UNIT - III 5/06/2026

Transformers

Magnetic Circuit:-

Magnetic induction:- The process of a magnet which can induce magnetism in a magnetic material without any physical contact is called magnetic induction.

Magnetic field:- The region around the Magnet within the influence of other magnet is called a Magnetic field.

Magnetic flux (ϕ):- The total number of flux lines existing in a magnetic field is called as a magnetic flux.

Units:- Weber.

$$1 wb = 10^8 \text{ lines of force}.$$

Magnetic flux density (B):-

It is defined as flux per unit area

$$B = \frac{\phi}{A}.$$

Magnetic flux intensity (H):- It gives the value of strength or weakness of a magnetic field is called Magnetic field strength.

$$H = \frac{NI}{l} = \frac{\text{ampere turns}}{\text{length}}.$$

Transformer :-

It is a static electric machine which transforms power from one circuit to other circuit without change in frequency.

Working Principle :-

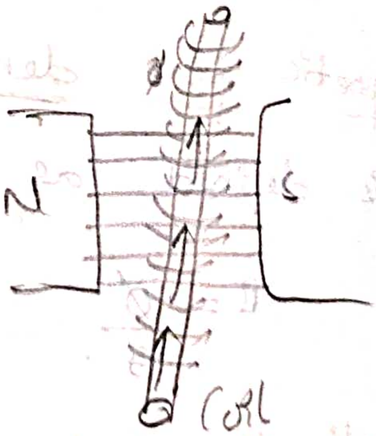
Transformer works on the principle Faraday's laws of Electromagnetic induction.

Faraday's laws :-

Faraday's I law :- Whenever current carrying conductor is placed in the magnetic field and when conductor cuts the magnetic flux lines then Emf (e) will be induced.

Faraday's II law :- Induced Emf (e) in any conductor is directly proportional to rate of change of flux linkage.

$$E \text{ (or) } e_L \propto \frac{d\psi}{dt}$$



$$e_L = \frac{d(N\phi)}{dt}$$

$$e_L = N\frac{d\phi}{dt}$$

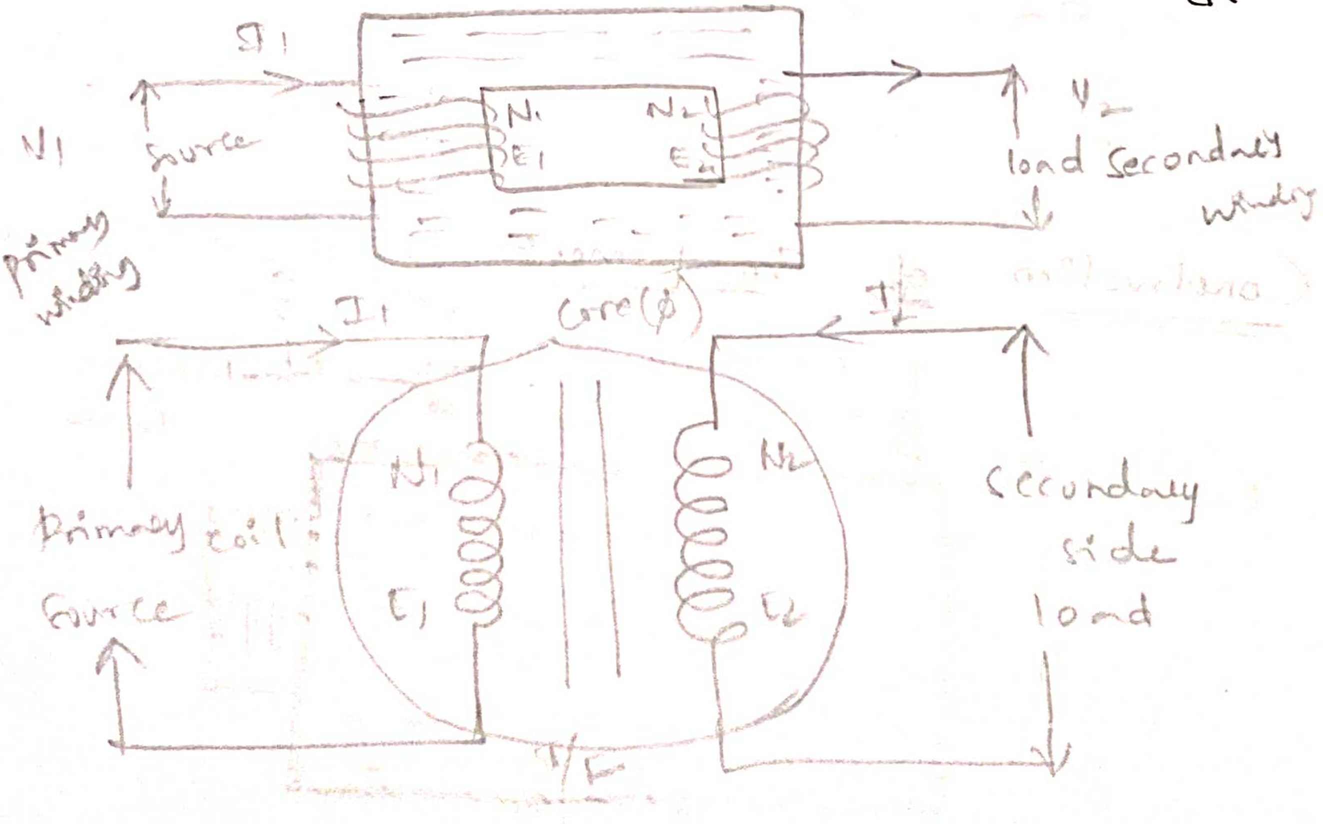
$$e_L = -N\frac{d\phi}{dt}$$ [due to Lenz law]

In a transformer there is a production of two Emf's.

* Self induced Emf
* Mutual induced Emf.

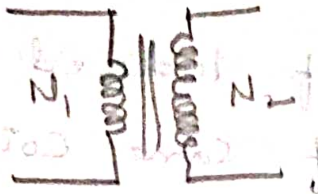
Self induced Emf :- An Emf induced in a coil due to the Excitation of same coil is known as self induced Emf $e_L = L\frac{di}{dt}$

Mutual induced Emf :- An emf induced in a second coil due to the Excitation of ~~second~~ first coil (E_2) and Emf induced in the first coil due to the excitation of ~~fir~~ second coil (E_1) i.e Mutual induced emf. $e_m = m\frac{di}{dt}$ *



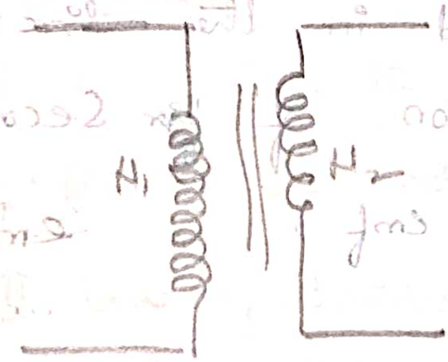
Two types of Transformers :-

Step-up :- when the Voltage is in the level low to high is called step-up



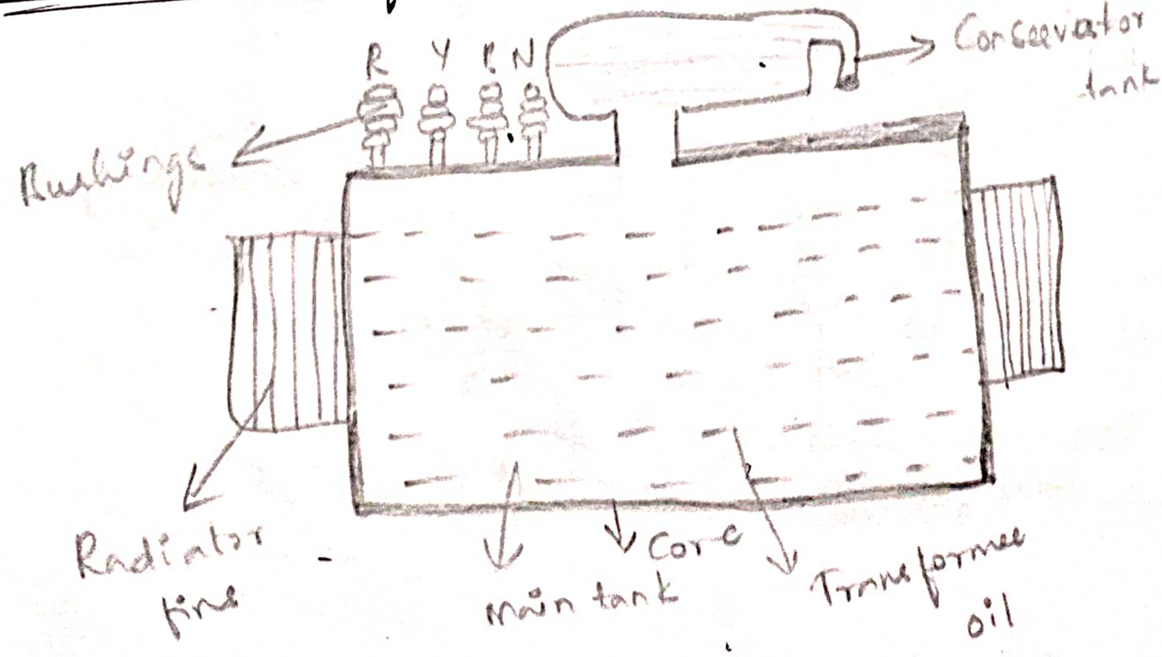
$\boxed{N_2 > N_1}$ $V\uparrow$

Step-down :- when the Voltage is in the level of high to low is called step down.



$\boxed{N_1 > N_2}$ $V\downarrow$

Construction of Transformer :-



Parts :-

Core :- the main function is to produce flux and it has low reluctance path & it has high current

maintained (above "has low")
resistance, impedance, Capacity (above "current")

it reluctance (S)

Windings :- It Carries Current.

Yoke :- top & bottom positions.

Limb

Radiator Fins

Conservator tank

Bushings.

1, 9, 10,

11 - D

12 - A

16 - A.

18 - copper

Core :- It provides production of flux and low reluctance path.

Core Carries flux and it is made up of Silicon steel.

~~Flux~~ Windings :- The function of winding to Carry the Current it is made up of Copper. and produce the flux in a transformer

Yoke :- Top and Bottom horizontal Portion is Yoke. It's function is to Carry flux.

limb :- Vertical portion is Core is limb. Its function is to Carry windings.

Radiator fins :- These are used to provide for natural Cooling.

~~Conservator tank~~ Bushings :- These are used to make the Connections.

~~Bushings~~ Conservator tank :- To avoid damage of main tank transformer oil Conservator tank is provided. It doesn't allow over flow of oil. when there is a temperature changes.

