D.C. GENERATORS

24.4.21

Principle

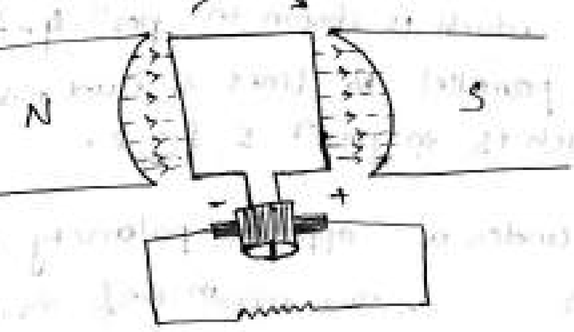
An electric generator is a machine that converts mechanical energy into electrical energy.

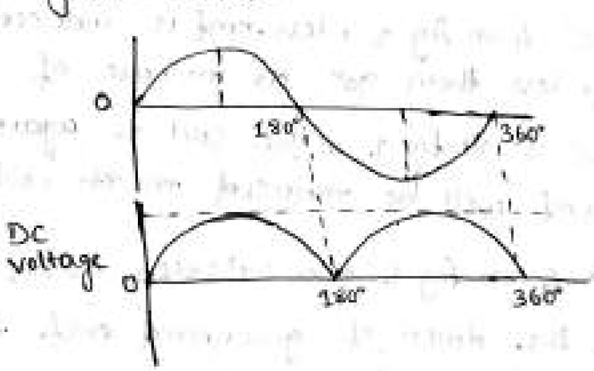
" An electric generator is based on the principle that whenever flux is cut by a conductor, an emf is induced which will cause a current to flow of the conductor circuit is closed".

* The direction of induced emf (also current) given by "Flemmings right hand rule".

Essentials components of a generator →

→ a magnetic field
→ Conductor or a group of conductors.
→ Motion of conductor wrt magnetic field.





Principle of DC generator →

Generator is a machine which converts mechanical energy into electrical energy.

It is based on the principle ~~of~~ that whenever a flux is cut by a conductor an emf is induced which will caused to flow of current in the conductor ckt when closed. Its direction is given by Flemming's Right hand rule.

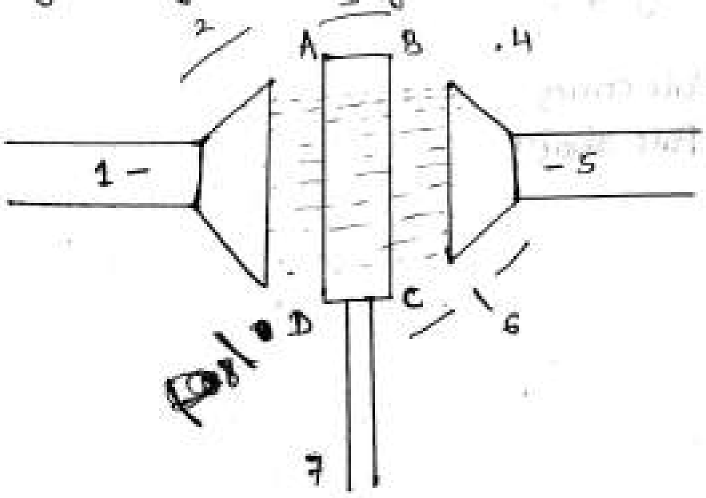
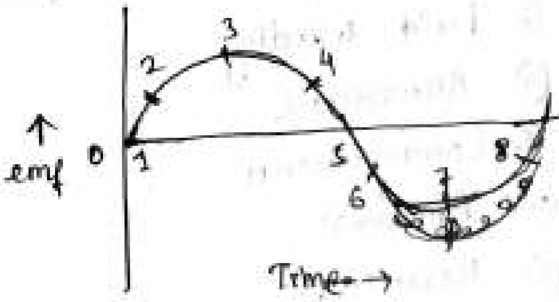


fig-1



Consider a coil rotate in a clockwise direction in a magnetic field. Hence the emf induced in these coil sides also changes. When the coil is in posn 1 in fig 1 the generator emf is zero, because the coilsides are parallel to the flux. But the rate of change of flux linkage is minimum.

• When the coil is in position 3 in fig 1, its position 90° to the lines of flux. So it cuts maxm lines of fluxes, the rate of change of flux linkage is maximum, so maxm emf induced which is shown in fig 2.

At posn 4 in fig 1, less emf is induced to coil cuts the flux by an angle less than 90° as in case of which is shown in posn 4 fig 2.

At posn 5 in fig 1, the coil is again parallel to lines of flux, so no emf will be induced in it, which is in posn 5 fig 2.

At posn 6 in fig 1 the coilsides moves under a opposite polarity & hence the direcn of generated emf is . The maxm emf is in this direcn will be produced position 7 and zero at posn 1. The cycle repeats with revolution of the coil. The alternating voltage generated the coil can be converted into direct voltage (D.C) with the of a mechanical rectifier known as commutator.

<u>Construction of D.C. Generator →</u>

D.C. Generator has following parts.

1. Yoke
2. Pole of generator → Pole cores, Pole shoes
3. Field Winding
4. Armature
5. Commutator
6. Brushes
7. Bearings

① Yokes →

→ Yoke act as cover of a generator.
→ It holds the magnetic pole cores of the generator.
→ It carries the magnetic field flux.
→ Yokes are made of cast iron for small generator.
→ But for large DC generator yokes are made of cast steel or rolled steel.

② Pole cores →

Pole cores of DC generators are made of cast iron or cast steel. Pole cores are laminated. The thickness of laminad varies from 0.04" to 0.01". The pole core is fixed to the inner periphery of yoke by means of bolts. Pole cores carry the field windings.

Pole shoes →

Pole shoes act as a support to the field coils (or windings) and spread out the flux uniformly over the armature periphery.

③ Pole coils (or windings) →

The pole coils or field coils (or windings) are wound around the pole core. It provides magnetic flux.

④ Armature core →

The purpose of armature core is to hold the armature windings. Armature core is made of thin silicon steel lamination. It is generally cylindrical or drum shaped. Aramature core rotates by the prime mover.

Armature Winding →

These are placed in the slots of the armature core. When these armature windings cuts by the magnetic flux, an emf is induced in it. Armature windings are made of copper.

⑤ Commutator →

It collects the ac current from armature and sends it to the load as direct current. It is also cylindrical in shape and made of from hard drawn copper.

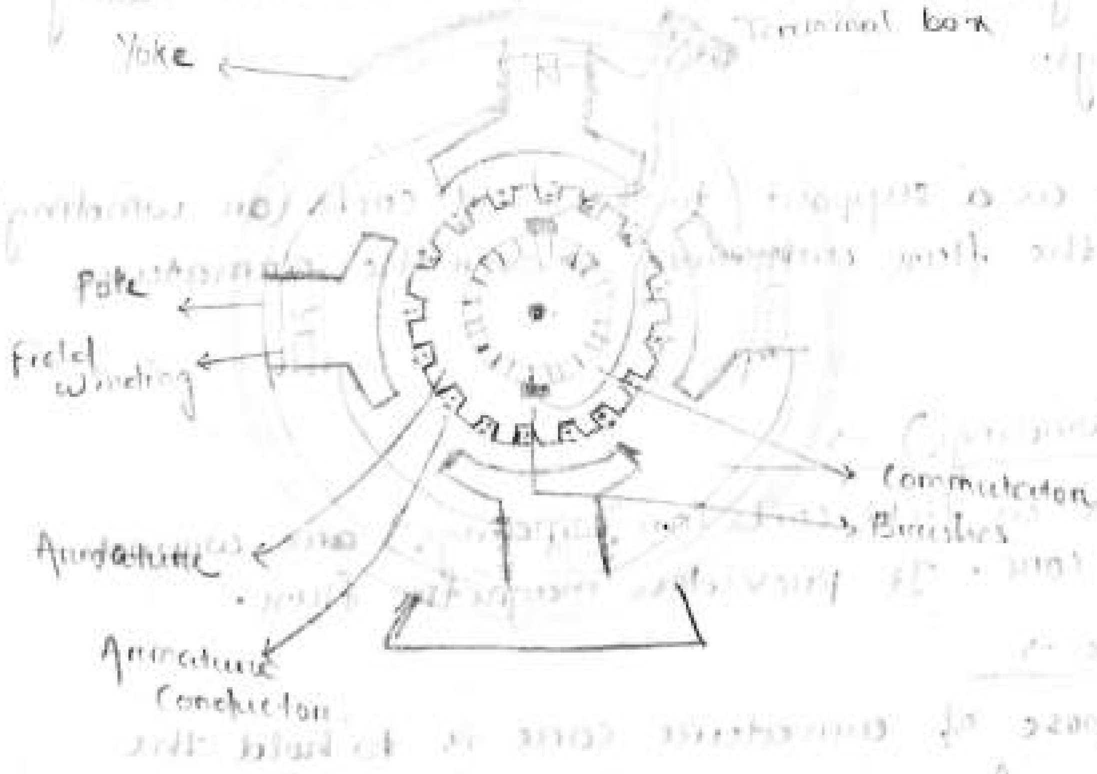
⑥ Brushes →

Brushes are made of carbon. These are rectangular block shaped. Brushes are placed in the rectangular box shaped box holder. Brushes collect current from the commutator segment to the load.

⑦ Bearings →

For small m/c ~~ball~~ ball bearing is used and for heavy duty dc generator, roller bearing is used.

→ The bearing must always be lubricated properly for smooth operation and long life of generator.



DC Armature windings→

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DC armature windings are wound by two methods. (i) Lap winding, (ii) Wave winding.

To know how armature windings are done, it is essential to know the following terminologies.

① **Pole pitch →**

It is the distance measured in terms of number of armature conductors per pole.

e.g:- If a dc generator has 4 poles and 16 slots, then

pole pitch = $\frac{16}{4}$ = 4 slots.

② **Coil span or Coil pitch →**

It is the peripheral distance betn two sides of a coil.

e.g:- If the coil span or coil pitch is 9 slots that means one of the coil is in slot 01 and the other side is in slot 10.

③ **Back pitch (Y_B) →**

The distance measured in terms of the armature conductors which a coil advances on the back of the armature is called back pitch and is denoted by 'Y_B'.

④ **Front Pitch (Y_F) →**

The number of armature conductors or elements spanned by a coil on the front is called the front pitch and is denoted by 'Y_F'.

⑤ **Resultant pitch (Y_R) →**

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

⑥ **Commutator pitch (Y_C) →**

It is the distance (measured in commutator bars or segments) between the segments to which the two ends of a coil are connected.

* For lap winding, $Y_C = Y_B - Y_F$
* For wave winding, $Y_C = Y_B + Y_F$

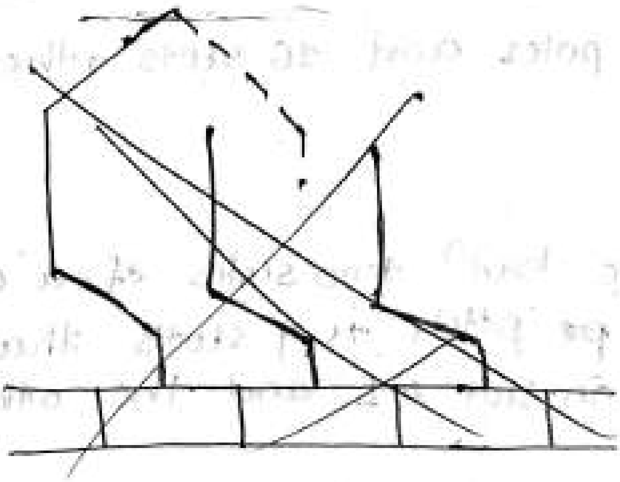
Lap winding →

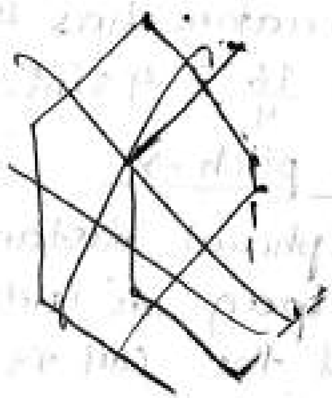
In lap winding, the successive coils overlap eachother.

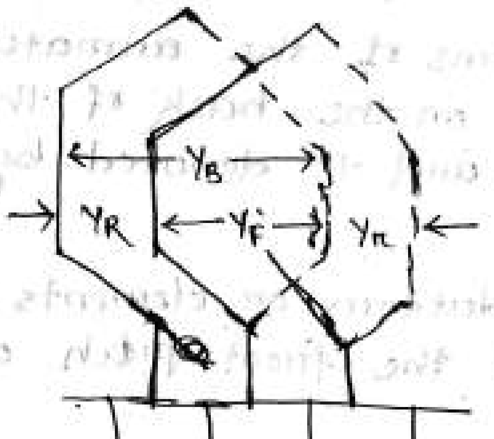
* In a simplex lap winding, the two ends of a coil are connected to adjacent commutator segments.

Wave winding →

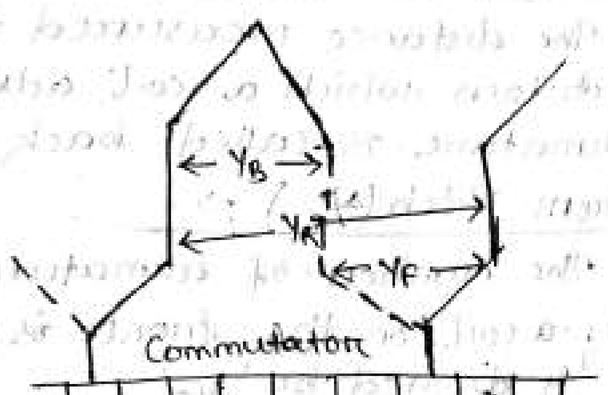
In this winding, the end of one coil is connected to the start of another coil of same polarity.







(Lap-winding)



(Wave winding)

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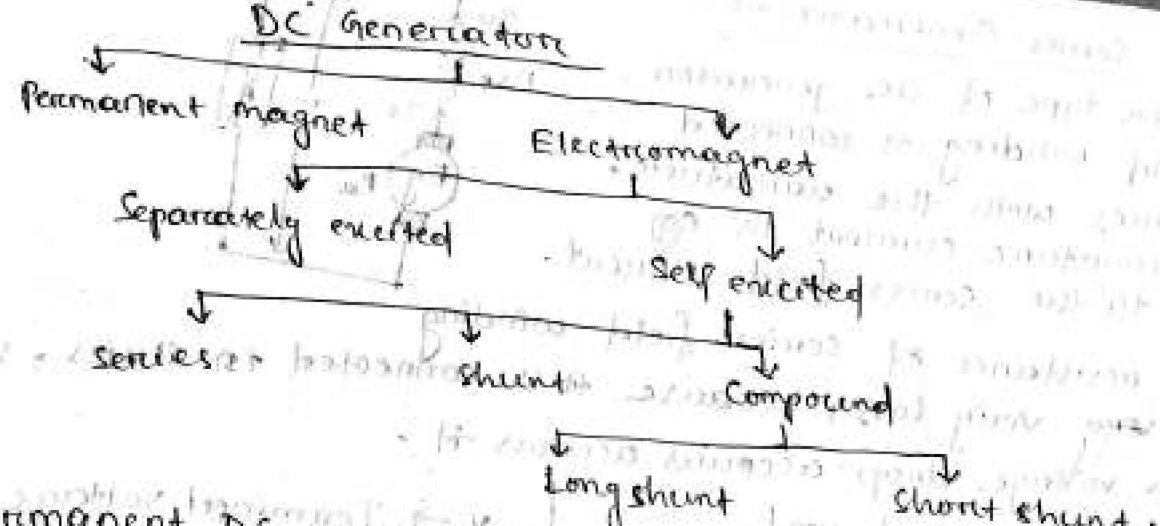
Types of DC generator →



① **Permanent DC generator →**

When flux in the magnetic circuit established by the help of permanent magnets then it is known as Permanent magnet DC generator.

→ This type of DC generator generates low power.

→ Used in meggar, dynamos in motor cycle.

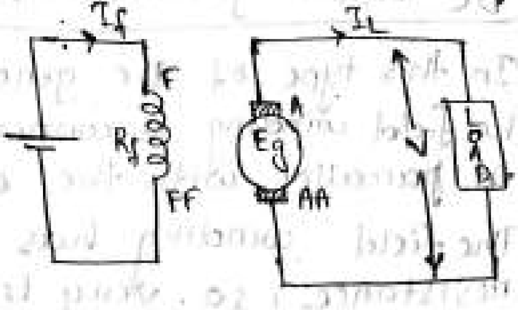
② **Electromagnet type DC generator →**

In this type of generator, field magnets are energized by dc source such as battery.

(i) **Separately excited DC generator →**

In this type of generator a separate source is required to excites its field winding.

$E_g = V + I_a R_a + B.D.$



E_g = Generated emf.

V = Terminal voltage.

I_a = Armature current.

R_a = Armature Resistance.

B.D. = Brush drop.

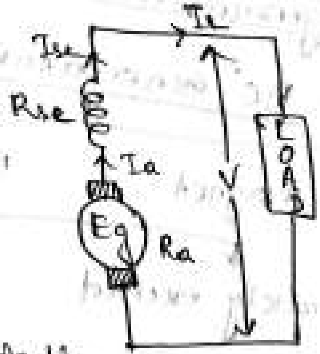
(F, FF) = field winding.

(A, AA) = Armature.

(ii) **Self excited DC generator →**

In this type of DC generator, the field is excited by the supply generated by the generator.

(A) DC Series Generator →



In this type of DC generator, the field winding is connected in series with the armature. So armature current is equal to the series field current.

→ The resistance of series field winding is very loss, because it is connected in series, so less voltage drop accours accross it.

E_g → Generated emf.
R_a → Armature resistance
I_a → Armature current
R_{se} → series field resistance
I_{se} → Series field current

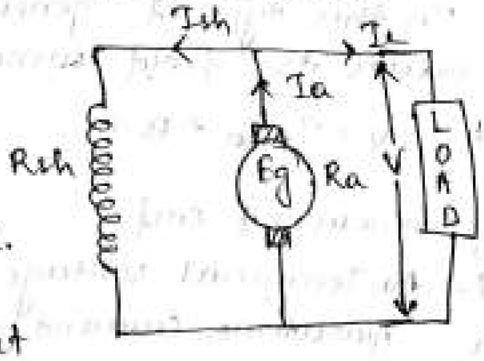
V → Terminal voltage
I_L = Load current.

∴ Generated emf, $\boxed{E_g = V + I_a R_a + I_{se} R_{se} + B.D}$

Here $\boxed{I_a = I_{se}}$

Power developed in armature = $E_g I_a$
Power delivered to the load = $V I_L$ or $V I_a$.

(B) DC Shunt generator →



In this type of DC generator the field winding is connected in parallel with the armature.

→ The field winding has high resistance, so very less amount of current flows through it. So the voltage drop accross the field winding is negligible. It produces constant voltage.

Generated emf., $\boxed{E_g = V + I_a R_a + B.D}$

R_{sh} → Shunt field resistance
I_{sh} → Shunt field current.

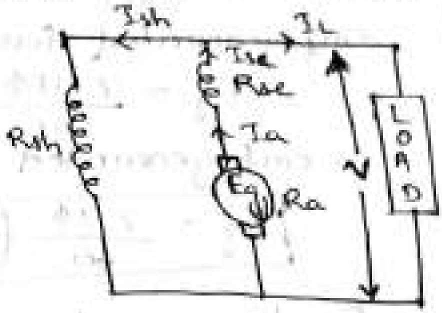
$\boxed{I_{sh} = \frac{V}{R_{sh}}}$ ∴ $\boxed{I_a = I_L + I_{sh}}$

(c) DC compound Generator →

DC compound generators have both series field winding and shunt field winding.

(a) Long shunt Compound DC generator →

In this type of DC generator, shunt field winding is in parallel with both series field and armature winding.



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

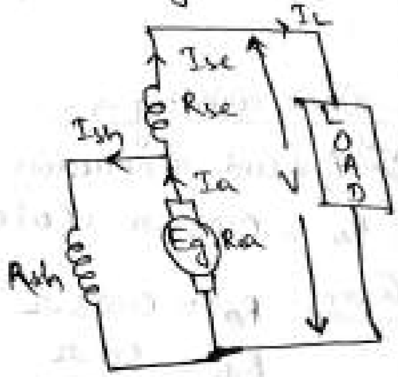
$$I_{sh} = \frac{V}{R_{sh}}$$

$$I_a = I_{se}$$

$$\boxed{E_g = V + I_aR_a + I_{se}R_{se} + BD}$$

(b) Short shunt DC compound generator →

In this type of DC generator, the shunt field resistance is connected in parallel with the armature only.



