Unit-II Ch-III

Elementary Concept of Electrical machines
DC & AC machines

DC GENERATOR

Introduction :-

* Generator converts mechanical energy into electrical energy using electromagnetic induction.

* An electrical generator is a machine which converts mechanical energy into electrical energy.

* The energy conversion is based on the Principle of the production of dynamically induced e.m.f.

↳ Parts of a DC generator ⇒

There are two basic parts

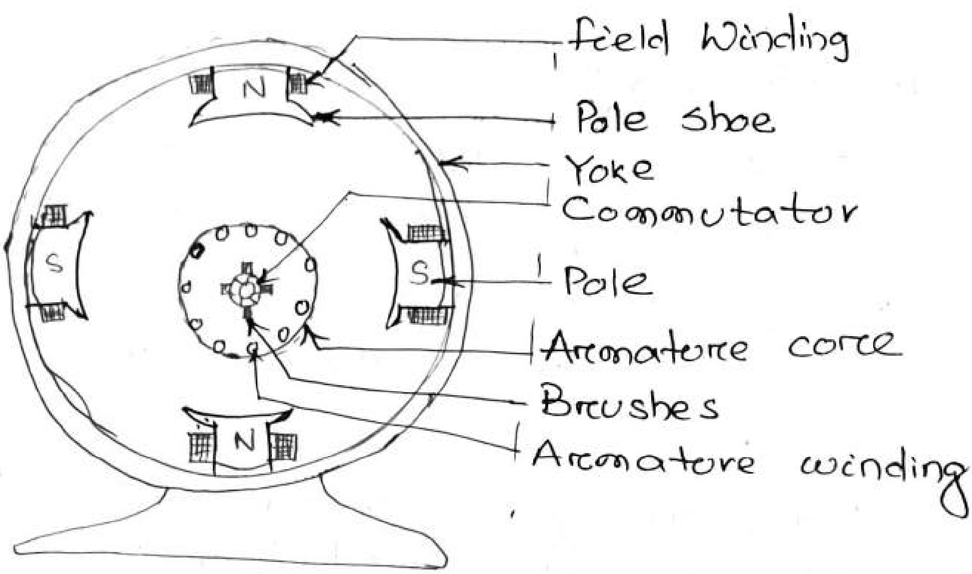
a) Stationary part: It's designed mainly for Producing a magnetic flux.

b) Rotating part: It's called the armature where mechanical energy is converted into electrical energy.

✓ Actual generator consists of following parts:

a) Yoke or outer frame
b) Pole core & pole shoes
c) Field winding
d) Armature core
e) Armature winding
f) Commutator
g) Brushes.

a) Yoke :- It's a hollow cylinder made up of cast steel or rolled steel.



< Construction >

* The Yoke serves following two purposes:

i) It supports the field pole core & acts as a protecting cover to the m/c.

ii) It provides a path for the magnetic flux produced by field winding.

b) Pole Core & Pole shoes ⇒ ~~They spre~~

The pole shoe serves two purposes:

i) It provides support to the field coils.

ii) It reduces the reluctance of magnetic ckt by increasing the cross-sectional area of it.

* The pole cores are made of thin laminations of sheet steel which are insulated from each other to reduce the eddy current loss.

* The field coils are connected in series with one another such that when current flows through the coils, alternate N & S poles are produced in the dirⁿ of rotation.

c) Field winding → It consist of copper wire. when current passes through these coils, they electromagnetise the poles which produce the necessary flux i.e. cut by armature conductor.

d) Armature Core →

↳ It's mounted on the shaft & rotates betn the field poles.

↳ It has slots on its outer surface & the armature Conductors are put in these slots.

↳ It's made up of soft iron laminations which are insulated from each other & tightly clamped together.

↳ The laminated armature core is used to reduce the eddy - current loss.

e) Armature windings ⇒

The interconnection of the armature Conductors, placed in the slots provided on the armature core is known as arm. winding.

↳

f) Commutator ⇒ ~~A Commuta~~

↳ Converts the alternating emf generated in winding into direct voltage across load terminals.

↳ Collect the current from arm. coil.

↳ Produce unidirectional torque in case of motor.

g) Brushes :-

↳ Brushes are mounted on the commutator

↳ Used to collect the current from commutator.

