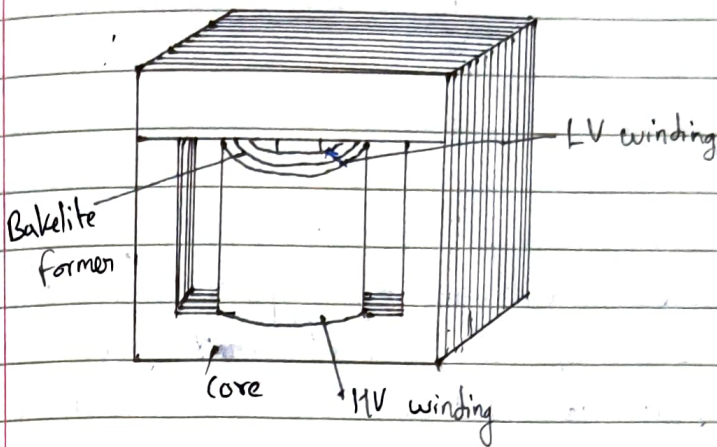
fig:- simple core type

- (6) Shell type transformer:- In case of shell type transformer individual laminations are cut in the form of long strips of E's & I's



In a shell type transformer the core has 3 limbs. The central limb carries whole of the flux, whereas the side limb carry half of the flux. Therefore the width of central limb is about double to that of the outer limb.





Both the primary & secondary winding are placed on the central limb. The low voltage winding is placed nearer to the core & the high voltage winding is placed outside the Low voltage winding to reduce the cost of insulation.

★ Ideal transformer :-

An ideal transformer is one which has no ohmic resistance & no magnetic leakage flux. i.e. all the flux produced in the core links with primary as well as secondary. Hence transformer has ~~no~~ no copper loss & core loss. In actual practice, It is impossible to realize such a transformer.

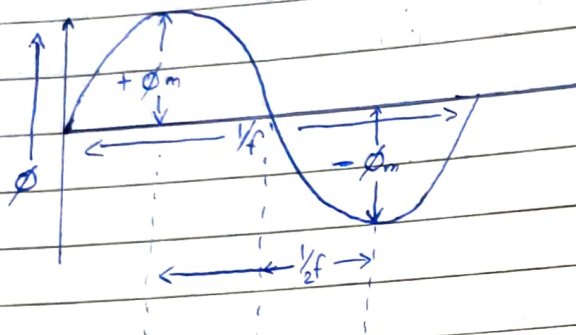
In an ideal transformer there is no power loss therefore output must be equal to input

$$E_2 I_2 \cos \phi = E_1 I_1 \cos \phi$$

$$\frac{E_2}{E_1} = \frac{I_1}{I_2} = \frac{V_2}{V_1} = \frac{N_2}{N_1} = K \text{ (Transformation ratio)}$$

★ EMF Equation

When sinusoidal voltage is applied to the primary winding of a transformer a sinusoidal flux is set up in the iron core which links with primary & secondary winding



- Let ϕ_m = maximum flux (wb)
- f = frequency (Hz) $[\frac{1}{s}]$
- N_1 = No. of turns in primary winding
- N_2 = No. of turns in secondary winding

As shown in figure, flux changes from $+\phi_m$ to $-\phi_m$ in a half cycle, $\frac{1}{2f}$ seconds.

$$\text{Avg. rate of change of flux} = \frac{\phi_m - (-\phi_m)}{\frac{1}{2f}}$$

$$= \frac{2\phi_m}{\frac{1}{2f}}$$

$$= [4f\phi_m \text{ wb/s}]$$

Avg. EMF induced per turn = $4f\phi_m$ volts

for a sinusoidal wave, rms value divided by average value

i.e. $\frac{\text{RMS value}}{\text{Avg. value}} = \text{form factor} = 1.11$

RMS value of EMF induced per turn $E = 1.11 \times 4f\phi_m$ volts

$$E \Rightarrow [4.44 f \phi_m] \text{ volts}$$

Since primary & secondary winding have N_1 & N_2 turns respectively.

So that RMS value of EMF induced in E_1

i.e. $E_1 = (\text{RMS value of EMF/turn}) \times \text{no. of turns}$

$$\therefore [E_1 = 4.44 f \phi_m N_1 \text{ volts}] \quad \text{--- (1)}$$

For secondary RMS value of induced EMF

$$[E_2 = 4.44 f \phi_m N_2 \text{ volts}] \quad \text{--- (2)}$$

We can find voltage ratio $\frac{E_2}{E_1} = \frac{N_2}{N_1} = k$

We can write flux max $\phi_m = B_m \times A_i$

where B_m = Magnetic flux density
 A_i = Area of iron core

$$\therefore [E_1 = 4.44 f B_m A_i N_1] \text{ volts}$$

a) A single phase 50 Hz transformer has 30 primary & 350 secondary turn. The net cross sectional area of core is 250 cm^2 . If the primary winding is connected to a 230 volt 50 Hz supply, calculate:-

- 1) Peak value of flux density in the core
- 2) Voltage induced in the secondary winding neglect losses, what is the primary current when the secondary current is 100 A

⇒ Given:-

$$f = 50 \text{ Hz}$$

$$N_1 = 30$$

$$N_2 = 350$$

$$A_i = 250 \text{ cm}^2 \quad \text{or} \quad 250 \times 10^{-4} \text{ m}^2$$

$$V_1 = E_1 = 230 \text{ volt}$$

$$B_m = ?$$

$$E_2 = ? , I_1 = ?$$

$$I_2 = 100 \text{ A}$$

We know that

$$[E_1 = 4.44 f B_m A_i N_1] \text{ volts}$$

$$E_1 = 4.44 \times 50 \times B_m \times 250 \times 30$$

$$230 = B_m = \frac{230}{4.44 \times 50 \times 250 \times 30 \times 10^{-4}}$$

$$\left[B_m = 1.38 \times 10^{-7} \text{ Tesla} \right]$$

$$\text{or} = [1.38 \text{ Tesla}]$$

$$\mathcal{E}_2 = 4.44 f B_m A_i N_2 \text{ volts.}$$

$$\mathcal{E}_2 = 4.44 \times 50 \times 1.38 \times 250 \times 10^{-4} \times 350$$

$$[\mathcal{E}_2 = 2680.65 \text{ volts}]$$

from transformation ratio

$$K = \frac{\mathcal{E}_2}{\mathcal{E}_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2}$$

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

$$\frac{350}{30} = \frac{I_1}{100}$$

$$I_1 = \frac{350}{30} \times 100$$

$$[I_1 = 1166.6 \text{ Amp}]$$

★ Transformer on No load.

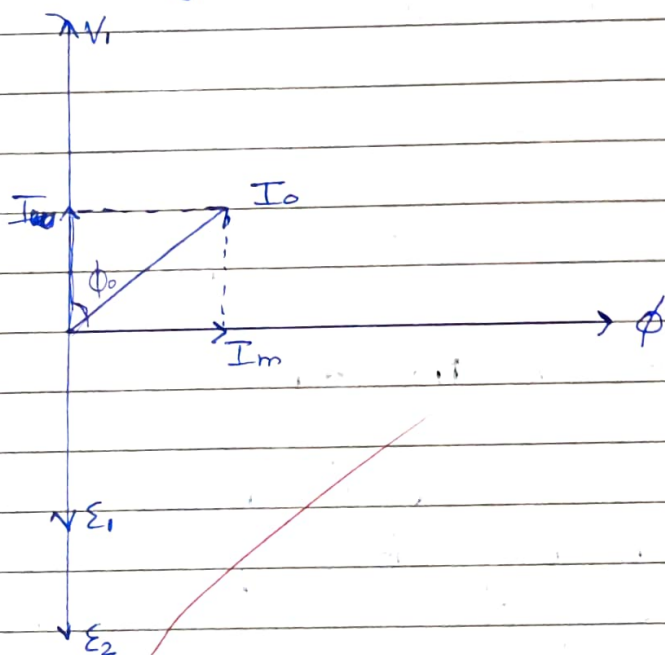
A transformer is said to be on no load when secondary winding is open ~~and~~ circuited & the secondary current I_2 is 0.

In actual transformer the losses can not be neglected therefore if transformer is on no load, a small current I_0 usually 2 to 10% of the rated value called exciting current is drawn by the primary.

This current has to supply in iron losses (Hysteresis & Eddy current losses) in the core & very small amount of [Cu.] losses in the primary.

The no load current I_0 has two components 1st I_w in phase with the applied voltage V_1 called active or working component it supplies the Iron losses & a small primary copper losses.

I_m in quadrature with the applied voltage V_1 called reactive or magnetizing from phaser diagram



Working Component $I_w = I_0 \cos \phi_0$ &
 $I_m = I_0 \sin \phi_0$

then no load current $I_0 = \sqrt{I_w^2 + I_m^2}$

No load power input = $P_0 = V_1 I_0 \cos \phi_0$

The no load current of a transformer is 5A at 0.25 power factor when supplied at 230 volts, 50 Hz. the no. of turns on primary winding are ~~two hundred~~ 200. Calculate:-

- 1) Max value of flux in the core ϕ_m
- 2) Core loss
- 3) Magnetizing current (I_m).

⇒ Given,

$$I_0 = 5A$$

$$\cos \phi_0 = 0.25$$

$$V_1 \text{ or } \mathcal{E}_1 = 230 \text{ volt}$$

$$f_{\text{req}} = 50 \text{ Hz}$$

$$N_1 = 200$$

1) We know that

$$\mathcal{E}_1 = 4.44 f \phi_m N_1 \text{ volt}$$

$$\phi_m = \frac{\mathcal{E}_1}{4.44 f N_1}$$

$$\phi_m = \frac{230}{4.44 \times 50 \times 200}$$

$$[\phi_m = 5.18 \times 10^{-3} \text{ mWb}]$$

$$= 5.18 \text{ mWb}$$

$$2) P_o = V_1 I_o \cos \phi_o$$

$$= 230 \times 5 \times 0.25$$

$$[P_o = 287.5 \text{ watt}]$$

$$3) \cos \phi_o = 0.25$$

$$\phi_o = \cos^{-1}(0.25)$$

$$\phi_o = 75.52$$

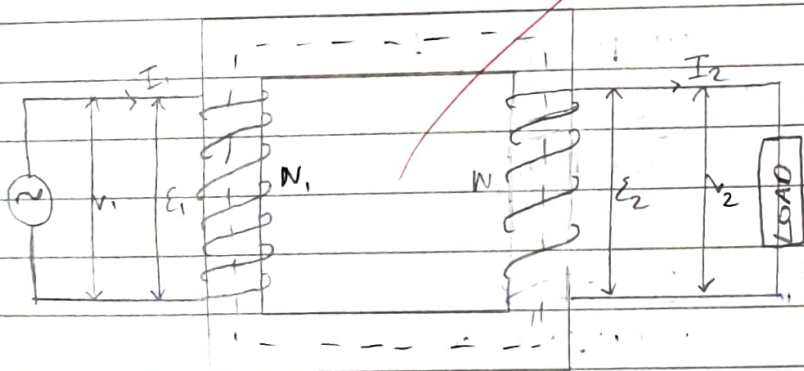
$$I_m = I_o \sin \phi_o$$

$$I_m = 5 \times \sin(75.52)$$

$$[I_m = 4.84 \text{ A}]$$

★ Transformer on load:- (neglecting winding resistance & leakage flux)

When a certain load is connected across the secondary, a current I_2 flows through it



The magnitude of current I_2 depends upon the

terminal voltage V_2 & Impedance of the load the phase angle of secondary current I_2 with respect to V_2 depends upon the nature of ~~flow~~ load. i.e. whether the load is resistive, inductive or capacitive.

* Equivalent circuit.

In transformers the problem of concerning voltage & current can be solved by the use of phaser diagram however it is more convenient to represent the transformer by an equivalent circuit. The resistance and leakage reactances of the primary & secondary are shown separately. in the primary & secondary circuit connected in parallel across the winding, the effect of core ~~is~~ loss is represented by non inductive resistance R_0 .

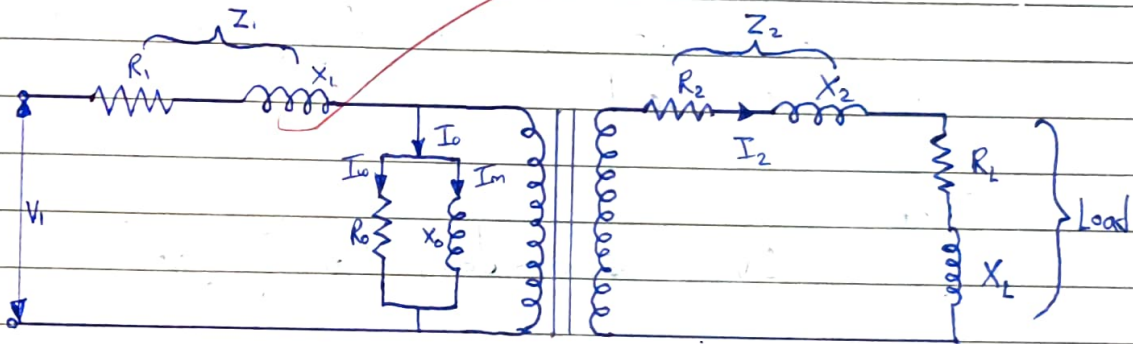


fig:- Equivalent circuit of a transformer.

★ Voltage regulation:- When a transformer is loaded with a constant supply voltage the terminal voltage changes depending upon the load & its power factor. The Algebraic difference between no load and full load terminal voltage is measured in terms of voltage regulation

Let E_2 = secondary terminal voltage at no load
 V_2 = secondary terminal voltage at full load

then voltage regulation = $\frac{E_2 - V_2}{E_2}$ (per unit)

Percent voltage regulation = $\frac{E_2 - V_2}{E_2} \times 100\%$

At a constant supply voltage the change in secondary terminal voltage from no load to full load with respect to no load voltage is called voltage regulation of transformer.

Thus if

OV_2 = secondary terminal voltage at no load
 $= V_2 + \text{Voltage drop}$

V_2 = Secondary terminal on load

$$\% \text{ V.R.} = \frac{OV_2 - V_2}{OV_2} \times 100 = \frac{\text{Voltage drop}}{V_2 + \text{Voltage drop}}$$

$$\%V.R = \frac{I_2 (R_{es} \cos \phi_2 + X_{es} \sin \phi_2)}{V_2 + I_2 (R_{es} \cos \phi_2 + X_{es} \sin \phi_2)} \times 100$$

Here :- R_{es} = Resistance in series
 X_{es} = Inductance in series.

★ Losses in a transformer

The losses which occur in an actual transformer are :-

- 1) Core or Iron losses (constant losses)
- 2) Copper losses (variable losses)

i) Core losses :- The alternating flux is setup in the core, therefore ~~the~~ hysteresis & eddy current losses occur in the magnetic core

ii) hysteresis loss :- When the magnetic material is subjected to reversal of flux, power is required for the continuous reversal of molecular magnets. This power is dissipated in the form of heat & is known as hysteresis losses.

$$[P_h = K_h V f B_m^{1.6}]$$

This loss can be minimized by using silicon steel material for the construction of core.

i) Eddy current loss:- Since the flux in a transformer core is alternating, It links with the magnetic material of the core. This induces EMF in the core & circulates Eddy current.