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

$$I_{se} = I_L$$

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

$$\boxed{E_g = V + I_aR_a + I_{se}R_{se} + B\cdot D}$$

EMF Equation of DC generator →

Let, Z = Total no. of armature conductors.

ϕ = Flux produce per pole.

N = Armature revolution in RPM.

P = No. of poles.

A = No. of parallel paths.

E_g = Generated emf in any one of the parallel path.

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

The flux cut per conductor in one revolution is $d\phi$

$$d\phi = P\phi$$

Time taken for revolution is dt.

$dt = \frac{60}{N}$

According to Faraday's laws of Electromagnetic Induction

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

$\therefore d\phi = \frac{P\phi}{\left(\frac{60}{N}\right)} = \frac{NP\phi}{60}$

emf generated for 'Z' no. of conductors,

$E_g = \frac{ZNP\phi}{60}$

$\therefore$ emf generated per parallel path,

$$\boxed{E_g = \frac{ZN\phi}{60}\left(\frac{P}{A}\right)}$$

For lap wound, $A = P$

for wave wound, $A = 2$

So $\boxed{E_g \propto ZN\phi P}$, by increasing Z, N, P, ϕ the emf generated increased.

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Wave winding →

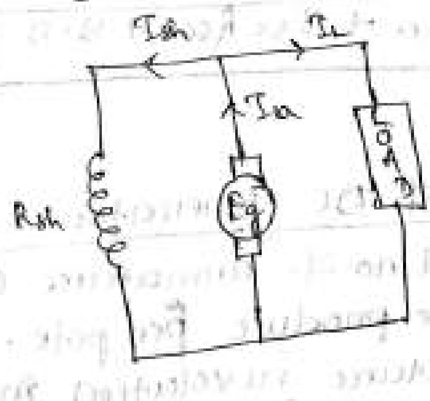
Q-1: A shunt generator deliver 450 A, 230 V, Given $R_{sh} = 50\,\Omega$, $R_a = 0.03\,\Omega$. Calculate the generated emf?

Given $R_a = 0.03\,\Omega$

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

$I_L = 450\,A$

$V = 230\,V$



Calculate $E_g = ?$

$E_g = V + I_aR_a + B.D.$

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

$\therefore I_a = 450 + 4.6 = 454.6\,A$

$\therefore E_g = 230 + (454.6 \times 0.03) + 0$

$= 243.638$ volt.

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

$= 4.6\,A$

B.D not given so taken zero.

Q-2 A short shunt 4-~~pa~~ pole ~~dc~~ dc compound generator supplies 200 A at 100 V. The resistance of armature, series field and shunt field windings are 0.04, 0.03 & 60 Ω respectively. Find the no of conductors if $\phi = 0.005$ wb, speed = 1000 rpm and the armature is lap connected winding. The brush drop is 2V per brush.

Sol

Data given

$P = 4$

$V_L = 100\,V$

$I_L = 200\,A$

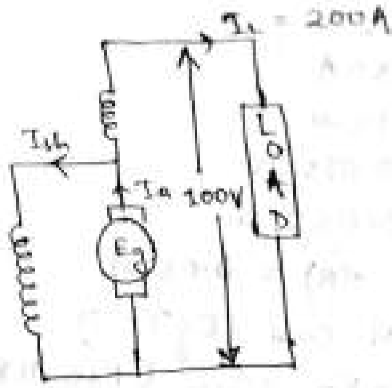
$R_a = 0.04\,\Omega$

$R_{se} = 0.03\,\Omega$

$R_{sh} = 60\,\Omega$

$\phi = 0.005$ wb

$N = 1000$ rpm



$A = P$ (Lap wdg), B.D $= 2\times2 = 4V$ (Brush drop).

Find $Z = ?$

We know, $E_g = \frac{\phi Z N}{60}\left(\frac{P}{A}\right) \Rightarrow Z = \frac{E_g \times 60 \times A}{N \times \phi \times P}$

For short shunt DC generator,

$E_g = V + I_aR_a + I_{se}R_{se} + BD$

And $I_a = I_L + I_{sh}$

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

Here, $I_{se} = I_L = 200\,A$

$I_{sh} = \frac{100 + (200 \times 0.03)}{60} = 1.76\,A$

$\therefore I_a = I_L + I_{sh} = 200 + 1.76 = 201.76\,A$

$E_g = V + I_aR_a + I_{se}R_{se} + B.D$

$= 100 + (201.76 \times 0.04) + (200 \times 0.03) + (2\times2)$

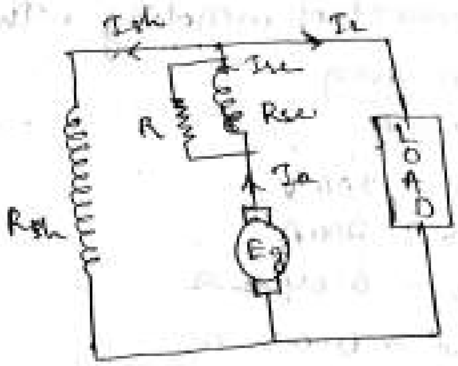
$= 100 + 8.074 + 6 + 4$

$= 118.07$ volt.

So $Z = \frac{E_g \times 60 \times A}{N \times \phi \times P} = \frac{118.07 \times 60 \times 4}{1000 \times 0.005 \times 4} = 1416$ (should be round)

Q-3 In a long shunt compound generator, the terminal voltage is 230 V, when generator delivers 150 A. Determine (1) induced emf, (2) Total power generated (3) Distribution of this power. Given that shunt field, series field, diverter and armature resistances are 92 Ω, 0.015 Ω, 0.03 Ω and 0.032 Ω respectively.

Sol



Data

$V = 230 V$

$I_L = 150 A$

$R_{sh} = 92 \Omega$

$R_{se} = 0.015 \Omega$

$R_a = 0.032 \Omega$

Diverter (R) = 0.03 Ω

Find Induced emf (E_g) = ?

$E_g = V + I_a R_a + I_{se}(R_{se} \parallel R) + B.D$

$\therefore (R \parallel R_{se}) = (0.03 \parallel 0.015)$

$= \frac{0.03 \times 0.015}{0.03 + 0.015} = 0.01 \Omega$

So, the total series field resistance = 0.01 Ω

$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{92} = 2.5 A$

$I_a = I_L + I_{sh} = 150 + 2.5 = 152.5 A$

$I_a = I_{se} = 152.5 A$

so $E_g = 230 + (152.5 \times 0.032) + (152.5 \times 0.01) + 0$

(B.D is given, so taken as zero)

$\therefore E_g = 236.4 V$

(2) Total power generated in armature,

$= (E_g \times I_a) = 236.4 \times 152.5 = 36015$ watt.

(3) Distribution of power

Power dissipited in load $= V_L \times I_L$

$= 230 \times 150 = 34500$ watt.

Power dispited in generator part

= Arm cu. loss + shunt field cu loss + series field cu loss.

Armature Cu loss $= I^2 R_a = (152.5)^2 \times 0.032$

$= 744\ \omega$.

Series field and diverter loss $= I_a^2 (R_{se} \parallel R)$

$= (152.5)^2 \times 0.01 = 232\ \omega$.

Shunt field loss $= I_{sh}^2 R_{sh}$ or $V I_{sh}$

$= (2.5)^2 \times 92 = 572$ watt.

$= 230 \times 2.5 = 575$ watt.

Losses in DC generator on Load →

Total loss

- Constant Loss
  - Fe loss or Iron loss or Core loss
    - Hysteresis loss
    - Eddy current Loss
  - Mechanical loss
    - Friction loss
    - Windage loss
  - Shunt field Cu loss ($I_{sh}^2 R_{sh}$)
- Variable loss
  - Armature Cu loss ($I_a^2 R_a$)
  - Series field Cu loss ($I_{se}^2 R_{se}$)

Rotational loss or Stray loss	= Fe loss + Mechanical loss

Constant Loss →

It is the loss which does not change (or remain constant) when load changes from no load to full load.

→ Fe loss and mechanical loss does not depends upon load.

→ The shunt field current is constant, so shunt field Cu loss is also constant.

→ Shunt field current does not change by changing the load from no load to full load.

Variable Loss →

It is the loss which changes with load (i.e. from no load to full load). When load changes, the load current (I_L) also changes.

→ As I_L changes, I_a & I_{se} also changes.

(a) So, armature Cu loss ($I_a^2 R_a$) and

(b) Series field Cu loss ($I_{se}^2 R_{se}$) are also changes.

Constant losses are of 3 types -

1. Iron or Core losses
2. Mechanical losses
3. Shunt field Cu loss.

① Iron or Core loss → These losses are occurred in the armature of DC machine and are due to the rotation of armature in the magnetic fields. Iron loss are of 2 types.

(a) Hysteresis loss

(b) Eddy current loss.

(a) Hysteresis loss → This loss occurs in the armature of DC m/c, since every part of armature is subjected to magnetic reversals as it passes successive pole (North & South)

→ The power loss is given by,

$$\boxed{P_h = \eta B_{max}^{1.6} f V} \rightarrow \text{watts}.$$

η → Steinmetz hysteresis co-efficient

B_{max} → Maxm flux density

f → Frequency of magnetic reversals.

V → Volume of armature in m^3.

* To minimize hysteresis loss, we used silicon ~~steel~~ steel as armature.

(∵ Silicon steel has low steinmetz hysteresis co-efficient)

(b) Eddy current loss → When the armature core rotates in the mag. field, an emf is induced in the core (just like it induces in armature conductors). Due to this induced emf current flows in the body of Armature. These currents are called eddy current. The losses occur due to these current is known as eddy current loss.

→ These eddy current loss can be minimised by constructing the core thin round iron sheets called lamination. The laminations are insulated from eachother by the coating of varnish.

Eddy current loss →

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

K_e → constant

B_{max} → Maximum flux density in wb/m²

t → Thickness of laminations.

V → Volume of core in m³

② Mechanical loss → These losses are of two types.

ⓐ Friction losses → These losses occurs due to friction in bearings and commutator.

→ Careful maintainance and proper lubrication are essential for reduction of bearing friction.

→ Brush friction can be reduced by using proper brushes, proper brushes seating

→ Smooth and clean commutator also reduce Brush friction

ⓑ Windage losses → Air friction on the armature when it rotates.

→ These losses are reduce the speed of the machine.

N.B

Iron losses + Mechanical losses = Rotational losses OR Stray losses.

③ Shunt field cu loss → ($I^2_{sh} R_{sh}$) → is known as shunt field cu loss.

→ Shunt field ~~cu~~ ~~loss~~ current (I_{sh}) does not change by changing the load from No-load to full load. So shunt field cu loss is a constant loss.

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Variation of Cu loss w.r.t. load →

$\boxed{\text{Cu loss} = I^2 R}$

Cu loss at $\frac{1}{2}$ load $= \left(\frac{1}{2}\right)^2 \times$ F.L cu loss

Cu loss at $\left(\frac{1}{4}\right)$th load

$= \left(\frac{1}{4}\right)^2 \times$ F.L. Cu loss.

Load $\propto I$

F.L cu loss $= I_a^2 R_a$

Half Load Cu loss $= \left(\frac{I_a}{2}\right)^2 R_a$

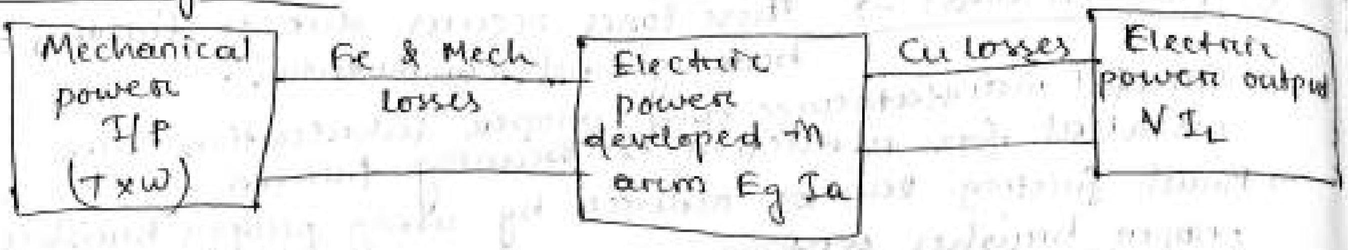
$= \left(\frac{1}{2}\right)^2 \times I_a^2 R_a$

Cu loss at $\left(\frac{3}{4}\right)^{th}$ load $= \left(\frac{3}{4}\right)^2 \times$ F.L. cu loss

Cu loss at 50% of full load $= \left(\frac{50}{100}\right)^2 \times$ F.L cu loss

Cu loss at 50% over full load $= \left(\frac{150}{100}\right)^2 \times$ F.L. cu loss.

Power stages →



* Output of the prime mover = Mech I/P to the Generator.

~~Mech~~ Mechanical I/P − Iron & Mech loss = $E_g I_a$

* $E_g I_a$ − Cu losses = $V I_L$

① Mechanical η = $\dfrac{\text{Electrical power developed in armature}}{\text{Mechanical I/P}}$

$= \dfrac{E_g I_a}{E_g I_a + \text{Fe \& Mech Losses}}$

② Electrical η = $\dfrac{\text{Electrical Power O/P}}{\text{Electrical power developed in armature}}$

$= \dfrac{V I_L}{E_g I_a} = \dfrac{V I_L}{V I_L + \text{Cu Losses}}$

③ Commercial η or overall η = $\dfrac{\text{O/P of DC generator}}{\text{I/P of DC generator}}$

$= \dfrac{V I_L}{V I_L + \text{Cu loss} + \text{Fe loss} + \text{Mech loss}}$

or $\eta = \dfrac{V I_L}{E_g I_a + \text{Fe loss} + \text{Mech loss}}$

Imp $\boxed{\text{Cu loss at any asking load} = \left(\frac{\text{Asking Load}}{\text{Full load}}\right)^2 \times \text{Full load cu loss}}$

Condition for max. Efficiency →

Consider a shunt generator, the terminal voltage is 'V' & load current is 'I_L'

Generator o/p = VI_L

Generator I/p = Output + losses.

$$= VI_L + \left(\begin{matrix}\text{Variable} \\ \text{loss}\end{matrix} + \begin{matrix}\text{const} \\ \text{loss}\end{matrix}\right)$$

$$= VI_L = I_a^2 R_a + W_c$$

∵ $I_a = I_L + I_{sh}$ (For shunt generator)

Though I_{sh} is very less as compared to I_L

So $I_a = I_L$ (Neglecting I_{sh})

∴ Generator I/p = $VI_L + I_L^2 R_a + W_c$

$$\eta = \frac{\text{Output}}{\text{Input}} = \frac{VI_L}{VI_L + I_L^2 R_a + W_c}$$

Dividing Both sides by VI_L

$$\eta = \frac{1}{1 + \left(\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right)}$$

The efficiency 'η' will be max when $\left(\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right)$ is minimum.

So $\frac{d}{dI_L}\left[\frac{I_L R_a}{V} + \frac{W_c}{VI_L}\right] = 0$

$$\Rightarrow \frac{R_a}{V} - \frac{W_c}{VI_L^2} = 0 \Rightarrow \frac{R_a}{V} = \frac{W_c}{VI_L^2}$$

$$\Rightarrow \boxed{I_L^2 R_a = W_c} \Rightarrow \boxed{\text{Variable loss} = \text{Constant loss}}$$

So, $\boxed{I_L = \sqrt{\frac{W_c}{R_a}}}$

Q→ A shunt generator delivers full load current of 200A at 240 V. The shunt field resistance is 60 Ω and full load efficiency is 90%. The rotational losses are 800 W. Find the armature resistance at current at which maximum 'η' occurs.

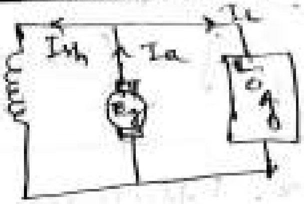
Data

$I_a = 200\ A$

$V_L = 240\ V$

$R_{sh} = 60\ \Omega$

$\eta = 90\%$



Rotational loss = Fe loss + Mech loss = 800 W.

Find Armature Cu loss = ?

Armature Cu loss = Total loss − Const. Loss.

Total losses = I/p power − O/p power.

O/p power $= V_L I_L = 240 \times 200 = 48000\ W$.

I/p power $= \frac{48000}{0.9} = 53833\ W$.

∴ Total losses = 53333 − 48000 = 5333 W.

Constant losses = Rotational loss + shunt field Cu loss.

Shunt field Cu loss $= I_{sh}^2 R_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{240}{60} = 4\ A$

∴ Shunt field Cu loss $= I_{sh}^2 R_{sh} = 4^2 \times 60 = 960\ W$.

Const. losses = 800 + 960 = 1760 W.

Arm. Cu loss = Total loss − Const. loss

= 5333 − 1760 = 3573 W.

$\therefore \boxed{I_a^2 R_a = 3573\ W}$

$\Rightarrow R_a = \frac{3573}{I_a^2}$

As $I_a = I_L + I_{sh} = 200 + 4 = 204\ A$

$\therefore R_a = \frac{3573}{(204)^2} = 0.0858\ \Omega$

(iii) Current at which maxm η occurs.

In maxm condn $I_L^2 R_a = W_c$ (Constant loss)

$\Rightarrow I_L = \sqrt{\frac{W_c}{R_a}}$

$= \sqrt{\frac{1760}{0.0858}} = 143.22\ A.$

Q② A 10 kW DC shunt generator has the following losses at full load. Mechanical losses = 290W, Fe losses = 240 W, shunt Cu loss = 120 W, Arm Cu loss = 595 W. Calculate the efficiency 'η' at (i) no load, (ii) at 25% of full load.

Sol (i) Find η at no load

$$\eta_{\text{at no load}} = \frac{\text{O/P at no load}}{\text{I/P at no load}}$$

O/P at no load is zero.
so 'η' at no load is always zero.

(ii) η at 25% of full load

$$\eta_{\text{at 25\% of F.L}} = \frac{\text{O/P at 25\% F.L}}{\text{I/P at 25\%} + \left(\text{Cu loss at 25\% of F.L}\right) + W_c}$$

($W_c \rightarrow$ Const loss remain same from no load to full load)

$$\text{O/P at 25\% of F.L} = (10 \times 10^3) \times \frac{25}{100} = 2500\ W$$

$$\text{Cu loss at 25\% of F.L} = \left(\frac{25}{100}\right)^2 \times \text{F.L Cu loss}$$
$$= \left(\frac{1}{4}\right)^2 \times 595 = 37\ W$$

$$\therefore \eta \text{ at 25\%} = \frac{2500}{2500 + 37 + 120 + 420 + 290} \times 100$$
$$= 74\%$$

Q③ A long shunt compound generator running at 1000 rpm supplies 22 kW at terminal voltage of 220 V. The resistance of the armature, shunt field and series field are 0.05 Ω, 110 Ω and 0.06 Ω respectively. The overall efficiency at the above load is 88%. Find (i) Cu losses (ii) Fe losses & friction losses (iii) Torque exerted by the prime-mover.

Sol

Data Long shunt compound Gen.

$O/P = 22\ kW$
$V_L = 220\ V$
$R_a = 0.05\ \Omega$
$R_{sh} = 110\ \Omega$

$R_{se} = 0.06\ \Omega$
$\eta = 88\% = 0.88$

(i) Arm. cu loss $= I_a^2 R_a$

In long shunt compound Gen, $I_a = I_L + I_{sh}$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2A$$

$$I_L = \frac{P}{V_L} \quad (\because P = V_L I_L)$$

$$I_L = \frac{22\times10^3}{220} = 100\,A$$

$\therefore I_a = 100 + 2 = 102\,A$

Arm. cu loss $= (102)^2 \times 0.05 = 520.2\,W$

Series field cu loss $= I_a^2 R_{se} = (102)^2 \cdot 0.06$
$= 624.3\,W$

Shunt field cu loss $= I_{sh}^2 R_{sh}$ or $V I_{sh}$
$= (2)^2 \times 110 = 440\,W$

$\therefore$ Total cu loss $= 520.2 + 624.3 + 440$
$= 1584.5\,W$

② Fe and Friction loss = ?

Fe and Friction loss = Total loss − Total cu loss

Total loss = I/P − O/P

$$I/P = \frac{O/P}{\eta} \quad \left(\because \eta = \frac{O/P}{I/P}\right)$$

$$= \frac{22\times10^3}{0.88} = 25000\,W$$

$\therefore$ Total loss $= 25000 - 22000 = 3000\,W$

Fe & Friction Loss $= 3000 - 1584.5 = 1415.5\,W$

③ Torque exerted the prime mover = ?