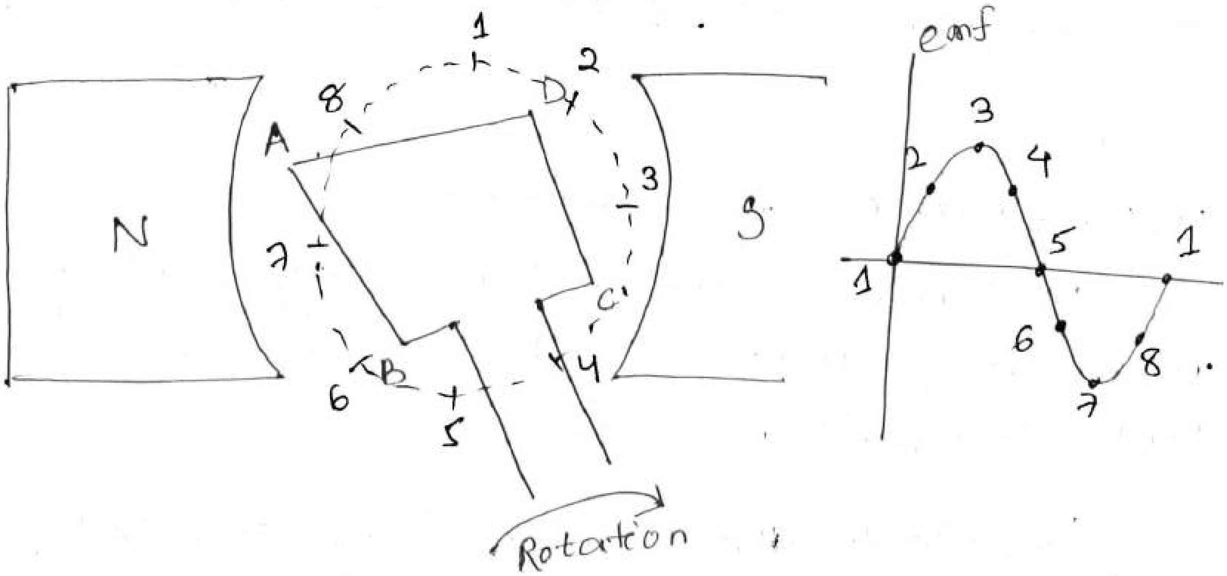
↳ Made of carbon or graphite and is supported by a metal box called brush holder.

↳

Working Principle →

Consider a single loop DC generator, in this a single turn loop 'ABCD' is rotating clockwise in a uniform magnetic field with a const. speed.

↳ When the loop rotates, the magnetic flux linking the coil sides 'AB' & 'CD' changes continuously. This change in flux linkage induces an emf in coil sides & the induced emf in one coil side adds the induced emf in the other.



Hence, an emf is induced in it which is proportional to the rate of change of flux linkage ($e = N d\phi dt$).

The emf induced in a generator can be explained as follows

a) when the loop is in position-1, the generated emf is zero because, the movement of coil sides is parallel to the magnetic flux.

b) When the loop is in pos-2, the coil sides are moving at an angle to the magnetic flux & hence, a small emf is generated.

c) in pos-3, the coil sides are moving at right angle to the magnetic flux, therefore the generated emf is max.

d) in pos-4, the coil sides are cutting the flux at an angle, thus a reduced emf is generated in the coil sides.

e) in pos-5, no flux linkage with the coil side & are moving $||^{el}$ to the magnetic flux. Therefore, no emf is generated in coil.

f) At pos-6, the coil sides move under a pole of opposite polarity & hence polarity of generated emf is reversed. The max emf will generate in this dir^n at pos-7 & zero when at pos-1,

This cycle repeats with revolution of coil

emf eq^n :-

Let P = no. of poles in a generator

Z = Total no. of armature conductor

A = no. of $||^{el}$ lanes/path within armature

N = rotation of armature in r.p.m

E = induced emf in any $||^{el}$ lane within armature

ϕ = Flux produced by each pole in Wb

Therefore total flux produced by all the

& time taken to complete one revolution =

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

According to Faraday's law of induction, the induced emf of the armature conductor is 'e' which is equal to rate of cutting the flux.

$$e = \frac{d\phi}{dt} = \frac{\text{total flux}}{\text{time taken}}$$

emf generated by one coil $= \frac{d\phi}{dt}$

$$= \frac{\phi \times P}{(60/N)} = \frac{\phi P N}{60}$$

Induced emf in each path is same across the line. Hence,

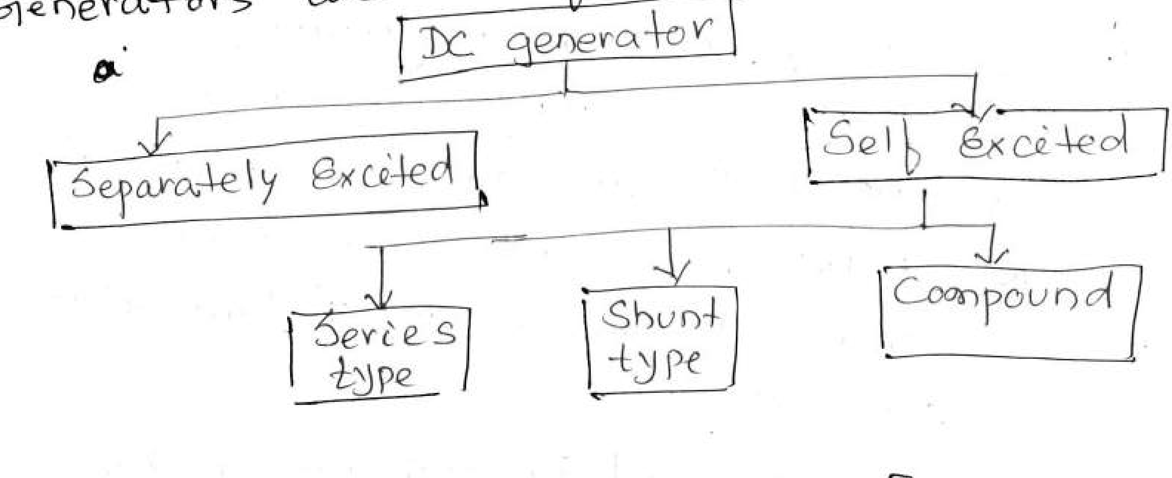
Induced emf of DC gen^r (E) = emf of one conductor X no. of conductor connected in series.