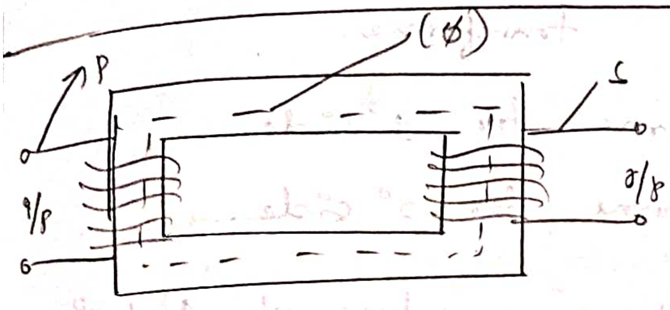
Corrected & Admitted

Omesh 21

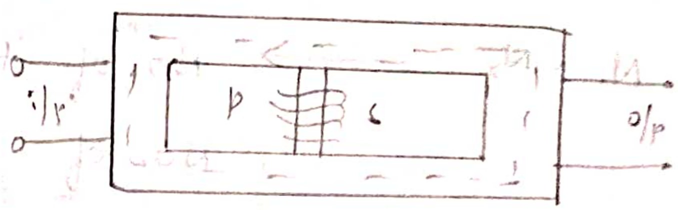
Types of Transformers :-

1] step up & step down T/F ⟶ Based on operation

2] Core type & shell type T/F ⟶ Based on Construction

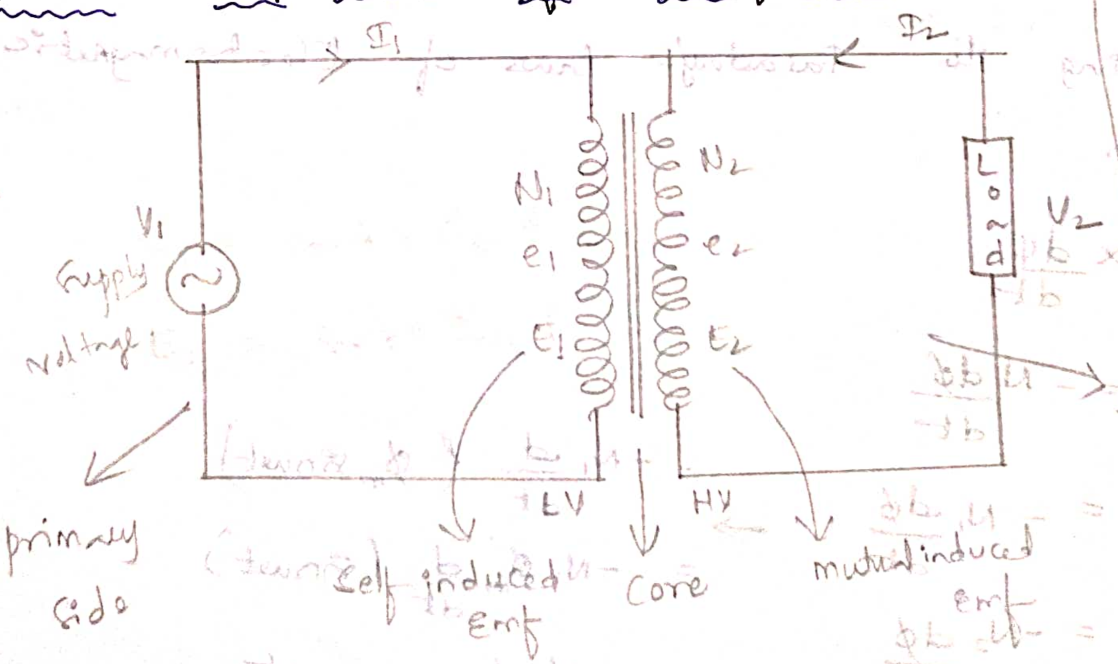


* Winding is dominated than Core
* 2 limbs, 2 yokes
* high η
* High voltage application.
* It is used in Commercial & Industrial purpose



* Core is dominated than windings
* 2 yoke, 3 limbs
* low η
* low Voltage Application.
* It is used in Domestic purpose

EMF Equation of Transformer :-



From input to output the Conversion of Energy is called EMF

Let us Consider V_1, V_2 are Voltages (input voltage, load Voltage) for the primary & secondary side of transformer.

$I_1, I_2 \longrightarrow$ input Current, and ~~load~~ Current for primary & secondary side of transformer.

$N_1, N_2 \longrightarrow$ No. of turns for 1° side
No. of turns for 2° side.

$e_1, e_2 \longrightarrow$ Instantaneous values of 1° & 2° side of transformer.

$E_1, E_2 \longrightarrow$ Induced Emf of 1° & 2° side of transformer.

Consider Current $\boxed{i = I_m \sin\omega t}$

$\boxed{\phi = \phi_m \sin\omega t}$

$\boxed{v = v_m \sin\omega t}$

According to Faraday's laws of Electromagnetic induction.

$$e \propto \frac{d\varphi}{dt}$$

$$e = -N\frac{d\phi}{dt}$$

$$e_1 = -N_1\frac{d\phi}{dt} \rightarrow = -N_1\frac{d}{dt}(\phi_m \sin\omega t)$$

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

$$e_2 = -N_2\frac{d\phi}{dt} \qquad = -N_1\phi_m\omega\cos\omega t$$

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

$$e_2 = -N_2 \frac{d\phi}{dt}$$

$$= -N_2 \frac{d}{dt}(\phi_m \sin\omega t)$$

$$= -N_2 \phi_m \frac{d}{dt}(\sin\omega t)$$

$$= -N_2 \phi_m \omega \cos\omega t$$

$$= +N_2 \phi_m \omega \sin(\omega t - 90^\circ)$$

$$\boxed{\begin{aligned} e_1 &= N_1 \phi_m \omega (\sin(\omega t - 90^\circ)) \\ e_2 &= +N_2 \phi_m \omega \sin(\omega t - 90^\circ) \end{aligned}}$$

$$E_{1\,RMS} = \frac{N_1 \phi_m \omega}{\sqrt{2}} = \frac{N_1 \phi_m 2\pi f}{\sqrt{2}} = 4.44\, \phi_m f N_1$$

$$E_{2\,RMS} = \frac{N_2 \phi_m \omega}{\sqrt{2}} = \frac{N_2 \phi_m 2\pi f}{\sqrt{2}}$$

$$= 4.44\, \phi_m f N_2$$

$$E_1 = 4.44\, \phi_m f N_1 \text{ V}$$

$$E_2 = 4.44\, \phi_m f N_2 \text{ V}$$

Probleme

Q:- A single phase 220/250 V, 50 Hz transformer has total core area 36 sq. cm & maximum flux density 6 wb/m². Calculate no. of turns for the primary & secondary transformer.

$$\frac{E_1}{E_2} = \frac{220V}{250V}$$

$A = 36$ sq.cm

$B_m = 6\ wb/m^2$

$N_1 = ?\quad N_2 = ?$

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

$E_2 = 4.44\, \phi_m N_2 f\ V$

$$B_m = \frac{\phi_m}{A}$$

$\phi_m = B_m \cdot A$

$= 6 \times 36 \times 10^{-4}$

$= 216 \times 10^{-4}$

$= 0.0216$ wb

$$N_1 = \frac{E_1}{4.44\, \phi_m \times f} = \frac{2200}{4.44 \times 0.0216 \times 50}$$

$$\boxed{N_1 = 459 \text{ turns}}$$

$$N_2 = \frac{E_2}{4.44\, \phi_m \times f} = \frac{250}{4.44 \times 0.0216 \times 50}$$

$$\boxed{N_2 = 52 \text{ turns}}$$

Q:- A single phase 440/220V, 50 Hz transformer has total core area 23 sq.cm and maximum flux density 8 wb/m² Calculate No. of turns for the primary and secondary?

Sol:-

Given

$$\frac{E_1}{E_2} \quad 440/220V$$

$$A = 23 \text{ sq.cm}$$

$$B_m = 8 \text{ wb/m}^2$$

$$N_1 = ? \quad , \quad N_2 = ?$$

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

$$E_2 = 4.44 \, \phi_m N_2 f \, V$$

$$B_m = \frac{\phi_m}{A}$$

$$\phi_m = B_m \times A$$

$$= 8 \times 23 \times 10^{-4}$$

$$= 0.0184 \text{ wb}$$

$$N_1 = \frac{E_1}{4.44 \phi_m f} = \frac{440}{4.44 \times 0.0184 \times 50}$$

$$= 108 \text{ turns}$$

$$N_2 = \frac{E_2}{4.44 \phi_m f} = \frac{220}{4.44 \times 0.0184 \times 50}$$

$$= 53.85$$

$$= 54 \text{ turns}$$

Q:- Why the transformer is rated in KVA?

A:- Transformer is a Constant power device always Expressed in $\boxed{\text{VA or KVA}}$ the transformer ratings depends on Voltage, power, Current and losses.

Primary	Secondary
110V × 2A	220V × 1A
220VA	220VA.

→ <u>step up</u> & stepdown of voltage (V)

<u>Ratio of the Transformer</u> :-

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

$E_2 = 4.44\, \phi_m N_2 f\ V$

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

<u>Turns Ratio</u> :- $\frac{E_1}{E_2} = \frac{N_1}{N_2}$

<u>Voltage Ratio</u>:- $\frac{V_1}{N_2} = \frac{I_2}{I_1}$

<u>Current Ratio</u>:- $\frac{I_2}{I_1} = \frac{V_1}{N_2}$

$V_1 I_1 = V_2 I_2$

because of constant power.

<u>Losses in Transformer</u>

1] Iron loss or Core loss

- Eddey Current loss $- k_e B_m^2 f^2 t$
- Hysterisis loss $- \eta B_m^e f v$

$\underbrace{\qquad}_{\text{Constant lo}}$

2] Copper loss or I^2R — $I_1^2 R_1$, $I_2^2 R_2$ } Variable losses

Total losses = Constant losses + Variable losses

1] Iron losses (or) Core losses:-

Iron (or) Core losses are due to the presence of flux in the Core.

* Eddy Current loss:-

An induced Emf has closed path Currents in the Core is Called Eddy Current or leakage Current.

$$= K_e B_m^2 f^2 t^2$$

where K_e - Eddey Current Const

B_m^2 - Magnetic flux

f - frequency

t - thickness of Core.

* Hysterisis loss :-

Because of Hysterisis Effect i.e (B-H Curve) there is loss of Energy

Hysterisis loss = $\eta B_m^2 f V$.