O/P power prime mover = T × Angular velocity

O/P power prime mover = I/P to generator
$= T \times \omega$

$$\Rightarrow T = \frac{I/P \text{ to Gen.}}{\omega} = \frac{25000}{\frac{2\pi N}{60}}$$

$$= \frac{25000 \times 60}{2\pi \times 100} = 238.74\ N\text{-}m$$

Q-4 18.5.21

In a dc machine the total iron loss is 8 KW at its rated speed and excitation remain same but speed is reduced by 25% to total iron loss is found to be 5 KW. Calculate the hysterisis and eddy current losses at full speed and half of the rated speed.

Sol^n Total iron loss = 8 KW.

Total Iron loss = 5 KW (when speed reduced by 25%.)

(i) Find hysterisis loss & eddy current loss at full speed and half of the rated speed ?

We know ; $W_h = K B_{max}^{1.6} f V$

$$W_e = K B_{max}^2 f^2 V^2$$

$W_h \propto f$ and $W_e \propto f^2$

$\Rightarrow W_h \propto N \quad W_e \propto N^2 \quad (\because f \propto N)$

So $W_h = AN$, $W_e = BN^2$

(where A and B are constants)

$\therefore$ Total Iron loss $= W = W_h + W_e = AN + BN^2$

Assume the full rated speed $(N) = 1$

$8 KW = 8000 W = A(1) + B(1)^2 = 8$ —— ①

In 2nd case :- speed is reduced by 25% means

speed present is 75%.

So Iron loss $= 5 KW = 5000 W = A(0.75) + B(0.75)^2$. —— ②

Solving ① & ②

A = 2.67 KW

B = 5.33 KW

(i) W_h at full speed / rated speed $= A(1) = 2.67$ KW.

W_e at full speed / rated speed $= B(1)^2 = 5.33$ KW.

(ii) W_h at half of rated speed $= A\left(\frac{1}{2}\right) = \frac{2.67}{2} = 1.335$ K

W_e at " " " $= B\left(\frac{1}{2}\right)^2 = 5.33 \times \frac{1}{4}$

$= 1.3325$ KW.

Q-2 (5) A shunt generator supplies 100 A at a terminal voltage of 200 V. The prime mover is developing 32 b.h.p shunt field resistance = 50 Ω, armature resistance = 0.1 Ω, find,
(i) The Fe and friction losses.
(ii) The Cu losses
(iii) The commercial, electrical and mech. efficiency.

Sol Given $I_L = 100A$, $V_L = 200V$ | $R_{sh} = 50\Omega$, $R_a = 0.1\Omega$

primemover o/p = 32 bhp = Input to the generator

(i) Find Friction & Fe loss →

Fe & Friction Loss = I/p − Electrical power developed
= I/p − $E_g I_a$

I/P = 32 BHP = 32 × 746 = 23872 W.

Emf generated: $E_g = V + I_a R_a$ (B.w. not given)

$I_a = I_L + I_{sh}$ | $I_{sh} = \frac{V_L}{R_{sh}} = \frac{200}{50} = 4A$

∴ $I_a = 100 + 4 = 104$ A

$E_g = 200 + (104 \times 0.1) = 210.4$ V

$E_g I_a = 210.4 \times 104 = 21882$ W.

∴ Fe and friction loss = 23872 − 21882 = 1990 W.

(ii) Cu losses = $E_g I_a$ − Electrical power o/p.

Electrical power o/p = $V_L I_L$ = 200×100 = 20000 W.

∴ Cu loss = 21882 − 20000 = 1882 W.

(iii) Commercial 'η' = $\frac{\text{Electrical o/p}}{\text{Electrical o/p + Cu loss + Wc}} \times 100$

or 'η' = $\frac{\text{Electrical o/p}}{\text{Electrical power developed}} \times 100$

$= \frac{20000}{E_g I_a} \times 100 = \frac{20000}{21882} \times 100 = 91.39\%$

Mech 'η' = $\frac{\text{Electrical power developed}}{\text{I/p to the generator}} \times 100$

$= \frac{E_g I_a}{23872} \times 100 = \frac{21882}{23872} \times 100 = 91.66\%$

or Mech $\eta' = \frac{\text{Electrical power developed}}{\text{Elect. power dev + Fe \& Friction loss}} \times 100$

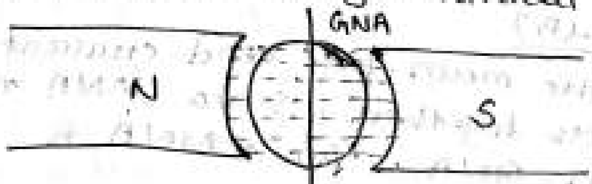
$= \frac{E_g I_a}{E_g I_a + 1990} = \frac{21882}{21882 + 1990} \times 100$

$= 91.66\%$

Armature Reaction →

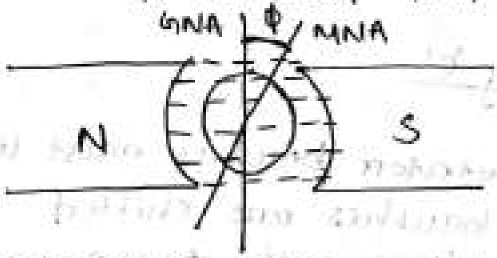
22.05.21

GNA → It is the geometrical neutral axis or plane.



MNA → It is the magnetic neutral axis or plane.

At no load GNA coinside with MNA.



At load MNA create an angle 'ϕ' with GNA due to Armature reacn.

Armature Reacn →

Armature reacn means the effect of magnetic field set up by the armature current on the distribution of flux under the main poles flux of the generator.

It has two effects.

① It demagnetise or weakens the main flux.

② It cross magnetise or distorts it.

* The demagnetising effect leads to reduce the generated voltage.
* Due to cross magnetising effect the sparking takes place at the brush.
* At no load no current flows through the armature and no armature reacn takes place in the generator. So both planes (GNA & MNA) are coinside to eachother as shown in fig (1).

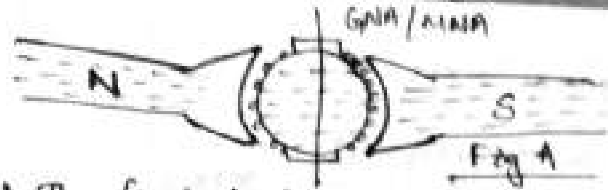


Fig A

* The fig.(B) shows the flux due to the current flowing through Armature conductor only. The armature cond^n which are left to the GNA carries current in forward direc^n and those are right to the GNA carries current in outward direc^n

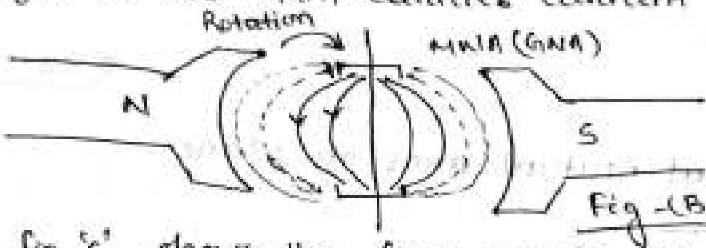


Fig-(B)

The fig 'C' shows the flux due to the main pole and current flowing through the armature acts together, since MNA is shifted through an angle ϕ with GNA. The MNA is shifted in the direc^n of rotation of generators.

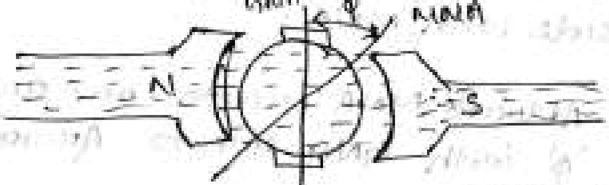


Fig 'C'

* In order to achieve sparkless commutator brushes must lie along the MNA consegently. The brushes are shifted through an angle 'ϕ'. So as to lie along with MNA as shown in the fig 'D'.

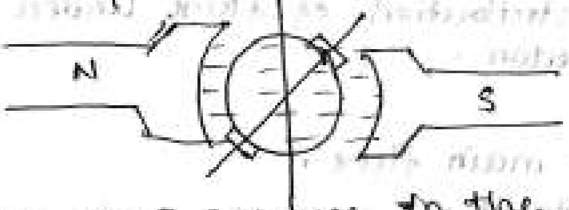
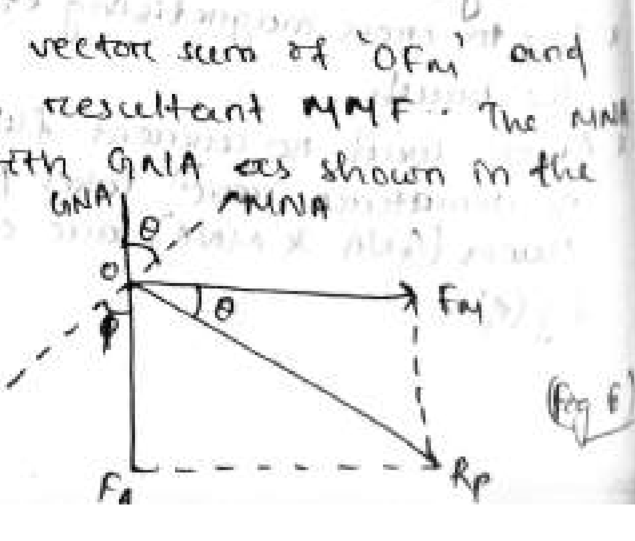


Fig 'D'

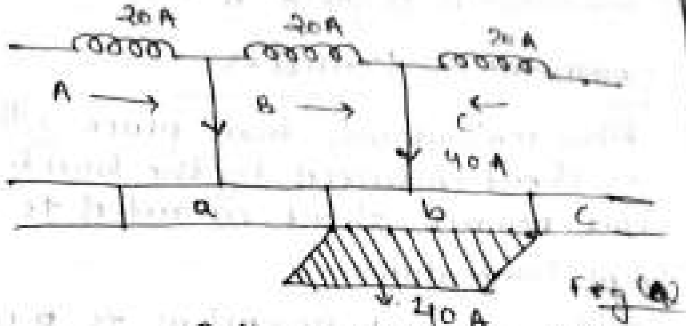
The MMF produce in the main flux is ϕ represented by the .on of OF_M. The MMF produce in the armature flux is resented as OF_A.
The OF_M is always perpendicular to GNA.
The resultant MMF OR_F is the vector sum of 'OF_M' and since MNA is perpendicular to resultant MMF. The MNA is shifted to an angle ϕ with GNA as shown in the fig 'E'.



Commutation →

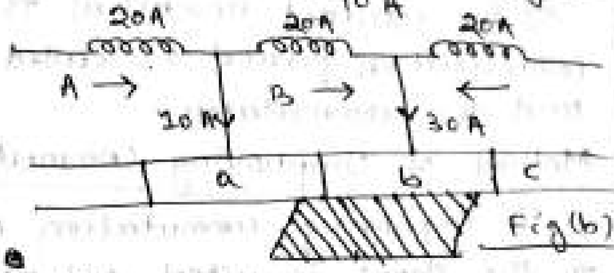
The reversal of current direcⁿ as the coil passes the brush is called commutation.

→ In fig 'a' the coil 'A' & 'B' are about to short ckted so current 40 A flows through the brush (i.e. 20 A from coil A and 20 A from coil C. The direcⁿ of current in coil 'B' is clockwise.



Fig(a)

→ In fig 'b' there are two parallel ~~point~~ path into the brush as long as the short ckt coil 'A' is exist. The brush again conduct a current of 40 A & (30 A current - thorough segment b and 10 A current from segment 'a'). The direcⁿ of the coil 'B' is clockwise.



Fig(b)

→ The fig shows the

as a short ckt so no current flows through the coil B, current flows through the brush is 40 A. (i.e. 20 A current from coil A & 20A from coil C)

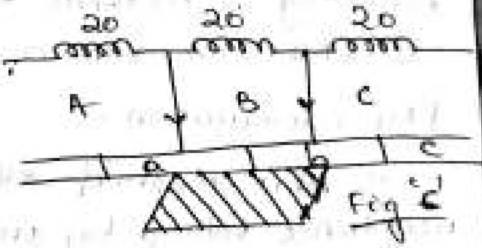


Fig 'c'

→ The fig 'd' shows the brush short ckted 3/4 of segment 'a' and 1/4 of segment 'b' so 40 A current flows through the brush (10 A thorough the coil 'B' and 30 A current from coil 'A'). Here the current direcⁿ of coil 'B' is reversed i.e. anticlockwise.

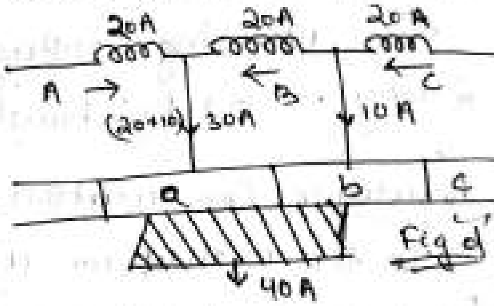


Fig 'd'

→ The fig 'e' shows the coil 'B' is almost at the end of commutation. So again the brush carries current 40A (35A - from segment a and 5A from segment 'b') This 5A produces sparking. The direcⁿ of coil 'B' is anticlock wise.

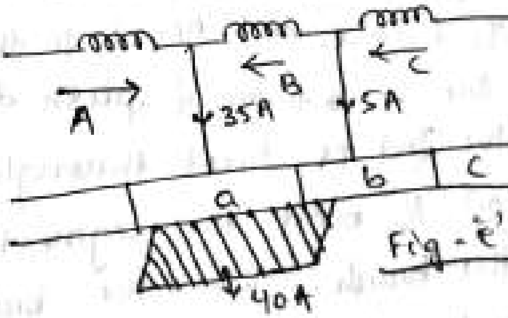


Fig-'e'

For ideal commutation current flows through coil A is 20A so current flows through the brush is 40 A through the commutator segment 'a' only.

Commutation Period →

When commutation takes place, the coil undergoing commutation is short circuited by the brief period during ~~coil~~ which the coil remain short circuited is known as commutation period.

Ideal Commutation →

If the current reversal is completed by the ends of commutation period is called ideal commutation bet the brush and the commutator.

Method of Improving Commutation →

To improving commutation means make current reversal in the short circuited coil as sparkless as possible. following 2 methods is used to improving commutation,
① EMF Commutation, ② Resistance commutation,

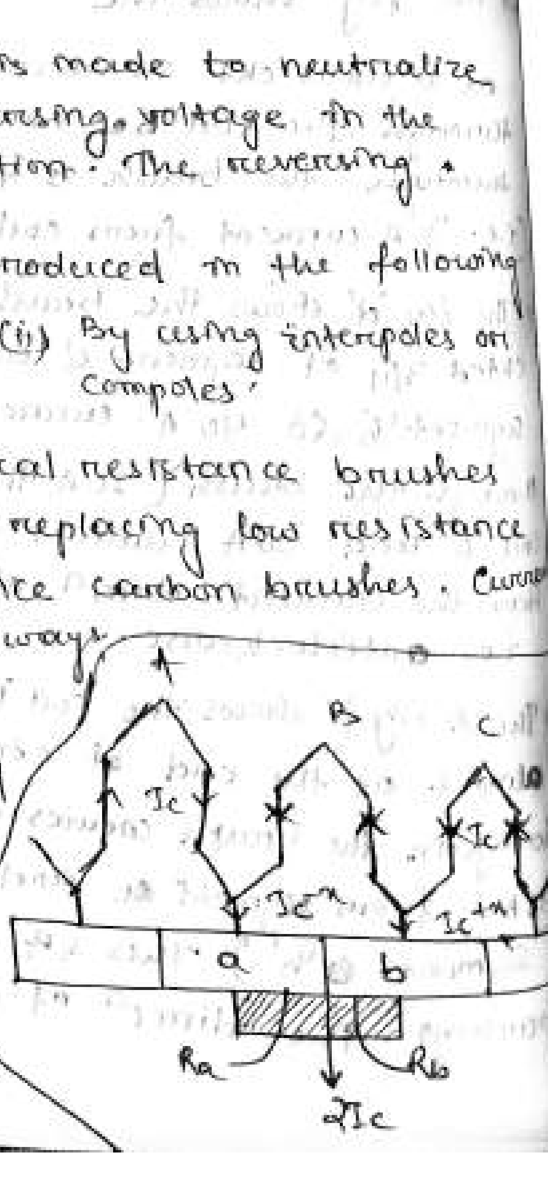
EMF commutation →

In this method all arrangement is made to neutralize reactance voltage by producing a reversing voltage in the short circuited coil under commutation. The reversing neutralize it to some extend.

The reversing voltage may be produced in the following 2 way. (i) By Brush shifting, (ii) By using interpoles or compoles.

Resistance Commutation →

In this method we use high electrical resistance brushes for getting sparkless commutation by replacing low resistance copper brushes with high resistance carbon brushes. Current I_c from 'C' coil reach to the brush in 2 ways. One is from 'b' path directly, and the 2nd is first through short ckted coil B and the segment a and to the brush. When the brush resistance is low the current 'I_c' from coil 'C' follow the shortest path as electrical resistance is comparatebly low.



As electrical resistance $R \propto \frac{1}{A}$ the R_b will increase and R_a decreases. $R = \rho \frac{l}{A}$

ρ = resistivity of condn | l = length
A = Area (Contact area)

Advantages of Operating DC generators In parallel →

In d.c power plant, power is usually supplied from several generators of small rating connected in parallel instead of from one large generator. This is due to following reasons.

Continuity of Service →

If a single large generator is used in the power plant, then in case of its brkdown the whole plant will be shut down. However if power is supplied from a number of small units operating in parallel, then in case of failure of one unit, the continuity of supply can be maintained by other healthy units.

Efficiency →

Generator runs more efficiently when loaded to there rated capacity. Electric power costs less per ~~kwh~~ Kwh when the generator producing it is efficiently loaded. Therefore, when load demand on power plant decreases, one or more generators can be shut down and the remaining units can be efficiently loaded.

Maintenance and repair →

Generators generally require routine maintenance and repair. Therefore, if generators are operated in parallel, the routine or emergency operations can be performed by isolating the affected generator while load is being supplied by other units. This leads to both safety and economy.

Increasing Plant Capacity →

In the modern world of increasing population, the use of electricity is continuosly increasing. When added capacity is required, the new unit can be simply paralleled with the old units.

Non-availability of Single large unit →

In many situations, a single unit of desired large capacity may not be available. In that case a number of smaller units can be operated in parallel to meet the load requirement. Generally a single large unit is more expensive.

Conditions for parallel operation of Generators →

In case of DC generating stations, there are heavy thick copper bars which acts as positive and -ve terminals for entire stations. These bars are called bus bars. While connecting the DC generators in ||^n the +ve & -ve terminals of the generator should be respectively connected to the +ve and -ve terminals of bus bars. It results in short ckt which will cause damage to the commutator and brushes ultimately shutting down the station. Before making the ||^n operation, it should be checked for reversal polarity of the generators otherwise brakers are tripped off as a result of heavy fault current.