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

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

Types of DC generator →

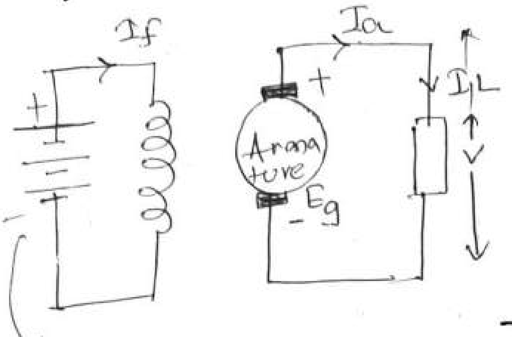
Generators are usually classified according to the way in which their fields are excited. Generators are classified as



[Types of DC generator]

4)

i) <u>Separately excited</u> → The field coils are energized from an independent exterenal source of dc current.



Separate soure of excitat^n

I_a = Armature Current

I_L = Load current

V = Terminal voltage

E_g = generated emf

Let $I_a = I_L = I$,

Then

Voltage across load $V = IR_a$

Power : $P_g = E_g I$

Power delivered to external load $P_L = VI$

ii) <u>Self-excited</u> → The field coils are energized from the generated current within the generator.

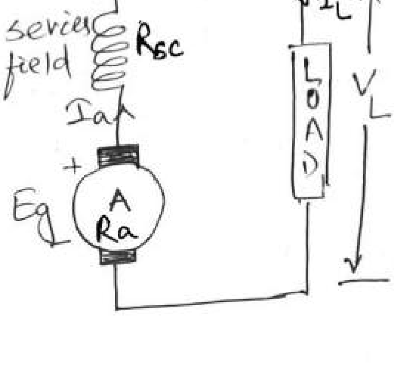
↳ Here, field Coils are internally connected with the armature. Due to residual magnetism, some flux is always present in the poles.

↳ According the ~~the~~ position of the field coils, self-excited DC generators may be divided as:

a) Series wound b) shunt wound

c) Compound "

a) Series wound ⇒ The field windings are joined in series with armature conductors.



Let

R_{sc} = Series Winding resistance

R_a - Armature resistance

$I_a = I_{sc} = I_L = I$

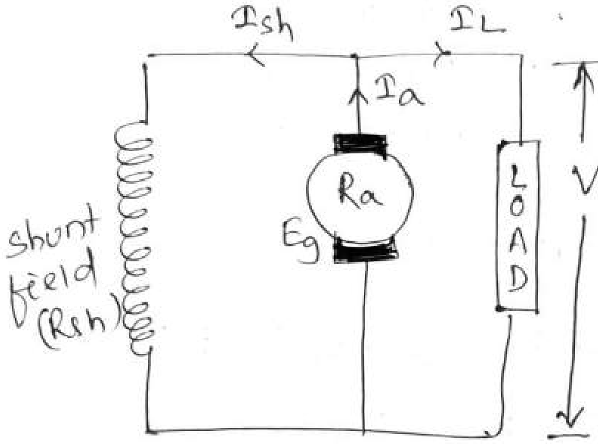
Voltage across load $V = E_g - (I_a \times R_a) - (I_a R_{sc})$

Power generated $P_g = E_g \times I$

" delivered to load $P_L = VI$

b) Shunt wound → The field windings are connected in parallel with arm. conductors.

→ Voltage in the field winding is same as the voltage across terminal.



Here
R_{sh} = Shunt winding resistance

I_{sh} = Current flowing through shunt field

R_a = Armature resistance

I_a = Arm. current

I_L = Load current , V = Terminal voltage
E_g = Generated emf

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

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

Volt. across load $V = E_g - I_a R_a$

Power generated $P_g = E_g \times I_a$

" delivered to load $P_L = V I_L$

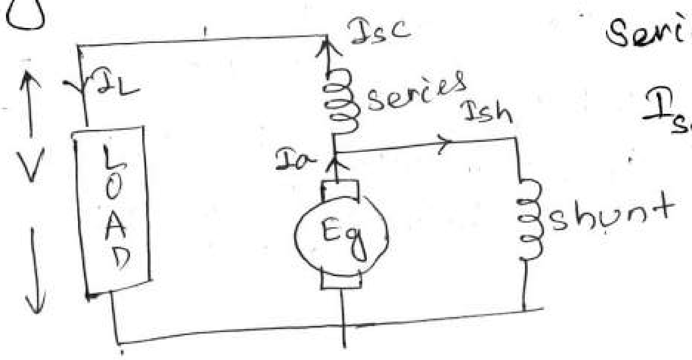
c) Compound wound ⇒ It's a combination of a few series & a shunt windings and can be either short-shunt or long-shunt resp.