* **Copper loss:-** Copper loss is due to the presence of transformer winding refers to primary & secondary

primary = $I_1^2 R_1$

Secondary = $I_2^2 R_2$

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

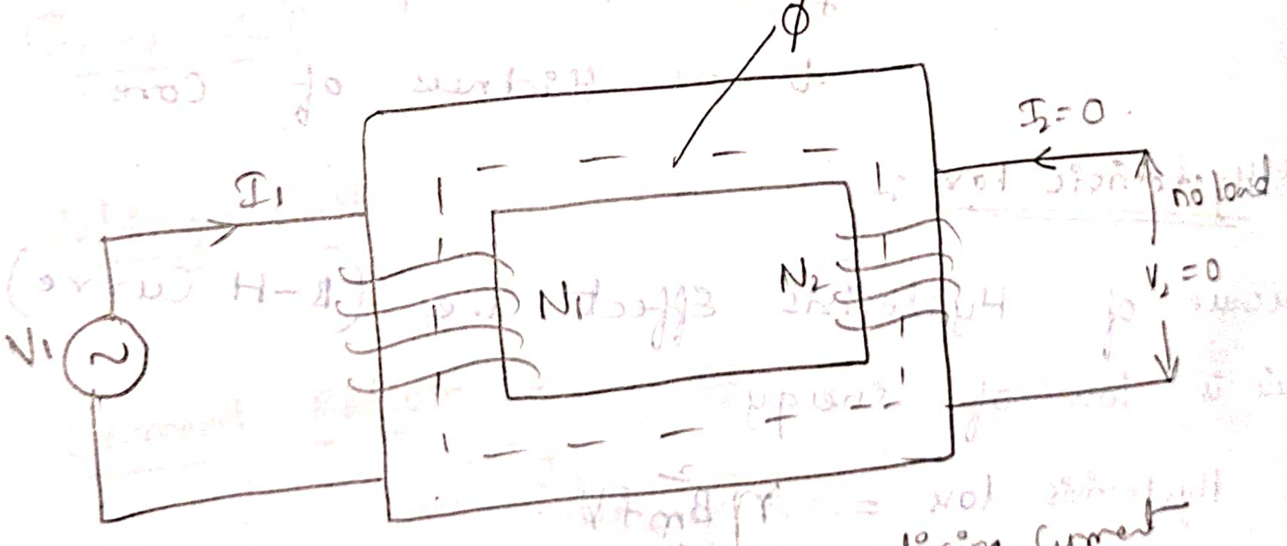
* Copper losses are also called as Variable losses.

* **Ideal and Practical transformer**

A transformer is said to be ideal if it consist
① no loss
② no winding resistance $(R)=0, I=\infty$
③ no leakage flux $\phi \cong$ (constant)
④ High permability, low reluctance.

Case-①:-

* **Ideal Transformer on No load:-**

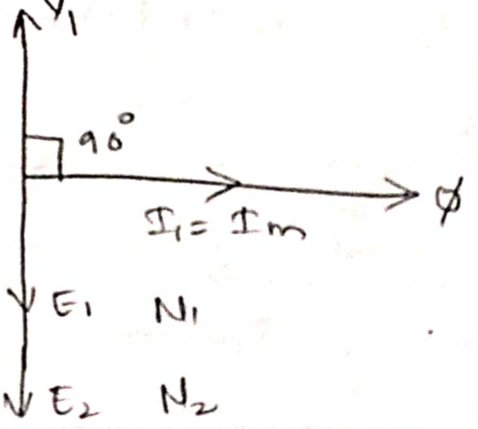


$I_1 = I_m$ = Magnetising current

$I_m \rightarrow$ Pure inductive current

Iron $\rightarrow$ voltage
Copper $-$ Current

Phasor Diagram:-



* Ideal transformer at no load i.e Secondary side is open i.e $I_2 = 0$.

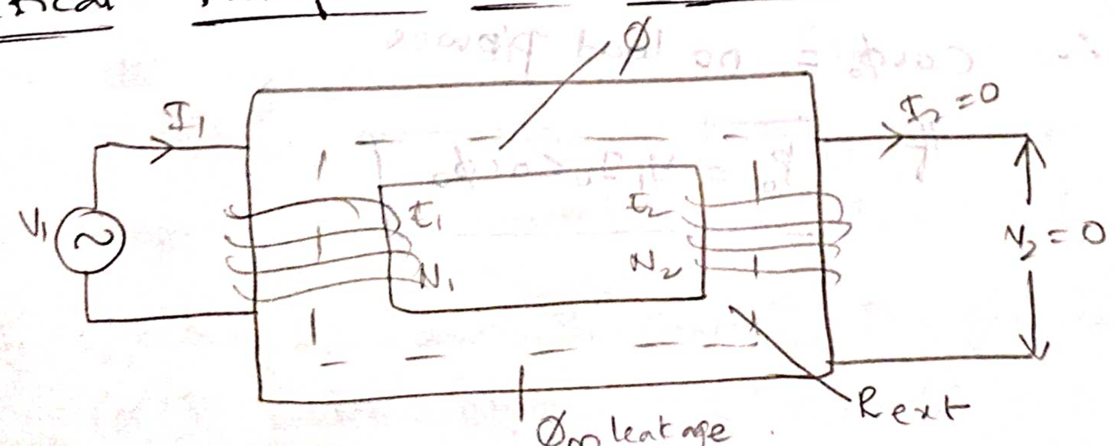
* So in the Circuit only one Current is responsible to produce the flux. So the Current is called as Magnetising Current (I_m).

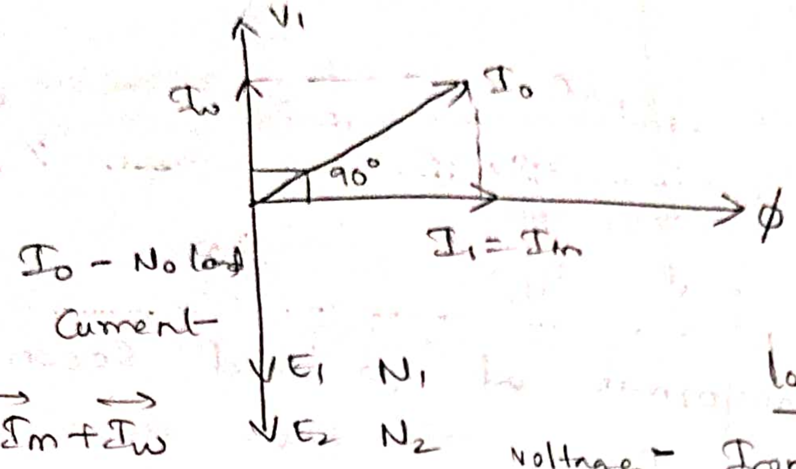
* In a Ideal transformer $R = 0$, $I_2 = 0$. then the Circuit acts as a pure Inductive Circuit.

* Current (I_m) lags behind the Voltage with an angle is 90°. and (I_m) is very small.

* Flux Links with both the windings and produces E_1 & E_2. According to lenz's law $\boxed{\text{Effect causes input}}$ E_1 & E_2 opposes to V_1, But the Magnitude is same and it depends on the N_1 & N_2

Practical Transformer on No load :-





$\vec{I_0} = \vec{I_m} + \vec{I_w}$

$I_m = I_0 \sin\phi_0$

$I_w = I_0 \cos\phi_0$

losses

voltage - Iron (I_m) - Core

Current - Copper (I_w) - winding

* In Practical transformer because of iron & Copper loss the resultant Current is no load Current (I_0).

* (I_0) has two Components

1] Active Component (or) Working Current (I_w)

2] Reactive Component (or) Magnetizing Current (I_m)

* From the phasor diagram

$I_m = I_0 \sin\phi_0$

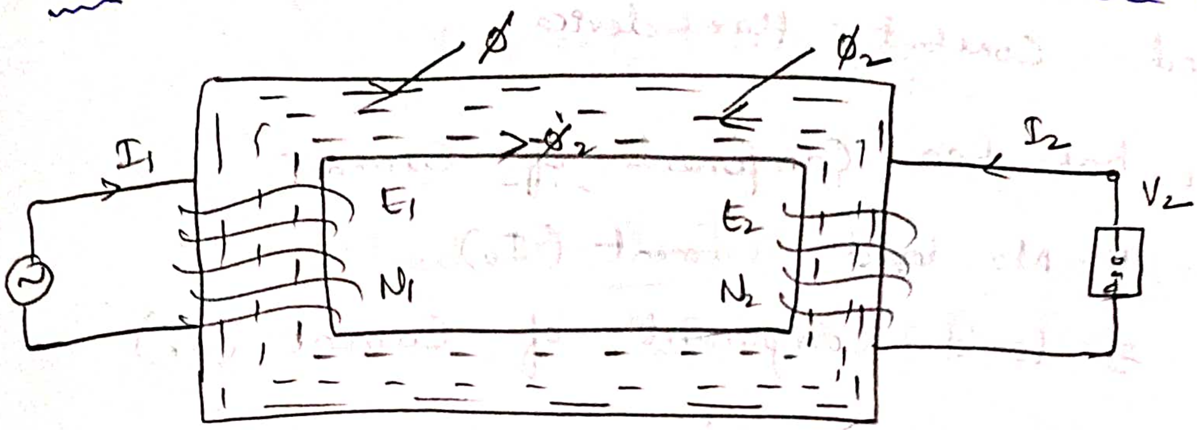
$I_w = I_0 \cos\phi_0$

$\vec{I_0} = \vec{I_m} + \vec{I_w}$

$\therefore$ $\cos\phi_0$ = no load power

If $\boxed{P_0 = V_1 I_0 \cos\phi_0}$

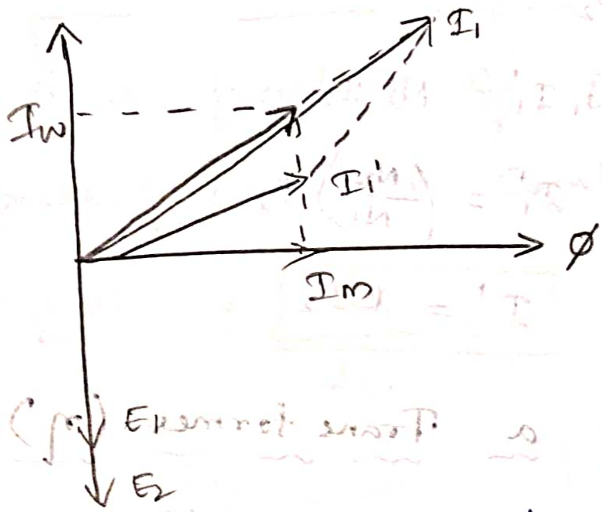
Practical Transformer at load Condition:-



$$I_1 = I_0 + I_1'$$

$$I = I_m + I_w + I_1'$$

Phasor diagram :-



* When the practical transformer loaded Current I_2 flows through the secondary winding and produces flux (ϕ_2). According to lenz law secondary flux (ϕ_2) opposes the main flux (ϕ).

* So the flux is (ϕ_2) slowly reduces main flux Hence the changes in V_1 & E_1. [input & output] Causes changes in Current Primary Current known a load Component of Current i.e I_1'.

* I_1' opposes I_2 and I_1' Consists flux changes i.e (ϕ_2') which opposes (ϕ_2). So the net Core

flux is Constant. So, the transformer is called Constant flux device.