30.5.21

Imp

Q → Separately excited DC generator when running at 1200 rpm supplies 200 A at 125 V, to a ckt of constant resistance, what will be the current when the speed is droped 1000 rpm and field resistance is reduced to ~~...~~ 80 V. Armature resistance 0.04 Ω & total B.D is 2V (Ignore Armature reac^n)

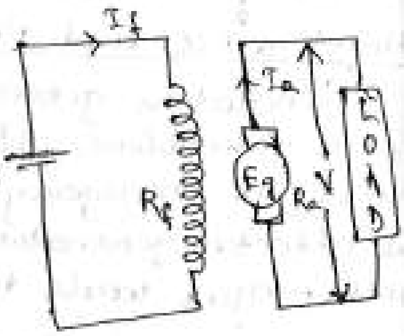
Sol^n In $N_1 = 1200$ rpm

$I_L = 200A$

$V = 125V$

$R_a = 0.04\Omega$

$B.D = 2V$ $(I_f \propto \phi)$



$N_2 = 1000$ ~~...~~

field resistance drop = 80%

$E_{g_1} \propto \phi_1 N_1$

$E_{g_2} \propto \phi_2 N_2$

$$E_{g_1} = V + I_aR_a + B.D$$
$$= 125 + (200 \times 0.04) + 2$$
$$= 125 + 0.8 + 2$$
$$= 135\,V$$

$$\frac{E_{g_1}}{E_{g_2}} = \frac{\phi_1}{\phi_2} \times \frac{N_1}{N_2}$$

$$\Rightarrow \frac{135}{E_{g_2}} = \frac{\phi_1}{0.8\phi_1} \times \frac{1200}{1000}$$

$$\Rightarrow E_{g_2} = \frac{135 \times 0.8 \times 1000}{1200} = 90V$$

$\therefore E_{g_2} = V + I_aR_a + B.D$

$90 = 80 + I_a \times (0.04) + 2$

$10 - 2 = I_a \times 0.04$

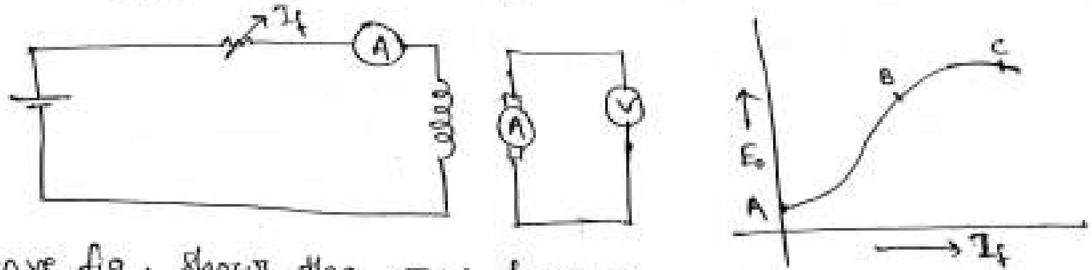
$\Rightarrow I_a = \frac{8}{0.04} = \frac{800}{4} = 200\ A$

Shunt

DC Generator Characteristics →

① Open ckt Characteristics (O.C.C) / N/O load Characteristics curve →

It is the curve betn generated emf at no load (E_0) and field current (I_f) at constant speed.



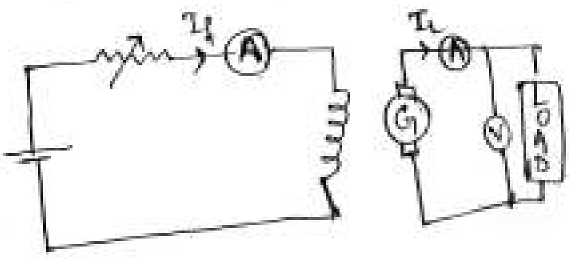
In the above fig. shows the wave form of a open ckt characteristics.

when the armature rotates at the time of starting emf will be induced in the armature (when field current (I_f) is zero). This is due to the residual magnetism for which the curve starts from 'A' instead of pt 'O'.

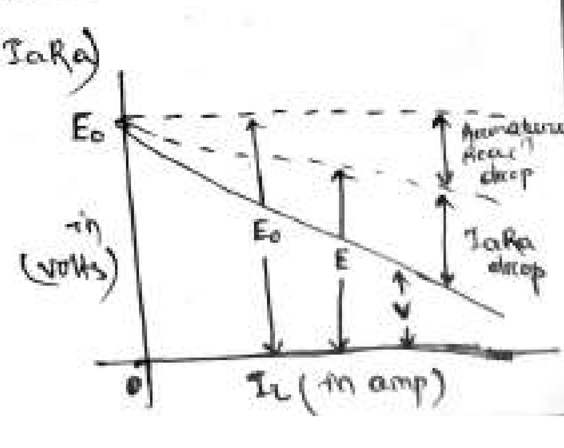
When the emf current increases, the emf generated is also increases. This process continuous till the field magnetisation is saturated. After the saturation pt. by increasing the field current, the emf will remain constant which shown in the fig. after pt. 'C'.

② External Characteristics →

It is the curve betn the terminal voltage (V) and load current (I_L). As the load current (I_L) increases, the terminal voltage decreases due to the armature reacn and voltage drop across armature resistance ($= I_aR_a$).

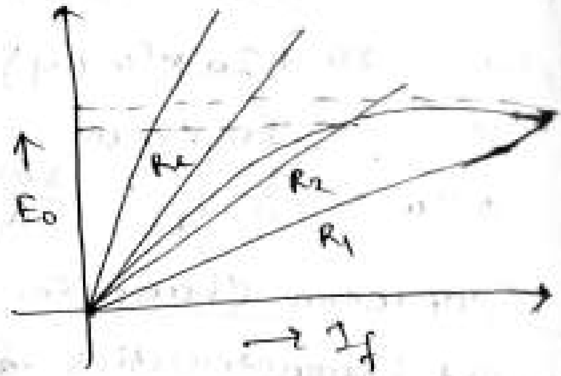


Due to this reasons, the external characteristics is a drooping curve.



Critical field Resistance →

The maximum field ckt resistance with which the shunt generator would excite is known as critical field resistance.



D.C. MOTORS

5·6·21

DC motor is a machine which converts direct current (DC) electrical power into mechanical power.

Principle → It is based on the principle that when a current carrying conductor is placed in the magnetic field, the conductor produced a mechanical force. The direcⁿ of the force is given by Flemming's left hand rule.

Working →

When DC supply is given to the armature as shown in fig(1) current starts flowing through the armature condⁿs, which is placed in a magnetic field. A mechanical force or torque ($T \propto \phi I_a$) is produced on the armature condⁿ the sum of all the force produced on the condⁿs of the armature produced a large force which rotate the armature.

* The condⁿs under N-pole carries current in one direcⁿ (down-ward) and under S-pole carries current in opposite direcⁿ shown in fig (1).

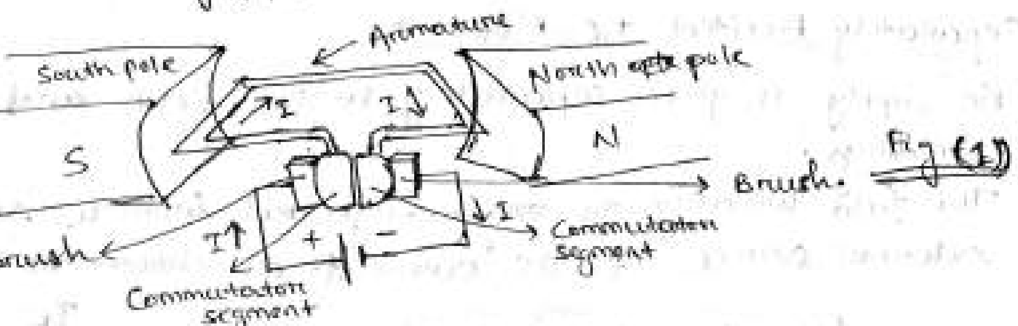
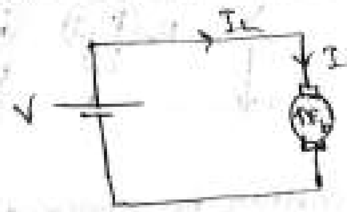


Fig (1)

Equivalent ckt of DC Motor →



$$\boxed{V = E_b + I_a R_a + B.D}$$

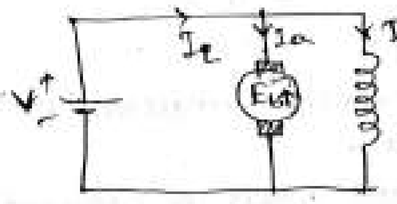
$$\Rightarrow E_b = V - I_a R_a - B.D$$

Back emf (E_b) →

When the armature of the motor is rotating the condⁿ are cutting the magnetic flux lines and hence according to Faraday's laws of Electromagnetic Induction, an emf induced in the armature condⁿs. The direcⁿ of this induced emf is such that it opposes the armature current (I_a).

So the name as back emf (E_b)

$$\boxed{E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right)}$$



$V \rightarrow$ supply voltage
$I_L \rightarrow$ Line current
$I_a \rightarrow$ Armature "
$E_b \rightarrow$ Back emf.
$I_f \rightarrow$ field current.

Types of DC Mototores

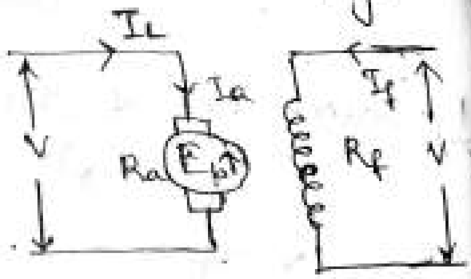
DC Motor
- Permanent Magnet
- Electromagnet.
  - Self excited
    - DC series
    - D.C. Shunt
    - D.C compound
      - Long shunt
      - ~~Short shunt~~
  - Separately excited.

Separately Excited DC Motor →

DC supply is given separately to the field and armature windings.
The field winding is ~~eng.~~ energised from a separate external source of DC current as shown in the fig.

$$\boxed{V = E_b + I_a R_a + B.D}$$

$$\Rightarrow E_b = V - I_a R_a - B.D$$



Self Excited D.C Motor →

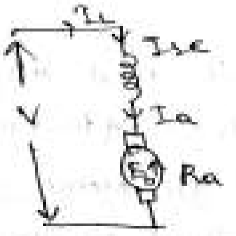
In this type of Motor, field winding is connected either in series or parallel or partly series or parallel to the armature windings.

① DC series Motor →

In this type of Motor, the field winding is connected in series with the armature. It has high starting torque.

Here, $I_L \rightarrow$ Line current.

$I_L = I_{se} = I_a$



$$\boxed{V = E_b + I_aR_a + I_{se}R_{se} + B.D}$$

$\Rightarrow E_b = V - I_aR_a - I_{se}R_{se} + B.D$

N.B Torque $\propto \phi I_a$

In series motor, $\phi \propto I_a$

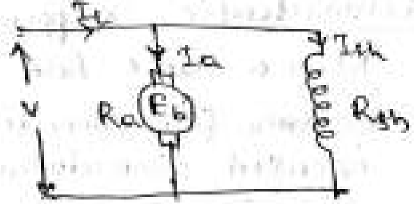
$\therefore \boxed{T \propto I_a^2}$

Uses $\rightarrow$ This motor has a high starting torque, so used in electric traction, cranes, elevators, air compressors, vaccume cleaner, also used in rolling mills, hoists, lifts etc.

② **DC Shunt Motor** $\rightarrow$

Field winding is connected in parallel with the armature.

Here, $\boxed{I_L = I_a + I_{sh}}$



$I_{sh} = \frac{V}{R_{sh}}$ & $\therefore \boxed{V = E_b + I_aR_a + B.D}$

$\Rightarrow E_b = V - I_aR_a - B.D$

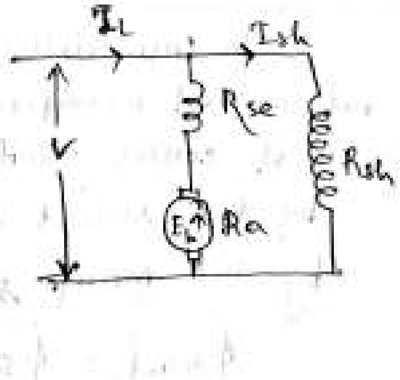
N.B $\boxed{T \propto I_a}$

* So shunt motor is a constant speed motor as the speed does not vary with the mechanical load.

Uses $\rightarrow$ It is a constant speed motor, so used in centrifugal ~~forces~~ pumps, blowers, fans etc.

③ **Long shunt compound DC motor** $\rightarrow$

If the shunt field winding is parallel to both the series field winding and armature winding, then it is known as long shunt compound DC generator.



$$\boxed{V = E_b + I_aR_a + I_{se}R_{se} + B.D}$$

$$\Rightarrow \boxed{E_b = V - I_aR_a - I_{se}R_{se} - B.D}$$

Here $I_L = I_a + I_{sh}$, $I_{sh} = \frac{V}{R_{sh}}$

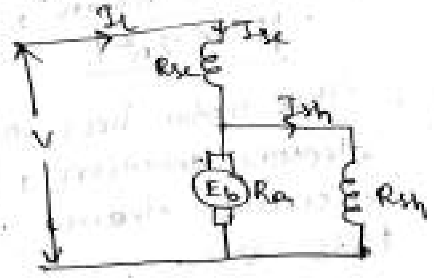
$I_a = I_{se}$.

Uses →

It is a variable and adjustable speed DC motor with high starting torque, used in conveyor, elevators etc.

(4) Short Shunt DC Motor →

If the shunt field winding is only parallel to the armature winding, and not the series field winding, then known as short shunt DC motor.



$$V = E_b + I_aR_a + I_{se}R_{se} + B.D$$

$$\Rightarrow E_b = V - I_aR_a - I_{se}R_{se} - B.D.$$

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

$$\Rightarrow \boxed{I_{sh} = \frac{V - I_{se}R_{se}}{R_{sh}}}$$

Commulative Compound DC Motor →

When a shunt field flux assists the main field flux, produced by the main field connected in series to the armature winding then it is called commulative compound dc motor.

$$\phi_{total} = \phi_{series} + \phi_{shunt}$$

Application of Commulative Compound DC Motor →

It is a varying speed motor with high starting torque and is used for driving compressors, variable - head centrifugal pumps, rotary ~~spaces~~ presses, circular saws, shearing machines, elevators and continuous conveyors.

Differential Compound DC Motor →

In case differentially compounded self excited dc motor i.e. differential compound dc motor, the arrangement of shunt and series winding is such that the field flux produced by the shunt field winding diminishes the effect of flux by the main series field winding.

$$\phi_{total} = \phi_{series} - \phi_{shunt}.$$

The net flux produced in this case is lesser than the original flux and hence does not find much of a practical Application

Losses in DC Motor →

The losses of DC motor is same as DC generator.

Losses
- Constant loss
  - Mesh loss
    - Windage loss
    - Friction loss
  - Fe loss
    - Eddy current loss
    - Hysteresis loss
  - Shunt field Cu loss
- Variable loss
  - Armature Cu loss ($I_a^2 R_a$)
  - Series field Cu loss ($I_{se}^2 R_{se}$)

Rotational losses = Stray loss = (Mech loss + Fe loss)

Power stages →

A: Electrical I/p to motor (VI_L) $\xrightarrow{\text{Cu losses}}$ B: Mech power developed ($T_a \times \omega$) Electrical power developed ($E_b I_a$) $\xrightarrow{\text{Fe losses, Mech losses}}$ Mech o/p Pact ($T_{sh} \times \omega$)

$$\boxed{\eta_e = \frac{B}{A}}$$

$$\text{Electrical } \eta = \frac{\text{Electrical o/p}}{\text{Electrical power I/p}} \times 100$$

$$= \frac{E_b I_a}{VI_L} \times 100$$

$$\text{or, } \eta_{elect} = \frac{\text{Elect I/p} - \text{Cu losses}}{\text{Electrical I/p}} \times 100$$

$$= \frac{VI_L - \text{Cu losses}}{VI_L} \times 100$$

$$\text{or, } \eta_{elect} = \frac{\text{Mech. power developed}}{\text{Elect. Power I/p}} \times 100$$

$$= \frac{T_a \times \omega}{VI_L} \times 100$$

Mechanical η = $\boxed{\eta_m = \frac{C}{B}}$

$$\eta_{mech} = \frac{\text{O/P power of motor}}{\text{Mech. power developed}} \times 100$$

$$\eta_{mech} = \frac{(T_{sh} \times \omega)}{(T_a \times \omega)} \times 100$$

or, $$\eta_{mech} = \frac{\text{o/p power of motor in KW}}{\text{o/p power of motor in KW} + (\text{Fe \& Mech loss})} \times 100$$

or, $$\eta_{mech} = \frac{E_b I_a - (\text{Fe \& Mech loss})}{E_b I_a} \times 100$$

Overall Efficiency → $\boxed{\eta_c = \frac{c}{A}}$ ~~η = Motor o/p~~

$$\eta = \frac{\text{Motor I/P} - \text{Total losses}}{\text{Motor I/P}} \times 100$$

$$= \frac{VI_L - [\text{Fe loss} + \text{Mech loss} + \text{Cu loss}]}{VI_L} \times 100$$

~~$\eta = \frac{\text{Motor I/P} - \text{Total losses}}{\text{Motor I/P}} \times 100$~~

~~$= VI_L - [\text{Fe loss}$~~

or $$\eta = \frac{\text{Motor o/P}}{\text{Motor I/P}} \times 100 = \frac{(T_{sh} \times \omega) \times 746}{VI_L} \text{ in KW}$$

or $$\eta = \frac{(T_{sh} \times \omega) \text{ in KW}}{(T_{sh} \times \omega) + \text{Total losses}}$$

or $$\eta = \frac{(T_{sh} \times \omega) \text{ in KW}}{(E_b I_a) + \text{Cu Losses}} \times 100$$

Torque → Torque means a twisting / turning force about an axis.

Consider a pulley having radius 'r' in a meter, a force (F) Newton acting in it, ~~meter; a force~~ which causes to ~~rotate~~ & rotate the pulley at 'N' r.p.s.

$$\boxed{\text{Torque } 'T' = F \times r}$$

Power developed = Force × distance × N

∴ Power developed = $F \times 2\pi r \times N$

$P = (F \times r) \times 2\pi N$, N in rps.

$\boxed{P = T \times \omega}$; $N \to$ rps.

$\boxed{P = T \times \frac{\omega}{60}}$; $N \to$ rpm.

Armature Torque $(T_a) \to$

The torque developed by the armature of the dc motor. We know from the power stages block 'B' "Electrical power $(E_b I_a)$ is converted in to mechanical power in the armature.

So, $E_b I_a = T_a \times \omega$ —— ①

$\Rightarrow E_b I_a = T_a \times (2\pi N)$

$\Rightarrow T_a = \frac{E_b I_a}{2\pi N}$ —— ② $N \to$ rps

$\therefore T_a = \frac{E_b I_a}{2\pi \frac{N}{60}}$, $N \to$ rpm. —— ③

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

By putting; $E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right)$ in eqn ③

$$\therefore T_a = \frac{\frac{\phi Z N}{60}\left(\frac{P}{A}\right) \times I_a}{2\pi \frac{N}{60}} = \frac{1}{2\pi} \times Z \times I_a\left(\frac{P}{A}\right) \times \phi$$

$$\Rightarrow \boxed{T_a = 0.159\ Z I_a \phi\left(\frac{P}{A}\right)}$$

$A = P$, Lap winding

$A = 2$, Wave winding.

Shaft Torque $\to (T_{sh})$

The torque which is available for doing useful work in a motor is known as shaft torque (T_{sh}).

We know that, o/p of the motor is equal to

$T_{sh} \times \omega$

$P_{out} = T_{sh} \times \omega = T_{sh} \times 2\pi N$, $N \to$ rps

$\Rightarrow P_{out} = T_{sh} \times \frac{2\pi N}{60}$, $N \to$ rpm $\Rightarrow T_{sh} = \frac{P_{out}}{2\pi \frac{N}{60}}$

$$\boxed{T_{sh} = 9.55 \cdot \frac{P_{out}}{N}}$$

N.B. $T_a \propto \phi I_a$

In series motor $\rightarrow \phi \propto I_a$, $T_a \propto I_a^2$

In shunt motor $\rightarrow \phi$ is const, ($\because I_{sh}$ is const)

$\therefore T_a \propto I_a$

& $E_b = \frac{\phi Z N}{60}\left(\frac{P}{A}\right)$

$E_b \propto N\phi$

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

Hence, $N_1 \propto \frac{E_{b1}}{\phi_1}$, $N_2 \propto \frac{E_{b2}}{\phi_2}$

$$\therefore \frac{N_2}{N_1} = \frac{\left(\frac{E_{b2}}{\phi_2}\right)}{\left(\frac{E_{b1}}{\phi_1}\right)} = \frac{E_{b2}}{\phi_2} \times \frac{\phi_1}{E_{b1}} \Rightarrow \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$$

In Series motor

$\phi \propto I_{a1}$, $\phi_2 \propto I_{a2}$

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

Shunt Motor

$$\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \quad (\because \phi \text{ is const})$$

$$\% \text{ Change in Torque} = \frac{T_1 - T_2}{T_1} \times 100$$

9.6.21

Q-> A 220 V, d.c shunt motor takes a total current of 80 A and runs at 800 rpm. $R_{sh} = 50\,\Omega$ and $R_a = 0.1\,\Omega$. If Iron and friction losses 1600 W, Find (i) Cu losses, (ii) Armature torque, (iii) Shaft torque, (iv) Efficiency.