↳ One winding is placed in series with the armature and the other is placed in $||^{el}$ with the armature.

↳ Short shunt compound wound dc genʳ are generators where only the shunt field winding is in $||^{el}$ with the armature winding.

Series field current

$$I_{sc} = I_L$$



(6)

(3) A 4-pole generator, having wave-wound arm. winding has 51 slots, each slot containing 20 Conductors. What will be the voltage generated in the machine when driven at 1500 rpm assuming the flux per pole to be 7 mWb ?

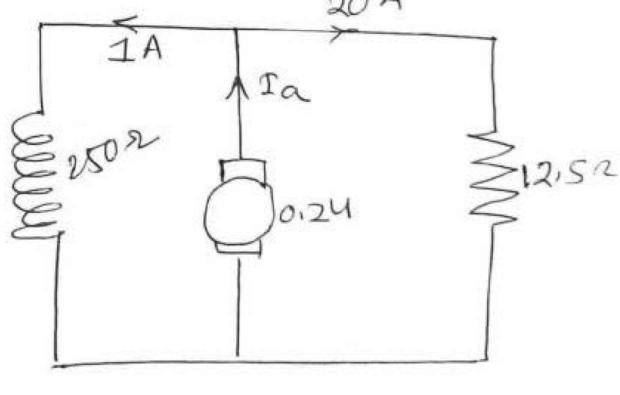
$\phi = 7 \times 10^{-3}$ wb, $N = 1500$ rpm, $A = P = 4$

$Z = 51 \times 20 = 1020$

$$E_g = \frac{\phi Z N P}{60 A} = \frac{7 \times 10^{-3} \times 1020 \times \cancel{1500}^{50} \times \cancel{4}^{2}}{\cancel{60}_{30} \times \cancel{2}}$$

$= 357$ V

(4) An 8-pole dc shunt generator with 778 wave-connected armature conductors & running at 500 rpm supplies a load of 12.5 Ω resistance at terminal voltage of 50 V. The armature resistance is 0.24 Ω & the field resistance is 250 Ω. Find the arm. current, induced emf & flux per pole.



$$I_L = \frac{V}{R} = \frac{250}{12.5} = 20 \text{ A}$$

$$I_{sh} = \frac{V}{R_{sh}} = \frac{250}{250} = 1 \text{ A}$$

$I_a = I_L + I_{sh} = 21$ A

emf $= V + (I_a \times R_a)$

$= 250 + (21 \times 0.24) = 255.04$ V

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

$$\Rightarrow 255.04 = \frac{\phi \times 778 \times 500}{60}\left(\frac{8}{2}\right)$$

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

DC Motor

Introduction :- A dc motor is an electrical m/c that converts electrical energy into mech. energy.

↳ In a DC motor, the input electrical energy (direct current) is transformed into mechanical rotation & then further into a rotational force.

↳ DC motors are used in toys, electric vehicle propulsion, elevator, paper mill, steel rolling mills etc.

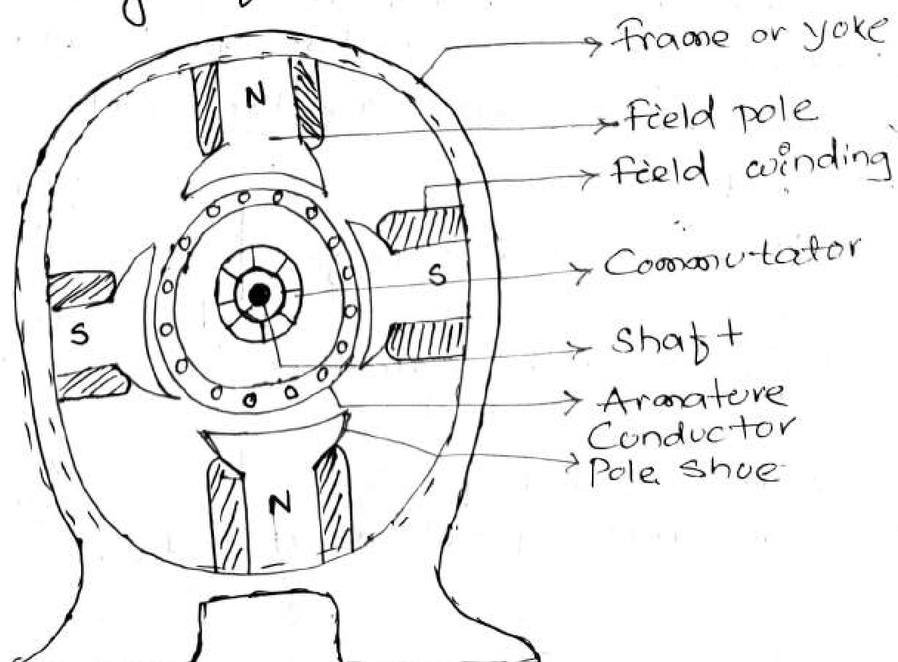
Working principle →

The working principle of motor is Fleming's left hand rule i.e "when a current-carrying conductor is placed in a magnetic field, it experiences a torque & has a tendency to move. This is known as motoring action."