* I_1 has two Components of Currents

1] No load Current (I_0)

2] load Component of Current (I_1')

$$I_1 = I_0 + I_1'$$

$$I_1 = I_m + I_w + I_1'$$

$$\phi_2 \propto N_2 I_2$$

$$\phi_2' \propto N_1 I_1'$$

$$N_1 I_1' = N_2 I_2$$

$$I_1' = \left(\frac{N_2}{N_1}\right) I_2$$

$$\boxed{I' = K I_2}$$

Efficiency of a Transformer (η):-

It is defined by the ratio of power output to the power input.

input (i/p) = o/p (output) + losses

output (o/p) = i/p (input) − losses

$$P_{o/p} = V_2 I_2 \cos\phi_2$$

P_i = Iron loss Constant ; P_{cu} = Copper loss = I_1^2 I_2^2

$$\eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + \text{losses}} \quad (o/p + \text{losses})$$

$$\% \eta = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}} \times 100$$

$$\% \eta_{\text{full load}} = \frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + P_{cu}} \times 100$$

$$\% \eta_{\text{half load}} = \frac{\left(\frac{V_2 I_2}{2}\right)\cos\phi_2}{\left(\frac{V_2 I_2}{2}\right)\cos\phi_2 + \frac{P_i}{2} + \frac{P_{cu}}{4}} \times 100$$

Condition for Maximum Efficiency :-

Efficiency is a function of load current voltage or power factor are constants. For maximum efficiency $\frac{d\eta}{dI_2} = 0$

$$\frac{d}{dI_2}\left[\frac{V_2 I_2 \cos\phi_2}{V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2}\right] = 0$$

$$= \left[V_2 I_2 \cos\phi_2 + P_i + I^2 R_2\right]\left[V_2 \cos\phi_2\right] -$$

$$\left[V_2 I_2 \cos\phi\right]\left[V_2 I_2 \cos\phi_2 + 0 + 2 I_2 R_2\right] = 0.$$

$$= \left[V_2 I_2 \cos\phi_2 + P_i + I_2^2 R_2\right]\left[\cancel{V_2} \cancel{\cos\phi_2}\right] = \left[\cancel{V_2} I_2 \cancel{\cos\phi_2}\right]$$

$$\left[V_2 \cos\phi_2 + 2 I_2 R_2\right]$$

$$= \cancel{V_2} \cancel{I_2} \cos\phi_2 + P_i + I_2^2 R_2 = \cancel{V_2} \cancel{I_2} \cos\phi_2 + 2 I_2^2 R_2$$

$$P_i = 2 I_2^2 R_2 - I_2^2 R_2 \longrightarrow P_i = I_2^2 R_2$$

$\therefore \boxed{P_i = P_{cu}}$ // [$\because$ Iron loss = Copper losses]

Q:- The full load Iron and Copper losses of 15 kVA transformer for a power of (0.8) are 320 W and 200 watts. Find efficiency at full load.

Sol:-

$$\% \eta = \frac{\text{VAR Rating } (V_2 I_2 \cos\phi_2)}{\text{kVA Rating } (V_2 I_2 \cos\phi_2) + P_i + P_{cu}} \times 100$$

$$\% \eta = \frac{(15 \times 10^3) \times 0.8}{(15 \times 10^3) 0.8 + 320 + 200} \times 100$$

$= 95.84$

$= 96\%$

Voltage Regulation of a Transformer :-

Voltage regulation defines the change in voltage from no load to full load w.r.to no load voltage, to decrease the voltage limit

$$\% V.R = \frac{E_2 - V_2}{E_2} \times 100 \downarrow \text{ To decrease}$$

$$\% V.R = \frac{E_2 - V_2}{V_2} \times 100 \uparrow \text{ To increase}$$

where

E_2 – no load voltage

V_2 – Full load voltage.

Testing of Transformer :-

To Calculate efficiency and voltage Regulation there are two indirect methods to test the transformers

i] O.C test (open circuit test)

ii] S.C test (short Circuit test)

Open Circuit Test :-

* In O.C test primary is Connected to single phase DC supply through Ammeter, Voltmeter, wattmeter. and Variac

* Secondary is kept open to Conduct O.C test.

* primary is Excited with rated voltage with the help of Auto transformer / Variac.

* Wattmeters measures $P_o = V_o I_o \cos\phi_o$

$$\cos\phi_o = \frac{P_o}{V_o I_o}$$

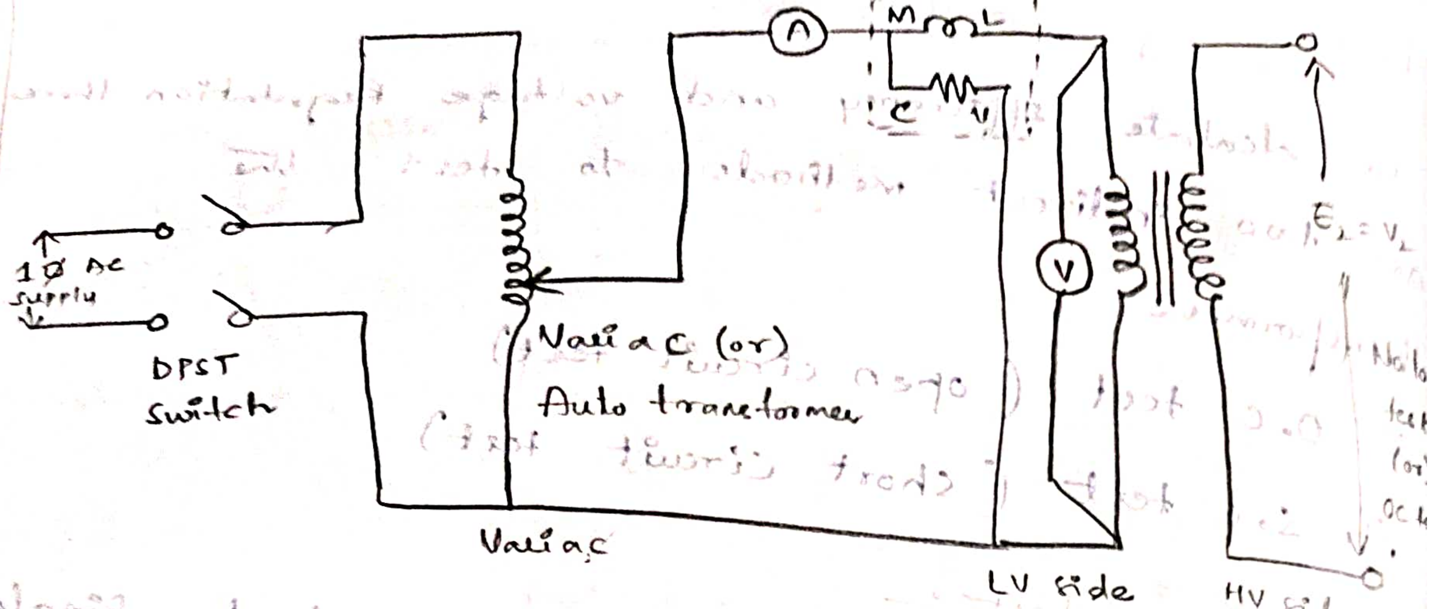
$$I_o = I_m + I_w$$

$$I_m = I_o \sin\phi_o$$

$$I_w = I_o \cos\phi_o$$

V_o	I_o	P_o
rated	?	P_i

$P_i \rightarrow$ Iron loss



Open Circuit test :- (No load test)

DPST - Double poll single through switch

M - main   L - line   C - Common   V - voltage

$\cos\phi > 1$ — high voltage

$\cos\phi = 1$ — Normal

$\cos\phi < 1$ — low voltage

Short Circuit Test :-

* In short circuit test secondary side is short circuited with thick wires i.e $V_2 = 0$

* To limit short circuit current primary of the Transformer supplies low voltage to maintain Rated current.

V_{sc}	I_{sc}	P_{sc}
?	rated	P_{cu}

Copper loss

$R_0 = \frac{V_0}{I_m}$, $X_0 = \frac{V_0}{I_w}$

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

$P_{sc} = V_{sc} I_{sc} \cos\phi_{sc}$, $X_{sc} = \frac{V_{sc}}{I_w}$

$\cos\phi_{sc} = \frac{P_{sc}}{V_{sc} I_{sc}}$ $R_{sc} = \frac{V_{sc}}{I_m}$

Q:- A 200/400 V, 50 Hz, 10 kVA single phase transformer conducted a test and obtain the following Readings.

	V	I	P
OC test	200 V	0.7A	70W
SC test	15 V	10 A	80W

Find Efficiency & Voltage Regulation at 0.8 powerfactor lagging

Sol:- $P_i = 70W$ $P_{cu} = 80W$

10 kVA, $E_1/E_2 = 200/400$, $\cos\phi = 0.8$

$V_{sc} = 15V$ $I_{sc} = 10A$.

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{15}{10} = 3/2 = 1.5\ \Omega$$

$$R_{sc} = \frac{P_{sc}}{I_{sc}^2} = \frac{80}{(10)^2} = \frac{8\cancel{0}}{10\cancel{0}} = 0.8\ \Omega$$

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

$$= \sqrt{(1.5)^2 - (0.8)^2}$$

$$= 1.26\ \Omega$$

% Voltage Regulation = $E_2 + X_{L_2}$

$$\%\ V.R = \frac{I_{sc}\left[R_{sc}\cos\phi \pm X_{sc}\sin\phi\right]}{E_2} \times 100$$

$$= \frac{10\left[0.8 \times 0.8 + 1.26 \times 0.6\right]}{400} \times 100$$

$$\%\ V.R = 3.49\ \%$$

$$\%\ \eta = \frac{(10 \times 10^3)\ 0.8}{(10 \times 10^3)\ 0.8 + 70 + 80}$$

$$= 98.15\ \%$$

(2)

OC test	220	0.9A	100 W
SC test	20 V	5 A	50 W

0.945 × 100

4.5

$P_i = 70 W$ $\quad P_{cu} = 80 W$

$E_1/E_2 = 200/400$ $\quad \cos\phi = 0.8$

15 kVA T/F

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} = \frac{20}{5} = 4\,\Omega$$

$$R_{sc} = \frac{P_{sc}}{I^2_{sc}} = \frac{50}{(5)^2} = \frac{50}{25} = 2\,\Omega$$

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

$$= \sqrt{(4)^2 - (2)^2}$$

$$= \sqrt{16-4}$$

$$= \sqrt{12} = 3.46\,\Omega$$

% Voltage Regulation

$$\% V.R = \frac{I_{sc}\left[R_{sc}\cos\phi \pm X_{sc}\sin\phi\right]}{E_2} \times 100$$

$$= \frac{5\left[2 \times 0.8 + 3.46 \times 0.6\right]}{400} \times 100$$

$$= 4.5\,\%$$

$$\%\eta = \frac{(15\times10^3)\,0.8}{(15\times10^3)\,0.8 + 100 + 50}$$

$$= 98.76\%$$

Index – flux
middle – volt, curr
thumb – force or magnit

UNIT - IV

06/07/2023

DC MACHINES & INDUCTION MOTORS

→ the generator which runs on the Constant Speed of 1500 called synchronous generator.
Variable speed - Asynchronous

→ Generator [Mechanical energy to Electrical Energy]

DC motor :- trains, textiles Etc —

AC motor :- Synchronous Eg:- Lift, Elevator.
Asynchronous Eg:- Mixee Grinder, Fans Cable.