Sol: $V_L = 220V$

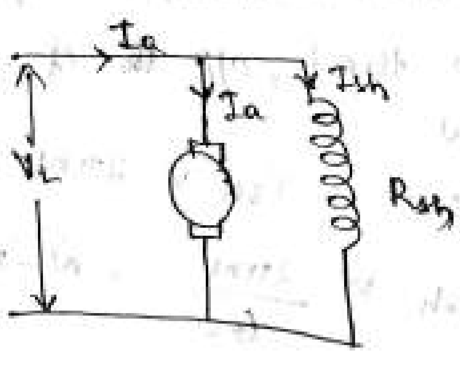
$I_L = 80A$

$N = 800$ rpm

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

$R_a = 0.1\,\Omega$

Fe & Friction loss $= 1600\,W$



Cu loss = ?

Cu loss = $I_a^2 R_a$, $I_a = I_L - I_{sh}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{50} = 4.4 A$

$\therefore I_a = 80 - 4.4 = 75.6 A$.

(i) Arm. Cu loss = $I_a^2 R_a = (75.6)^2 \times 0.1 = 571.53 W$.

(ii) shunt field cu loss = $I_{sh}^2 R_{sh}$

$= (4.4)^2 \times 50 = 968 W$.

Total cu loss = 968 + 571.63 = 1539.53 W.

② Armature Torque (T_a).

$T_a = 0.159 \, Z I_a \phi \left(\frac{P}{A}\right)$

Here, Z, Φ, P, & A values are not given.

So we have to put

$T_a = \frac{E_b I_a}{\omega} = \frac{E_b I_a}{2\pi \frac{N}{60}} \Rightarrow T_a = \frac{60}{2\pi} \frac{E_b I_a}{N}$

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

$E_b = V - I_a R_a = 220 - (75.6 \times 0.1)$

$= 212.44 V$

$T_a = \left(\frac{212.44 \times 75.6}{800}\right) \times 9.55 = 192 N\text{-}m$

③ Shaft torque

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

P_{out} = VI_L − Total losses

= VI_L − Fe & friction Loss − $I_a^2 R_a - I_{sh}^2 R_{sh}$

= (220 × 80) − 1600 − 571 − 968.

= 14460 W

$T_{sh} = 9.55 \times \frac{P_{out}}{N} = \frac{9.55 \times 14460}{800}$

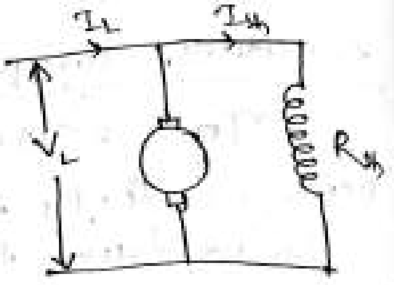
$= 172.6 N\text{-}m$

Efficiency

$$\eta = \frac{o/p \text{ in kW}}{I/P} = \frac{14460}{(220 \times 80)} \times 100$$

$\Rightarrow \eta = 82.1\%$

Q→ The input to a 220 V, dc shunt motor is 11 kW. Calculate the (i) torque developed
(ii) Efficiency in No load current = 5A, No load speed = 1150 r
$R_a = 0.5\,\Omega$, $R_{sh} = 110\,\Omega$



Data $V_L = 220$ V | $R_a = 0.5\,\Omega$
$o/p = 11 \times 10^3$ W | $R_{sh} = 110\,\Omega$
$I_{L0} = 5$A

(i) Torque developed in the armature

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

$E_b = V - I_a R_a$, $I_a = I_L - I_{sh}$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{220}{110} = 2\text{ A}$$

$$I_L = \frac{P}{V_L} \quad \left[\because P = V_L I_L\right]$$

$$= \frac{11 \times 10^3}{220} = 50\text{ A}$$

$I_a = 50 - 2 = 48$A

$E_b = 220 - (48 \times 0.5) = 196$ volt.

$$\therefore T_a = 9.55 \frac{(196 \times 48)}{N}$$

Find $N = ?$

$$E_{b0} = \frac{Z N_0 \phi}{60}\left(\frac{P}{A}\right) \quad \text{— ① At no load.}$$

$$E_b = \frac{Z N \phi}{60}\left(\frac{P}{A}\right) \quad \text{— ② At full load.}$$

Dividing Eqn ② by eqn ①

$$\frac{E_b}{E_{b0}} = \frac{N}{N_0} \Rightarrow N = \frac{E_b}{E_{b0}} \times N_0$$

Find E_{b0} at no load

$E_{b0} = V - I_{a0} R_a$

At no load, $I_{a0} = I_{L0} - I_{sh} = 5 - 2 = 3A$.

$E_{b0} = 220 - (3 \times 0.5) = 218.5V$.

$N = \frac{196}{218.5} \times 1150 = 1031$ rpm

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

$= 9.55 \times \frac{(196 \times 48)}{1031} \Rightarrow T_a = 87.1$ N-m

(ii) $\eta = \frac{O/P}{I/P} \Rightarrow O/P = I/P -$ total ~~tot~~ losses.

Find constant loss

Constant loss are found from no load

At no load, I/P = Total loss

= Fe loss + friction loss + Cu loss.

no load $I/P = V_L I_{L0}$

$= 220 \times 5 = 1100$ W.

Arm Cu loss at no load $= I_{a0}^2 \times R_a = 3^2 \times 0.5 = 4.5$ W.

Const loss = No load I/P − Arm Cu loss at no load

$= 1100 - 4.5 = 1095.5$ W

O/P at F.L $= (11 \times 10^3) - 1095 - I_a^2 R_a$

$= 11 \times 10^3 - 1095 - [(48)^2 \times 0.5]$

$= 8752$ W.

$\eta = \frac{8752}{11,000} \times 100 = 79.6\%$

Speed control of DC Motor

We know $E_b = \frac{\phi Z N}{60} \left(\frac{P}{A}\right)$

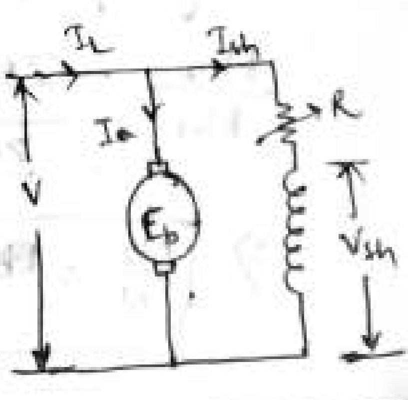
$\Rightarrow N = \frac{60 \times A \times E_b}{Z P \phi}$

$\boxed{N \propto \frac{E_b}{\phi}}$ ∵ A, Z, P, 60 are fixed value.

Speed ~~contract~~ control of DC shunt motor

(i) Field control method →

In this method speed variation occurs by inserting variable resistance in series with the shunt field.



By connecting ~~rheo~~ rheostat, with some resistance value, the voltage drop occurs at the rheostat and net voltage across the shunt field resistance drop.

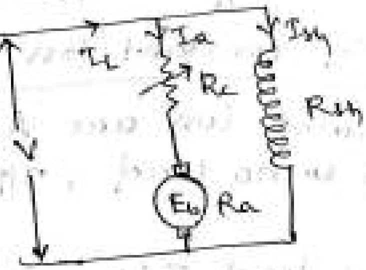
So $I_{sh} = \frac{V}{R_{sh}}$ is also drops.

* In this method, we can achieve a speed which is more than rated speed. If we removed the rheostat, we will achieve the rated speed, of motor.

Advantages → (i) It is easy and convenient method.

(ii) Less expensive method, due to less power wasted.

Armature control of DC shunt motor →



We know, $N \propto \frac{E_b}{\phi}$

* $N \propto E_b$

Here, $E_b = V - I_aR_a - I_aR_c$

By varying the ~~rheo~~ rheostat we can change R_c. So E_b also changes & N is also changes.

If we remove the resistance 'R_c' from the circuit, we will get the rated speed of the motor and when we add 'R_c' (variable resistor), E_b decreases as a result 'N' also decreases 'c'.

* This method is suitable to achieve a speed, below the rated speed

Advantages →

(i) Very fine method of speed control.

(ii) Good speed regulation.

Speed control (Relation betn N, E_b, ϕ, I_a)

We know $E_{b_1} = \frac{ZN_1\phi_1}{60}\left(\frac{P}{A}\right)$ — ①

$E_{b_2} = \frac{ZN_2\phi_2}{60}\left(\frac{P}{A}\right)$ — ②

Dividing eqn ② & eqn ① we get.

$$\frac{E_{b_2}}{E_{b_1}} = \frac{\frac{ZN_2\phi_2}{60}\left(\frac{P}{A}\right)}{\frac{ZN_1\phi_1}{60}\left(\frac{P}{A}\right)} \Rightarrow \frac{E_{b_2}}{E_{b_1}} = \frac{N_2\phi_2}{N_1\phi_1} = \frac{N_2}{N_1} \times \frac{\phi_2}{\phi_1}$$

$$\Rightarrow \boxed{\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \times \frac{\phi_1}{\phi_2}}$$

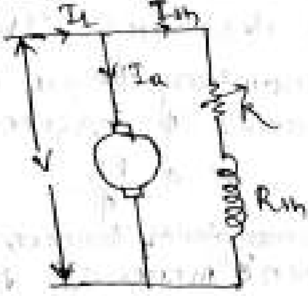
In DC series motor, $\phi \propto I_a$

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

In DC shunt motor

$$\boxed{\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}}} \text{ , } \phi \text{ is constant}$$

Q→ A 500 V, dc shunt motor runs at its speed of 250 rpm, when the armature current is 200 A. The resistance of the armature is 0.12 Ω. Calculate the speed when a resistance is inserted in the field reducing the shunt field to 80% of normal value and armature current is 100 A.



Given $V_L = 500V$ | $R_a = 0.12\ \Omega$
$N_1 = 250 rpm$ | $\phi_2 = 0.8\ \phi_1$
$I_{a1} = 200 A$ | $I_{a2} = 100 A$

Find $N_2 = ?$

We know, $\frac{N_2}{N_1} = \frac{E_{b2}}{E_{b1}} \times \frac{\phi_1}{\phi_2}$

$E_{b1} = V - I_{a1} R_a = 500 - (200 \times 0.12) = 476 V$

$E_{b2} = V - I_{a2} R_a = 500 - (100 \times 0.12) = 488 V$

$\therefore \frac{N_2}{250} = \frac{488}{476} \times \frac{\phi_1}{0.8\phi_1} \Rightarrow N_2 = 320.4$ rpm.

17.6.21

Speed control of DC series motor →

Speed control of DC series motor can be obtained by:-

(i) Flux control method
(ii) Armature resistance control method.

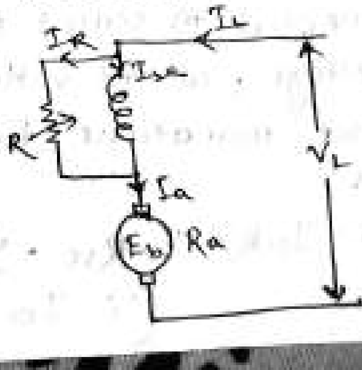
(i) Flux control method →

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

By varying the flux of DC series motor, the speed of the motor varies, hence the speed varies. This can be done by various methods like:-

(a) Field diverters (b) Armature diverter.
(c) Tapped field control (d) Paralleling field coil.

(a) Field diverters →



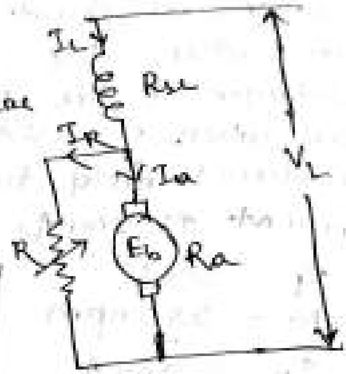
In this method, a variable resistance is connected in parallel with series field winding. Here,

$$\boxed{I_L = I_{se} + I_R}$$

When the resistance of the parallel rheostat is less than the series field winding, then current starts flowing through the rheostat and net current 'I_{se}' decreases, also flux decreases. By decreasing the flux, speed will increases.

(b) Armature diverter →

In this method, we connect a rheostat in parallel with the armature.



As a net current in armature ckt decreases. Though $\boxed{T \propto I_a}$

To maintain torque const, if I_a decreases ϕ increases.

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

~~To maintain torque const~~

When ϕ increases the speed will decrease

In this method we achieve a speed which is less than the rated speed.

(c) Tapped field control →

In this method tapping is done in the series field winding by reducing the no of turns in the series field, we can reduced the flux produces.

$N \propto \frac{E_b}{\phi}$, as a result speed increases.

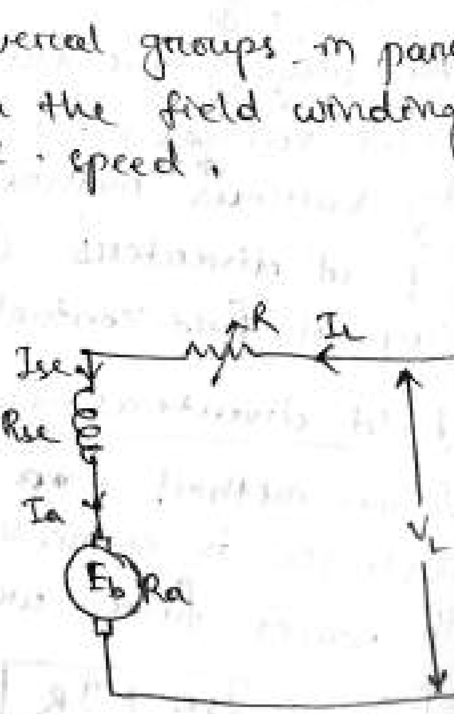
⇒ In this method we can achieve the speed more than the rated speed.

(d) Paralleling field coils →

By connecting the field windings in several groups in parallel we can divert the current flows through the field winding and we will get the desired amout of speed.

Armature Resistance Control →

In this method a variable resistance 'R' is connected in series with the supply voltage, so net voltage appears across the armature terminal decreases



$$E_b = V - I_aR - I_aR_{se} - I_aR_a - B.D.$$

$$(\because I_a = I_{se} = I_L)$$

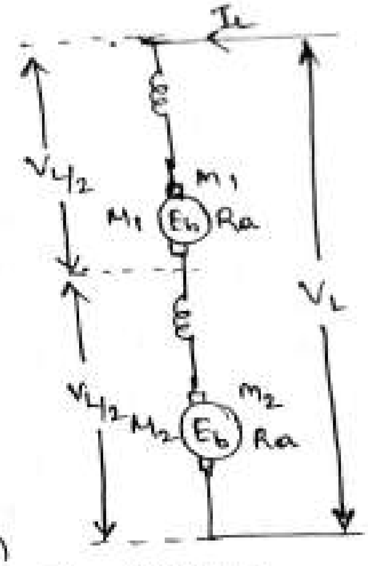
∴ As E_b decreases, 'N' is also decreases

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

In this method, we can achieve the speed below the rated speed

Series - Parallel control of DC series motor →

(i) When two ~~.~~ DC series motors are connected in series →



When two similar series motors are connected in series, the supply voltage is divided equally and appears across each motor.

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

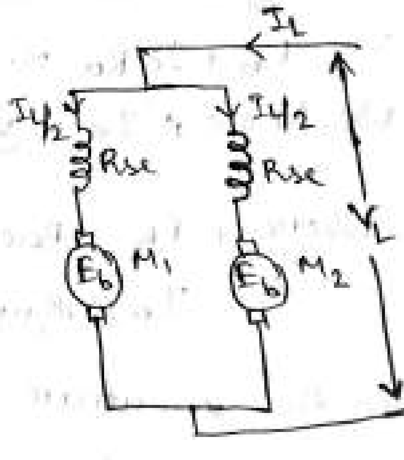
We know $E_b \propto V$ & $\phi \propto I_L$

$\therefore N \propto \frac{V}{I_L}$

In this case; $V = V_L/2$

$\therefore \boxed{N \propto \frac{V_L/2}{I_L}}$ so speed decreases from the rated speed of individual motor.

(ii) When two series DC motors are connected in parallel →



When two similar DC series motors are connected in parallel, the current 'I_L' is equally divided into two parts '$\frac{I_L}{2}$'

$N \propto \frac{E_b}{\phi}$ (or) $N \propto \frac{V}{I}$ $\left[\because \begin{array}{l} E_b \propto V \\ \phi \propto I_L \end{array}\right]$

But here, $I = I_L/2$

$\therefore N \propto \frac{V_L}{(I_L/2)} \propto \frac{2V_L}{I_L}$

So speed increases in parallel connection as compared to series connection.

Necessecity of Starter →

$V = E_b + I_a R_a \Rightarrow I_a R_a = V - E_b$

We know, $I_a = \frac{V - E_b}{R_a}$

where, E_b = Back emf

I_a = Armature current

V = Terminal voltage

R_a = Armature Resistance

When the armature is at stand still, there is no back emf, so the armature current I_a is equal to the ratio of terminal voltage to the armature resistance.

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

So max. will be flow through the armature winding at the time of starting when the armature is steady. The high current may damage the armature winding. So to protect the armature from high current a resistance is introduced in series with the armature whi limit the starting current and save the armature.

It is known as starter.

When supply is given to the motor through the starter very less amount of current flow through the armature ckt and motor start rotating slowly also develop back emf. The starter resistance is generally cut out as the motor gain speed and develop the back emf till it reaches its rated speed. It also protect the motor ckt at the limit of running when heavy current flows through it.

3-Point Starter →

Construction →

It has 3 terminals L, Z, A. These terminals are +ve to +ve line terminal, shunt field terminal, armature terminal. The no volt release coil (NVC) is connected with shunt field ckt. One end of the handle is connected to the line through the overload release coil (OLRC). The other end of the handle moves against a special spring and make contact of each resistance stud during starting operation in clockwise direc^n.

Operation →

Supply is given to the starter then the handle is moved in clockwise direct^n from its off position when the handle contacts the first stud, the shunt field winding is directly connected across supply, when the whole starting resistance is cut out from the armature ckt by steps. Now the handle held magnetically the NVC, so direct supply is fed to the armature ckt without any external resistance.

When high current flow through the ckt at the time running of the motor the OLRC is magnetised. So the handle comes its off position.

4 - Point Starter →

Construction →

The four point starter has 4 terminals L, N, Z, A. The supply is given to the terminal 'L' a resistance 'R' is connected at terminal 'B'. The shunt field coil is connected to point 'Z'. The armature and the series field are connected to point 'A'. The NVC is connected directly across the supply lying and a high resistance 'R''. The supply is given to the handle through the OLRC.

Operation → "Same as 3 point starter"

Swinburne's Test →

This method is used to find the constant losses of DC machine by running the machine at no load after calculating constant losses we can calculate the efficiency of the machine (This method is applicable to m/cs where is flux is practically constant. (ex. shunt & compound machines).

Determine the constant losses →

Assuming the DC motor at no load here two ammeters are connected to the circuit. One ammeter A_1 is connected to the supply & the other A_2 is connected to field to give the shunt field (I_{sh}) current reading at no load.

No load armature current $I_{a0} = I_0 - I_{sh}$

No load I/p power $= V_L I_0$

Arm. Cu loss at no load $= I_{a0}^2 R_a$

We know at no load, the total I/p is the total loss.

∴ So no load input $= V_L I_0 =$ Total loss.

$V_L I_0 =$ Constant loss (W_c) + Arm. Cu loss at no load. ($I_{a0}^2 R_a$)

Constant loss (W_c) $= V I_{L0} - I_{a0}^2 R_a$

$= V I_{L0} - (I_a - I_{sh})^2 R_a$

To find the efficiency of the machine as a motor on load →

W_c = constant loss found from no load.

$V_L I_L$ = Input power to the motor on load.

$I_a^2 R_a$ = Arm Cu loss of the motor on load.

$$\eta_{motor} = \frac{\text{Output}}{\text{Input}} = \frac{\text{Input} - \text{Total loss}}{\text{Input}} \times 100$$

$$\eta_{motor} = \frac{V_L I_L - I_a^2 R_a - W_c}{V_L I_L} \times 100$$

(where, $I_a = I_L - I_{sh}$)

To find the efficiency when running as Generator on load →

O/P of generator = $V_L I_L$

W_c = constant loss

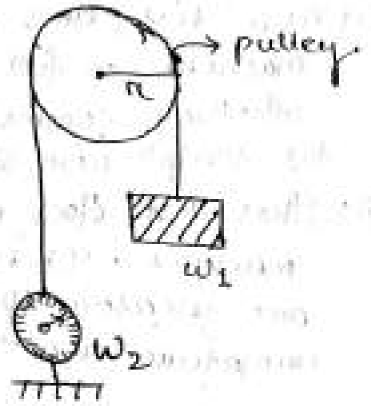
Arm. Cu loss = $I_a^2 R_a = (I_L + I_{sh})^2 R_a$

$$\eta_{open} = \frac{V_L I_L}{V_L I_L + (I_L + I_{sh})^2 R_a + W_c} \times 100$$

Break Test →

This is the method to ~~fin~~ find the efficiency of a DC motor by direct loading. In this method,

$$\eta = \frac{\text{Mechanical O/P}}{\text{Electrical I/P}} \times 100$$



To find the mechanical output we have to applied break to the water cooled pulley mounted on the shaft of the motor as shown in the figure.