• Power is required to maintain this Eddy current this power is dissipated in the form of heat & is known as Eddy current loss.

• Formula:- $[P_e = K_e V f^2 t^2 B_m^2]$

• This loss can be minimized by making the core of thin laminations

⇒ The flux setup in the core of the transformer remains constant from no load to full load. Hence iron loss are independent of the load and are known as constant loss.

2) Copper loss:-

Copper losses occur in both the primary & secondary windings due to their ohmic resistance. If I_1, I_2 are the primary & secondary currents & R_1, R_2 are the primary & secondary resistance then $[Total Cu. loss = I_1^2 R_1 + I_2^2 R_2]$

The current in the primary & secondary windings vary according to the load therefore

this losses vary or vary according to the load & are known as variable losses.

- This losses vary as the square of load current

★ Efficiency of a transformer:-

- The efficiency of a transformer is defined as the ratio of output power to the input power

- Transformer efficiency $\eta = \frac{\text{Output power}}{\text{Input power}}$

$$\left[\eta = \frac{\text{o/p}}{\text{i/p}} = \frac{\text{output power}}{\text{output power} + \text{losses}} = \frac{\text{O/P Power}}{\text{O/P power} + \text{iron loss} + \text{Cu loss}} \right]$$

$$\left[\eta = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + P_i + P_c} \right]$$

Where:- P_i = fe. loss or Iron loss (Hysteresis + Eddy current loss) (constant losses)

P_c = Cu. loss ^{full load} or Copper loss (Variable losses)

V_2 = secondary terminal voltage

I_2 = secondary current (full load)

$\cos \phi_2$ = power factor of the load.

- IF x is the fraction of full load the efficiency of the transformer at this fraction is given by the relation

$$\eta_x = \frac{x \times \text{o/p}}{x \times \text{o/p} + P_i + x^2 P_c}$$

$$\left[\eta = \frac{x V_2 I_2 \cos \phi_2}{x V_2 I_2 \cos \phi_2 + P_i + x^2 I_2^2 R_{es}} \right]$$

* Condition For Maximum efficiency

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

$$\left[\eta = \frac{V_2 \cos \phi_2}{V_2 \cos \phi_2 + \frac{P_i}{I_2} + I_2 R_{es}} \right] \quad \text{--- (1)}$$

on taking I_2 common

The terminal voltage V_2 is Approximately constant.

Thus for a given power factor efficiency depends upon the load current I_2 . The numerator is constant & the efficiency will be maximum if denominator is minimum.

Thus the maximum condition is obtained by differentiating the quantity in denominator with respect to variable ' I_2 ' & equating that to zero.

$$\therefore \frac{d \left(V_2 \cos \phi_2 + \frac{P_i}{I_2} + I_2 R_{es} \right)}{d I_2} = 0$$

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

$$R_{es} = \frac{P_i}{I_2^2}$$

$$[I_2^2 R_{es} = P_i] \rightarrow (2)$$

$$\therefore [I_2^2 R_{es} = P_c]$$

$$\text{hence :- } [P_c = P_i]$$

therefore the maximum efficiency achieved when copper loss is equal to iron loss.

$$\left[\eta_{\max} = \frac{V_2 I_2 \cos \phi_2}{V_2 I_2 \cos \phi_2 + 2P_i} \right] \quad (P_i = P_c)$$

From eqn (2)

$$\left[I_2 = \sqrt{\frac{P_i}{R_{es}}} \right]$$

If x is the fraction of full load then copper loss is equal to $x^2 P_c$

$$[P_c = x^2 P_c]$$

$$\text{Iron loss} = P_i$$

for maximum efficiency of fraction of load

$$x^2 P_c = P_i$$

$$\left[x = \sqrt{\frac{P_i}{P_c}} \right]$$

Output KVA (kilo watt Ampere)

$$\text{Output KVA} = x \times \text{full load KVA}$$

$$\Rightarrow \sqrt{\frac{P_i}{P_c}} \times \text{full load KVA}$$

Qn) In a 25 KVA, 2000/200V power transformer the iron and full load Cu losses are 350 watt & 400 watt respectively. Calculate the efficiency at unity power factor at:-

- 1) Full load
- 2) Half load

⇒ Given:

$$V_1 = 2000 \text{ volt}, P = 25 \text{ KVA}$$

$$V_2 = 200 \text{ volt}$$

$$P_i = 350 \text{ watt}$$

$$P_c = 400 \text{ watt}$$

$$\cos \phi = 1$$

- i) Full load ($x = 1$)

$$\eta = \frac{x V_2 I_2 \cos \phi_2}{x V_2 I_2 \cos \phi_2 + P_i + x^2 P_c}$$

$$\eta = \frac{1 \times 25 \times 1000}{1 \times 25 \times 10^3 + 350 + (1)^2 \times 400}$$

$$\eta = 0.9708 \times 100\% = 97.08\%$$

2) Half load ($\alpha = 0.5$)

$$\eta = \frac{\alpha V_2 I_2 \cos \phi_2}{\alpha \times \frac{1}{2} I_2 \cos \phi_2 + P_i + \alpha^2 P_c}$$

$$\eta = \frac{0.5 \times 25 \times 10^3 \times 1}{0.5 \times 25 \times 10^3 + 350 + (0.5)^2 \times 400}$$

$$\eta = 0.965 \times 100\%$$

$$\eta = 96.52\%$$

Q. A $\frac{220}{400 \text{ volt}}$, 10 KVA, 50 Hz single phase transformer has at full load a ca. loss of 120 watt. if it has an efficiency of 98% at full load, unity power factor determine the iron losses. What would be the efficiency of the transformer at half load at 0.8 power factor lagging.

⇒ Given:

$$V_1 = 220 \text{ volt}$$

2nd condition

$$V_2 = 400 \text{ volt}$$

P

$$P_i = 120 \text{ watt}$$

$$P = 10 \text{ KVA}$$

$$\text{Frequen} = 50 \text{ Hz}$$

$$\eta = 98\%$$

$$\eta = \frac{x V_2 I_2 \cos \phi_2}{x V_2 I_2 \cos \phi_2 + P_i + x^2 P_c}$$

$$98\% = \frac{1 \times 10 \times 1000 \times 1}{10 \times 1000 * P_i + (1)^2 \times 120} \times 100\%$$

$$98\% = \frac{10000 \times 100\%}{10000 + 120 + P_i}$$

$$98\% = \frac{1000000}{10120 + P_i}$$

$$10120 + P_i = \frac{1000000}{98}$$

$$10120 + P_i = 10204.08$$

$$P_i = 10204.08 - 10120$$

$$[P_i = 84.08 \text{ watt}]$$

2nd condition at half load ($x = 0.5$)

& given $\cos \phi = 0.8$

$$\text{i.e. } \eta = \frac{x V_2 I_2 \cos \phi_2}{x V_2 I_2 \cos \phi_2 + P_i + x^2 P_c}$$

$$\eta = \frac{0.5 \times 10 \times 10^3 \times 0.8}{0.5 \times 10 \times 10^3 \times 0.8 + 84.08 + 0.5^2 \times 120}$$

$$\eta = 0.9722 \times 100\%$$

$$[\eta = 97.22\%]$$

Q₁ The efficiency of a 400 kVA single phase transformer is 98.77% when delivery full load at 0.8 power factor and 89.13% at half load and unity power factor. calculate:-

- 1) P_i (iron loss)
- 2) full load (Cu. loss P_c)

Q₂ A 50 kVA transformer has on full load a copper loss of 600 watt and iron loss of 500 watt. calculate the maximum efficiency η_{max} and the load at which it occurs.

★ All day efficiency :

The all day efficiency is defined as the ratio of output in kWh (kilo watt hour) or watt hour (wh) to the input in kWh or (wh) of a transformer over 24 hours.

$$\text{All day efficiency } \eta_{\text{all day}} = \frac{\text{Output in kWh}}{\text{Input in kWh}}$$

Qn A transformer has a maximum efficiency of 98% at 15 kVA at unity power factor it is loaded as follows.

- 1) 12 hours - 2 kW at power factor 0.5
- 2) 6 hours - 12 kW at power factor 0.8
- 3) 6 hours - 18 kW at power factor 0.9

Calculate all day efficiency of transformer.

Solution We know $\eta_{\text{max}} = \frac{x \text{ kVA} \cos \phi}{x \text{ kVA} \cos \phi + 2P_i}$

$$98\% = \frac{1 \times 15 \times 1}{1 \times 15 \times 1 + 2P_i} \times 100$$

$$98 = \frac{15}{15 + 2P_i} \times 100$$

$$15 + 2P_i = \frac{1500}{98}$$

$$15 + 2P_i = 15.306$$

$$2P_i = 15.306 - 15$$

$$P_i = \frac{0.306}{2}$$

$$P_i = 0.153 \text{ kW}$$

$$P_c = 0.153 \text{ kW}$$

$$[\text{at max } P_i = P_c]$$

During 24 hours the transformer is loaded as under.

S/no	Hrs	load in kW	P.F.	load in KVA $\text{kVA} = \frac{\text{kW}}{\cos \phi}$	fraction of load $x = \frac{\text{given load in KVA}}{\text{full load in KVA}}$
1)	12	2	0.5	$\frac{2}{0.5} = 4$	$x = \frac{4}{15} = 0.267$
2)	6	12	0.8	$\frac{12}{0.8} = 15$	$x = \frac{15}{15} = 1$
3)	6	18	0.9	$\frac{18}{0.9} = 20$	$x = \frac{20}{15} = 1.33$

$$\text{KWH output in 24 hours} = 2 \times 12 + 12 \times 6 + 18 \times 6$$

$$= 204 \text{ KWH}$$

$$\text{Iron loss (P}_i\text{) for 24 hours} = 0.153 \times 24$$

$$= \cancel{3.67} \text{ KWH} \quad 3.67 \text{ KWH}$$

$$\text{Cu. loss (P}_c\text{) for 24 hours} = 0.153 \times 12 \times (0.267)^2 + (1)^2 \times 0.153 \times 6 + (1.33)^2 \times 0.153 \times 6$$

$$P_c = 2.67 \text{ KWH}$$

$$\text{Input in KWH} = \text{O/p in KWH} + \text{losses}$$

$$= 204 + 3.6 + 2.67$$

$$= 210.27 \text{ KWH}$$

$$\text{All day efficiency } \eta_{\text{all day}} = \frac{\text{Output in kWh}}{\text{Input in kWh}}$$

$$= \frac{204}{210.27} \times 100\%$$

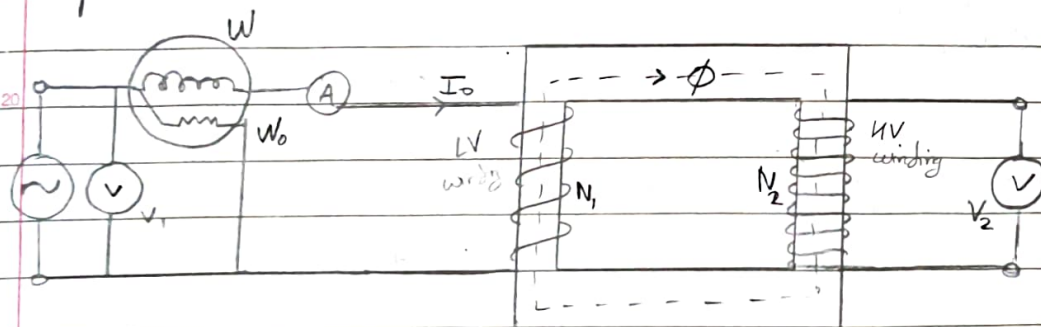
$$[\eta_{\text{all day}} = 97.01\%]$$

* Testing of transformer:

In order to determine the parameter of transformer voltage regulation & efficiency, the following two test are carried out.

- 1) Open circuit or no load test:-
- 2) short circuit test

∴ Open circuit or no load test:-

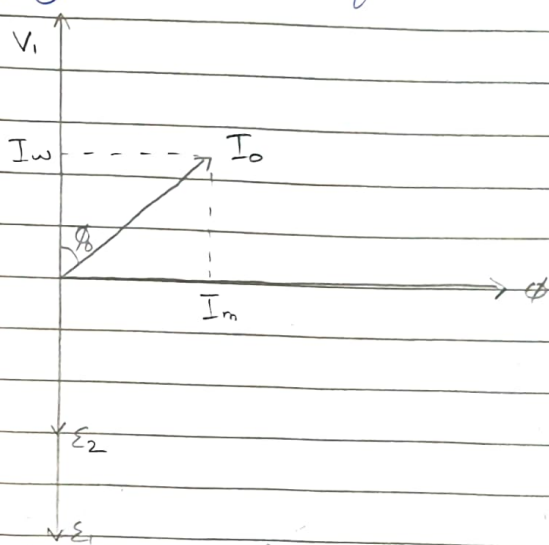


This test is carried out to determine no load loss or core loss or iron loss or constant loss and no load current I₀ which is helpful in finding no load parameters R₀ & X₀.

This test is usually carried out on the LV side.

Since the HV winding is open, ~~since~~ the current drawn by the primary is no load current I_0 measured by Ammeter (A). The value of I_0 is very small usually 2 to 10% of the rated full load current. Thus, the copper loss in the primary are negligibly small & no Cu. loss in the secondary as it is open therefore wattmeter reading W_0 only represent core or iron loss.

The ratio of voltmeter readings, $\frac{V_2}{V_1}$ gives the transformation ratio of the transformer.



The phases diagram of transformer at no load is shown:

Let the watt meter reading = W_0
 Volt meter reading = V_1
 Ammeter reading = I_0

Then, Iron loss (P_i) of the transformer = W_0
 & $V_1 I_0 \cos \phi_0 = W_0$

No load power factor $\left[\cos \phi_0 = \frac{W_0}{V_1 I_0} \right]$

Working component of current no load * $I_w = I_0 \cos \phi_0$

$$I_w = I_0 \times \frac{W_0}{V_1 I_0}$$

$$\left[I_w = \frac{W_0}{V_1} \right]$$

Using pythagorass theorem

$$I_0^2 = I_w^2 + I_m^2$$

$$\left[I_m = \sqrt{I_0^2 - I_w^2} \right]$$

No load parameters i.e. equivalent exciting resistance

$$\left[R_0 = \frac{V_1}{I_w} \right]$$

Equivalent exciting reactance $\left[X_0 = \frac{V_1}{I_m} \right]$

The iron loss measured by this test are required for the calculation of efficiency of the transformer.