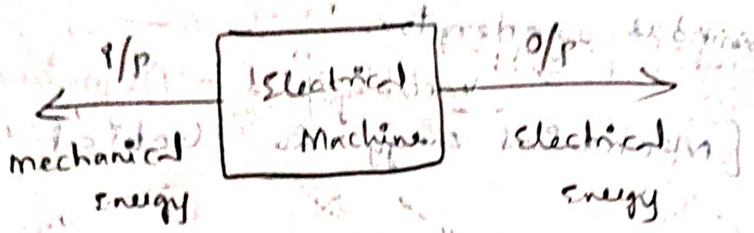
Electrical Machines

- Generator
  - DC Generator
    - Separately Excited
    - Self Excited
      - Series
      - shunt
      - Compound
  - AC Generator (or) Synchronous Generator (or) Alternator
- Motor
  - DC motor
    - Separately Excited
    - Self Excited
      - Series
      - shunt
      - Compound
  - AC motor
    - * Synchronous motor
    - (2) Asynchronous motor (or) Induction motor
      - 1-Ø IM
      - 3-Ø IM

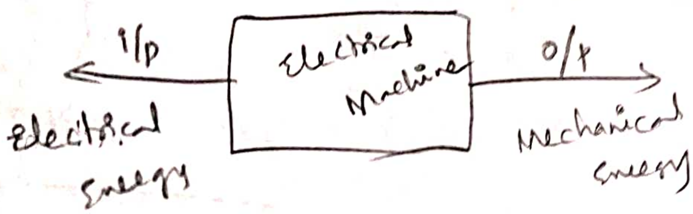
DC Generator :- Faraday's law & Flemmings right hand rule
Dynamic induced Emf application

DC Motor :- Faraday's laws & Dynamic induced Emf applicable on flemmings left hand rule.

DC Generator :- the Electrical machine which Converts from mechanical Energy into Electrical Energy is known as DC Generator.



DC Motor :- the Electrical machine which Converts from electrical Energy into Mechanical Energy is known as DC motor.



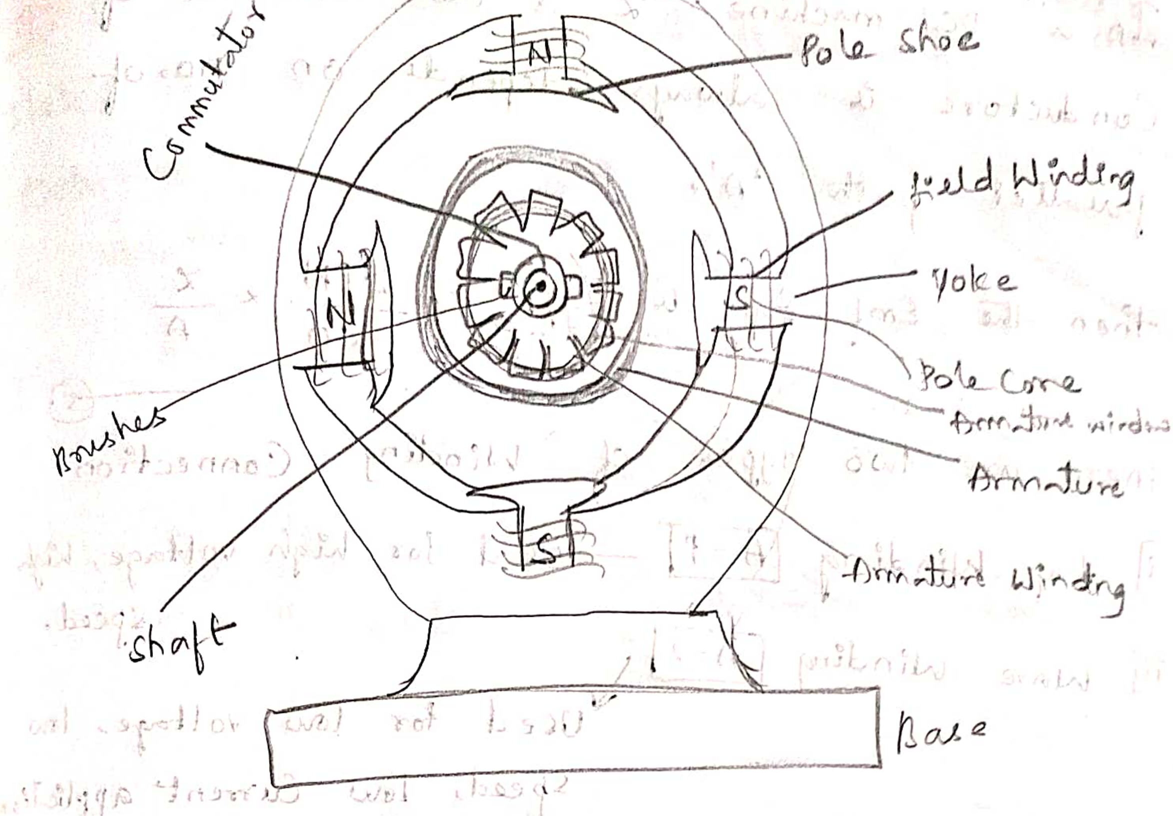
DC motor

→ the Construction of both DC Generator and DC motor remains Same.

Construction of DC Machine:-

1] Stator
- 1] Field Winding
- ② Yoke
- ③ Pole Core
- ④ pole shoe

② Rotor
- 1] Armature winding
- 2] ~~wird~~ Armature Conductor
- 3] Armature slot
- 4] Commutator
- ⑤ brushes



Sectional View of DC machine

EMF Equation of a DC machine :-

From faraday's laws

$$E_b \text{ (or) } E_g = -N \frac{d\phi}{dt} \quad \text{—— (1)}$$

$d\phi$ = Total amount of flux

dt = Total time taken for N revolutions

$$d\phi = \phi * P \quad \text{—— (2)}$$

$$dt = N/60 \text{ rps} \quad \text{—— (3)}$$

let us assume $\times N = 1$

$$E_b \text{ (or) } E_g = \frac{d\phi}{dt}$$

$$= \frac{\phi P}{\text{Time taken for 1 revolution}}$$

$$E_b \text{ (or) } E_g = \frac{\phi P}{(1/N/60)} = \phi \frac{PN}{60} \text{ V} \quad \text{—— (4)}$$

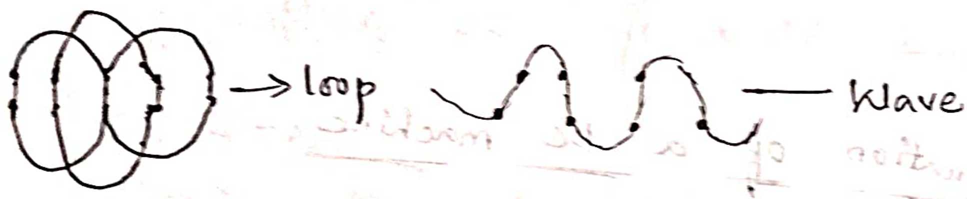
In a DC machine Z is the total no. of Conductors is always depends on no. of parallel path 'A'.

then the Emf Eqn is $E_g/E_b = \frac{\phi P N}{60} \times \frac{Z}{A}$ —— (5)

there are two types of Winding Connection

i] Lap Winding $\boxed{A=P}$ —— Used for high voltage, high Speed.

ii] Wave Winding $\boxed{A=2}$ —— Used for low voltage, low Speed, low Current application



P - No. of poles

Lap Winding:-

$$E_b \text{ (or) } E_g = \frac{\phi P N}{60} * \frac{Z}{A}$$

$$E_g \text{ (or) } E_b = \frac{\phi P N}{60} * \frac{Z}{P} = \frac{\phi Z N}{60} V \quad \text{—— (6)}$$

Wave Winding:-

$$E_b \text{ (or) } E_g = \frac{\phi P N}{60} * \frac{Z}{A}$$

$$= \frac{\phi P N}{60} * \frac{Z}{2} \Rightarrow \frac{\phi Z N P}{120} V \quad \text{—— (7)}$$

Q:- A four pole, wave consisting DC generator has 50 slots, 24 conductors per slot. flux / pole is 10 mwb. Determine an induced Emf in the armature if it is rotating at a speed of 700 r.p.m.

Sol:- $P = 4$; $\phi = 10 \times 10^{-3}$ wb

$N = 700$ rpm   slots $= 50$

Cond/slot $= 24$

$Z = \text{cond/slot} * \text{slot}$

$= 24 \times 50$

$= 1200$ cond

$A = 2$ ($\because$ wave)

$$E_g = \frac{\phi Z N P}{60A} = \frac{10 \times 10^{-3} \times 1200 \times 700 \times 4}{60 \times 2}$$

$= 280$ V

Q:- A 6 pole lap winding DC generator has 150 slots and 75 conductors / slot, flux / pole is 8 mwb. Determine an induced Emf at a speed of 900 rpm.

Sol:- slots $= 150$ $P = 6$

Cond/slot $= 75$ $\phi = 8 \times 10^{-3}$ wb

$A = P \Rightarrow A = 6$ ($\because$ lap)

$$E_g = \frac{\phi Z N P}{60 A} \Rightarrow \frac{8 \times 10^{-3} \times 11250 \times 900 \times 6}{60 \times 6}$$

$= 1350$ V

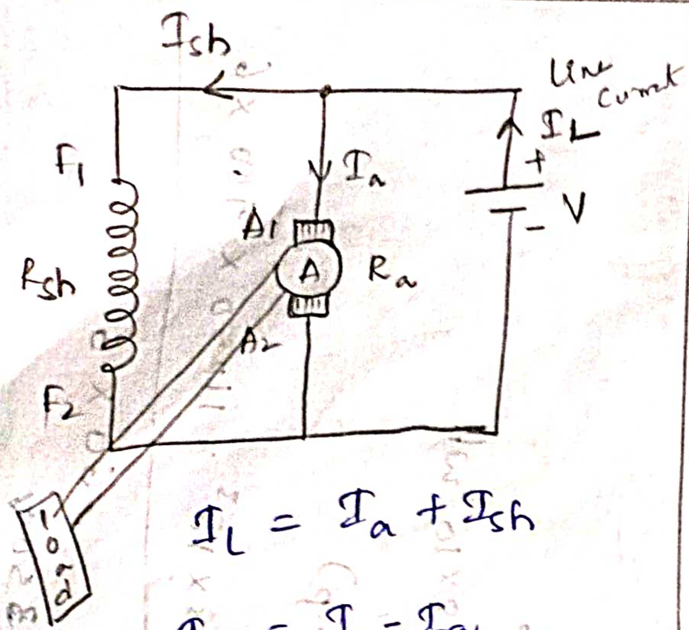
Z = cond/slot * slot

= 75 x 150

$\boxed{Z = 11{,}250}$

Classification of DC motor:-

1] Shunt Motor



$I_L = I_a + I_{sh}$

$I_{sh} = I_L - I_a$

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

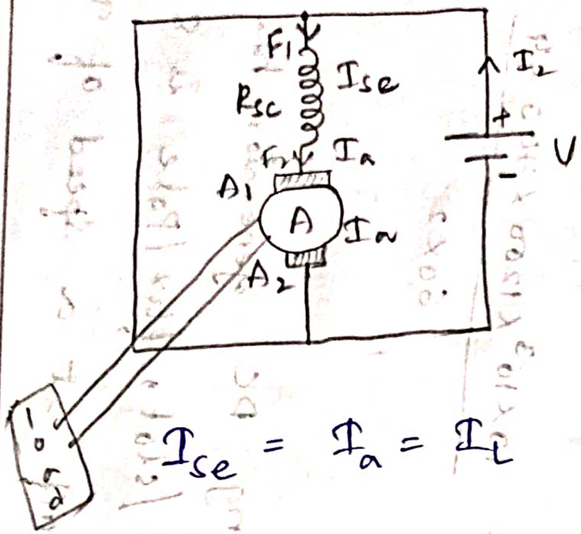
$V = E_b + I_a R_a + I_{sh} R_{sh} + \cancel{\text{Brushdrop}}$