⇒ One end of the rope is fixed to the base through spring balance having weight W_2 and a mass of weight W_1 is suspended on the other hand.

r = radius of the pulley.

So O/P = $T_{sh} \times \omega$

$= \frac{2\pi N}{60} \times T_{sh}$ $\left(\because T_{sh} = \frac{O/P}{\omega}\right)$

T_{sh} = (weight in newton on pulley × radius of the pulley)

$T_{sh} = (W_1 - W_2) \times 9.81 \times r$

O/P $= \frac{2\pi N}{60} \times (W_1 - W_2) \times 9.81 \times r$

$= 1.027 (W_1 - W_2)\, rN$

I/P is electrical power to the motor = $V_L I_L$

$$\eta = \frac{\frac{2\pi N}{60}(W_1 - W_2) \times 9.81 \times r}{V_L I_L} \times 100$$

$$\eta = \frac{2\pi N (W_1 - W_2) \times 9.81 \times r}{60 \times V_L I_L} \times 100$$

$$\eta = \frac{61.68 (W_1 - W_2) \times 9.81 \times r}{V_L I_L} \times 100$$

Advantages of Swinburne's test →

(i) The power required to carry out the test is small because it is no load test. Therefore this method is quite economical.

(ii) The efficiency can be determined at any load because constant losses are known.

(iii) This test is very convenient.

Disadvantages →

(i) It does not take into account the stray load losses that occur when the machine is loaded.

(ii) This test does not enable us to check the performance of the machine on full load. For example it does not indicate whether commutation on full load is satisfactory and whether the tempⁿ rise is within the specified limits.

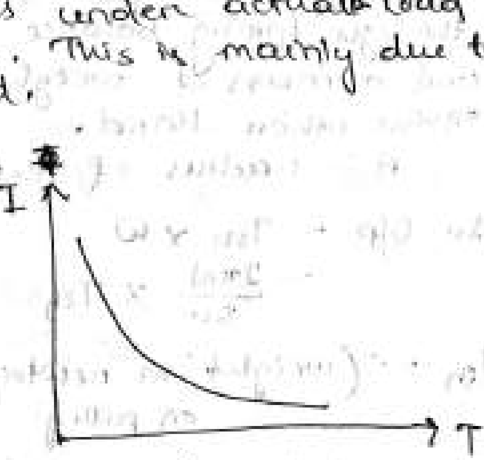
(iii) This test does not give quite accurate efficiency of the machine. It is because iron losses under actual load are greater than those measured. This is mainly due to armature reacⁿ distorting the field.

→ The torque speed characteristics

Torque $T \propto \phi I_a$

In series motor $\phi \propto I_a$

So $\boxed{T \propto I_a^2}$



Applications of DC series motor →

Since it has high starting torque and variable speed. The speed is low at high torque. At light or no load, the motor speed attains dangerously high speed. (elevators, electric traction).

Industrial Uses →

Electric traction, Cranes, Elevators, Air compressor, Vaccum cleaner, ~~Hai~~ Hair dryer, Sewing machine.

* It is used for heavy duty applications such as electric locomotives, steel rolling mills, hoists, lifts.

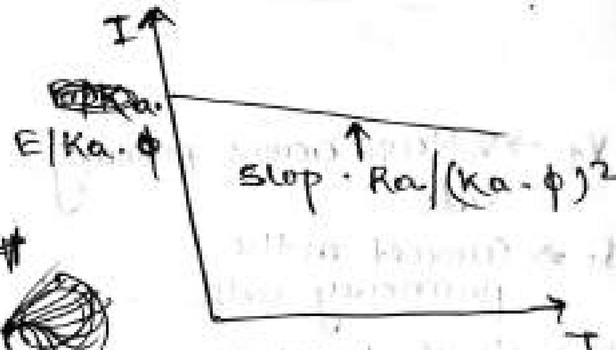
This is similar to the eqⁿ of a a straight line, and we can graphically representing the torque speed -

- characteristic of a shunt wound self excited dc motor as :

Torque $T \propto \phi I_a$

In shunt moto ϕ is constant because I_{sh} is constant.

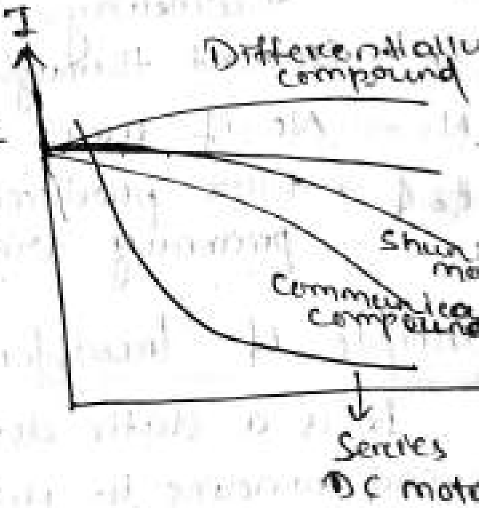
So $\boxed{T \propto I_a}$



The shunt wound dc motor is constant speed motor as the speed does not vary here with the variation of mechanical load on the output.

Application of DC shunt motor →

* It has medium starting torque and a nearly constant speed.



(F) =1 B = 2

SINGLE PHASE TRANSFORMER

25.6.21

$V_1 \rightarrow$ Voltage across primary side

$I_1 \Rightarrow$ Current in the primary side

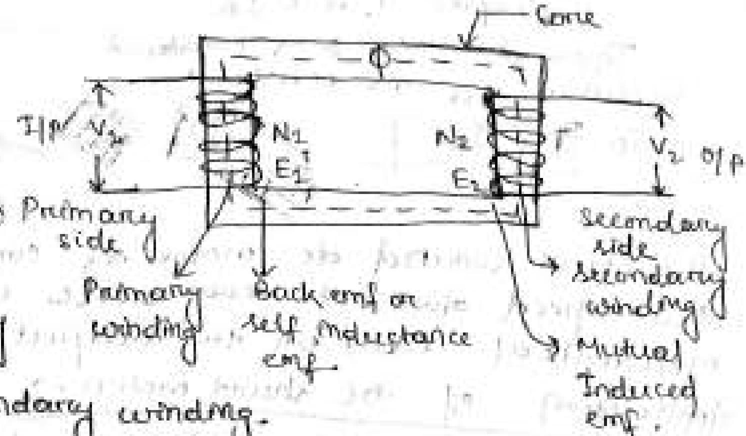
$N_1 \rightarrow$ No. of turns in primary side.

$V_2 \rightarrow$ Voltage across secondary winding

$I_2 \rightarrow$ Current through secondary winding.

$N_2 \Rightarrow$ No. of turns in secondary winding.

$\phi \rightarrow$ Flux produced when current flows through the primary winding.



Principle of Transformer →

It is a static device. It transfer electrical energy from one end winding to another winding without changing its frequency by the method of mutual induction.

When supply is given to the primary winding current flows through it, so fluxes are produced in it. These fluxes links with the secondary winding and produces emf according to Faraday's laws of EMI. So current ~~flows~~ flows through the secondary winding when it is loaded. This method of energy transfer is known as mutual Induction method. So $E_1 \rightarrow$ (emf induced in primary side) and $E_2 \rightarrow$ Emf induced in the secondary side of transformer,

EMF Eqn of the transformer →

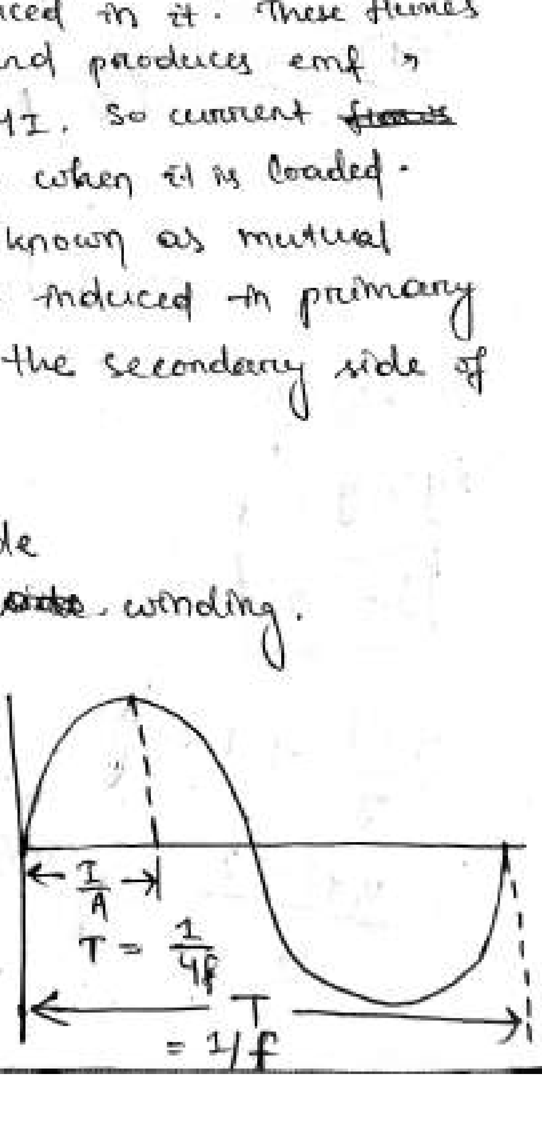
N_1 = no. of turns in primary side

N_2 = no. of turns in secondary ~~side~~ winding.

ϕ_m = Maxm flux in the core
$= B_m \times A$

f = frequency of A.C I/P.

The flux increases from zero to maxm value in $(1/4f)$ sec.



The ~~avrag~~ avarage rate of change of flux = $\frac{\phi_m}{(1/4 f)}$ = $4 f \phi_m$

The avarge emf per turn = $4 f \phi_m$

we know, form factor = $\frac{\text{RMS value}}{\text{Avarage value}}$ = 1.11.

RMS value of emf per turn = 1.11 × avarage value
= 1.1 × $4 f \phi_m$
= $4.44 f \phi_m$ ($\because B_m \times A$)

The rms value of induced emf in the total primary winding = $4.44 f \phi_m N_1$ = $4.44 f B_m A N_1$

$$\boxed{E_1 = 4.44 f \phi_m N_1}$$

Similarly rms value of induced emf in secondary winding
= $4.44 f \phi_m N_2$ = $4.44 f B_m A N_2$

$$\boxed{E_2 = 4.44 f \phi_m N_2}$$

Ideal transformer →

The conditions are :-

(i). The I/p power = O/p power.
$V_1 I_1 = V_2 I_2$

(ii) There are no losses in the transformer.

(iii) No winding resistance.

(iv) No leakage flux.

Transformer Ratio (K) →

We know,

the emf induced in the primary side $(E_1) = 4.44 f \phi_m N_1$ —— ①

the emf induced in the secondary side $(E_2) = 4.44 \phi_m N_2$ —— ②

Dividing Eqn ② with eqn ①

$$\frac{E_2}{E_1} = \frac{4.44 f \phi_m N_2}{4.44 f \phi_m N_1} \Rightarrow \frac{E_2}{E_1} = \frac{N_2}{N_1} \text{ —— ③}$$

From ideal condn, I/p power = O/p power.

$$\Rightarrow V_1 I_1 = V_2 I_2$$

$$\Rightarrow \frac{V_1}{V_2} = \frac{I_2}{I_1} \quad (or;) \quad \frac{V_2}{V_1} = \frac{I_1}{I_2}$$

Though $\frac{V_2}{V_1} = \frac{E_2}{E_1}$

Then, $\frac{I_1}{I_2} = \frac{E_2}{E_1}$

Putting the values in eqn (3),

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

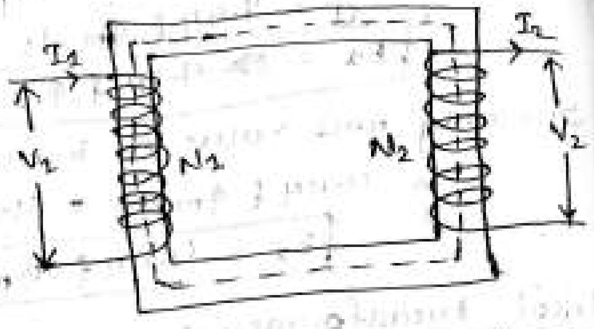
where 'K' = transformation ratio

Types of Transformer →

① According to construction; It is two types.
(a) Core-type, (b) Shell type.

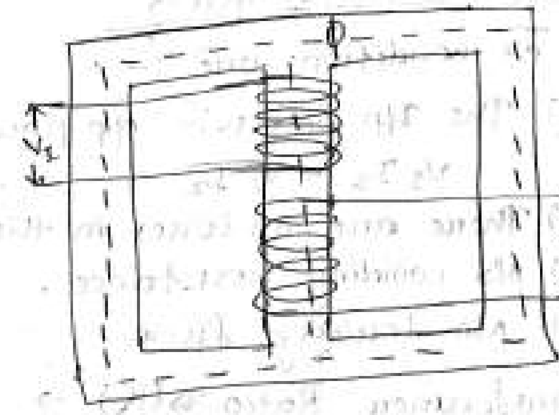
Core type →

In this type of transformer core is surrounded by the winding.



Shell type →

In this type of transformer, the winding is surrounded by the core.

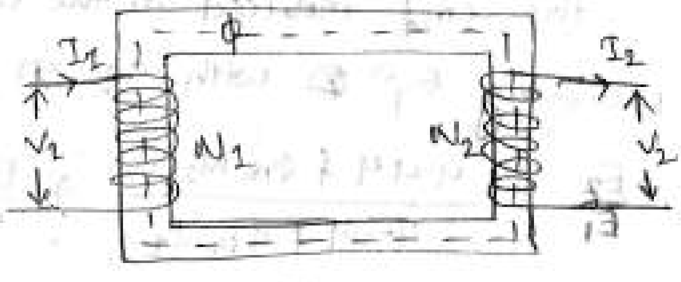


According to operation →

Transformers are two types.
(a) Step up transformer
(b) Step down transformer.

Step up transformer →

In this type of transformer the no. of turns in secondary side is greater than the no. of turns in primary sides.

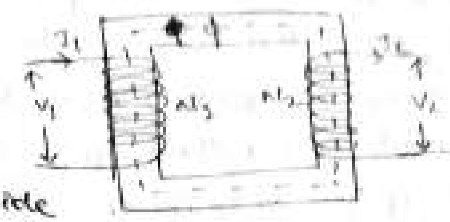


So $N_2 > N_1$

& $V_2 > V_1$, but $I_1 > I_2$

Step down transformer →

In this type of transformer the no of turns at secondary side is less than the no of turns in primary side.



So the voltage in secondary side is less than the voltage in primary side.

i.e. $N_1 > N_2$ & $V_1 > V_2$ but $I_2 > I_1$

Q→ Why the Transformer Rating is in KVA? →

Ans- The transformer has 2 types of losses, one is Cu loss and another is Iron loss. The cu loss depends upon the current and the Iron loss is depends upon the voltage but not depends upon the power factor. Hence the rating of transformer is in KVA.

Practical Transformer on no load →

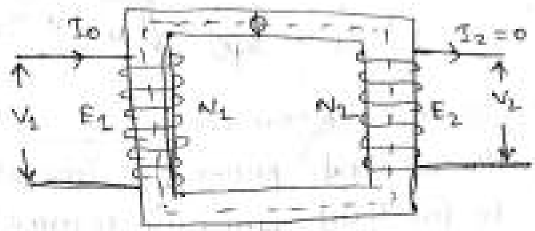
I_0 = No load primary current,

I_w = Active or working component

I_w is in phase with V_1

I_μ = Magnetising component

I_μ lags behind V_1 by $90°$

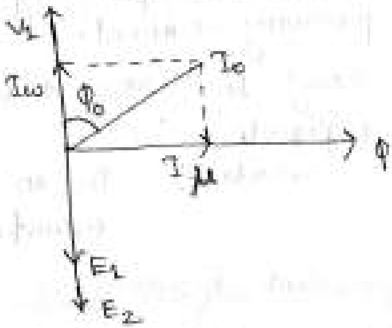


$I_w = I_0 \cos\phi_0$; $I_\mu = I_0 \sin\phi_0$

$\therefore I_0 = \sqrt{I_w^2 + I_\mu^2}$

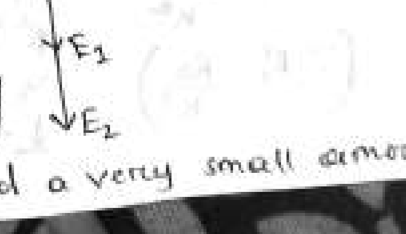
$\therefore$ Total I/p power,

$$\boxed{W_0 = V_1 I_0 \cos\phi_0}$$



Transformer on no load →

When an actual transformer but no load there is iron loss the core & cu loss in the winding. These losses are not negligible. When the transformer on no load, the primary input current on no load cond^n is to supply iron losses in the and a very small amount -



- of cu losses in the primary but there is no ~~current~~ ~~loss~~ cu loss in the secondary winding because the secondary side open ckted ($I_2 = 0$); hence no load primary current I_0 is not at $90°$ behind V_1 but lag it by an angle ϕ_0 which is less than $90°$. So no load primary input power $(P_0) = V_1 I_0 \cos\phi_0$

$\cos\phi_0$ = Primary power factor under no load condition.

The vector diagram shows the no load primary ~~ckt~~ current 'I_0' has two component. One is phase with V_1 know as active or working or iron loss component (I_w)

$I_w = I_0 \cos\phi_0$

The other component is known as magnetising component (I_μ).

$$I_\mu = I_0 \sin\phi_0$$

So I_0 is the vector sum of I_μ and I_w.

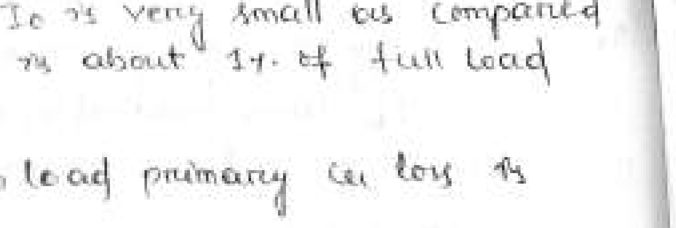
$$\left(\because I_0 \text{ or } \cancel{I_{\phi}} = \sqrt{I_\mu^2 + I_w^2}\right)$$

Points to be Remember →

* The no load primary current I_0 is very small as compared to full load primary current is about 1% of full load primary current.
* Though I_0 is very small the no load primary cu loss is negligible.
  which ⇒ The no load primary I/P = Iron loss of the transformer.

Equivalent Resistance →

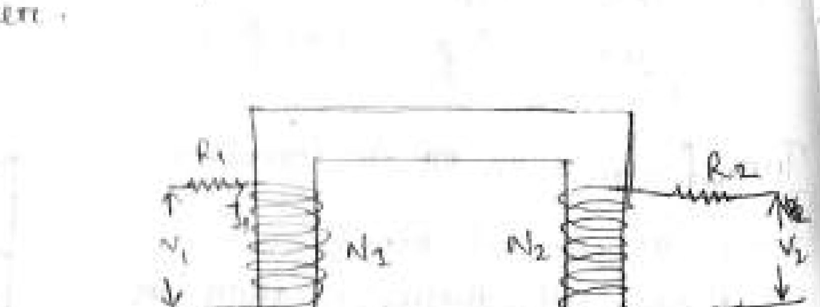
The equivalent resistance of a transformer w.r.t primary side.