The magnitude is given by

$$\boxed{F = BIL} \text{ newton}$$

∵ B = flux density
I = current in conductor, A
l = length of conductor, m



[DC Motor Parts]

Constructionally, there is no basic difference bet^n a dc gen^r & motor.

↳ When the DC motor, field coil is energized, a magnetic field is created in the air gap.

↳ The magnetic field i.e created is in the dir^n of the radii of the arm.

↳ The magnetic field enters the armture from the side of the north pole of the field coil & exits from south pole side.

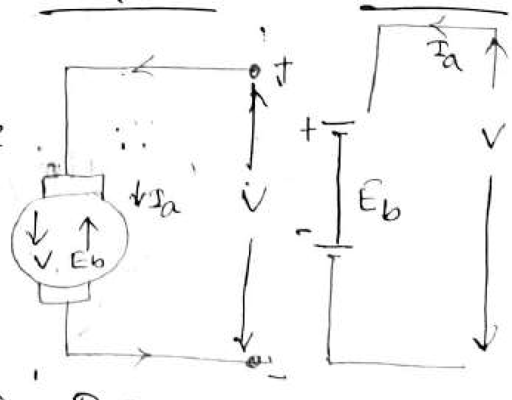
↳ The conductors located on the other pole get subjected to a force of the same intensity in the opposite dir^n.

↳ These two forces create a torque that leads to the motor armature to rotate.

↳ If the direction of current in the wire is reversed, the dir^n of rotation also reverses. When magnetic field & electric field interact they produce a mechanical force that tends to rotate the armature.

Significance of Back emf ⇒

The emf induced in the armature conductor of a DC motor due to electromagnetic induction is known as Back emf or counter emf (E_b)



↳ The applied voltage V has to force I through armature against E_b.

↳ The power reqd to overcome this opposition is $E_b I_a$.

* Energy conversion in a dc motor is only Possible due to production of back emf E_b.
* Net Voltage across armature ckt $= V - E_b$
* $I_a = \dfrac{\text{Net Voltage}}{\text{Resistance}} = \dfrac{V - E_b}{R_a}$
* Let

  ϕ = flux per pole (Wb)

  Z = Total no. of armature conductors

  P = no. of poles

  A = no. of $\|^{el}$ paths in armature

  N = arm. speed in rpm

  E_b = Back emf generated in any one of the $\|^{el}$ path

↳ flux cut by 1 conductor in 1 revolution $= P * \phi$

↳ Time for one revolution $= \left(\frac{1}{N}\right)$ minutes

↳ Avg emf generated in 1 conductor =

(Flux cut by 1 conductor in one revolution)/(Time in second for 1 revolution)

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

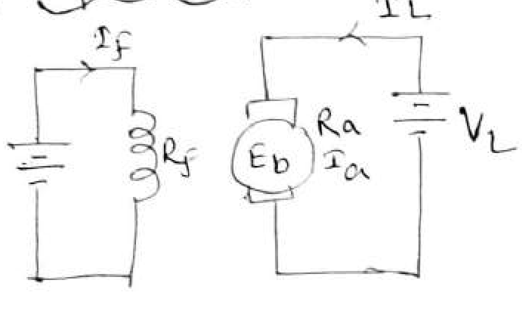
No. of conductors in each $\|^{el}$ path $= \dfrac{Z}{A}$