Brushdrop negligible

↓

Voltage Equation

2] Series Motor

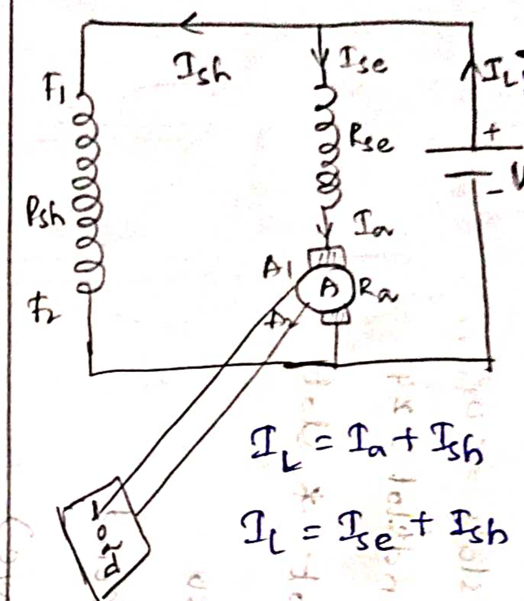


$I_{se} = I_a = I_L$

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

$\boxed{= E_b + I_a [R_a + R_{se}] + B/D}$

3] Compound Motor



$I_L = I_a + I_{sh}$

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

$V = E_b + I_a R_a + I_{se} R_{se} + I_{sh} R_{sh} + B/D$

$I_a = I_{se}$

$\boxed{V = E_b + I_a [R_a + R_{se}] + I_{sh} R_{sh}}$

rotor ↓ stator — Dynamic induced emf

rotor ↓ stator ↓ — Static induced emf

Principle of Operation of DC Motor 12/07/23

i] DC motor Converts Electrical Energy to Mechanical Energy.

ii] DC Motor Works on the principle of Faraday's laws of Electromagnetic induction.

iii] Whenever a Current Carrying conductor is placed in a magnetic field. It experiences a Mechanical force due to that rotor starts rotating

iv] In a Practical DC motor Field Winding produces main flux, Armature Winding produces rotating flux or auxilary flux.

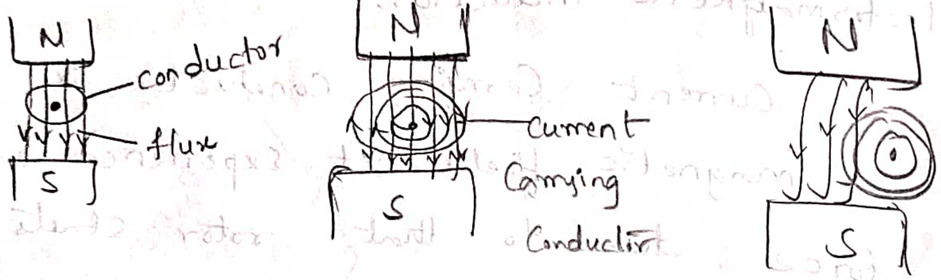
v] There are two fluxes in a DC motor:-

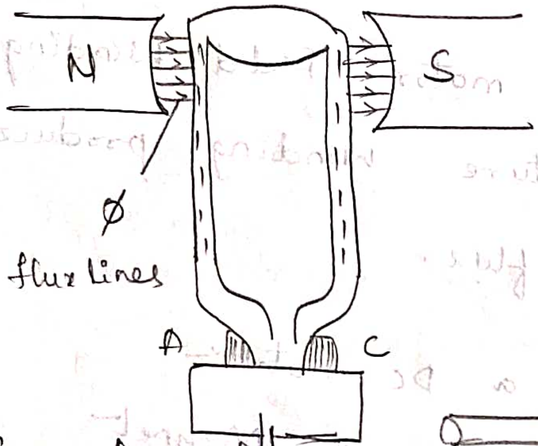
* The flux from the Permanent Magnet
* the flux produced by Current Carrying Conductor.

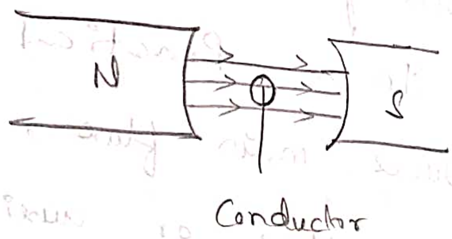
vi] Because of interaction of two fluxes the rotor starts rotating and it gives twisting force (or) Torque Calculated.

vii] Note:- Due to the interaction of fluxes at one side of the Conductor two fluxes are help other another side of a Conductor two flux are Cancel Each other. So, the Net (or) Total Flux Causes the rotation of Conductor.

Niii] In a DC motor, Armature Winding starts rotating then Induced Emf is develop which opposes always input voltage is called (E_b) [Back Emf].







Importance of Back EMF (E_b) *** Imp

$V = E_b + I_a R_a$ [i/p = o/p + losses]

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

at starting $E_b = 0$ $\quad I_a = \frac{V}{R_a} \uparrow$

after starting

$I_a \downarrow \; E_b \uparrow \; N \uparrow$

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

→ Back Emf acts as Voltage Regulator in a DC motor

Power Equation of DC Motor

$V = E_b + I_a R_a \longrightarrow$ voltage ~~regulation~~ Eqn of DC motor

Mul. I_a on both sides

$V * I_a = E_b + I_a R_a * I_a$

$$\boxed{V I_a = E_b I_a + I_a^2 R_a} \longrightarrow \text{Power Eqn.}$$

where $V I_a$ = Total Electrical input

$E_b I_a$ = Total Mechanical output

$I_a^2 R_a$ = Total losses

Torque Equation of DC motor

Torque
↓
Twisting force about an ~~axes~~ axis.

$T_{em} \times \omega = E_b * I_a$ [T_{em} - Torque at Electromechanical]

[Total torque i/p] [Total mech output]

$$E_b = \frac{\phi Z N P}{60 A}, \quad \omega = \frac{2\pi N}{60}$$

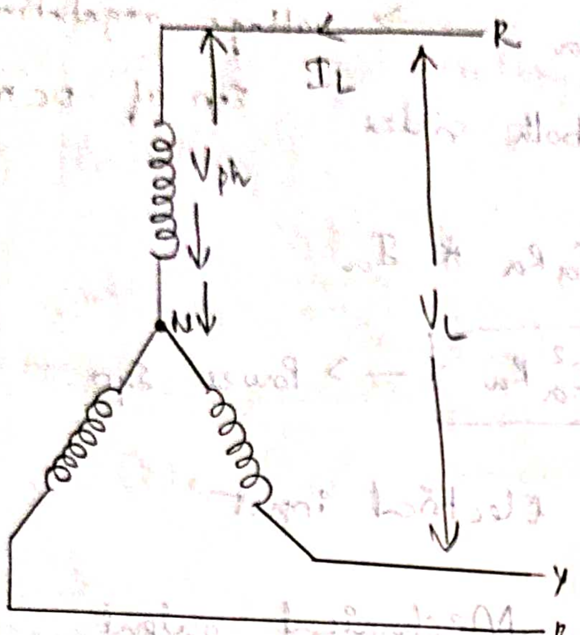
$$T_{em} \times \frac{2\pi N}{60} = \frac{\phi Z N P}{60 A} * I_a$$

$$T_{em} = \frac{\phi Z \cancel{N} P}{\cancel{60} A} * \frac{\cancel{60}}{2\pi \cancel{N}} * I_a$$

$$\boxed{T_{em} = \frac{1}{2\pi} * \phi I_a * \frac{ZP}{A}} \longrightarrow \text{constants}$$

$$\boxed{T_{em} \propto \phi I_a}$$

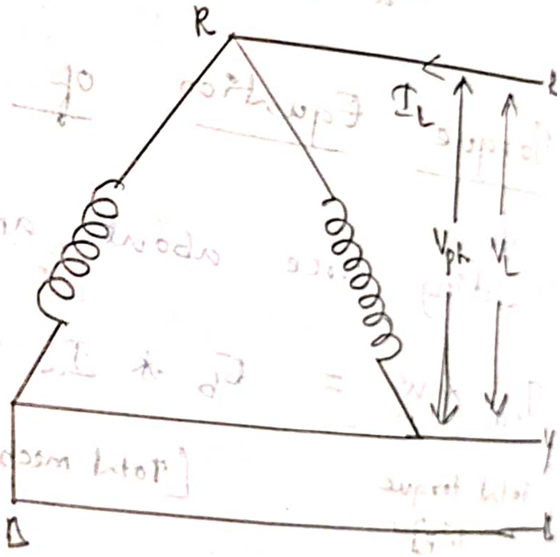
3 Phase System:-



$I_L = I_{ph}$

$V_L \neq V_{ph}$

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



$V_L = V_{ph}$

$I_L \neq I_{ph}$

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

* All the Industrial loads requires 3-phase System because of its advantages:-

i] Gives more output

ii] Easily Converted to single phase System

iii] All the Self starting machines starts with rune 1 - ∅ System

~~iv] There are~~

→ There are 2 types of Connections:

i] Star Connection (Y)

ii] Delta Connection (Δ) in these voltage currents are:

i] Line Current (I_L): The current passing through the any line is called I_L.

$$I_L = I_R, I_Y, I_B$$

ii] Phase Current (I_{ph}):

the current passing through the winding is called phase current.