Here $R_{01} = R_1 + R_2'$

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

$$\left(\because R_2' = \frac{R_2}{K^2}\right)$$

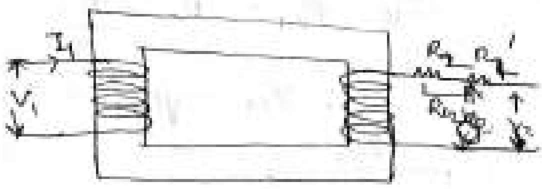


where K = transformation ratio

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

cu loss w.r.t primary side

$I_1^2 R_{01}$



The equivalent resistance of a transformer w.r.t. secondary side

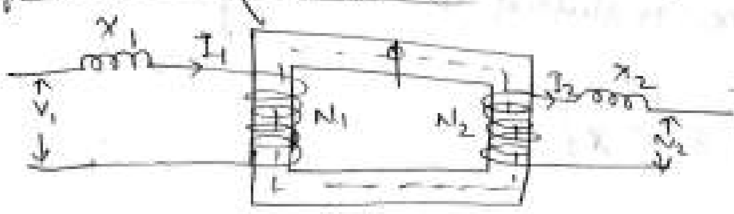
Here $R_{02} = R_1' + R_2$

$R_{02} = K^2 R_1 + R_2$ $[\because R_1' = K^2 R_1]$

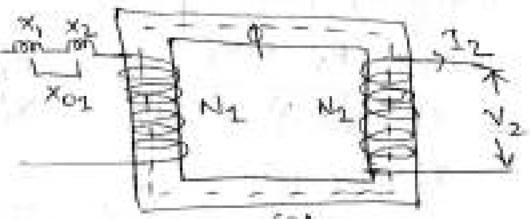
where $K \to$ transformation ratio

The cu loss w.r.t secondary side $= I_2^2 R_{02}$

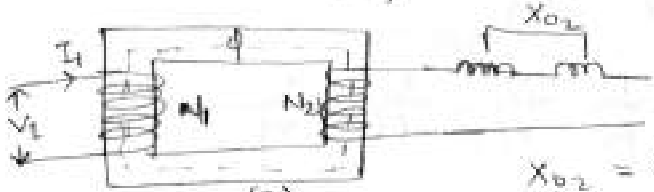
Equivalent Reactance →



(1)



(2)



(3)

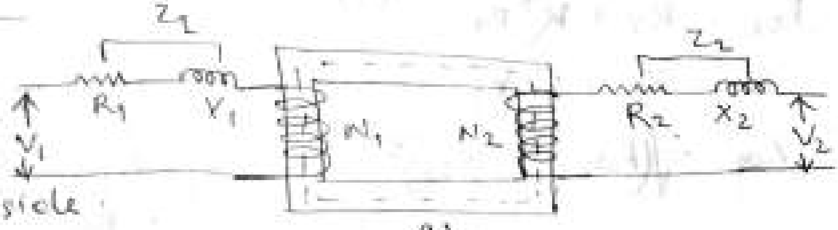
$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2}$

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

Equivalent Impedance →

In fig (2)

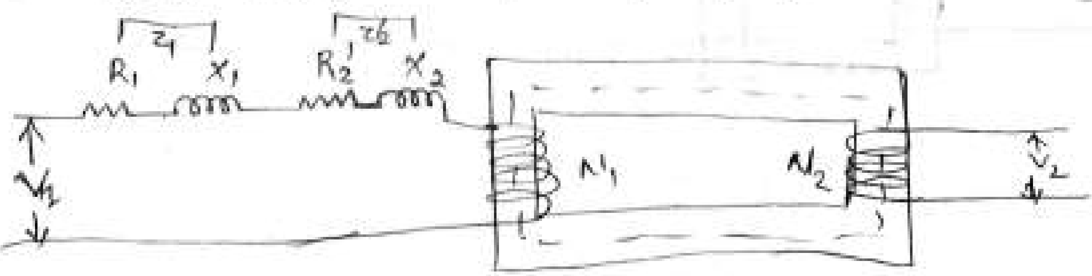
secondary impedance is shifted to primary side



(1)

$Z_1 = \sqrt{R_1^2 + X_1^2}$ $\quad Z_2' = Z_2 / K^2$

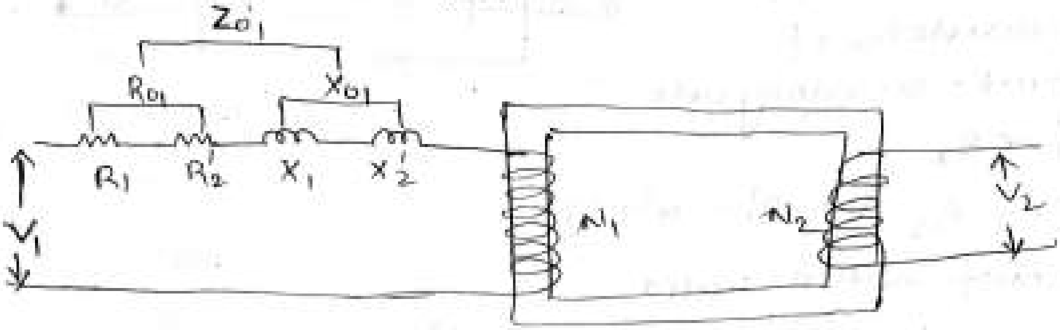
$Z_2' = \sqrt{(R_1')^2 + (X_2')^2}$ $\quad Z_{01} = Z_1 + Z_2'$ $[\because I_1 Z_{01} = V_1]$



(2)

In fig(3) Secondary impedance is shifted to primary side $R_{01} = R_1 + \frac{R_2}{K^2}$, $X_{01} = X_1 + \frac{X_2}{K^2}$

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



(3)

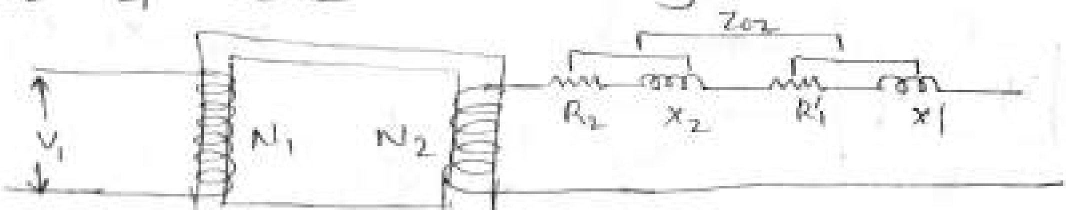
In fig(4) primary Impedance is shifted to secondary side

$Z_2 = \sqrt{R_2^2 + X_2^2}$ $\quad R_1' = K^2 R_1$

$Z_1' = \sqrt{(R_1)^2 + (X_1)^2}$ $\quad X_1' = K^2 X_1$

$Z_1' = Z_1 K^2$

$Z_{02} = Z_1' + Z_2$ $[\because I_2 Z_{02} = V_2]$

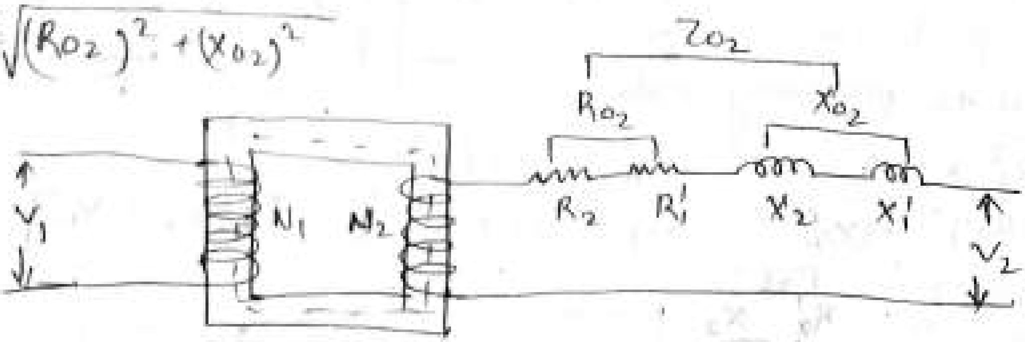


(4)

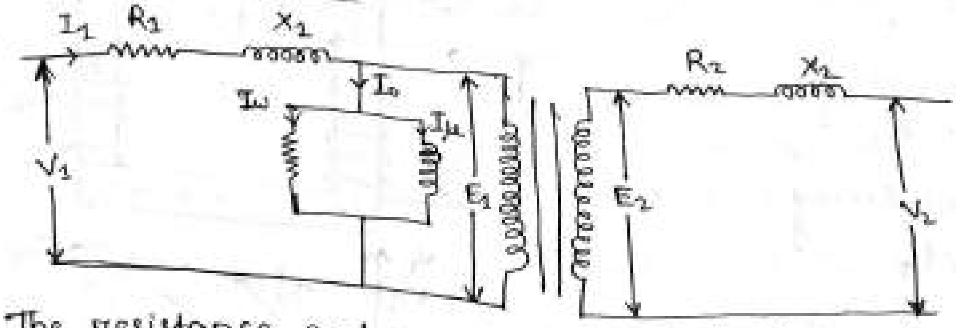
$R_{02} = R_2 + K^2 R_1$

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

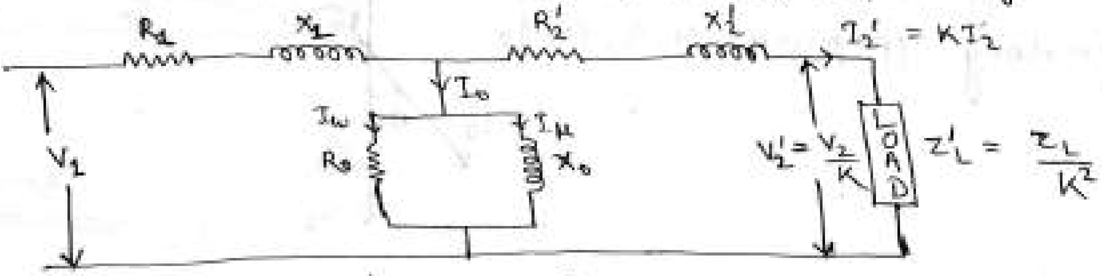
$Z_{02} = \sqrt{(R_{02})^2 + (X_{02})^2}$



Equivalent Circuit →

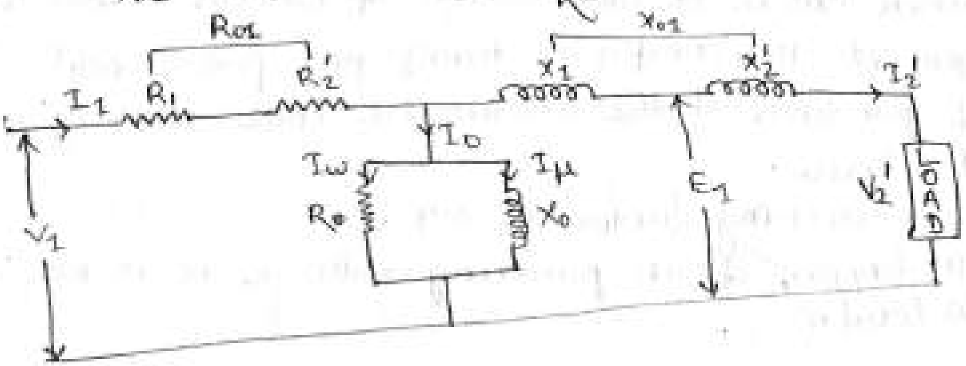


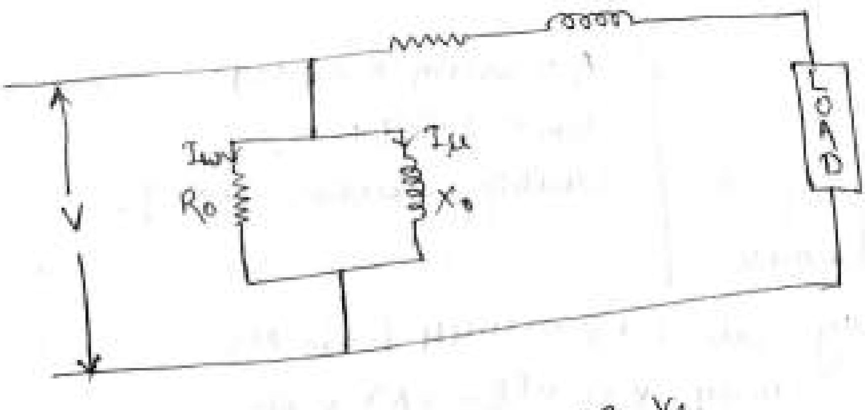
The resistance and reactance is shifted to primary side.



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

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





N.B

$R_2 = \frac{V_2}{I_2}$

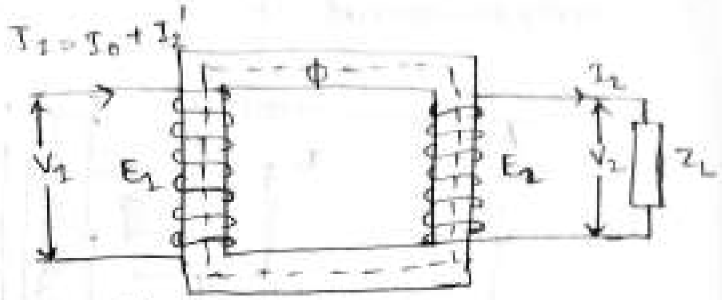
$\because V_2 = KV_1$

$I_2 = \frac{I_1}{K}$

So $R_1' = \frac{KV_1}{\frac{I_1}{K}} = K^2 \frac{V_1}{I_1}$

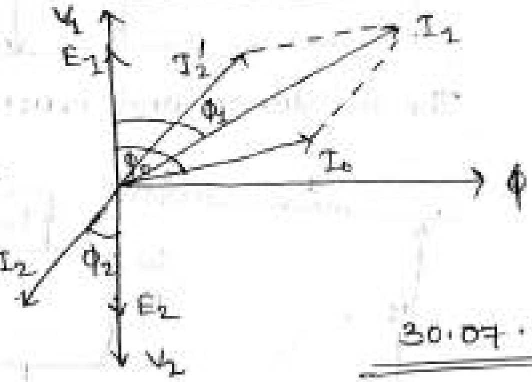
$\therefore \boxed{R_1' = K^2 R_1}$

Transformer on Load →



P.F in primary side = $\cos\phi_1$

P.F in secondary side = $\cos\phi_2$



∴ Primary I/P power = $V_1 I_1 \cos\phi_1$

Secondary I/P power = $V_2 I_2 \cos\phi_2$

30.07.21

Q→ The core of a 100 KVA, 11000/550V, 50Hz, 1-ϕ core type transformer has a ~~co~~ cross section of (20 cm × 20 cm). Find
(i) the number of H.V and L.V turns per phase and
(ii) The emf per turn if the maximum core density is not to exceed 1.3 Tesla.
Assume a stacking factor of 0.9.
What will happen if its primary voltage is increased by 10% on no load?

Sol^n Given

100 KVA,	$A = 20\,cm \times 20\,cm$
$V_1 = 11000\,V$	$B_m = 1.3\,T$
$V_2 = 550\,V$	Stacking factor = 0.9.
$f = 50\,Hz$	
1-ϕ transformer	

Emf of primary side, $E_1 = 4.44 f \phi_m N_1$

$\therefore 11{,}000 = 4.44 \times 50 \times (B_m \times A) \times N_1$

$11{,}000 = 4.44 \times 50\,(1.3 \times 20 \times 20 \times 0.9)\,N_1$

$\Rightarrow N_1 = 1060$

$\frac{N_2}{N_1} = \frac{E_2}{E_1} \Rightarrow N_2 = \frac{550}{11{,}000} \times 1060 = 53$

∴ Emf / turn in primary side $= \frac{11000}{1060} = 10.4$ volt.

Emf / turn in sec. side $= \frac{550}{53} = 10.3$ volt.

Q. A 50 KVA, 4400/220 V transformer has $R_1 = 3.45\,\Omega$, $R_2 = 0.009\,\Omega$. The values of reactances are $X_1 = 5.2\,\Omega$ and $X_2 = 0.015\,\Omega$. Calculate

(i) Equivalent resistance as refered to primary
(ii) Equivalent resistance as refered to secondary
(iii) Equivalent impedance as refered to both primary and secondary.
(iv) Equivalent reactance as refered to both primary and secondary.
(v) Total cu loss.

Sol. Given data

50 KVA, 4400/220 V

$R_1 = 3.45\,\Omega$ | $X_1 = 5.2\,\Omega$

$R_2 = 0.009\,\Omega$ | $X_2 = 0.015\,\Omega$

We know that K = transformation Ratio.

$$K = \frac{V_2}{V_1} = \frac{220}{4400} = \frac{1}{20}$$

(i) R_{01} ⇒ Equivalent resistance as refered to primary.

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 3.45 + \frac{0.009}{(1/20)^2} = 7.05\,\Omega$$

(ii) $R_{02} = R_2 + R_1'$

$$= R_2 + K^2 R_1 = 0.009 + \left(\frac{1}{20}\right)^2 \times 3.45 = 0.0176\,\Omega$$

or, $R_{02} = K^2 R_{01} = \left(\frac{1}{20}\right)^2 \times 7.05 = 0.0176\,\Omega$

(iii) X_{01} → Equivalent reactance w.r.t. primary.

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2} = 5.2 + \frac{0.15}{\left(\frac{1}{20}\right)^2} = 11.2\,\Omega$$

(iv) X_{02} = Equivalent reactance w.r.t. secondary

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

$$= 0.015 + 5.2 \times \left(\frac{1}{20}\right)^2 = 0.028\,\Omega$$

(v) Equivalent Impedance w.r.t primary

$$Z_{01} = \sqrt{(R_{01})^2 + (X_{01})^2} = \sqrt{(7.05)^2 + (11.2)^2} = 13.23\,\Omega$$

$$Z_{02} = \sqrt{(R_{02})^2 + (X_{02})^2} = \sqrt{(0.0176)^2 + (0.028)^2} = 0.03311\,\Omega$$

or $Z_{02} = K^2 Z_{01}$

$$= \left(\frac{1}{20}\right)^2 \times 13.23 = 0.0331\,\Omega$$

(vi) Total cu loss $= I_1^2 R_1 + I_2^2 R_2$

$$\text{So, } I_1 = \frac{P}{V_1} = \frac{50 \times 10^3}{4400} = 11.36\,A$$

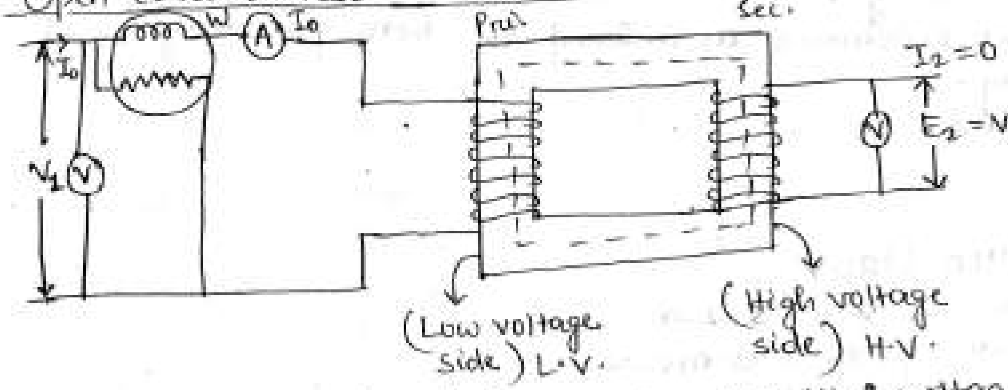
$I_2 = \frac{P}{V_2} = \frac{50\times10^3}{220} = 227\ A.$

$\therefore$ Total Cu loss $= I_1^2 R_1 + I_2^2 R_2$

$= (11.36)^2 \times 3.45 + (227)^2 \times 0.009$

$= 910\ w.$

Open Circuit Test → (O.C Test)



This test is conducted by opening the High voltage side, because small range of voltmeter, Ammeter and wattmeter are required.

* ~~ ~~ The purpose of this test is to determine no-load loss or core loss and no-load current (I_0) which is helpful to find X_0 and R_0
* When secondary side of a transformer is open ckted, then no current will flow through secondary side and (2-10)% of rated full-load current will flow through the primary side.

Ex→ If full load primary current is 100 A, then no load primary current is about (2-10) A.

$\therefore$ Due to negligible current in primary winding, cu loss in primary winding is negligible and cu loss in secondary winding is zero ($\because I_2=0$, $I_2^2R_2=0$)

→ The I/P power can be found from the wattmeter connected to the primary side.

→ The voltmeter connected to the primary side gives the reading of No load I/P primary current (I_0).

In this case wattmeter reading (w) $= V_1 I_{01} \cos\phi_0$

$\cos\phi_0$ → No load power factor.