Back emf $\boxed{E_b = \dfrac{P\phi Z N}{60A}}$ volt

* Voltage eq^n of DC motor $\Rightarrow V = E_b + I_a R_a$

Types of DC motor ⇒

a) Separately excited ⇒



$I_L = I_a$

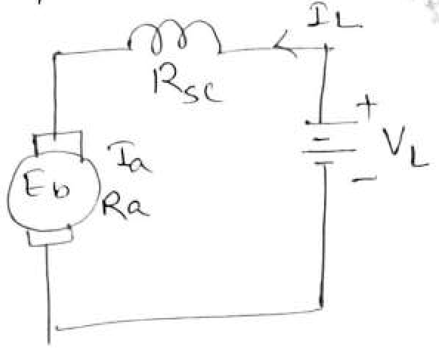
$V_L = E_b + I_a R_a$

$P_{gen} = E_b I_a$

$P_{del} = V_L I_L$

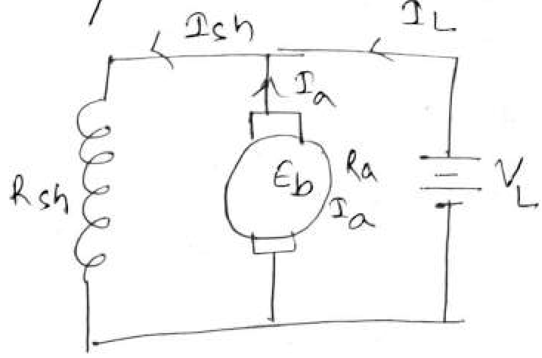
b) Self-excited

i) Series-wound →



$$I_L = I_a$$
$$V_L = E_b + I_a(R_a + R_{sc})$$

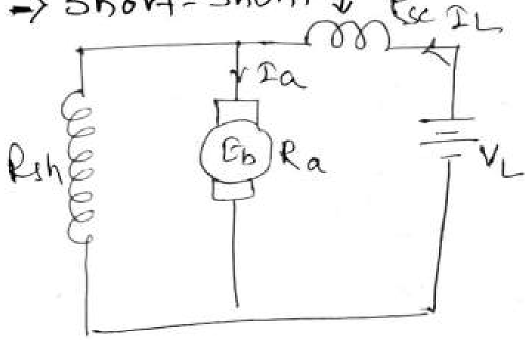
ii) Shunt-wound



$$I_L = I_a + I_{sh}$$
$$V_L = E_b + I_a R_a$$

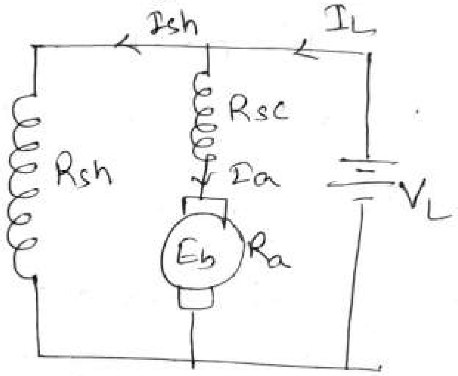
iii) Compound-type

→ Short-shunt ↓



$$I_L = I_a + I_{sh}$$
$$V_L = E_b + I_a R_a + I_L R_{sc}$$

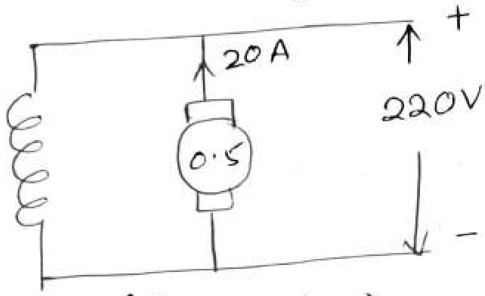
⇒ Long-shunt



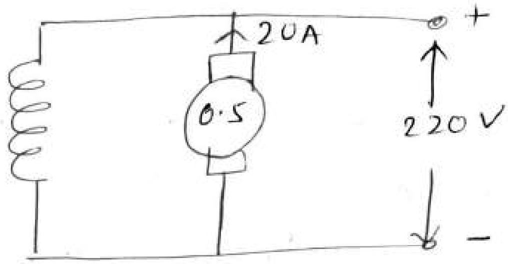
$$I_L = I_a + I_{sh}$$
$$V_L = E_b + I_a(R_a + R_{sc})$$

(9)

(1) A 220V dc machine has an armature res. of 0.5 Ω. If the full-load armature current is 20 A. Find the induced emf when the m/c acts as i) generator ii) motor.



(Generator)



(Motor)

Given :- $V = 220\,V$, $R_a = 0.5\,\Omega$, $I_L = 20\,A$

From fig, m/c is assumed to be shunt - connected

a) $E_g = V + I_aR_a = 220 + (0.5 \times 20) = 230\,V$

b) $E_b = V - I_aR_a = 220 - (0.5 \times 20) = 210\,V$

2) A 440-V shunt motor has arm. resistance of 0.8 Ω & field resistance of 200 Ω. Determine the back emf when giving an o/p of 7.46 kW at 85% efficiency,

$V = 440V$ $R_a = 0.8\,\Omega$ $R_{sh} = 200\,\Omega$, $P = 7.46\,kW$

$\eta = 85\,\% = 0.85$

$\Rightarrow \dfrac{P_{out}}{P_{in}} = 0.85 \Rightarrow \dfrac{7.46 \times 10^3}{0.85} = P_{in} \Rightarrow P_{in} = 8.77\,kW$

Motor i/p current $(I_L) = \dfrac{7.46 \times 10^3}{0.85 \times 440} = 19.95\,A$

$I_{sh} = \dfrac{V_L}{R_{sh}} = \dfrac{440}{200} = 2.2\,A$

$I_L = I_a + I_{sh} \Rightarrow I_a = I_L - I_{sh} = 19.95 - 2.2$
$= 17.75\,A$

$E_b = V - I_aR_a$

$= 440 - (17.75 \times 0.8)$

$= 425.8\,V$

3) A 250 V dc shunt motor has a shunt field resistance of 250 Ω & an armature resistance of 0.5 Ω. When running on no load, it takes 5 A from the line & its speed is 1500 rpm. calculate its speed, when taking 50 A from the line.