* Short circuit test :-

This test is carried out to determine the following

- 1) Copper losses at full load or any desired load
- 2) Equivalent impedance (Z_{ep} or Z_{es})

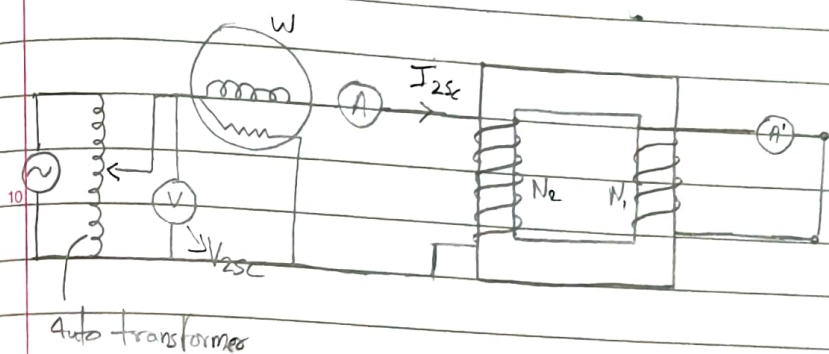


Fig. - Short circuit test.

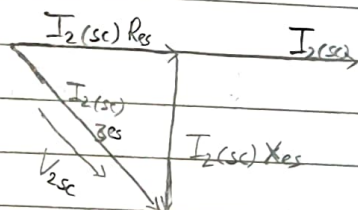


Fig. - Phasor diagram

This test is usually carried out on the high voltage side of the transformer.

The iron losses are negligibly small. Watt meter reading W_c only represents the copper losses in the transformer windings for all practical purposes. The Applied voltage $V_{2(sc)}$ is measured by the voltmeter V with which circulate the current $I_{2(sc)}$ in the impedance Z_{es} , let the wattmeter reading = W_c

Volt meter reading = $V_{2(sc)}$

Ammeter reading = $I_{2(sc)}$

Then the full load Cu. loss of the transformer

$$P_c = I_{2(sc)}^2 R_{es} = W_c$$

$$R_{es} = \frac{W_c}{I_{2(sc)}^2}$$

From phaser diagram $I_{2(sc)} \times Z_{es} = V_{2(sc)}$

$$Z_{es} = \frac{V_{2(sc)}}{I_{2(sc)}}$$

Equivalent reactance refer to secondary

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

Qn) The following test data is obtained on a 5kVA. 220 volt single phase transformer,

- 1) OC test - 220 volt, 2 Amp, 100 watt on LV side
- 2) SC test - 40 volt, 11.4 Amp, 200 watt on HV side

Determine the % age efficiency & regulation at full load 0.9 power factor lagging.

⇒ Given;

$$KVA = 5$$

$$N_1 : N_2 = 220/40$$

$$P_i = 100 \text{ watt}$$

$$P_c = 200 \text{ watt}$$

$$\cos \phi = 0.9$$

$$I_{sc} = 11.4 \text{ Amp}$$

$$I_o = 2 \text{ Amp}$$

$$V_{sc} = 40 \text{ volt}$$

$$\eta_x = \frac{x \text{ kVA } \cos \phi}{x \text{ kVA } \cos \phi + P_i + x^2 P_c}$$

$$\eta_x = \frac{1 \times 5 \times 10^3 \times 0.9}{1 \times 5 \times 10^3 \times 0.9 + 100 + (11)^2 + 200} \times 100 \Rightarrow 93.75 \%$$

From short circuit test

$$R_{es} = \frac{W_c}{I_2^2} = \frac{P_c}{I_2^2}$$

$$\Rightarrow \frac{200}{(11.4)^2} \Rightarrow 1.53 \Omega$$

$$Z_{es} = \frac{V_2(sc)}{I_2(sc)} = \frac{40}{11.4}$$

$$\Rightarrow 3.50 \Omega$$

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

$$= \sqrt{(3.50)^2 - (1.53)^2}$$

$$X_{es} \Rightarrow 3.14 \Omega$$

For finding % regulation formula will be

$$\% \text{ Regulation} = \frac{E_2 - V_2}{E_2} \times 100$$

$$E_2 = V_2 + I_2 R_{es} \cos \phi_2 + I_2 X_{es} \sin \phi_2$$

$$\cos \phi_2 = 0.9$$

$$\phi_2 = \cos^{-1}(0.9) = 25.84^\circ$$

$$\sin(25.84) = 0.435$$

$$\Sigma_2 = 40 + 11.4 \times 1.53 \times 0.9 + 11.4 \times 3.14 \times 0.435$$

$$\Sigma_2 = 71.26$$

$$\therefore \text{Regulation} = \frac{71.26 - 40}{71.26} \times 100$$

$$\therefore \text{Regulation} \Rightarrow 43.86 \%$$

★ Auto transformer:-

15 An auto transformer is a transformer with only one winding wound on a laminated core ~~apart~~ ~~of~~ a part of this winding is common to both primary & secondary winding.

20 In a auto transformer the primary & secondary windings are connected magnetically and electrically.

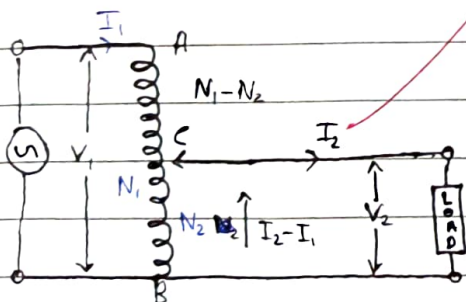


Fig:- Auto transformer

30 Winding A-B from which a tapping at C is taken, such that CB ACTs as a secondary winding. The supplied voltage is applied across AB and the load is connected across CB the tapping may be fixed or

variable.

* Uses of Auto transformer:-

- a. It is used as an autotransformer starter to give upto 50 to 60% of full load voltage to the starter of a squirrel cage induction motor during starting.
- b. It is used to give a small boost to a distribution cable to correct the voltage drop.
- c. It is used as a regulating transformer (the tap point is variable in this case).

i Disadvantage:-

- a. Autotransformer has less cost better regulation & low losses as compared to ordinary two winding transformer.
- b. Disadvantage:-
 - a. The major disadvantage of auto transformer is the secondary winding is not insulated from primary.
 - b. If an auto transformer is used to supply low voltage from high voltage & there is a break in secondary winding, the full primary voltage comes across the secondary terminals, which may be dangerous to the operator & equipment.

John

Polyphase transformer

★ 5.1: Formulation of 3 phase transformer by 3 single phase transformers.

Three single phase transformers are formulated into a three phase transformer by connecting their primary & secondary winding in either a star or delta configuration.

The choice of connection such as delta-star, star-star, delta-delta, affect the output voltage, phase shift & load characteristics of the system.

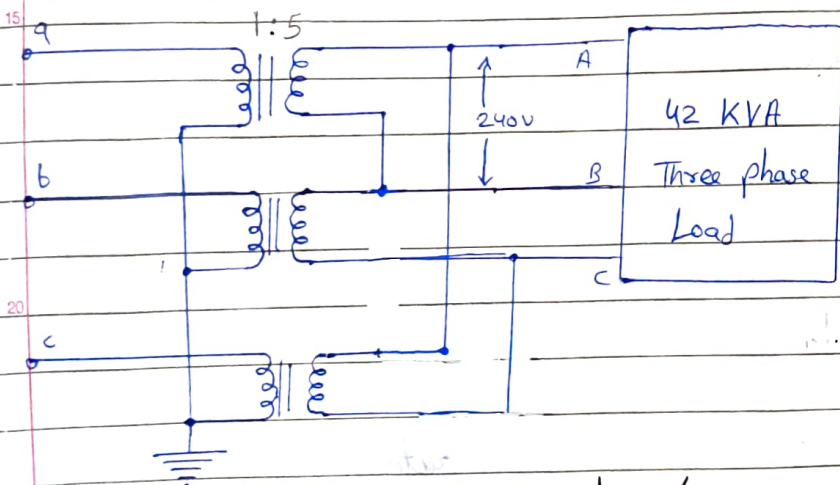


fig:- 3 phase transformer.

★ Primary & secondary connection:

- Each of the three single phase transformers has the primary & secondary winding. These windings are connected in either a star or delta configuration with different combinations possible.

Ex:- Delta-star, star-star, delta-delta.

- b) Star connection:- One end of each winding is connected to a common neutral point.
- c) Delta connection:- The windings are connected in a closed triangle or loop.

★ Voltage & current formula:-

a) The relationship between line voltage (V_L) & phase voltage (V_{ph}) depends on the connection.

b) Star:-

$$V_L = \sqrt{3} V_{ph}$$

$$I = I_{ph}$$

c) Delta:-

$$V_L = V_{ph}$$

$$I_L = \sqrt{3} I_{ph}$$

★ Important consideration:-

a) Phase displacement:- The connection type (Ex:- Delta-star) introduces a phase shift between the primary & secondary line voltages.

b) Three phase power:- The three phase power is calculated using the formula $P = \sqrt{3} V_L I_L \cos \phi$

★ 5.2: Three phase star delta connection

A three phase star delta transformer has a delta connected primary winding & a star connected secondary winding. This connection is commonly used at the start of high tension transmission to step up voltage & create a neutral point on the secondary side for grounding, allowing for a three phase 4-wire system.

i) Primary :- Delta winding

ii) Primary (Delta) winding:-

a) Connection:- The three primary windings are connected in a closed loop or a triangular delta shape.

b) Voltage:- The line voltage is equal to the phase voltage. ($V_L = V_{ph}$)

c) Current:- The line current is $\sqrt{3}$ times the phase current. ($I_L = \sqrt{3} I_{ph}$)

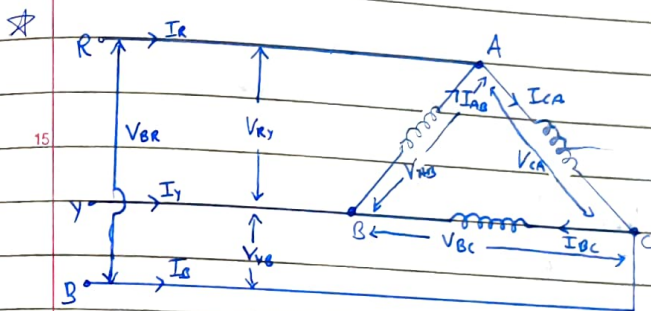
2) Secondary (star) winding:-

a) Connection:- The three secondary windings are connected to a common central point, creating a star configuration.

b) Voltage:- The line voltage is $\sqrt{3}$ times the phase voltage
($V_L = \sqrt{3} V_{ph}$)

c) Current:- The line current is equal to the phase current.
($I_L = I_{ph}$)

d) Neutral point:- The star connection provides a neutral terminal which is essential for grounding & creating a four wire system, enabling wider range of voltage output.



$$V_{RY}, V_{YB}, V_{BR} = V_L \text{ (line voltage)}$$

$$V_{AB}, V_{BC}, V_{CA} = V_{ph} \text{ (phase voltage)}$$

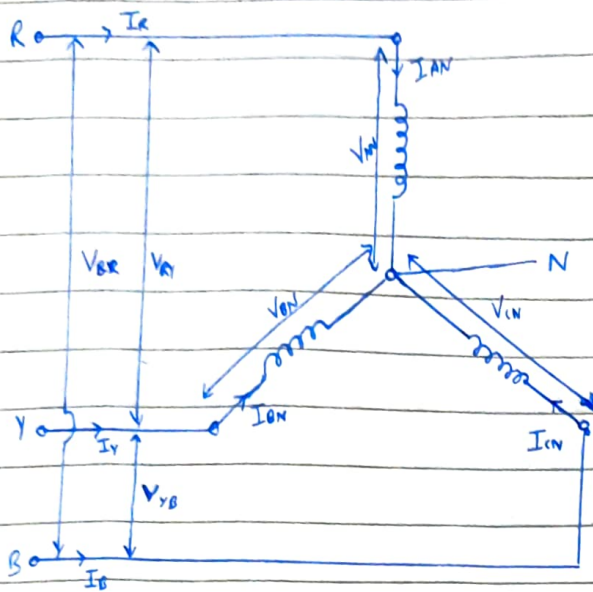
$$V_L = V_{ph}$$

$$I_L = \sqrt{3} I_{ph}$$

$$I_R, I_Y, I_B = I_L \text{ (line current)}$$

$$I_{AB}, I_{BC}, I_{CA} = I_{ph} \text{ (phase current)}$$

Fig:- Primary (delta) winding connection



$$[I_L = I_{ph}]$$

$$[V_L = \sqrt{3} V_{ph}]$$

$$I_R, I_Y, I_B = I_L \quad (\text{line current})$$

$$I_{AN}, I_{BN}, I_{CN} = I_{ph} \quad (\text{line phase current})$$

$$V_{RY}, V_{YB}, V_{BR} = V_L \quad (\text{line voltage})$$

$$V_{AN}, V_{BN}, V_{CN} = V_{ph} \quad (\text{phase voltage})$$

★ Application & Benefits

- 4-wire system:- The star connected secondary provides a neutral, allowing for both three phase & single phase load to be supplied from the same transformer.
- Voltage stepup:- The delta star connection is ideal for stepping up voltage at the beginning of a power transmitting system.
- Industrial motor starting:- It can reduce starting current & handle high inrush current making it suitable for starting large motors, pumps

2 compressors

★ Constructional details of 3-phase transformer:-

A three phase transformer is constructed from a common magnetic core & three sets of primary & secondary winding.

The core typically made of laminated steel, has three limbs, & the windings are placed on these limbs.

- 1) Core type :- a) Core:- Features 3 vertical limbs for the windings & two horizontal sections (Yoke) to complete the magnetic circuit.

b) Windings:- For each limb the low voltage, (LV) winding is placed next to the core, followed by the high voltage (HV) winding on top. Insulation & oil ducts are placed between the core & the LV winding & between the LV & HV windings.

◊ Lamination:- The core is made of laminated steel sheets to reduce eddy current losses.

2) Shell type construction:-

a) Core:- Consist of 3 single phase shell transformer units stacked together.

b) Windings:- The windings are arranged to balance the magnetic flux path with the central units winding direction often opposite to the outer units.

c) Advantages:- This construction offers a more balanced flux & is more resilient to magnetic imbalance.

★ Accessories of transformer:-

a) Bushing:- Provide insulated terminal for external electrical connection, preventing current leakage to the tank.

b) Conservator tank:- A separate tank mounted above the

main tank that stores excess oil as it expands due to heat preventing it from being released & preventing the main tank from being overfilled

- 5
- c) Breather:- Connected to the conservator tank, it filters moisture from the air that enters the transformer as the oil level drops it typically contains silica gel which changes colour when saturated with moisture.
- 10
- d) Buchholz relay:- A gas actuated safety device installed btwn main tank & the conservator tank. It detects ~~into~~ internal fault by sensing the gas bubbles produced which can cause it to trigger an alarm or shutdown the transformer.
- 15
- e) Explosion vent:- A safety device, often a thin aluminium pipe, that provides a quick release for excessive pressure inside the tank, preventing the tank from rupturing during a severe internal fault.
- 20
- f) Cooling system:- Larger transformers often have external radiators. The transformer oil is circulated through this radiator, where air cools it down before it is return to the tank.
- 25
- g) Valve:- Located on the tank for filling with oil, draining oil for maintenance & for taking oil sample.
- 30
- f) Thermometer:- Measures the oil temperature & can include a thermostat to activate cooling fans at a certain temperature.

g) Voltage regulator or tap changer:- Used to adjust the output voltage by changing the no. of turns on the windings, compensating for voltage fluctuations.

h) Terminal box:- A grounded weather resistant enclosure that houses & protect the external connections.