$$I_{ph} = I_{RY}, I_{YB}, I_{BR}$$

iii] Line Voltage (V_L):-

the voltage betwen ~~line~~ any two lines

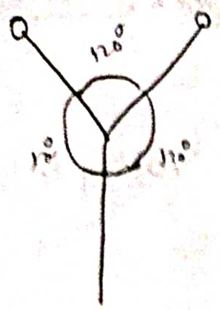
$$V_L = V_{RY}, V_{YB}, V_{BR}$$

iv] phase Voltage (V_{ph}):-

the voltage between b/w one winding to neutral called (V_{ph})

$$V_{ph} = V_{RN}, V_{YN}, V_{BN}$$

In a 3-phase system voltages & currents are displaced by 120° each other



$I_R = \angle 0°$

$I_Y = \angle 120°$

$I_B = \angle 240°$

$I_N = \angle 360°$

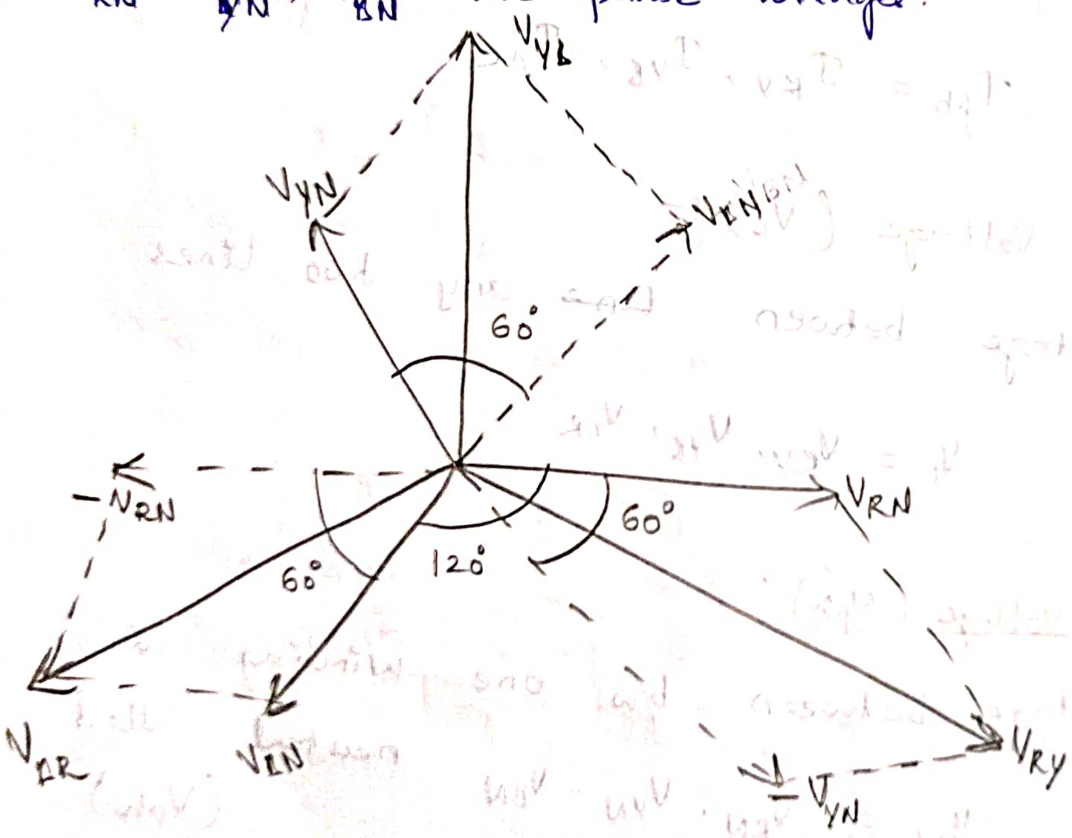
Expression for Voltage in a Star Connected Load

In a star Connection $I_L = I_{ph}$

Consider

V_{RY}, V_{YB}, V_{BR} are line voltages.

V_{RN}, V_{YN}, V_{BN} are phase Voltages.



$$V_{RY} = V_{RN} + V_{NY}$$

$$= V_{RN} + (-V_{YN})$$

$$V_{YB} = V_{YN} + V_{NB}$$

$$= V_{YN} + (-V_{BN})$$

$$V_{BR} = V_{BN} + V_{NR}$$

$$= V_{BN} + (-V_{RN})$$

From parallelogram law

$$V_{RY} = \sqrt{(V_{RN})^2 + (-V_{YN})^2 - 2(V_{RN})(-V_{YN})\cos 60^\circ}$$

$$V_{RY} = \sqrt{(V_{RN})^2 + (V_{YN})^2 + 2V_{RN}V_{YN}(1/2)}$$

$$V_L = V_{RY} = \sqrt{(V_{ph})^2 + (V_{ph})^2 + \cancel{2}V_{ph}V_{ph}(1/\cancel{2})}$$

$$V_L = \sqrt{3(V_{ph})^2}$$

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

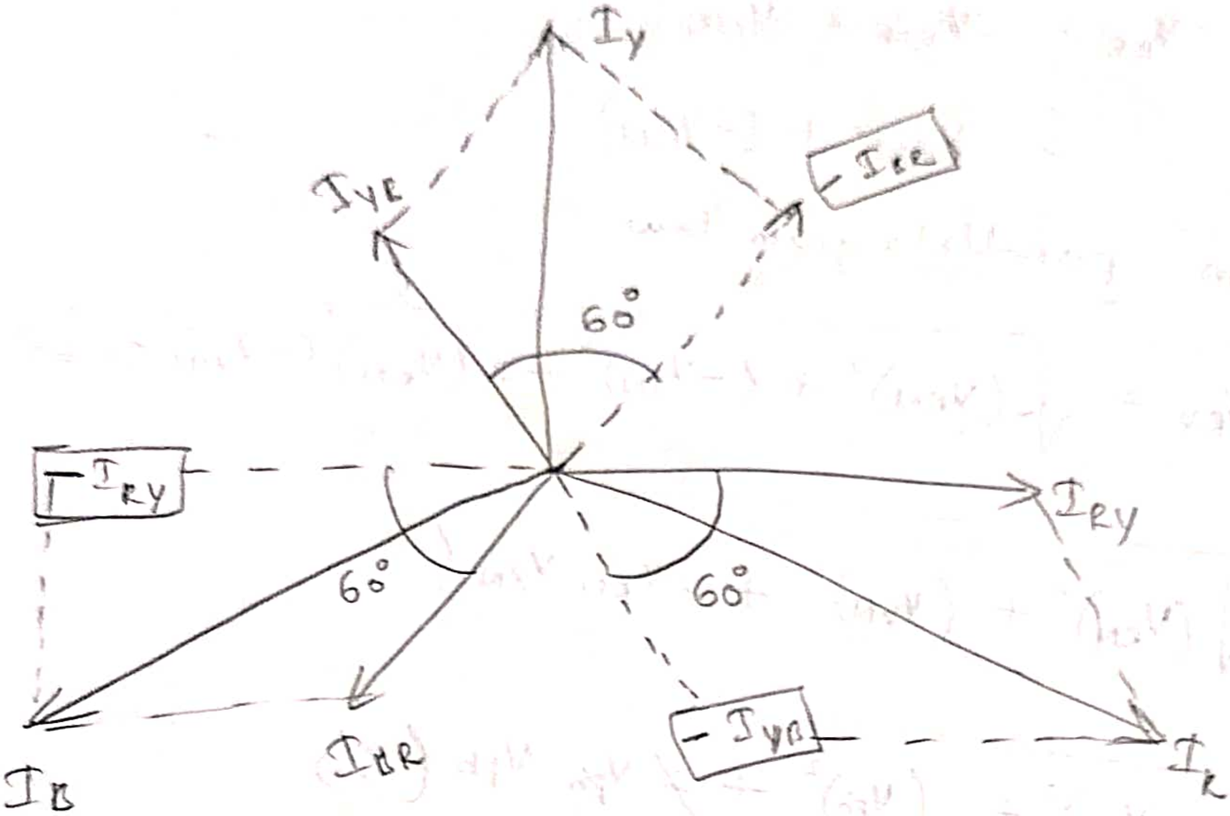
Expression for Current in a delta Connected load.

In a delta Connection $V_L = V_{ph}$

Consider

$I_R, I_Y, I_B = I_L \rightarrow$ are line Currents

$I_{RY}, I_{YB}, I_{BR} = I_{ph} \rightarrow$ are phase Currents



$$I_R = I_{RY} - I_{YB}$$

$$I_Y = I_{YB} - I_{BR}$$

$$I_B = I_{BR} - I_{RY}$$

From Parallelogram law

$$I_R = \sqrt{(I_{RY})^2 + (-I_{YB})^2 - 2\,(I_{RY})(-I_{YB})\cos 60^\circ}$$

$$I_L = I_R = \sqrt{I_{RY}^2 + I_{YB}^2 + 2 I_{RY} I_{YB} \cos 60^\circ}$$

$$I_L = I_R = \sqrt{(I_{ph})^2 + (I_{ph})^2 + \cancel{2}\, I_{ph} I_{ph} (1/\cancel{2})}$$

$$I_L = \sqrt{3 (I_{ph})^2}$$

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

26/03/21

*

Stator & rotor ⟶ air gap — 0.4 mm & 4 mm

Flux is Constant rotor is rotating
— Dynamic Induced Emf

Stator is rotating rotor is Constant
— Static Induced Emfs

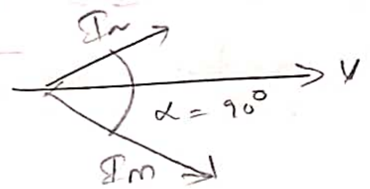
Induction machines —

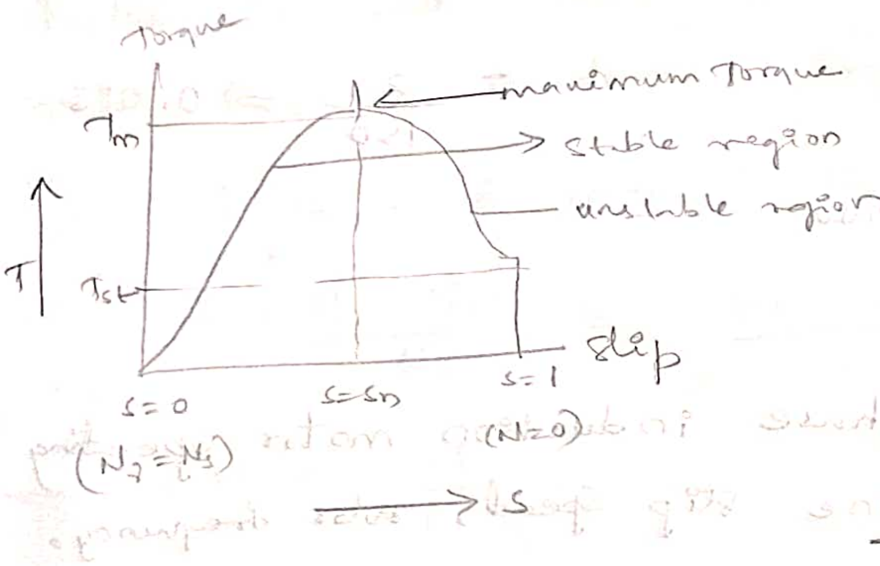
N_s — synchronous speed

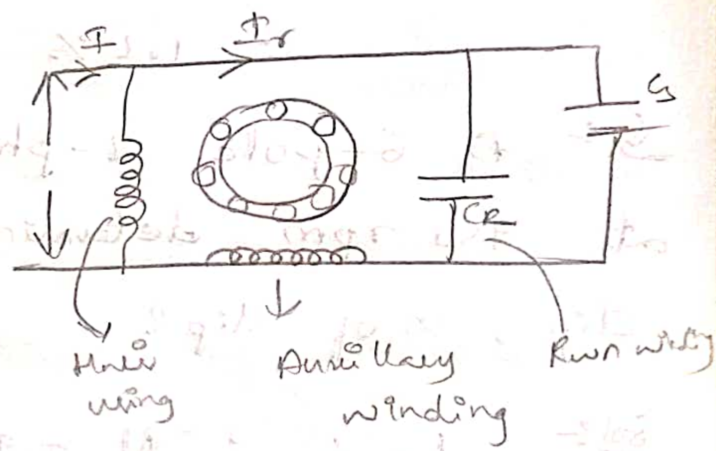
Induction — Asynchronous $> N_s$

Slip:- the difference b/w Synchronous &

$T \propto \frac{1}{S}$







Q:- A 3-phase four pole induction motor with 50Hz frequency is operating at 1480 rpm. Determine slip and percentage of slip?