Given :- $V_L = 250V$, $R_a = 0.5\,\Omega$, $R_{sh} = 250\,\Omega$,

$I_{L_1} = 5A$ at no load, $N_1 = 1500$ rpm

$N_2 = ?$ $I_{L_2} = 50A$ at full load.

$$I_{sh} = \frac{V_L}{R_{sh}} = \frac{250}{250} = 1A$$

$$I_{a_1} = I_{L_1} - I_{sh} = 5 - 1 = 4A \text{ (No load)}$$

$$\therefore E_{b_1} = V_L - I_{a_1}R_a = 250 - (4 \times 0.5) = 248V$$

$$I_{a_2} = I_{L_2} - I_{sh} = 50 - 1 = 49A \text{ (Load)}$$

$$\therefore E_{b_2} = V_L - I_{a_2}R_a = 250 - (49 \times 0.5) = 225.5V$$

Now $$\frac{N_2}{N_1} = \frac{E_{b_2}}{E_{b_1}} \quad (\because N \propto E_b)$$

$$\Rightarrow \frac{N_2}{1500} = \frac{225.5}{248}$$

$$\Rightarrow N_2 = \frac{222.5 \times 1500}{248} = 1363.91 \simeq 1364 \text{ rpm}$$

Application of DC motors

a) shunt motors

i) Drilling & milling m/c

ii) Lathe m/c

iii) pumps

iv) fans

b) Series

i) for traction work i.e

i) Electric locomotives

ii) Elevators

iii) Trolley, cars etc

iv) Cranes

c) Cumulative Compound

For intermittent high torque loads.

i) Heavy Planers ii) Rolling mills iii) Elevators

Single - phase Transformer

Introduction →

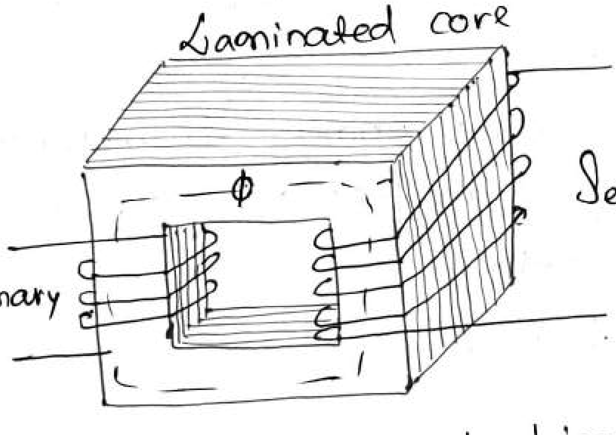
↳ A transformer is a static (or stationary) electrical device that accepts single phase AC Power & o/ps single phase AC.

↳ It can raise or lower the voltage in a ckt with a corresponding decrease or ↑ in Current.

↳ **Construction** → It consists of 2 windings i.e Primary & secondary winding put on a magnetic core.

↳ The magnetic core is made from thin sheets (called laminations) of high graded Silicon steel & provides a definite path to the magnetic flux.

↳



↳ These 2 coils are electrically isolated, but they are magnetically linked.

↳ The two coils possess high mutual inductance.

Working Principle →

* The working of the transformer is based on the principle of mutual inductance bet' two coils wound on the same magnetic Core.

* When an alternating voltage (V_1) is

... winding is sub-divided into ...

applied to the primary winding, an alternating magnetic flux (ϕ_m) sets up in the core & links with the secondary winding.

↳ The ϕ_m links both the windings of the transformer magnetically.

↳ When the primary of a transformer is connected to an AC supply, the current flows in the coil & the magnetic field build up. This condⁿ is known as mutual inductance.

↳ As the current increases from zero to its max. value, the magnetic field strengthens & is given by $\frac{d\phi}{dt}$.

↳ The strength of a magnetic field generated in the core depends on the no. of turns in the winding & the amount of I.

↳ The flux & current are directly proportional to each other.

↳ For a single phase transformer, there are 2 types of transformer constructions:

a) Core - type

b) Shell - type.

a) Core - type

* The magnetic circuit consists of 2 vert. legs (called limbs) & two horz. sections (called yokes).

*

b) Shell-type ⇒ Magnetic circuit consists of 3 limbs, both the primary & secondary windings are placed on the central limb & the two outer limbs complete low reluctance flux path.

(11)

* Each winding is sub-divided into sections i.e low voltage (LV) section & high voltage (HV) section, which are alterenatively put one over the other in the form of sandwich. Therefore, such windings are called sandwich winding or disc winding.

emf eq^n of a transformer →

Let N_1 = No. of turns in primary

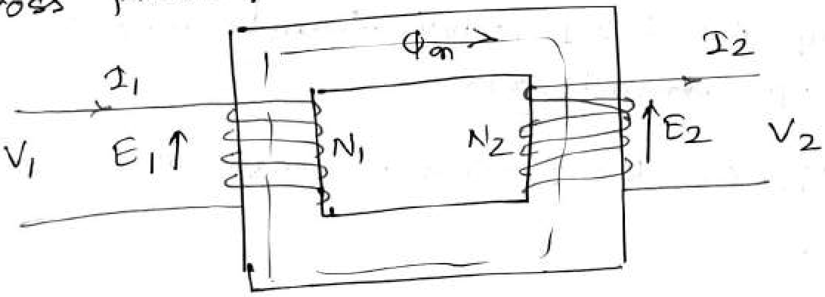
N_2 = " " Secondary

ϕ_m = Max. flux in core in webers

$= B_m \times A$

f = freq of ac i/p in Hz

Consider an alternating voltage V_1 is applied across primary winding.



i.e $V_1 = V_m \sin \omega t$

Due to this voltage, an alterenating current I_1 flows in the primary coil which induces an alternating flux.