5.4) Parallel operation of ^{two} 3-Phase transformer

Parallel operation of two - 3-Phase transformers allows for increased capacity, improved reliability, & greater flexibility in handling power distribution.

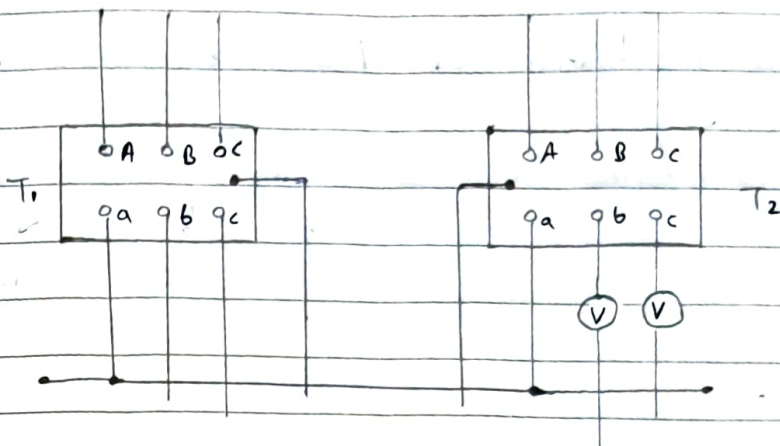
1) Increased capacity:- To meet the needs of a load i.e. greater than a single transformer capacitor.

2) Improved reliability:- If one transformer fails & or need maintenance, the other can continue to supply power, preventing a complete service interruption.

3) Greater flexibility:- Additional transformers can be added to a system as power demands grow in the future.

4) Economic Advantage:- It can be more cost-effective to add a smaller transformer in parallel than to replace a larger one with an even bigger.

unit.



★ 10 Conditions for Successful Parallel Operations

- Voltage ratio:- The line voltage ratings must be equal.
- Impedance:- The per unit impedance of each transformer should be same.
- Polarity:- They must have the same secondary winding polarity.
- Phase sequence:- The phase sequence must be identical for all transformers.
- Phase displacement:- The phase displacement btwn the primary and secondary winding must be the same.

S.S Cooling methods of Power transformers.

Power transformer cooling methods include ~~as~~ natural & forced air cooling for dry type transformers & natural & forced oil circulation for oil immersed transformers.

1) Air based cooling:-

a) Air natural (AN):- Uses ambient air to cool the transformer through natural convection typically for smaller, dry type units.

b) Air force (AF):- Uses fans or blowers to force air around the transformer for enhanced cooling, suitable for higher rated dry type transformers.

2) Oil based cooling (For oil immersed transformer)

a) Oil natural Air natural (ONAN): Heat is transferred to the oil; which then circulates naturally via convection. The hot oil rises, releases heat to the air in radiators, cools down & sink to be reheated.

b) Oil natural Air force (ONAF):- Like ONAN, but fans are used to force air over the radiators to speedup the cooling of the oil & dissipate more heat.

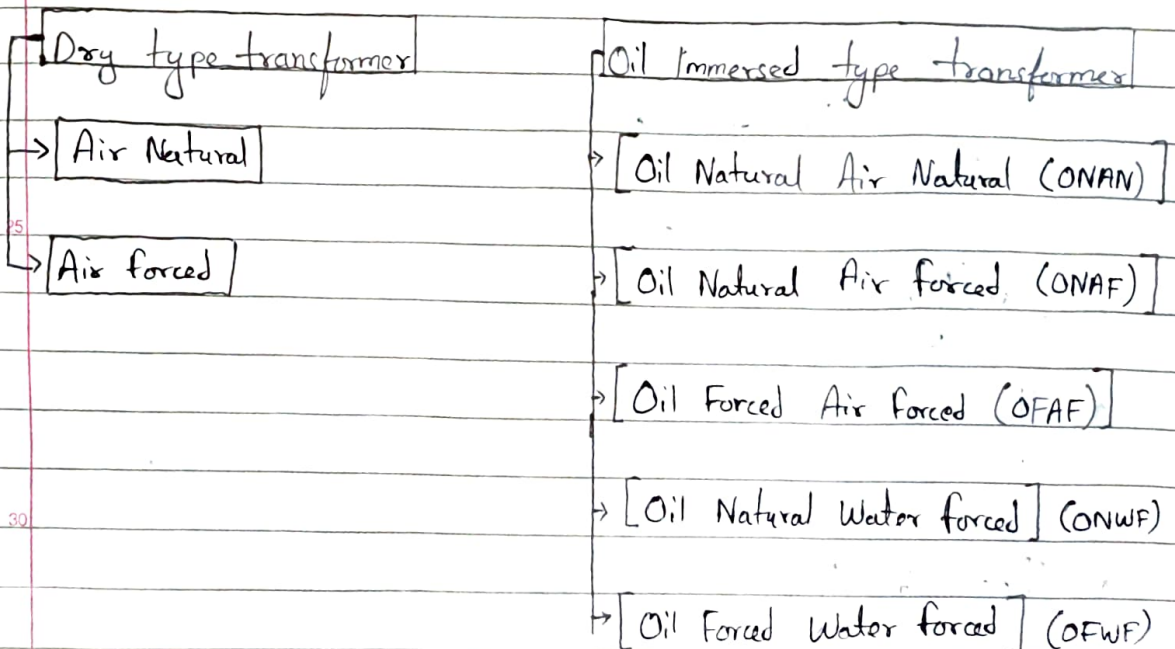
c) Oil forced Air forced (OFAF): Uses pumps to ~~force~~ force the circulation of oil through coolers & fans to force air over the coolers, providing efficient cooling for high power transformers.

d) Oil Air Forced Water forced (OAFWF): Uses forced oil and forced water circulation through heat exchangers for cooling.

3) Other methods:-

a) Oil water air forced:- Combines oil, water & air to provide high cooling efficiency for Ultra high capacity transformers.

b) Less flammable liquid cooling:- Similar cooling method to oil immersed transformers but with a different liquid & different IEEE designation
ex:- KNAN, KNAF



5.6) Maintenance procedure of different types of 3ϕ transformer.

- Maintenance for 3ϕ transformer is categorized into daily, monthly and yearly checks like checking oil levels & silica gel colours, inspecting bushing monthly & testing oil & tightening connections annually.

10 i) Daily checks:-

a) Road Gauges:- Check the main oil gauge on the conservator & main tank

15 b) Inspect silica gel:- look at the colour of the silica gel in the breather if it is pink then it is need to be reactivated.

20 c) Checks for oil leaks:- look for any oil leaks from the transformer.

d) Inspect the breather:- Ensure the breathing holes are clear for proper air passage

25 ii) Monthly checks:-

a) Clean breather:- Clean the breathing holes in silica gel breather if they are clogged.

b) Check bushing:- If the transformer has oil filled

bushing check the oil level in the attached oil gauge.

3) Annual checks:-

- a) Clean bushing:- Clean all transformer bushing with a soft cotton cloth.
- b) Test oil:- Take an oil sample & test it for moisture & dielectric strength.
- c) Tighten connection:- Check & tighten all control & relay wiring terminal connections.
- d) Inspect cooling system:- Check the auto remote & manual function of the cooling system ~~into~~ including oil pumps & fans.
- e) Check relays:- Ensure the proper function of bushholz & pressure relief device relay.
- f) Inspect surge arrester:- Check the spark gap assembly of any voltage transformers & clean the electrodes if needed.

★ Maintenance for Dry type transformers.

- a) listen for unusual sound:- Unusual noise can indicate mechanical problems ~~remove~~ obstructions.
- b) Remove obstruction:- Ensure the area around the transformer is clear to prevent

area heating & ensure proper ventilation.

- c) Clean surface:- De-energize the transformer to clean dust & dirt from the surface.

★ General safety precautions

- a) De-energize:- Never perform maintenance on a live transformer ensure it is completely de-energized & discharged before starting.
- b) Wear P.P.E:- Operator must wear insulating shoes & gloves.
- c) Follow proper procedure:- Donot attempt to switch on the transformer by mistake donot touch the transformer before it is fully discharge.
- d) Cleanliness:- Keep the area around the transformer clean & free of dirt to prevent damage and ensure efficient cooling.

[Signature]

Unit-2

DC - Generators

★ Introduction:- A DC machine is an electrical electro-mechanical energy conversion device. It can convert mechanical power (wt) to dc electrical power (EI) & is known as a d.c. generation. On other side, when it convert dc. electrical power into mechanical power it is known as dc. motor.

10 Although battery is an important source of d.c. electrical power but it can supply a limited power. There are some applications where large quantity of dc power is required, at such places dc generators are used to deliver power.

★ Main construction features:-

The complete assembly of various parts in a scattered form of dc machine is shown in figure. The essential parts of a dc machine are described below.

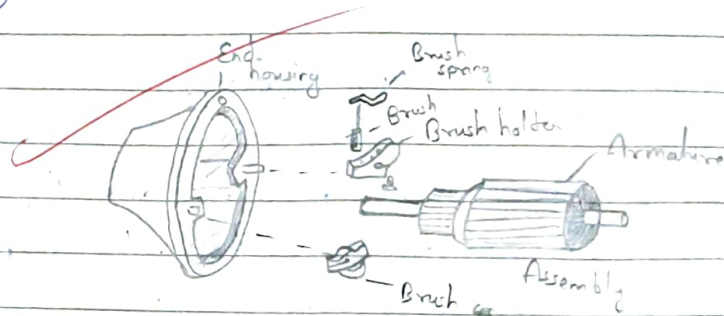


Fig:- Parts of motor/generator

★ Magnetic frame or Yoke:- The outer cylindrical frame to which main poles and inter-poles are fixed & by means of which the machine is fixed to the foundation is called the yoke. It serve two purposes.

1) It provides mechanical protection to the inner parts of the machine.

ii) It provides a low reluctance path for the magnetic flux

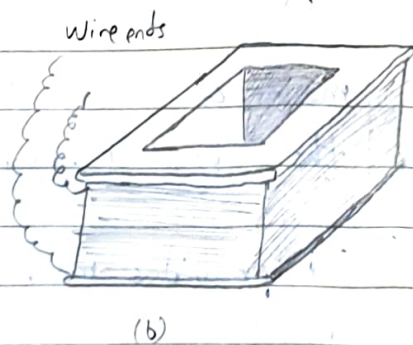
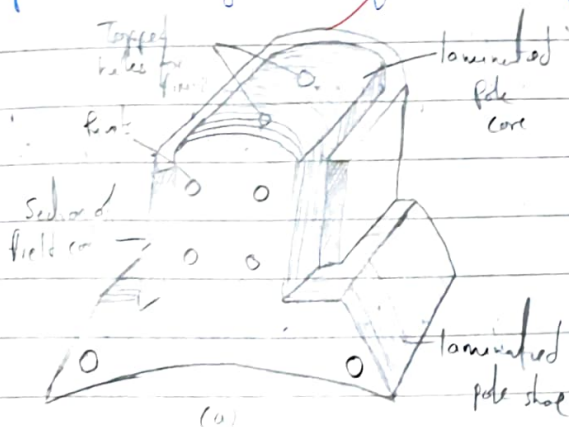
The yoke is made of cast iron for smaller machines and for larger machines, it is made of cast steel or fabricated rolled steel since these material have better magnetic properties as compared to cast iron

2) Pole Core & Pole shoes:- The pole core & pole shoes are fixed to the magnetic field frame or yoke by bolts. They serve the following purposes.

- 1) They support the field or exciting coils
- 2) They spread out the magnetic flux over the armature periphery more uniformly.
- 3) Since pole shoes have larger X-section, the reluctance of magnetic path is reduced

Usually, the pole core & pole shoes are made of thin cast steel laminations which are rivetted together under hydraulic pressure

3) Field or Exciting coils:- Anamelled copper wire is used for the construction of field or exciting coils. The coils are wound on the former and then placed around the pole core as shown in fig. When direct current is passed through the field winding.



It magnetises the poles which produce the required flux. The field coils of all the poles are connected in series in such a way that when current flows through them, the adjacent poles attain opposite polarity as shown in fig 6.3.

★ **Armature core:** It is cylindrical in shape and keyed to the rotating shaft at the outer periphery. Slots are cut as shown in fig:- which accommodate the armature winding. The armature core serves the following purposes:-

- 1) It houses the conductors in slots.
- 2) It provides an easy path for magnetic flux.

Since armature is the rotating part of the motor, reversal of flux takes place in core, hence hysteresis losses are produced. To minimize these losses silicon steel material is used for its construction. The rotating armature cuts across the magnetic field which induces an e.m.f. in it. The e.m.f. circulates ~~eddy~~ currents which results in eddy current loss in it. To reduce these losses, armature core is laminated. In other words we can say that about 0.3 to 0.5 mm thick stampings are used in construction.

★ **Armature winding:-** The insulated conductors housed in the armature winding. The armature slots are suitably connected. This is known as armature winding. The armature winding is the heart of d.c. machine. It is a place where conversion of power takes place i.e. in case of generator, mechanical power is converted into electrical power & in case of motor electrical power is converted

into mechanical power. On the basis of connections, there are two types of armature winding named as (1) lap winding & wave winding.

1) Lap winding:- In lap winding, the conductors are connected such a way that number of parallel paths are equal to the no. of poles.

i.e. $A = P$, If machine has P poles and Z armature conductors, then there will be P parallel paths, each path will have $\frac{Z}{P}$ conductors in series. In this case, the number of brushes is equal to the number of parallel paths out of which half the brushes are positive & the remaining half are negative.

2) Wave winding:- In wave winding, the conductors are so connected that they are divided into two parallel paths irrespective of the number of poles of the machine. Thus if machine has Z armature conductors there will be only two parallel paths each having $\frac{Z}{2}$ conductors in series. In this case the number of brushes is equal to two i.e. number of parallel paths.

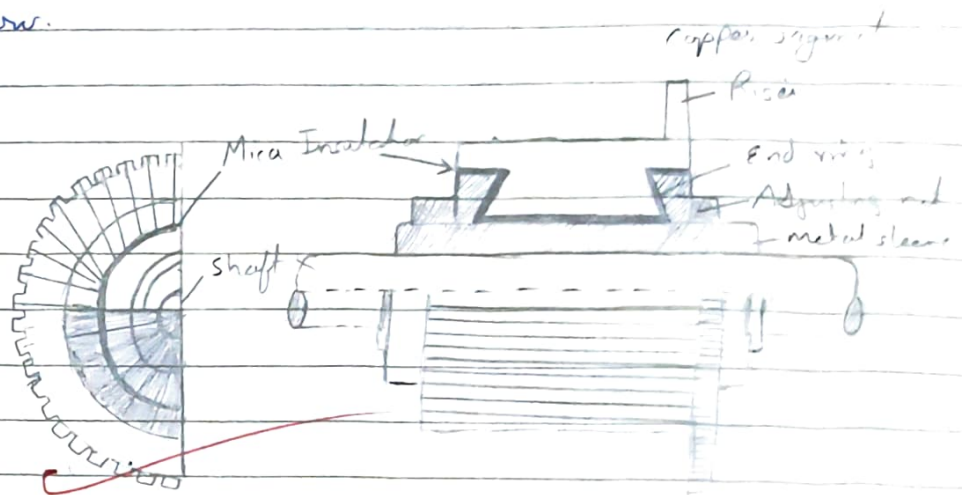
* Commutator $\Rightarrow$ It is the most ~~comm~~ important part of a dc machine & serves the following purposes.