$\therefore W = V_1 I_{01} \cos\phi_0 \Rightarrow \cos\phi_0 = \frac{W}{V_1 I_{01}}$

$I_w = I_{01}\cos\phi_0$, $I_\mu = I_{01}\sin\phi_0$

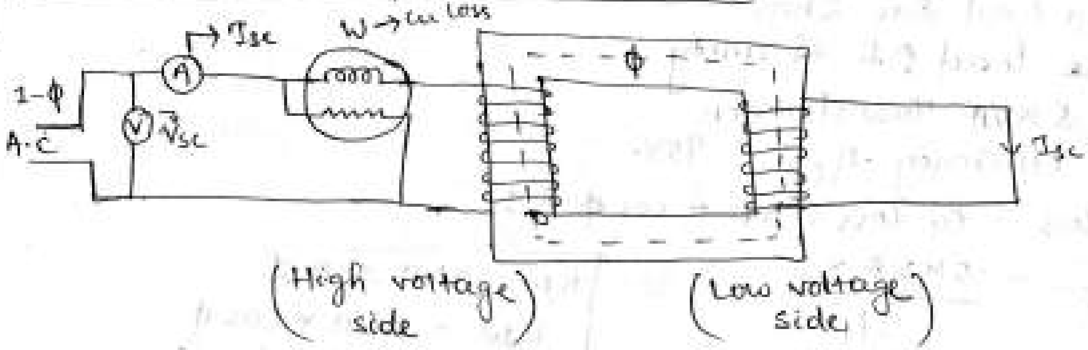
$$\Rightarrow \boxed{X_0 = \frac{V_1}{I_\mu} \ , \ R_0 = \frac{V_1}{I_w}} \rightarrow \text{From eq}^n\text{ ckt}$$

At No load, $W = V_1 I_0 \cos\phi_0$

$= \text{Total loss} = \text{Fe loss} + \text{Cu loss}$

$\therefore \boxed{W = \text{Fe loss}}$ As Cu loss = Negligible

Short-ckt or Impedance Test →



The short ckt test is conducted to find the cu losses and equivalent impedances (Z_{01}, Z_{02}), Resistances (R_{01}, R_{02}) and Reactances (X_{01}, X_{02})

* Always the low voltage side is kept short circuited and the meters are connected in high voltage side.
* Because if we short ckt the low voltage side, it is easy to handle the short ckt current.

Less amount of current flows through the circuit if low voltage side is short ckted.

When the low voltage winding is short ckted, the voltage across the short ckt winding is zero and voltage across H.V winding is (5% - 10%) of F.L primary voltage.

→ The H.V side is connected by a wattmeter, Ammeter and voltmeter.

Though the voltage in low voltage side is zero and high voltage side is neglible, the Fe losses is also negligible. So the wattmeter reading only shows the Cu loss.

$W = \text{cu loss} = I_{sc}^2 R_{01}$ or $I_{sc}^2 R_{02}$

$\therefore I_{sc}^2 R_{01} = W = \text{cu loss total}$

$\Rightarrow \boxed{R_{01} = \frac{W}{I_{sc}^2}}$ $\boxed{Z_{01} = \frac{V_{sc}}{I_{sc}}}$ $\boxed{X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}}$

Q-> A 5KVA distribution transformer has a full load efficiency at unity p.f of 95%. the copper and iron losses then being equal. calculate its all day efficiency if it is loaded through out the 24 Hrs as follows.

No load for 10 hrs

($\frac{1}{2}$) Half load for 5hrs.

($\frac{1}{4}$th) Quater load for 7 hrs.

Full load for 2hrs.

Assume load p.f of unity

Sol Given 5KVA Transformer

F.L efficiency $\eta_{F.L} = 95\%$

Iron loss = Cu loss, p.f = $\cos\phi = 1$

$$\eta = \frac{O/P}{I/P} = \frac{5KVA \times 1}{I/P}$$

$$\boxed{\begin{aligned} KW &= KVA \times P.f \\ KW &= KVA \times \cos\phi \\ P &= VI\cos\phi \end{aligned}}$$

$$\Rightarrow \eta = \frac{5KW}{I/P}$$

$$\Rightarrow I/P = \frac{5\times 10^3}{0.95} = 5.26\ KW.$$

Total losses = I/P − O/P

= 5.26 − 5 = 0.26 KW.

$\therefore$ Fe losses = $\frac{\text{Total Losses}}{2}$. [$\because$ Total loss = Iron loss + Cu loss]

$= \frac{0.26}{2} = 0.13KW.$

Also Iron loss = F.L Cu loss = 0.13 KW.

Iron loss for 24 Hrs = 24 × 0.13 = 3.12 KW.

Cu loss for 24 hrs

Cu loss for ($\frac{1}{4}$) load $= (\frac{1}{4})^2 \times$ F.L Cu loss

$= (\frac{1}{4})^2 \times 0.13 = 0.008$ KW.

Cu loss for $\frac{1}{2}$ load $= (\frac{1}{2})^2 \times$ F.L Cu loss

$= (\frac{1}{2})^2 \times 0.13 = 0.03$ KW.

Cu loss at 24 hrs = (0.008 × 7) + (0.03 × 5) + (0.13 × 2)

= 0.466 KW.

$\therefore$ Total losses in 24 hrs = Cu loss in 24 hrs + Iron loss in 24 hrs.

= 0.466 + 3.12 = 3.586 KW.

$\therefore \eta_{All\ day} = \dfrac{o/p \text{ for } 24 \text{ hrs}}{o/p \text{ for } 24 \text{ hrs} + Cu \text{ loss for } 24 \text{ hrs} + Fe \text{ loss for } 24 \text{ hrs}}$

Then calculate O/P for 24 hrs

O/P at $\left(\frac{1}{4}\right)^{th}$ load $= \left(\frac{5}{4}\right)$ KW.

O/P for $\left(\frac{1}{2}\right)$ load $= \left(\frac{5}{2}\right)$ KW.

O/P for full load = 5KW.

O/P for no load = 0

~~$\therefore \eta_{all\ day} =$ O/P 24 hrs~~

$$\therefore \eta_{all\ day} = \frac{O/P_{24 hrs}}{O/P_{24hrs} + Cu\ loss_{24hrs} + Iron\ loss_{24 hrs}}$$

$$= \frac{31.25}{(31.25 + 0.466 + 3.12)} \times 100$$

$$= \frac{31.25}{(31.25 + 3.586)} \times 100 = 89.7\%$$

Voltage Regulation →

① Voltage drop → Change in voltage from no load to full load voltage

2. $\boxed{V.D = V_0 - V_1}$

V_0 → No load voltage.

V_1 → Full load voltage.

$$\% \text{ Voltage Regulation (down)} = \frac{\text{Voltage drop}}{\text{No. load voltage}} \times 100$$

$$\% \text{ voltage Regulation (up)} = \frac{V.D}{\text{Full load voltage}} \times 100$$

Efficiency of transformer →

$$\eta = \frac{O/P \text{ in KW}}{I/P \text{ in KW}} \times 100$$

$$\therefore \eta = \frac{O/P \text{ in KW}}{O/P \text{ in KW} + Fe \text{ loss in KW} + Cu \text{ loss in KW}}$$

All day Efficiency → It is the efficiency of a transformer in 24 hrs (on a day).

$$\eta_{all day} = \frac{O/P \text{ for } 24 \text{ hrs}}{O/P\ 24 \text{ hrs} + Fe \text{ loss for } 24 \text{ hrs} + Cu \text{ loss for } 24 \text{ hrs}} \times 100$$

Voltage drop in sec. side →

for leading p.f → $(I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi)$

for lagging p.f → $(I_2 R_{02} \cos\phi + I_2 X_{02} \sin\phi)$

Voltage drop on primary side →

for leading ~~side~~ p.f → $(I_1 R_{01} \cos\phi - I_1 X_{01} \sin\phi)$

for lagging p.f → $(I_1 R_{01} \cos\phi + I_1 X_{01} \sin\phi)$

Voltage Regulation →

It is the ratio of change in secondary terminal voltage from no load to full load a no load is known as regulation ~~down~~.

If V_{02} → no load voltage on sec. side.

V_2 → secondary load voltage.

Then % regulation down $= \frac{V_{02} - V_2}{V_{02}} \times 100$

% regulation up $= \frac{V_{02} - V_2}{V_2} \times 100$

(or)

$$\frac{I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi}{V_2} \text{ (for leading p.f.)}$$

Q→ Obtain the equivalent circuit of a 200 / 400 V , 50 Hz , 1-phase transformer from the following data :-

O.C Test : 200V , 0.7A , 70W - on L.V side.

S.C Test : 15V , 10A , 85W - on H.V side

Calculate the secondary voltage when delivering 5kW at 0.8 p.f lagging , the primary voltage being 200V.

Sol Given 1-ϕ , transformer

$f = 50 Hz$

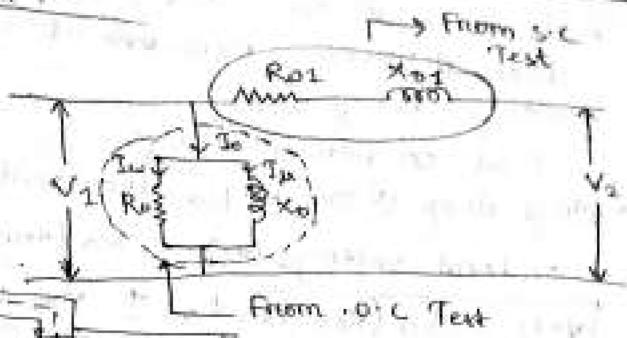
$V_1 = 200V$

$V_2 = 400 V$

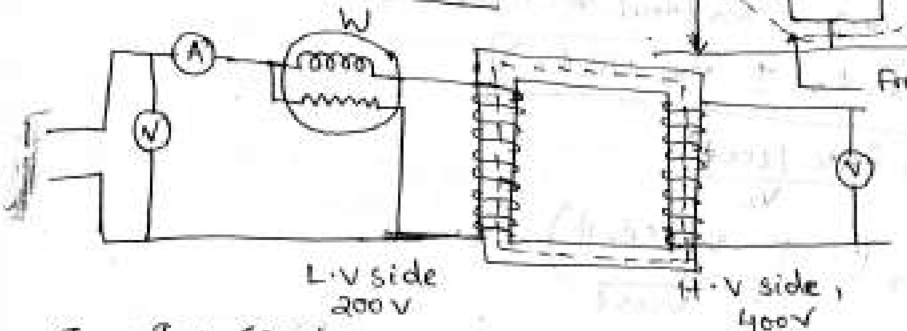
O.C Test	S.C Test
$V_1 = 200V$	$V_{sc} = 15V$
$I_{01} = 0.7A$	$I_{sc} = 10A$
Iron loss $= 70W$	Cu loss $= I_{sc}^2 R_{02} = 85W$

For obtaining equivalent ckt :-

From O.C Test →



From . O.C Test →



$I_w = I_{01} \cos\phi_0$

No load I/p power = Iron loss = $V_1 I_0 \cos\phi_0$

$\Rightarrow \cos\phi_0 = \dfrac{\text{Iron loss}}{V_1 I_0} = \dfrac{70}{200 \times 0.7} = 0.5$

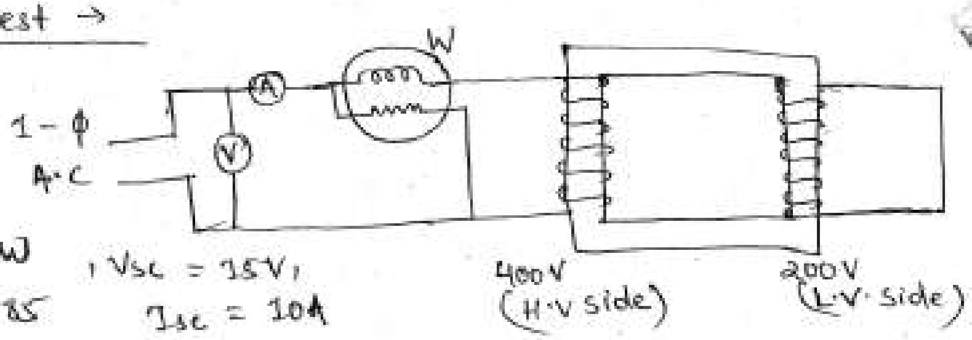
$\therefore I_w = 0.7 \times 0.5 = 0.35\,A.$

$I_\mu = I_{01} \sin\phi_0 = 0.7 \times 0.866 = 0.606\,A \qquad [\because \sin\phi_0 = 0.866]$

$\therefore R_0 = \dfrac{V_1}{I_w} = \dfrac{200}{0.35} = 571.4\,\Omega$

$X_0 = \dfrac{V_1}{I_\mu} = \dfrac{200}{0.606} = 330\,\Omega$

From s.c Test →



Cu.loss = 85 W , V_{sc} = 15 V,

$I_{sc}^2 R_{02} = 85 \qquad I_{sc} = 10\,A$

$\Rightarrow R_{02} = \dfrac{85}{(10)^2} = 0.85\,\Omega$

$Z_{02} = \dfrac{V_{sc}}{I_{sc}} = \dfrac{15}{10} = 1.5\,\Omega$

$\because K = \dfrac{V_2}{V_1} = \dfrac{400}{200} = 2$

$R_{01} = \dfrac{R_{02}}{K^2} = \dfrac{0.85}{(2)^2} = 0.21\,\Omega$

$Z_{01} = \dfrac{Z_{02}}{K^2} = \dfrac{1.5}{4} = 0.375\,\Omega$

$\therefore X_{01} = \sqrt{(Z_{01})^2 - (R_{01})^2}$
$= \sqrt{(0.375)^2 - (0.21)^2} = 0.31\,\Omega$

and $X_{02} = K^2 X_{01} = 4 \times 0.31 = 1.24\,\Omega$

When delivering 5KW at 0.8 p.f lagging the primary voltage being 200V

Find secondary voltage = ?

Voltage drop (V.D) = No-load voltage − Load voltage (V_2)

$\Rightarrow$ Load voltage (V_2) = No load voltage − V.D

$$\boxed{V.D = I_2 (R_{02} \cos\phi_2 \pm X_{02} \sin\phi_2)}$$

$\therefore I_2 = \dfrac{KVA}{V_2} = \dfrac{(kW / \cos\phi)}{V_2}$

$\Rightarrow I_2 = \dfrac{5 \times 10^3}{400 \times 0.8}$ $\left(\because P = VI \cos\phi \quad I = \dfrac{P}{V\cos\phi}\right)$

$VD = I_2 (R_{02} \cos\phi_2 + X_{02} \sin\phi_2)$ (for lagging p.f)

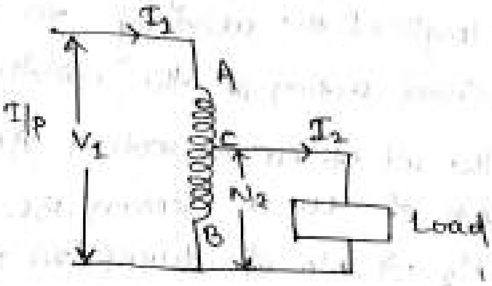
$= 15.6 (0.85 \times 0.8 + 1.24 \times 0.6 = 22.2V$

$\therefore V_2 = 400 - 22.2 = 377.8V.$

ON-4

AUTO TRANSFORMER

→ It is a transformer with one winding only.
→ The winding part is common to both primary and secondary
→ In this transformer, the primary and secondary are not electrically isolated eachother.
→ But its operation is same as that of 2-winding transformer
→ Because of one winding, less Cu is used in Auto transformer than 2-winding Transformer.
→ In Auto transformer the same winding is used as primary and secondary

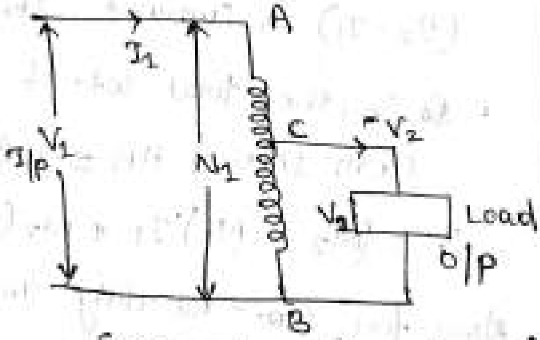


How we save Cu material in case of Auto transformer →

The fig shows the step down Transformer.

In step down tr, $V_1 > V_2$ & $I_2 > I_1$

We know that in Tr,



$V_1 I_1$ is approximately equal or slightly less than $V_2 I_2$

(step - down Transformer)

In the section, CB → the amount of current is vector difference of current I_2 and I_1

∴ The resultant current in $(I_2 - I_1)$

N.B Due to single winding, as compare to 2-winding Tr, auto-transformer is smaller in size & having more efficiency for the same rating.

Saving of Cu →

(1) Volume and weight of 'Cu' is proportional to the length and area of the cross section of the conductor.
(2) The length of the conductor is proportional to the no. of turns.
(3) The area of cross section depends on the amount of current flows through the conductor.

Here in the fig, the winding is in bet^n AB.
The winding is divided into two parts one is AC and other is CB.

The primary side (AB), the no. of turn $= N_1$

For secondary side (BC), the no of turn $= N_2$

$\therefore$ The total wt of Cu in Auto transformer

$= $ wt of Cu in AC + wt of Cu in BC.

$\therefore$ The weight of Cu in section 'AC' $\propto$ the length of the wdg within AC $\times$ cross section of the winding.

So, length of the winding in section AC $= (N_1 - N_2)$

Cross section of the winding $\propto$ current flow in the wdg (I_1)

$\therefore$ The wt of Cu in section AC $\propto (N_1 - N_2) I_1$

wt of Cu in section BC $\propto N_2 (N_2 - I_1)$

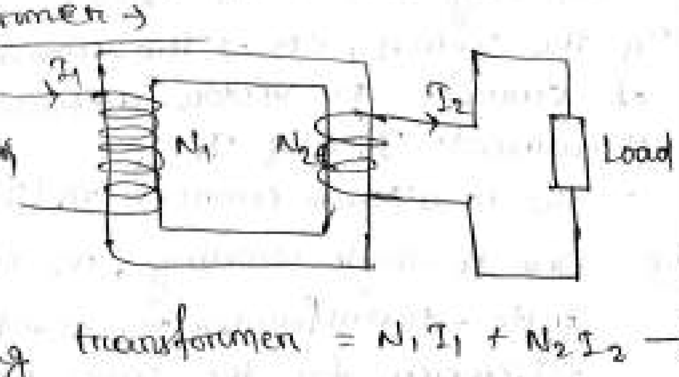
$N_2 \rightarrow$ No of turns in section (BC)

$(I_2 - I_1) \rightarrow$ Current flow through 'BC'.

$\therefore$ So, the total wt of Cu in auto Tr. is the wt of Cu in section AB = wt of Cu in (AC + BC)

$\therefore = (N_2 - N_1) I_1 + N_2 (I_2 - I_1)$ —— ①

Now for 2-winding Transformer $\rightarrow$



The wt of Cu in primary side $= N_1 I_1$

& the wt of Cu in secondary side wdg $= N_2 I_2$

$\therefore$ The total wt of Cu in 2 wdg transformer $= N_1 I_1 + N_2 I_2$ —— ②

$$\therefore \frac{\text{wt of Cu in Auto Tr.}}{\text{wt of Cu in 2-winding Tr}} = \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

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

$$\Rightarrow \quad " \quad = \frac{N_1 I_1 + N_2 I_2 - 2 N_2 I_1}{N_1 I_1 + N_2 I_2} \quad —— ③$$

We know that, In Tr.

$N_1 I_1 = N_2 I_2$

Putting the value in eqn (2)

$$\therefore \frac{\text{wt of Cu in Auto Tr}}{\text{wt of Cu in 2-wdg Tr}} = \frac{N_1 I_1 + N_1 I_1 - 2N_2 I_1}{N_1 I_1 + N_1 I_1}$$

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

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

$$= 1 - K$$

$$\therefore \text{So } \frac{\text{wt of Cu in Auto Tr.}}{\text{wt of Cu in 2wdg Tr}} = (1-K) \quad \left(\because \frac{N_2}{N_1} = K\right)$$

$$\therefore \boxed{\text{wt of Cu in Auto Tr} = (1-K) \times \text{wt of Cu in 2-wdg Tr}}$$

If we assume:-

wt of Cu in Auto Tr $= W_a$

" " " " 2wdg Tr $= W_0$

$$\therefore \boxed{W_a = (1-K) W_0}$$

Saving = wt of Cu in 2wdg - wt of Cu in auto Tr.

~~Saving~~ $= \cancel{\frac{W_0 - W_a}{W_0 - (1-K) W_0}} =$

$\therefore$ Saving $= W_0 - W_a$

$= W_0 - (1-K) W_0 = W_0 - W_0 + KW_0$

$$\therefore \boxed{\text{Saving} = KW_0 = K \times \text{wt of Cu in ordinary Tr}}$$