Sol:-

$$p = 4, \quad f = 50Hz, \quad N_r = 1480 \text{ rpm}$$

$$S = \frac{N_s - N_r}{N_s}$$

$$N_s = \frac{120f}{p}$$

$$= \frac{\overset{30}{\cancel{120}} \times 50}{\cancel{4}}$$

$$\boxed{N_s = 1500} \text{ rpm}$$

$$S = \frac{1500 - 1480}{1500} = \frac{2\cancel{0}}{150\cancel{0}}$$

$$= \frac{2}{150} = 0.013$$

$$\% \text{ of slip} = 0.013 \times 100$$

$$= 1.3\ \%$$

Q:- A 6-pole 3-phase induction motor operating at 950 rpm determine slip speed, rotor frequency, slip, % of slip?

Sol:-

$P = 6$; $N_r = 950$ rpm & Assume ($f = 50Hz$)

$$N_s = \frac{120f}{p} = \frac{\overset{20}{\cancel{120}} \times 50}{\cancel{6}} = = 1000\text{rpm}$$

Slip speed $= \frac{N_s - N_r}{N_s} = \frac{1000 - 950}{1000} = \frac{50}{1000}$

$= 0.05$

slip speed $= N_s - N_r = 1000 - 950 = 50$ rpm

% slip $= 0.05 \times 100 = 0.5$ %.

rotor frequency $f = \frac{P N_s}{120}$

$= \frac{6 \times 1000}{120}$

$f = 50 Hz$

Q:- Calculate % of a slip for a 3-phase 4-pole, 50 Hz induction motor running at 1460 rpm Further Calculate Motor speed in rpm when the rotor frequency is found 2 Hz ?

$P = 4$, $f = 50 Hz$, $N_r = 1460$.

$S = \frac{N_s - N_r}{N_s} = \frac{1500 - 1460}{1500} = \frac{40}{1500} = \frac{4}{150}$

$= 0.026$

$N_s = \frac{120 f}{P}$

$= \frac{120 \times 50}{4} = 1500$ rpm

$N_s = \frac{120 \times 2}{4}$

$\boxed{N_s = 60}$

$= \frac{\cancel{140}}{4}$

% of slip $= 0.026 \times 100$

$= 2.6$ %.

RMF :- (Rotating Magnetic Field)

The rotating magnetic field can be defined as the field (or) flux having constant amplitude but whose axis is continuously rotating in a plane with a certain speed.

AC Generator (or) Alternator (or) Synchronous Generator

The machine which converts mechanical energy into 3-ϕ electrical energy always runs with constant speed is called synchronous generator, Alternator (or) AC Generator.

Construction:-

The main parts of AC Generator mainly:-

* Stator
* Rotor

Stator:-

→ In stator is connected with poles, poles cores, pole shoe and field winding. But in AC Generator stator field is rotating to produce rotating magnetic field (RMF).

Rotor:-

There are two types of rotors:-

i] Projected type

ii] Non-projected type.

i] :- Projected type rotor is used for low & medium voltage applications

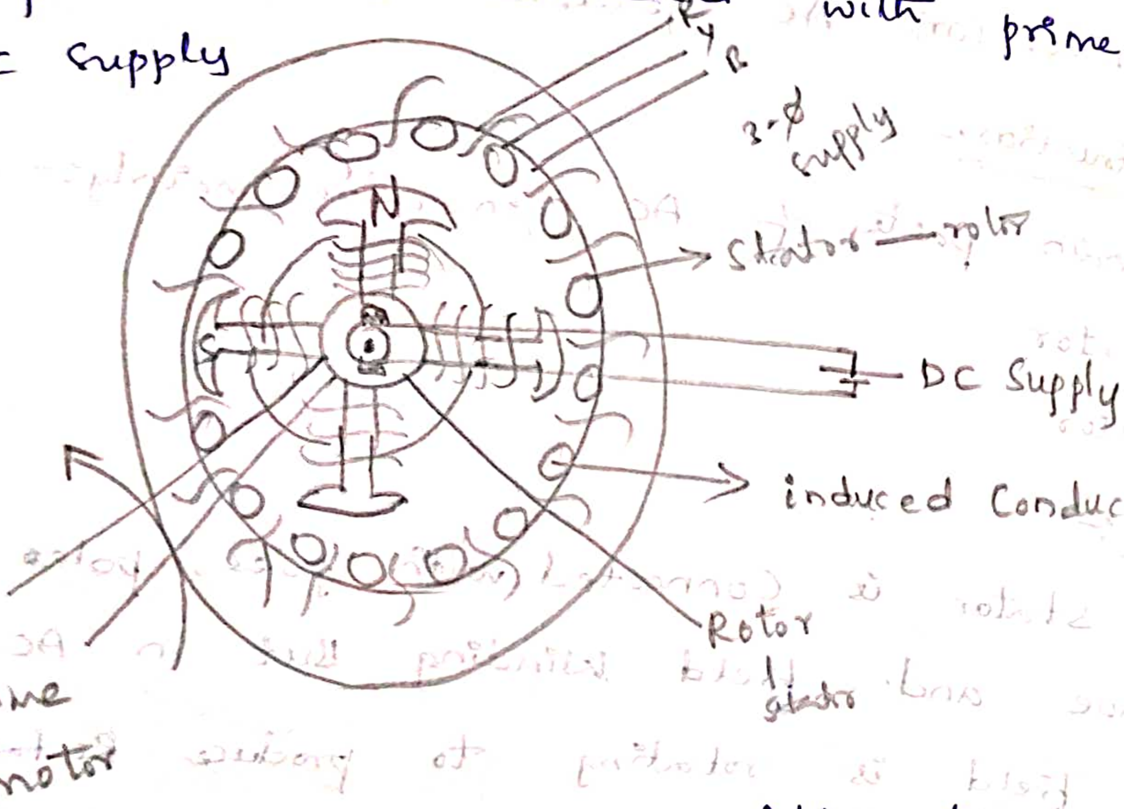
Eg:- Hydro power ~~banks~~ plant

ii) Non-projected type :- It is used for high voltage applications.

Ex:- thermal Power Project

→ In AC Generator rotor Armature is constant Connected Commutator & brushes.

***
⇒ In AC Generator Rotor is Connected with two inputs one is Connected with prime mover & DC supply



Alternator :-

principle of Operation of ~~AC Generator~~:-

* Alternator works on the principle of Faraday's laws of Electromagnetic induction.

* When prime mover is Connected rotor starts slowly rotation to maintain Const speed at the same time DC Supply is Connected to the field Winding with the help of slip rings. So, field winding produces RMF

flux RMF cuts the conductor EMF will be induced. ∴ the output is 1-∅ phase induced Emf from the Faraday's laws.

EMF Equation of Alternator:-

let us consider in an AC Generator

p = no. of poles

Z = No. of conductors

N_s = Synchronous speed

ϕ = no. of flux lines

T = no. of Turns   ∵ $1T = 2$ conductors (z)

In synchronous Generator $N_s = \frac{120f}{P}$,

$$f = \frac{PN_s}{120}.$$

Acc. to Faraday's laws $e = N\frac{d\phi}{dt}$

Assume $N=1 \Rightarrow e = \frac{d\phi}{dt}.$

$d\phi$ = Total flux per one revolution

$= \phi * P$

dt = Total time per one revolution

$= 60/N_s$

$$e = \frac{\phi P}{60/N_s} = \frac{\phi P N_s}{60}.$$

* In

So, $\boxed{\text{form factor} = \frac{e_{rms}}{e_{avg}} = 1.11}$

$$e_{rms} = 1.11 \times e_{avg}$$

$$= 1.11 \times \frac{\phi N_s}{60}$$

$$= 1.11 \times \frac{\phi \cancel{P} \cancel{120}^{2} f}{\cancel{60} \cancel{P}}$$

$$= 1.11 \times 2 f \phi$$

$$e_{rms} = 2.22 f \phi$$

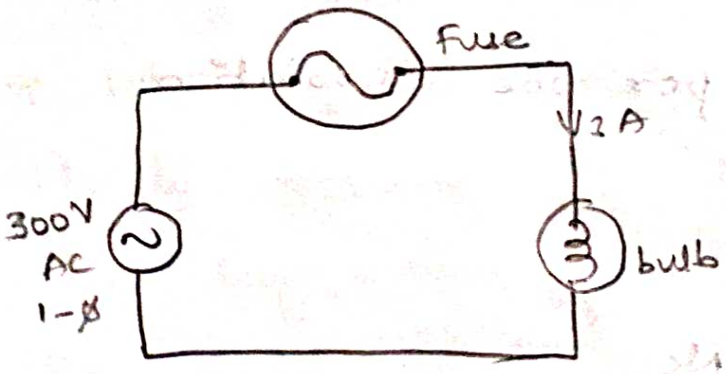
$$1T = 2Z/ph$$

$$e_{rms} = 2.22 \times f \times \phi \times 2Z/ph$$

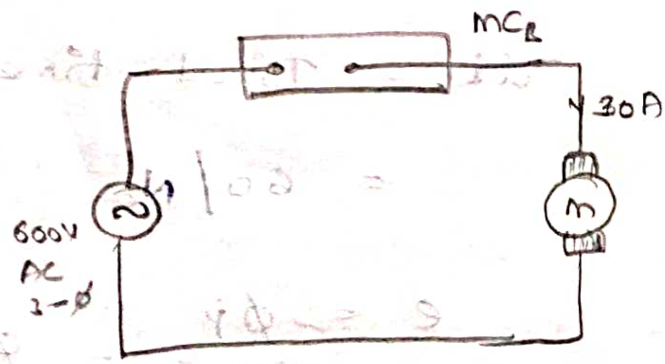
$$\boxed{e_{rms} = 4.44 f \phi Z/ph}$$

Electric Installation: **

Fuse



Circuit Breaker



Fuse	Circuit Breaker
Fuse :- It is a protective device it breaks the Circuit whenever there is a Current Exceeds ~~as~~ its ~~decide value~~ desired value immediately fuse wire melts, Automatically it's break the Circuit.	**Circuit Breaker** :- * It is a switching device Can be used to make or break the Circuit automatically or manually under fault Condition
* Fuse wire is made up of Copper	* Circuit breaker is made up of Copper, zinc alloys.
Advantages of Fuses :- * Cheap in Cost * less maintainance * pollution free * Operation time is less.	* **Advantages of Fuses** :- * less maintainance * Easy to Operate * At normal Condition it acts as a switch at abnormal Condition it acts as a circuit breaker.
Disadvantages of Fuse :- * restricted to low range of Currents	**Disadvantages of Fuse** :- * cost is high Compared to fuse
* It is based on the principle of Electric & thermal Properties of Conducting Material	* It is based works on the principle of Electromagnetism & switching principle

* Fuses Can be only used as at once.

* Fuse operates Completely Automatic Operation

Applications :-

* Fuses are applicable for all Electricalbic devices

* Circuit breakers Can be used no. of times Can operate.

* Circuit breaker is manual & automatic Operation.

Applications :-

* It is used in all power Equipment devices (motors, heavy machines) which draws high amount of ~~work~~ Current.

Fuse Characteristics :-

* low melting point
* high Conductivity
* low Oxidation
* low Cost

Battery :-