1) It ~~converts~~ ^{converts} the alternating current induced in the armature into unidirectional current in the external load circuit in generator action, whereas it converts the alternating torque into continuous torque produced in armature motor action.

2) It connects the rotating armature conductors to the

stationary external circuit through brushes.

The commutator is of cylindrical shape & is made up of wedge-shaped hard drawn copper segments. The segments are insulated from each other by a thin sheet of mica. The segments are held together by means of two V-shaped rings that fit into the V grooves cut into the segments. Each armature coil is connected to the commutator segment through riser. The sectional view of the commutator assembly is shown in fig below.



★ Brushes

The brushes are pressed upon the commutator & form the connecting link between the armature winding & the external circuit. They are usually made of high grade carbon because C is conducting material & at the same time in powdered form provides lubricating effect on the commutator surface. The brushes are held in particular position around the commutator by brush holders.

8) End housings:-

End housings are attached to the end of the machine frame & support bearings. The front housing supports the bearing & the brush assemblies whereas the rear housing usually supports the bearing only.

A Bearing:-

The ball or roller bearings are fitted in the end housings. The functions of the bearings is to reduce friction between the rotating & stationary parts of the machine. Mostly high carbon steel is used for the construction of bearing as it is very hard material.

A Shaft:-

The shaft is made of mild steel with a maximum breaking strength. The shaft is used to transfer mechanical power from or to the machine. The rotating part like armature core, commutator, cooling fan etc. are keyed to the shaft.

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4/12/25

2.1 Working & applications of different types of DC generator (DC series & DC shunt)

★ Types of DC generators :-

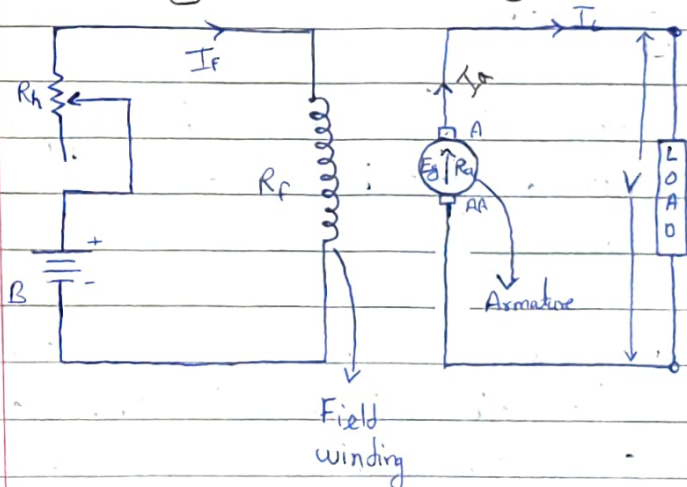
DC generators are generally classified according to the method of their field excitation on the basis of these criteria, They can be classified as:-

- 1) Separately excited DC generator
- 2) Self excited DC generator.

Self excited DC generator further classified as:-

- 1) Shunt wound DC generator
- 2) Series wound DC generator
- 3) Compound wound DC generators - 1) Long shunt compound wound generator
2) Short shunt compound wound DC generator

★ Separately excited DC generators



A DC generator whose field winding is supplied current from an external DC source is called a separately excited DC generator.

The flux produced by the poles depends upon the field current (i.e. ϕ is proportional to I_f) or ($\phi \propto I_f$). But in the saturated region ϕ The flux remains constant

• Important Relation:- Here $I_a = I_L$ where I_a = armature current & I_L = load current.

• Terminal voltage:- $V = E_g - I_a R_a$

• If contact or brush drop (V_b is known then $V = E_g - I_a R_a - 2V_b$)

• Power developed $\Rightarrow E_g \times I_a$

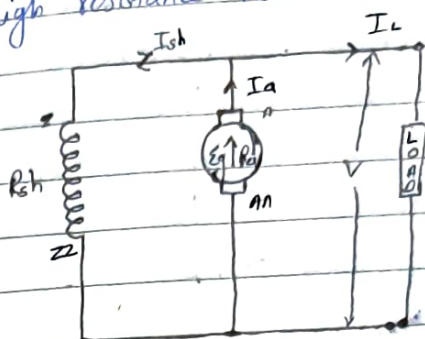
• Power output $\Rightarrow V \times I_L$ or $V \times I_a$

★ Self excited DC generator

A DC generator whose field winding is supplied current by the generator itself is called a self excited DC generator.

a) Shunt wound generator: In a shunt wound generator the field winding is connected across the armature winding forming a parallel or shunt circuit.

Therefore full terminal voltage is applied across it.
 A very small current I_{sh} (shunt current) flows through it
 because this winding has many turns of fine wire having very
 high resistance R_{sh}



Important relation:-

a) Shunt field current:- $I_{sh} = \frac{V}{R_{sh}}$

- The field current I_{sh} is practically constant at all loads
 therefore the DC shunt machine is considered to be
 constant flux machine.

b) Armature current:- $I_a = I_L + I_{sh}$

c) Terminal voltage:- $V = E_g - I_a R_a$

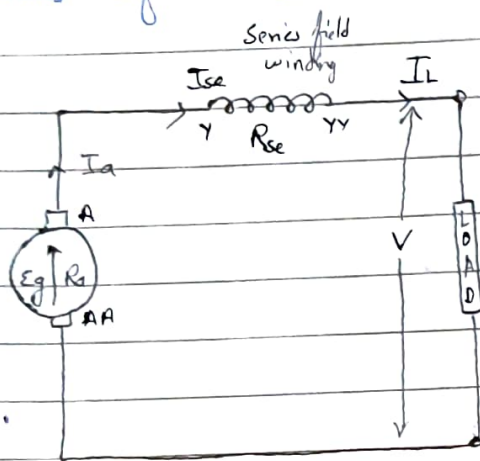
Including brush contact drop V_b Then
 $V = E_g - I_a R_a - 2V_b$

d) Power developed:- $E_g \times I_a$

e) Power output:- $V \times I_L$

* Series wound generator:

In a series wound generator the field winding is connected in series with the armature winding forming a series circuit. Therefore full line current I_L or armature current I_a flows through it. Since the series field winding carries the full load current therefore it has a few tons of thick wire having low resistance.



Important Relation

• Series field current: $I_{se} = I_L = I_a$

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

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

Including brush contact drop then

$$V = E_g - I_a (R_a + R_{se}) - 2V_b$$

Note: The flux developed by the series field winding is directly proportional to the current flowing through it. i.e. $\phi \propto I_{se}$

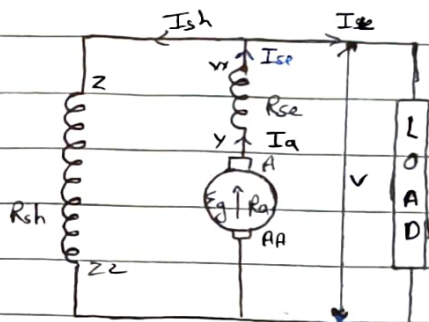
After saturation flux become constant even if the current flowing through it is increased.

* Compound wound generator

In a compound wound generator there are two set of field winding on each pole. One of them is connected in series (having few turns of thick wire) and the other is connected in parallel having many turns of fine wire (with armature).

A compound wound generator may be:-

- 1) Long shunt compound wound generator:- in which the shunt field winding is parallel with both armature and series field winding.



Important Relation:-

- Shunt field current:- $I_{sh} = \frac{V}{R_{sh}}$

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

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

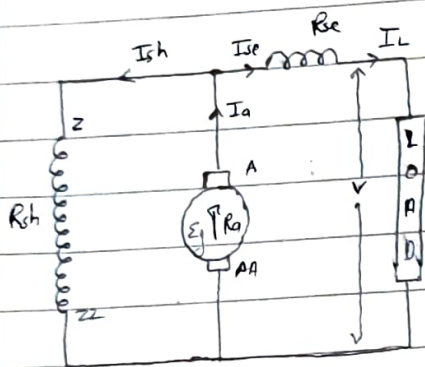
Including brush then $V = E_g - I_a (R_a + R_{se}) - 2V_b$

★ Power developed:- $E_g \times I_a$

• Power output:- $V \times I_L$

★ Short shunt compound wound Generator:-

In which shunt field winding is in parallel with only armature winding. The conventional diagram of short shunt compound wound generator is shown:-



Important Relations

• Series field current:- $I_{se} = I_L$

$$I_{sh} = \frac{V + I_L R_{se}}{R_{sh}} \Rightarrow \frac{E_g - I_a R_a}{R_{sh}}$$

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

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

$$V = E_g - I_a R_a - I_{se} R_{se} - 2V_b$$

• Power developed:- $E_g \times I_a$

• Power output = $V I_L$

② EMF Equation of DC generator

Let,

P = no. of poles of the machines

ϕ = flux per pole in wb (weber)

Z = total no. of Armature conductor.

N = Speed of armature in rpm

A = No. of parallel path in the armature winding

In one revolution of the armature, flux cut by one conductor = $P\phi$ wb

Time taken to complete one revolution: $(t) = \frac{60}{N}$ sec

Average induced emf in one conductor (e) = $\frac{P\phi}{t}$

$$= \frac{P\phi}{60/N}$$

$$\left[e = \frac{P\phi N}{60} \right]$$

The no. of conductors connected in series in each parallel path = $\frac{Z}{A}$

Average induced emf across each parallel path or across the armature terminals, $E = \frac{P\phi N}{60} \times \frac{Z}{A}$

$$\left[E = \frac{P\phi ZN}{60A} \right] \text{ volts}$$

$$\text{or } \left[E = \frac{P\phi nZ}{A} \right]$$

where $n = \frac{N}{60}$

n = speed in rps

For a given machine the no. of poles, no. of conductors per parallel path ($\frac{Z}{A}$) are constant

Then $\mathcal{E} = k\phi n$ where,

$$k = \frac{PZ}{A} \text{ is constant}$$

then $[\mathcal{E} \propto \phi n]$

or $[\mathcal{E} \propto \phi N]$

$$\mathcal{E} = k_1 \phi N \quad \text{where } k_1 = \frac{PZ}{60A}$$

or $\mathcal{E} = \phi \omega$ where $\omega = \frac{2\pi N}{60}$ = Angular velocity

When the machine is working as a generator this induced emf is called generated emf = $\frac{P\phi NZ}{60A}$

$$\left[\mathcal{E}_g = \frac{P\phi NZ}{60A} \right] \text{ volts}$$

In case of the machine is working as a motor, this induced emf is called Back emf and it acts opposite to the supplied voltage.

$$\left[\mathcal{E}_b = \frac{P\phi NZ}{60A} \right] \text{ volts}$$

Q. A four pole DC shunt generator with a shunt field resistance of 100Ω & Armature resistance of 1Ω has 378 wave connected conductor in its armature. The flux per pole is 0.02 wabers. If a load resistance of 10Ω is connected across the armature terminals & the gener

motor is driven at 1000 rpm, calculate the power absorbed by the load.

⇒ Given,

no. poles $P = 4$

$$R_{sh} = 100 \Omega$$

$$R_a = 1 \Omega$$

$$Z = 378$$

$$A = 2 \text{ (for wave winding)}$$

$$\phi = 0.02 \text{ wb}$$

$$R_L = 10 \Omega$$

$$N = 1000 \text{ rpm}$$

Generated emf
$$E_g = \frac{P \phi N Z}{60 A}$$

$$E_g = \frac{4 \times 0.02 \times 1000 \times 378}{60 \times 2}$$

$$E_g = 252 \text{ volts}$$

Armature current $I_a = I_L + I_{sh}$ ——— (1)

line current $I_L = \frac{V}{10}$ ——— (1)

shunt ^{field} current $I_{sh} = \frac{V}{100}$ ——— (2)

Substituting the value of I_L & I_{sh} in eqn A

$$I_a = \frac{V}{10} + \frac{V}{100}$$

$$I_a = V \left(\frac{1}{10} + \frac{1}{100} \right) \Rightarrow I_a = 0.11V$$

Putting the value of I_a in $V = E_g - I_a R_a$

$$V = 252 - 0.1V \times 1$$

$$V + 0.1V = 252$$

$$V = \frac{252}{1.1}$$

$$V = 229.09V$$

$$\therefore \text{Line current } I_L = \frac{229.09}{10}$$

$$= 22.9$$

$$\therefore \text{Power output} = VI_L$$

$$= 229.09 \times 22.9$$

$$P_{\text{output}} = 5246.16 \text{ watt}$$

$$\text{Power o/p} = 5.2 \text{ kw}$$

★ Applications of DC Generator

- Separately excited DC generator:- These generators are more costly than self excited generators. These are employed where quick & definite response to control is important such as Ward Leonard system of speed control.
- Shunt wound DC generator:- As they provide constant terminal voltage they are best suited for battery charging. Along with field regulators they are also used for light & power supply purpose.

• Series wound DC generators:- These generators have very few applications, their best application is in the DC locomotive, where they supply field current for regenerative braking. They are also employed in series arc lighting. Another application of these generator is as series booster for increasing DC voltage across the feeders.

• Compound wound DC generators:- Over compounded type

• Over compounded type:- (long shunt):- These are more suited for lighting and power services, as they compensate for the voltage drop in the lines and voltage at the terminals of the loads remains constant.

• Different compounded type (short shunt) They are usefully employed as arc welding set in such cases generator is practically short circuited every time the electrode touches the metal plate to be welded.

2.3 Performance of DC generators:- Efficiency & losses

A DC generator performance hinges on its efficiency the ratio of electrical output to mechanical input and its various losses, which reduce this efficiency. Efficiency is highest when variable losses equal constant losses.

1) Losses in DC generator:

a) Copper losses (Electrical losses):- I^2R losses in winding

• Armature copper loss:- $(I_a^2 R_a)$:- In the armature winding variable with load

• Field copper loss:- $(I_f^2 R_f)$:-

• Brush contact loss:- Due to resistance at brush commutator interface often included with armature loss.

★ b) Iron loss:-

• Hysteresis loss:- Due to repeated magnetization or demagnetization of core material

• Eddy current loss:- Induced currents within the core itself, proportional to the square of flux density & frequency.

c) Mechanical losses:-

• Friction loss:- Bearing & brush etc.

• Windage loss:- Air resistance on rotating parts.