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

Emf induced in the primary coil -

$$e_1 = -N_1 \frac{d\phi}{dt}$$

$$= -N_1 \frac{d}{dt}(\phi_m \sin \omega t)$$

$$= -N_1 \phi_m (\cos \omega t)\omega$$

$$= N_1 \phi_m \omega \sin\left(\omega t - \frac{\pi}{2}\right)$$

$$= E_{m_1} \sin\left(\omega t - \frac{\pi}{2}\right)$$

where $E_{m_1} = N_1 \phi_m \omega = 2\pi f N_1 \phi_m$

$$(E_{m1})_{rms} = \frac{E_{m1}}{\sqrt{2}} = \frac{N_1 \phi_m \omega}{\sqrt{2}}$$

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

$$\boxed{E_{m1\,rms} = 4.44 f N_1 \phi_{max}} \quad -(1)$$

Similarly $= 4.44 f N_1 B_m A$

$$\boxed{E_2 = 4.44 f N_2 \phi_{max}} \quad -(2)$$

$$= 4.44 f N_2 B_m A$$

Voltage Transformation ratio (k)

from eq^n (1) & (2),

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

i) If $N_2 > N_1$ i.e $k > 1$, then transformer is called step-up transformer.

ii) If $N_2 < N_1$ i.e $K < 1$, then transformer is Step-down.

for an ideal transformer,

i/p VA = o/p VA

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

Hence, currents are in the inverse ratio of the (voltage) transfor^n ratio.

Ideal Transformer ⇒

An ideal transformer is one which has

a) No losses

b) Windings have no ohmic resistance

c) No magnetic leakage

↳ An ideal transformer consists of two purely inductive coils wound on a loss-free core.

(12) A transformer is said to be on no load, when the secondary winding is open circuited. The 2^{nd} current is thus zero.

↳ when an alternating voltage is applied to the primary, a small current I_0 called as no load current flows in the primary.

1. The max. flux density in the core of a 250/3000 volts, 50-Hz single-phase transformer is 1.2 Wb/m². If the emf per turn is 8 volt. Determine
i) Primary & secondary turns ii) area of the core.

$B_m = 1.2\ Wb/m^2$ $E_1 = 250V$ $E_2 = 3000\ V$ $f = 50\ Hz$

[

i) $E_1 = N_1 \times$ emf induced / turn

$\Rightarrow N_1 = \frac{E_1}{\text{emf induced}} = \frac{250}{8} = 32$

$N_2 = \frac{E_2}{8} = \frac{3000}{8} = 375$

ii) $E_2 = 4.44\ f N_2 B_m A$

$\Rightarrow 3000 = 4.44 \times 50 \times 375 \times 1.2 \times A$

$\Rightarrow A = \frac{3000}{4.44 \times 50 \times 375 \times 1.2} = 0.03\ m^2$

2) A single-phase transformer has 400 primary & 1000 secondary turns. The net cross-sectional area of the core is 60 cm². If the primary winding be connected to a 50 Hz supply at 520V. find
i) the peak value of flux density in the core
ii) the voltage induced in the secondary winding.

$N_1 = 400$ $N_2 = 1000$ $A = 60\ cm^2$, $f = 50\ Hz$

$E_1 = 520\ V$

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

$\Rightarrow$ Let $\frac{N_2}{N_1} = K \Rightarrow \frac{1000}{400} = K \Rightarrow K = 2.5$

Then $\frac{E_2}{E_1} = k \Rightarrow E_2 = KE_1 = 2.5 \times 520 = 1300\ V$

ii) $E_1 = 4.44\, f N_1 B_m A$

$\Rightarrow 520 = 4.44 \times 50 \times 400 \times B_m \times (60 \times 10^{-4})$

$\Rightarrow \frac{520}{532.8} = B_m \Rightarrow B_m = 0.976\ Wb/m^2$

(8) A 25 KVA, Single phase transformer has 250 turns on the primary & 40 turns on the secondary winding. The primary is connected to 1500 V, 50Hz mains. Find i) Primary & Secondary Currents on full-load ii) Secondary emf iii) max. flux in the core.

$N_1 = 250, \quad N_2 = 40, \quad E_1 = 1500\ V, \quad f = 50\ Hz$

If V_2 = Secondary emf

ii) $\frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow E_2 = \frac{N_2 E_1}{N_1} = \frac{40 \times 1500}{250}$

$= 240\ V$

i) $I_1 = \frac{25 \times 10^3}{E_1} = \frac{25000}{1500} = 16.67\ A$

$I_2 = \frac{25000}{E_2} = \frac{25000}{240} = 104.2\ A$

iii) If ϕ_m is max core-flux in wb

$E_1 = 4.44\, f N_1 \phi_m$

$\Rightarrow \frac{1500}{4.44 \times 50 \times 250} = \phi_m \Rightarrow \phi_m = 0.027\ Wb$

$\simeq 27\ mWb$