• Stray load losses:- Minor losses not accounted for by other categories varying with load

★ Efficiency of DC generator

$$\eta = \frac{\text{Output power}}{\text{Input power}} \times 100\%$$

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

Total losses =

$$W_{\text{Total}} = (I_a^2 R_a + I_f^2 R_f) + (W_{\text{hyst}} + W_{\text{eddy}}) + (W_{\text{mech}})$$

★ Condition for maximum efficiency

Occurs when variable losses is equal to constant losses
i.e. $I_a^2 R_a = W_{\text{iron}} + W_{\text{mech}}$

• Output power (P_o):- $V I_L$ (Terminal voltage multiplied by Load current)

• Input power (P_{in}):- $P_o + W_{\text{Total}}$ (Power output + total losses)

★ Concept of Armature reaction & its effect:-

Armature reaction is the magnetic effect of the current in a motor or generator's armature windings on the main magnetic field causing flux distortion weakening demagnetization or strengthening (magnetization) depending on load power factor. This phenomenon shifts the ~~mag~~ magnetic neutral axis (MNA), leading to voltage drops in generators & sparking at brushes.

Requiring Compensation techniques like interpoles or brush shifting to manage its ~~na~~ negative impact

5 Working:-

- a) Current create flux:- When current flows through armature conductor, it produces its own magnetic field (Armature flux).
- 10 b) Interaction:- This armature flux interact with main field flux from the field poles.
- c) Result:- The interaction distorts the main field, reducing total flux in some area & increasing in others

★ Effects on DC machine:- (Generators & Motors)

- 1) Demagnetization:- Reduces the main flux, leading to a drop in generated voltage.
- 2) Cross magnetization:- Distorts the main field, shifting the magnetic neutral axis MNA.
- 25 3) Commutation issue:- Shifting the ~~the~~ MNA causes sparking at the brush
- 30 4) Direction of shift:- For generators MNA shift in the direction of rotation for ~~generators~~, for motors it shift opposite to rotation.

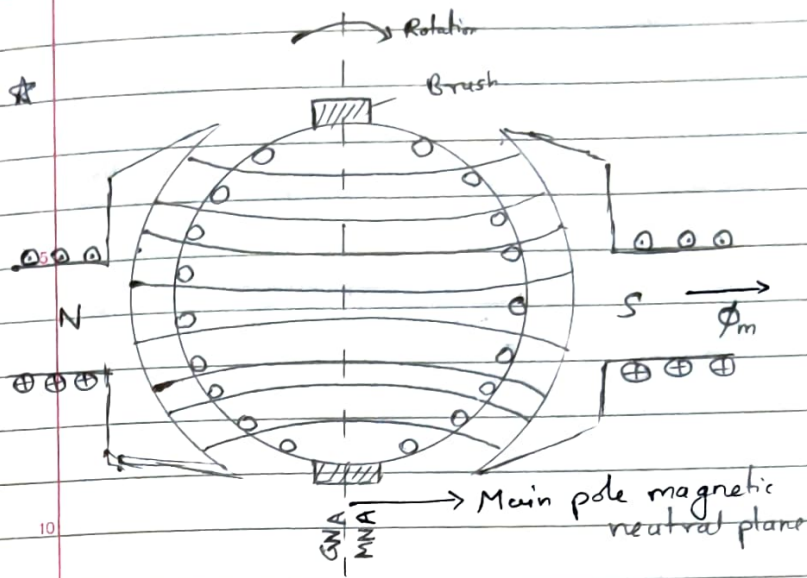


Fig:- Main pole magnetic flux distribution

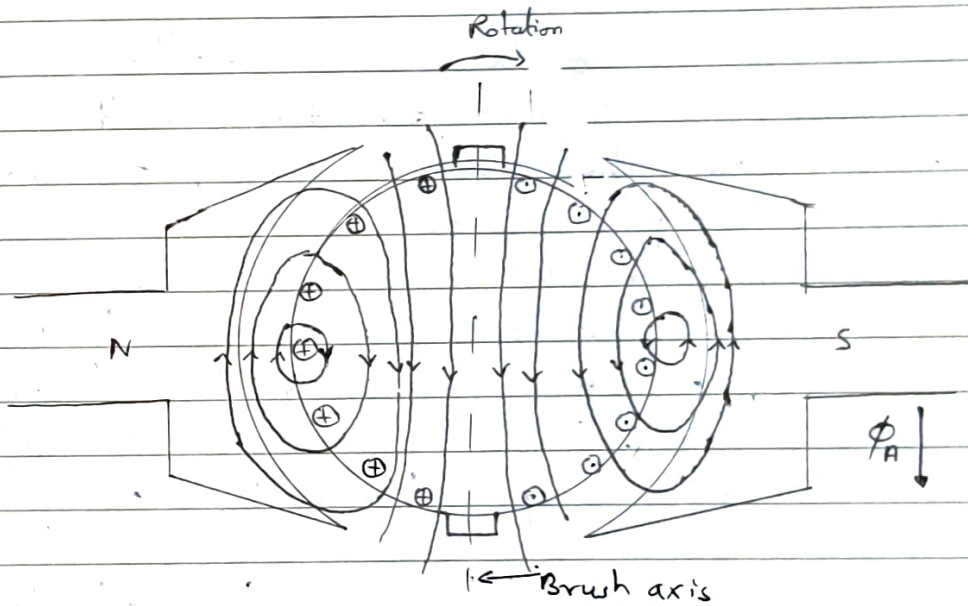


Fig:- 6.12) Armature flux distribution

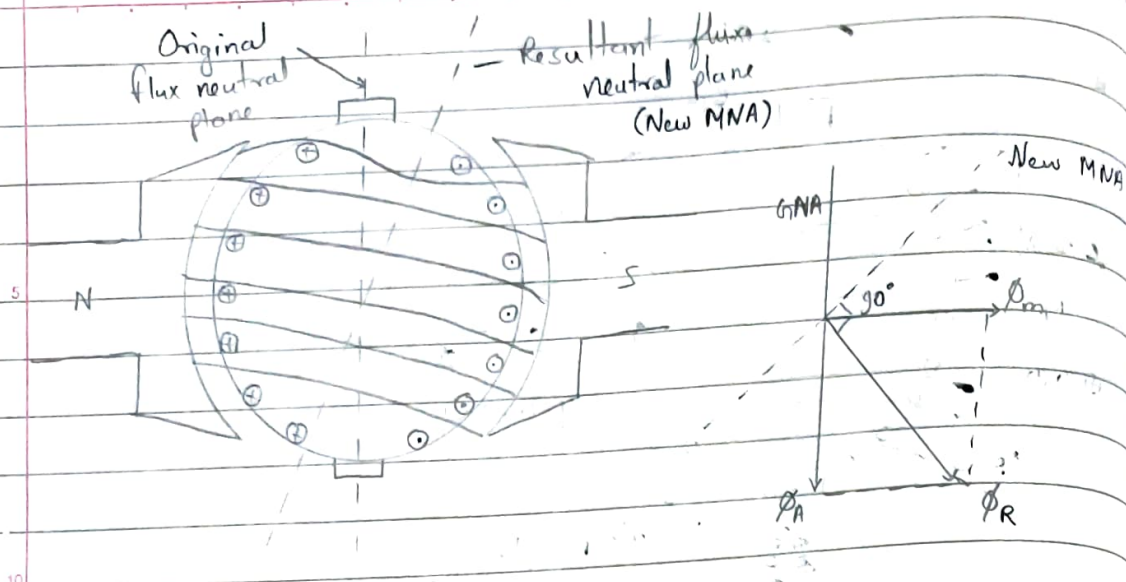


Fig. Resultant flux distribution

★ Concept of commutation:

Commutation in a DC machine is the process of reversing the current direction in the armature windings as the rotor spins, enabling the machine to produce or utilize unidirectional DC power, essentially acting as a rotary switch to convert AC generated in coils to DC output (Generator), or ~~to~~ to keep motor torque in one direction (Motor). This happens as the coil moves from one magnetic pole to another and the commutator segment along with the stationary brushes, briefly short circuit the coil to facilitate these current reversal ideally without sparking.

★ Working:-

- Induced AC:- In a DC generator, the conductor under north & South pole induce alter

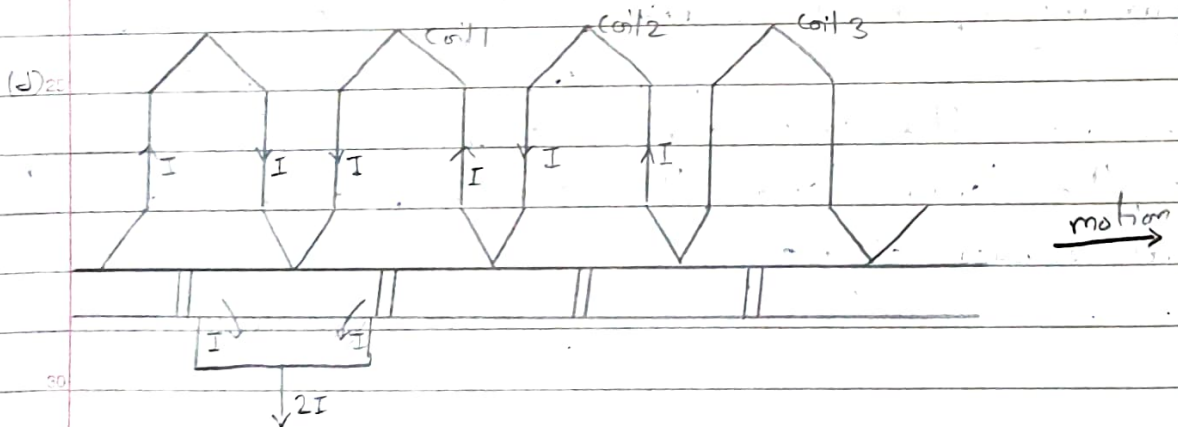
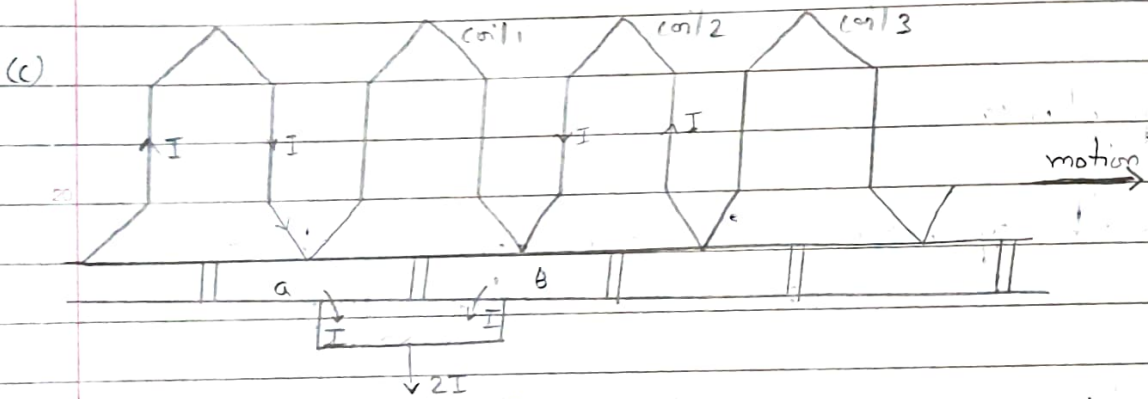
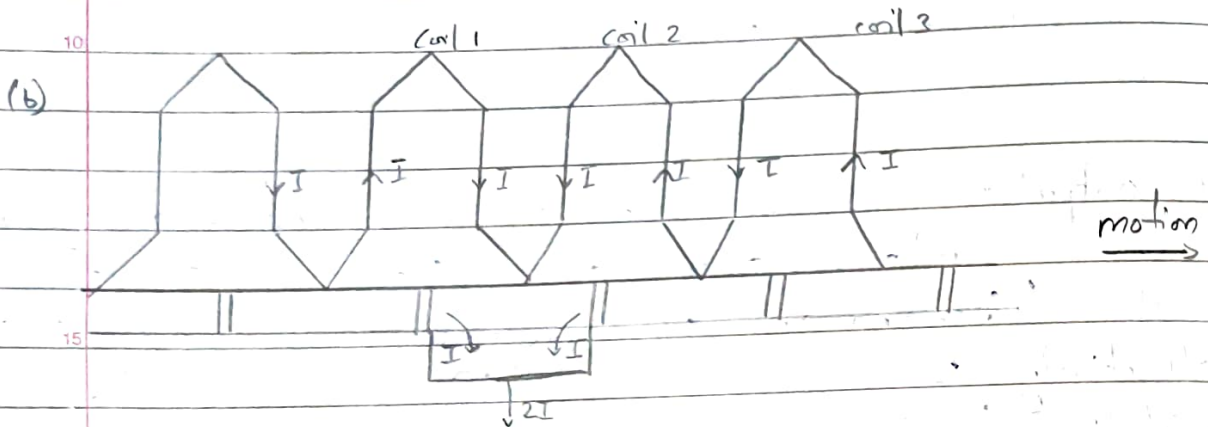
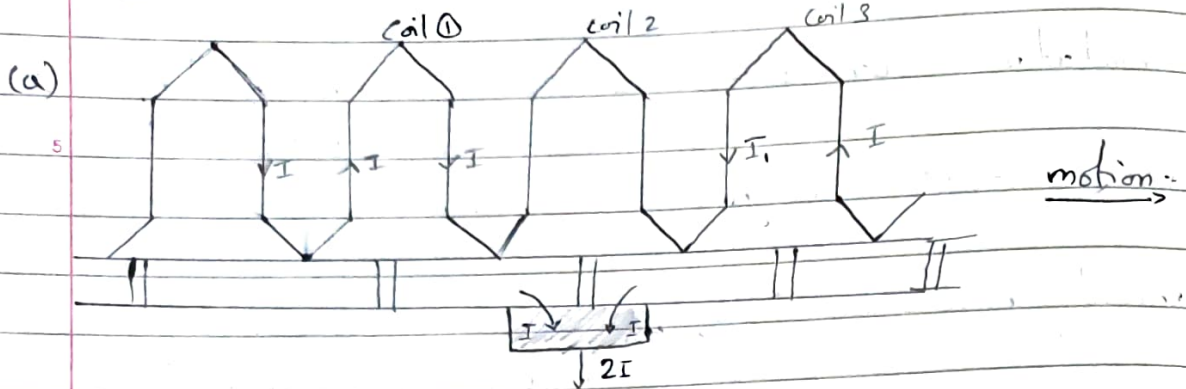
-nating current in the armature coil.

- 6) Commutator & Brushes:- The commutator rotates with the armature, while the brushes remain stationary, Against them.
- 5
- c) Current reversal:- When a coil moves under a pole & approaches neutral axis ~~MNA~~ (MNA) the brushes move from one segment to the next, short circuiting the coil & reversing current direction.
- 10
- d) DC output:- This reversal converts the internal AC into a ~~sted~~ steady DC output at the brushes (Generator) or ensures the input DC effectively reverses current in the coils to maintain rotation. (Motor).
- 15

★ Importance:-

- 20
- Smooth operation:- Essential for smooth continuous DC output / torque, preventing flickers
 - Sparking (poor commutation):- If the current doesn't reverse quickly enough (Due to inductance) the coil's stored energy causes the spark as the brush leaves the segment, leading to wear and reduce efficiency.
- 25
- 30

Figure:-



- In position shown in figure (a) the current I flowing towards the brush from the left hand side passes round the coil in a clockwise direction.
- In position shown in figure (b) this coil carries the same ~~can~~ current in the same direction, but the coil is short circuited by the brush.
- In position shown in figure (c) the brush makes contact with bars a & b thereby short circuiting coil 1. The current is still I from the left hand side & I from the right hand side. It is seen that these two currents can reach the brush without passing through coil 1.
- Fig (d) shows that bar B has just left the brush & short circuit of coil 1 has ended. It is now necessary for the current I reaching the brush from the right hand side in the anticlockwise direction.

From the above discussion it is seen that during the period of short circuit of an armature coil by a brush the current in that coil must be reversed and also brought up ~~to~~ to its full value in the reversed direction. The time of short circuit is called period of commutation.

Methods of improving commutation

- 1) Resistance commutation
- 2) Voltage commutation

3) Compensating winding

4)

1) Resistance commutation:- Using carbon brushes, this makes the contact resistance between commutator segment & brushes high. This high contact resistance has the tendency to force the current in the short circuited coil to change according to the commutation requirements

2) Voltage commutation:- Two methods may be used to produce the injected voltage ϕ in opposition to the reactance voltage.

1) Brush shift

2) Interpoles

→ Compensating winding:- Compensating windings are the most effective means for eliminating the problem of armature reaction & flashover by balancing the armature m.m.f. These are connected in series with the armature winding. The direction of current in compensating winding must be opposite to that in the armature winding just below the pole face.

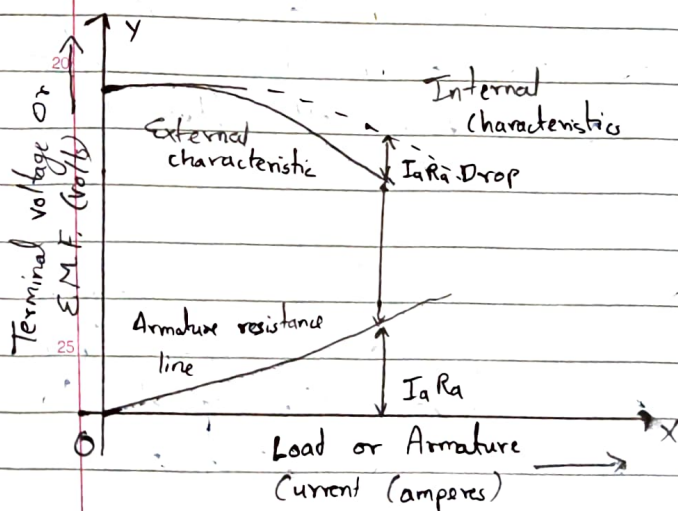
2.5) Internal & External characteristics:-

At present time ~~the~~ bulk of electrical energy is generated in the form of Alternating current. DC generators are no more used in modern power system. The characteristics of DC generators are briefly given here.

1) Magnetization characteristics:- Magnetization characteristics gives the variation of generated voltage or (no load voltage) with field current at a constant speed it is also called no load or open circuit characteristics (OCC).

2) Internal characteristics:- It is the plot between generated voltage & load current

3) External characteristics:- (load characteristics)



Q2.4 Condition for building up EMF in self excited DC generator.

For a self excited DC generator to build up EMF it needs residual magnetism, correctly connected field windings to ~~add~~ aid this flux, a prime mover speed above critical speed & a field circuit resistance below its critical value.

★ Conditions:-

- 1) Residual magnetism:- The field pole must possess some residual magnetism, A weak inherent magnetic field. Even when no current flows, which acts as the initial flux.
- 2) Correct field winding connection:- The field winding must be connected so its generated magnetic adds to the residual magnetism not opposes it this can force the flux & emf
- 3) Sufficient speed (Above critical speed):- The generator's rotational speed (Prime mover must be high enough above critical speed) to induce a small initial voltage from the residual flux.
- 4) Field resistance (Below critical resistance):- The total resistance of the field circuit must be less than the critical resistance. This allows

enough field current to flow to built up voltage but not so much that it causes demagnetization or prevents voltage rise.

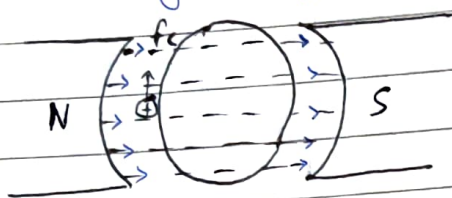
- 5) Field saturation:- The process continues untill the field force become magnetically saturated at which point the EMF & current reach a stable operating point.

Unit - 3

DC - Motor

★ Introduction:- A motor is a machine that converts electrical energy into mechanical energy.

★ Principle:- When a current carrying conductor is put in a magnetic field, a force is produced on it. The effect of placing the current carrying conductor in a magnetic field is shown in figure.



by applying left hand rule it is found the conductor has a tendency to move to the left hand side.

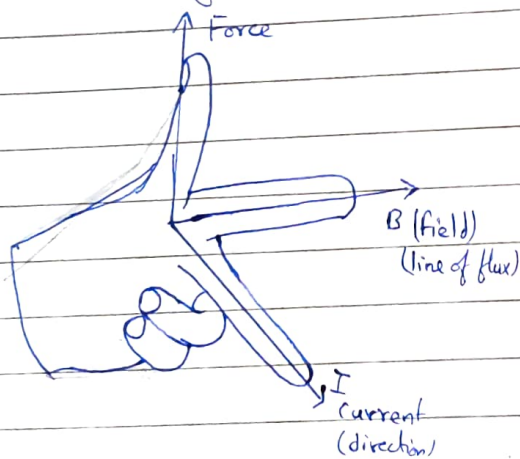


Fig:- Fleming's left hand rule

The torque produced on the rotor is transferred to the shaft of the rotor and can be utilized to drive a mechanical load.

★ Back Emf:- When the motor armature rotates, its conductor cuts the magnetic flux therefore the emf of rotation (E_b) is induced in them. In case of a motor the emf of rotation is known as back emf. The back emf opposes the applied voltage. Since the back emf induced & the expression is same for motor & generator.

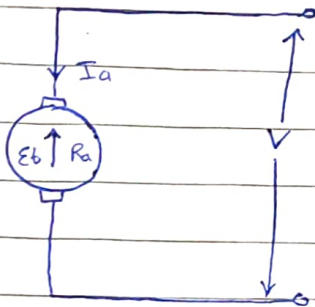
$$E_b = \frac{P \phi N Z}{60 A}$$

where:- P = no of poles

Z = no of armature conductor

A = no. of parallel path in armature windings

N = speed of armature in rpm n = speed in rps.



$$V = E_b + I_a R_a$$

★ Torque of a DC machine

When a DC machine is loaded either as a motor or as a generator, The rotor conductors carrying current. This conductors lie in the magnetic field of the air gap. Thus each conductors experience a force hence a torque is produced around the circumference of the rotor & the rotor starts rotating.

The voltage equation of DC motor is $[V = E_b + I_a R_a]$ — (1)

multiplying both sides of equation by I_a

$$V I_a = E_b I_a + I_a^2 R_a \quad \text{--- (2)}$$

but, $V I_a =$ Input power to the armature
 $I_a^2 R_a =$ Copper loss in the armature

$$\left[\begin{array}{c} \text{Input} \\ \text{Power} \end{array} = \begin{array}{c} \text{Output} \\ \text{Power} \end{array} + \text{losses} \right] \quad \text{--- (3)}$$

Let $T_{avg} =$ Avg. Electromagnetic torque developed by the armature (N.m)

$$\text{Mechanical power developed by the armature (Pm)} = \omega T_{avg} = 2\pi n T_{avg}$$

$$\text{Therefore, } P_m = E_b I_a$$

On comparing both ^{expression} we get

$$2\pi n T_{avg} = E_b I_a$$

$$T_{avg} = \frac{E_b I_a}{2\pi n} \quad \text{--- (4)}$$

$$\therefore E_b = \frac{P \phi n Z}{A}$$

on putting the value of E_b in eqn (4) we get

$$\text{Hence, } T_{avg} = \frac{P \phi n Z I_a}{2\pi n A}$$

$$\left[T_{avg} = \frac{P \phi Z I_a}{2\pi A} \right]$$

For a given DC machine P, Z, A and 2π are constant

$$\text{Let, } \frac{PZ}{2\pi A} = K$$

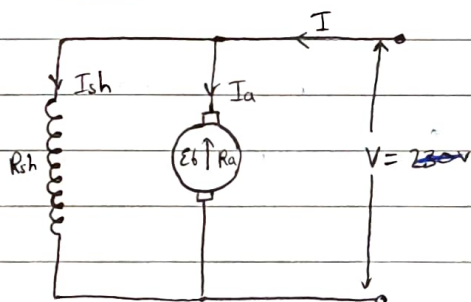
$$\therefore \left[T_{avg} = K \phi I_a \right]$$

$$\text{So, } \left[T_{avg} \propto \phi I_a \right]$$

★ Types of DC motors:-

- 1) Shunt motor or shunt wound motor
- 2) Series wound motor or series motor
- 3) Compound wound motor or Compound motor.

1) Shunt motor :-



This is the most common type of DC motor. The field winding is connected in parallel with the armature.

$$\therefore \left[I = I_a + I_{sh} \right]$$

- 2) Terminal voltage:- $V = I_{sh} R_{sh}$ (In field winding)
 $V = \mathcal{E}b + I_a R_a$ (for In armature)

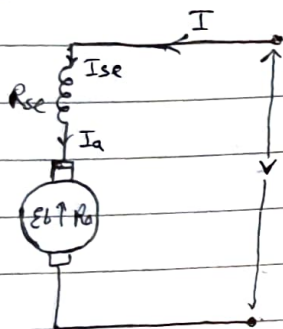
- 3) Power input $\Rightarrow$ Mechanical power developed + losses in armature + losses in field winding;

$$VI \Rightarrow P_m + I_a^2 R_a + I_{sh}^2 R_{sh}$$

$$VI \Rightarrow \mathcal{E}b I_a + I_a^2 R_a + I_{sh}^2 R_{sh}$$

- 4) Power output:- $P_m = \mathcal{E}b I_a$

- 2) Series motor:-



In series motor the field winding is connected in series with the armature.

- 1) Current eqn:- $I = I_{se} = I_a$

- 2) Voltage terminal:- $V = \mathcal{E} + I(R_a + R_{se})$

- 3) Power input $\Rightarrow$ mechanical power + losses in armature + losses in field
 $VI = P_m + I^2 R_a + I^2 R_{se}$

- 4) Power output $= P_m = \mathcal{E}b I$

★ Compound motor :- A dc motor have both shunt & series winding is called compound motor. It is of two types:-
 1) Long shunt compound motor.
 2) Short shunt compound motor.

★ Long shunt compound motor:- If the shunt field is in parallel with both armature & series field winding then the motor is called long-shunt compound motor.

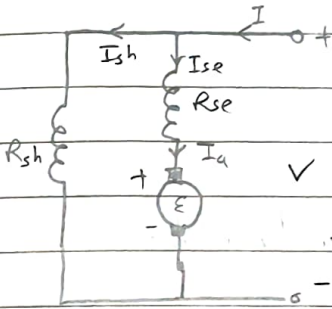


fig:- long shunt DC motor.

★ Short shunt compound motor:- If the shunt field is connected parallel with the armature alone the machine is called short shunt compound motor.

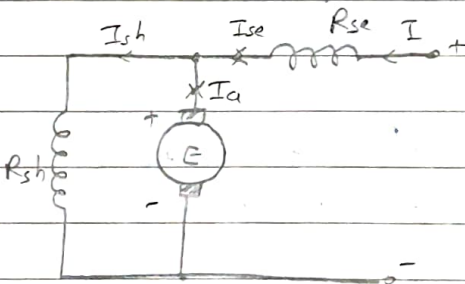


fig short shunt DC motor.

★ Speed of DC machine:-

The emf equation is given by :- $\frac{P\phi NZ}{60A}$

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

$$\therefore \frac{1}{K} (\text{constant}) = \frac{60A}{PZ}$$

$$\therefore \left[N = \frac{E}{K\phi} \right]$$

$$\text{so, } N \propto \frac{E}{\phi}$$

3.5) Speed control of DC motor / machine -

The speed of a DC motor is given by relation-ship, ~~A~~

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

$$\begin{cases} \therefore E = V - I_a R_a \\ \text{or } V = E + I_a R_a \end{cases}$$

$$\left[N = \frac{V - I_a R_a}{K\phi} \right] \quad \text{--- (1)}$$

Equation 1 shows that the speed is ~~inde~~ dependent upon supplied voltage (V) armature circuit resistance (R_a) & field flux (ϕ)

There are 3 methods of speed control of DC motors

1) Variation of resistance in the armature circuit (this method is called armature resistance control "Rheostatic control")

- 2) Variation of field flux ϕ (This method is called field flux control)
- 3) Variation of applied voltage (Armature voltage control)
- ★ Armature resistance control (Rheostatic control)

In this method a variable series resistor R_e is put in the armature circuit. Below figure shows the method of connection for a shunt motor. In this case the field is directly connected across the supply & therefore the flux ϕ is not affected by variation of R_e .

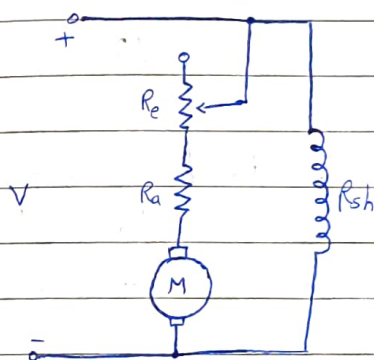


fig:- Speed control of a d.c. shunt motor by armature resistance control

Series motor:- In this case the current & hence the flux are affected by the variation of the armature circuit resistance. The voltage drop in R_e reduces the voltage applied to the armature & therefore the speed is reduced. Below figure shows the method of connection of external resistance R_e in the armature circuit of d.c. series motor.

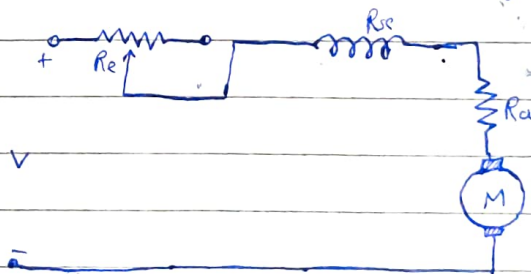
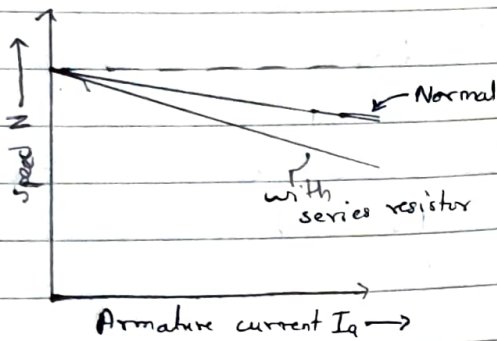
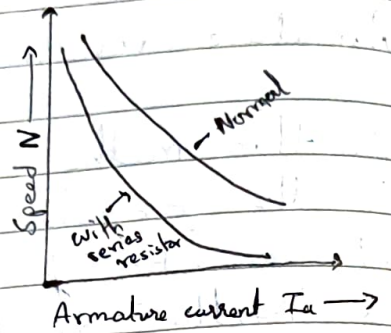


fig:- Speed control of a d.c. series motor by armature resistance control

In both cases the motor runs at a lower speed as the value of R_e is increased. Since R_e carries full armature current, it must be designed to carry continuously the full armature current.



(a) Shunt motor



(b) Series motor

★ Variation of field flux ϕ (field flux control)

Since the flux is produced by the field current, control of speed by using this method is obtained by control of field current. In the shunt motor, this is done by connecting a variable resistor R_c in series with the shunt field winding as shown in fig 7.17. The resistor R_c is called the shunt field regulator.

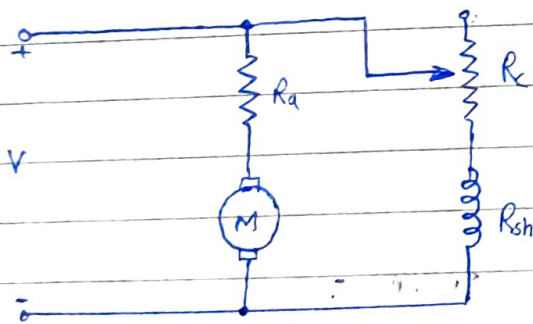


fig:- Speed control of a dc. shunt motor by variation of field

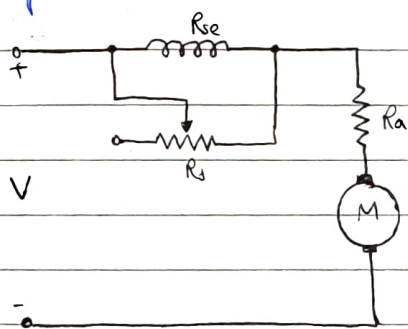
The shunt field current is given by $I_{sh} = \frac{V}{R_{sh} + R_c}$

The connection of R_c in the field reduces the field current & hence the flux ϕ is also reduced. The reduction in flux will result in an increase in the speed consequently. ~~the~~ the motor runs at a speed higher than normal speed. For this ~~regio~~ reason this method of speed control is used to give motor speeds above normal or to correct for a fall in speed due to load.

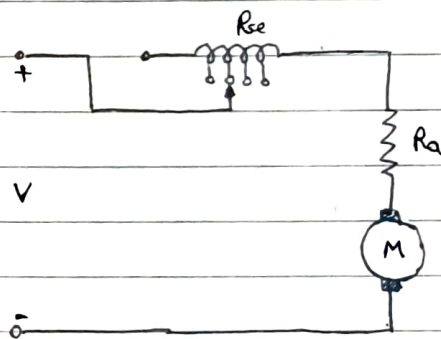
* 10 The variation of field current in a series motor is done by any one of the following methods:-

- (a) A variable resistance R_d is connected in parallel with the series field winding as shown in figure below. The parallel resistor is called the diverter. A portion of the main current is diverted through R_d .

Thus, the diverter reduces the current flowing through the field winding. This reduces the flux & increases the speed.



fig₁:- Diverter in parallel with series dc motor

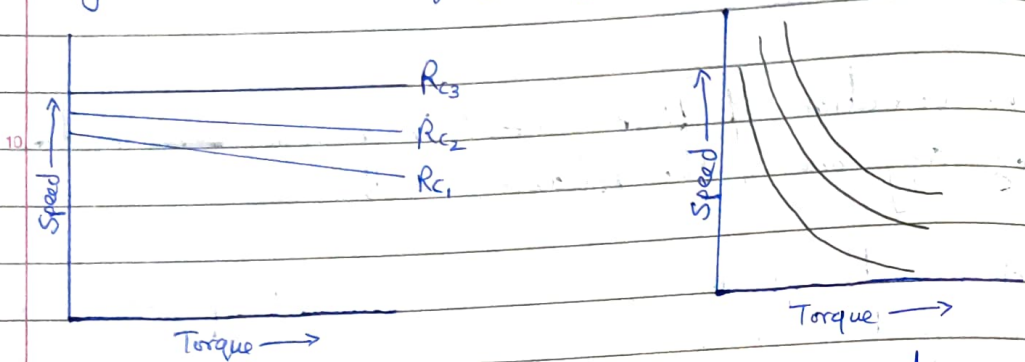


fig₂:- Tapped series field on dc motor

- b) The second method uses a tapped field control as shown in figure 2.

Here the ampere-turns are varied by varying the number of field turns. This arrangement is used in electric traction.

Figure a & b shows the typical speed/torque curves for shunt & series motors respectively, whose speeds are controlled by the variation of field flux.



a) shunt motor

b) series motor

Fig:- Typical speed/torque curves.

★ Armature Voltage Control

Speed control of dc motors can also be obtained by varying the applied voltage to the armature. Ward-leonard System of speed control is based on this principle. This method was introduced in 1891. The schematic diagram of this method is shown below. In this system, M is the main dc motor whose speed is to be controlled & G is a separately excited dc generator. The generator G is driven by a 3- ϕ driving motor which may be an induction motor or a synchronous motor. The combination of AC driving motor & the dc generator is called the motor generator (M-G) set.

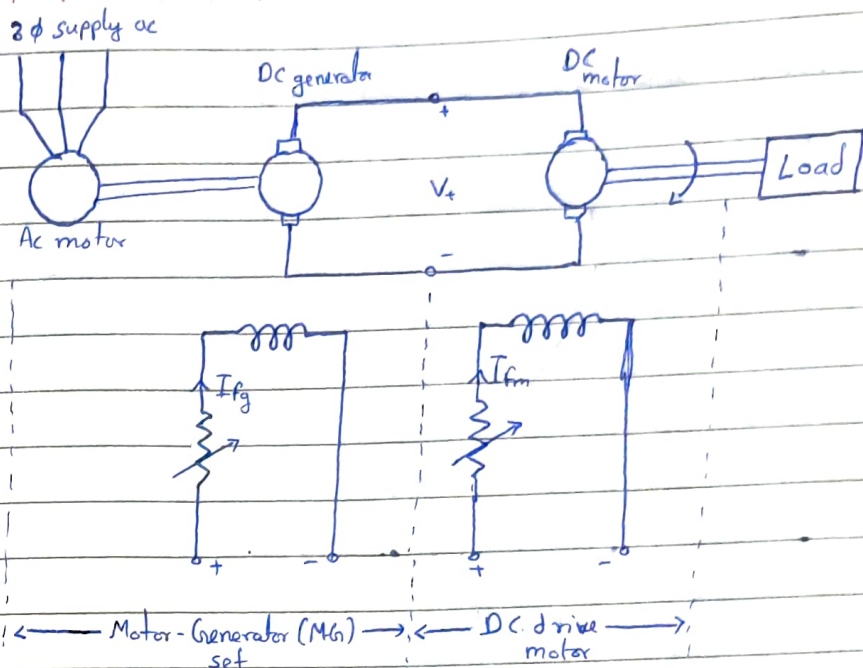
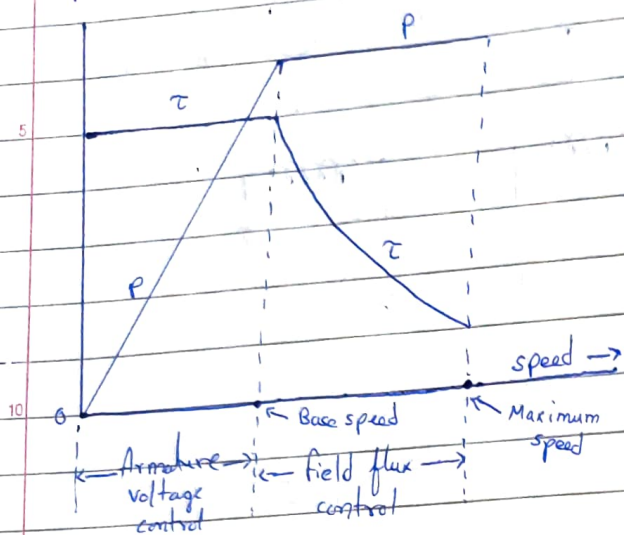


fig:- Ward-leonard drive:-

- By changing the generator field current, the generator voltage is changed. This voltage when applied ~~if~~ direct to the armature of the main dc motor M changes its speed. The motor field current I_{fm} is kept constant so that the motor field flux ϕ_m also remain constant. The motor armature current I_a is kept equal to its rated value during the speed control. The generator field current I_{fg} is varied such that the armature voltage V_t changes from zero to its rated value. The speed will change from zero to the base speed. Since the speed control is carried out with rated current I_a and with constant motor flux ϕ_m a constant torque ($\propto \phi_m I_a$) upto base (rated) speed is obtained. Since the power ($P = \text{torque} \times \text{speed}$) is proportional to the speed, it increases with speed. Hence with armature voltage control method constant torque & variable power drive is obtained from

speed below the base speed



★ Advantages of Ward Leonard Drives:

The main advantages of ward leonard drives are as follow.

- 1) Smooth speed control of DC motors over a wide range in both direction is possible.
- 2) It has inherent regenerative braking capacity
- 3) By using over excited synchronous motor as the drive for dc-generator, the lagging reactive voltamperes of the plant are compensated. Therefore the overall power factor of the plant improves.

* Drawbacks: -

- 1) Higher initial cost due to the use of two additional machines (M-G set) of the same rating as the main dc motor.
- 2) Larger size and weight
- 3) Requires more floor area & costly foundation
- 4) Frequent maintenance is needed
- 5) Lower frequency due to higher losses.
- 6) The drive produces more noise.

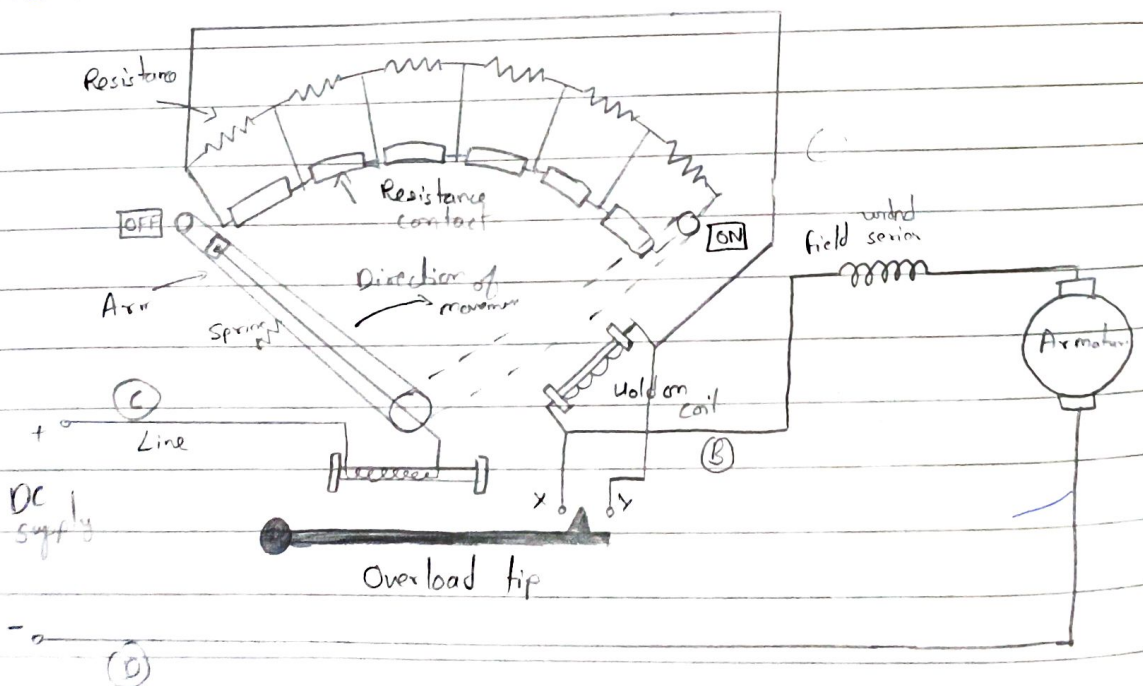
Need of Starter & types

A starter is a device to start and accelerate a motor. A controller is a device to start, control speed, reverse, stop & protect the motor.

A starter is needed for a dc motor to limit the massive current surge (Inrush current) that occurs at starter ~~at~~ which ~~was~~ would otherwise damage the motor windings & power supply.

Two point starter

A two point starter is a simple device used for starting small DC series motor, featuring two terminals line & field that connect the field & armature windings in series, limiting high starting current with external resistance that gradually reduced as the motor speed up using the hold on coil.



★ Key component of functions:

- 1) Two terminals:- Line (L) & Field (F)
- 2) Field & armature windings are in series
- 3) Starting resistance R_s :- Added in series with armature to limit initial surge current
- 4) Control arm/handle:- Moved to gradually cutout resistance as the motor accelerates.
- 5) Hold-on coil (NVC):- An electromagnet that hold the handle in the run position during normal operation.

★ Working principle

- 1) Start:- Handle is moved from off to on, 'Inserting full resistance in series with the armature.'
- 2) Acceleration:- Handle moves clockwise, gradually reducing resistance as the motor gains speed.
- 3) Run:- Handle reaches the final run position, by passing all external resistance and the hold-on coil keeps it engaged
- 4) Protection:- If supply fails or voltage drops the hold on coil de energizes, releasing the handle back to off position to preventing dangerous over speeding (As the motor acts like a series motor on no load).

Application of Two pt starter

Primarily used for DC series motor (like those in cranes, hoist, electric traction) where load loss can cause over speeding

Three point starter:

A three point starter is a device for starting shunt & compound DC motors, featuring 3 terminals (line, armature, field) to limit high starting current by inserting resistance. that gradually reduced as the motor speed up.

* Components & terminals

- 1) L (Line):- Connect the positive supply A
- 2) A (Armature):- Connect the armature wind
- 3) F (Field):- connect to the field winding
- 4) Resistance:- A tapped resistance in series with the Armature.
- 5) Handle:- Moves across studs to cut out resistances
- 6) No volt coil (NVC):- Connected in series with the field, Hold the handle in the run position but releases it on power failure.

* Working Principle:-

- 1) Start:- Handle is at off. Supply is switched on. Handle is moved to stud one, putting all resistance in series with the armature.
- 2) Acceleration:- As the handle moves across studs 2, 3 etc resistor is gradually cut out, increasing voltage to the armature & reducing current.
- 3) Run:- Handle reaches the run position, all resistance is bypassed and the motor runs at normal speed
- 4) Protection:- The NVC hold the handle if power drops

The magnetic field weakness & spring pulls the handle back to off cutting power to the motor.

★ 5 Key function:-

1) Limits high starting current:- Prevent damage from excessive current when back emf is zero.

2) Protects motor:- NVC prevent the motor from restarting unexpectedly after a power outage.

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