Unit-III

# Transformer

[99.5%]

Ques: Explain the operations of transformer and
1 derive the emf equation of transformer.

Ques. Explain the losses in transformer & Derive the
2 condition for maximum efficiency in transformer.

Ques. Draw the equivalent circuit diagram of
3 transformer.

Ques. Draw the phasor diagram of transformer
4 (a) ON No-load
(b) ON load

## # What is transformer?

1. It is a static device (There is no rotating parts.
2. It transfer energy or power from one side to other side with same frequency.
3. It has two winding - primary and secondary. There is no inter connection b/w them.
4. Its basic operation based on mutual induction i.e ~~Farada~~ Faraday's law of ~~mag~~ electromagnetic induction.
5. It is also known as constant flux machine.

# Classification of Transfes-

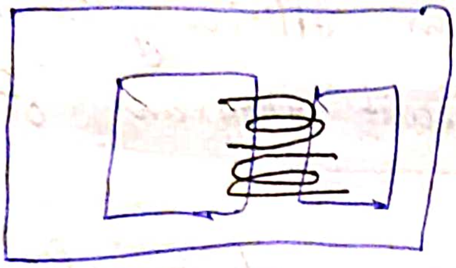
Classify the transfer on the following ways-

(A) On the basis of phase-

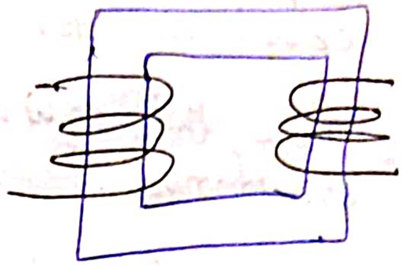
(i) 1-$\phi$ phase Tr.

(ii) 3-$\phi$ phase Tr.

(B) On the basis of construction-



(i) Shell-type Tr.



(ii) Core-type Tr.

(C) On the basis of application-

(i) Step-up Tr.

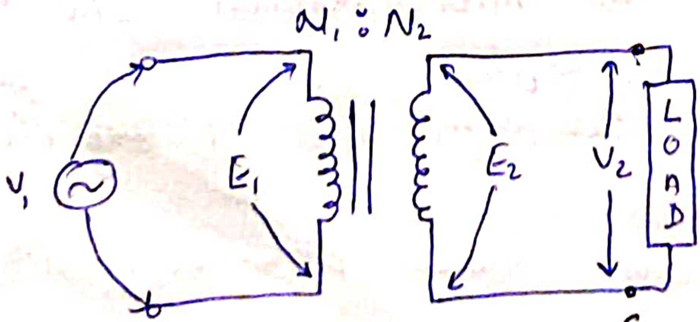
(ii) Step-down Tr.

(D) On the basis of service-

(i) Distribution type Tr. (rating upto 200KVA)

(ii) Power type Tr. (rating above 200KVA)

# Explain the operations of Transformer-




(i) As soon as the primary winding is connected to single phase A.C supply voltage $V_1$ and A.C current start flowing through it.

(ii) The AC primary current produces alternating flux ($\phi$) in the core.

(iii) Most of this changing flux get linked with the secondary winding due to mutual induction, so emf induced.

(iv) Therefore, emf $E_2$ is known as mutual induced emf and $E_1$ is known self induced emf.

* Derive the emf equation of transformer-

Let:

$E_1$ = Self induced emf

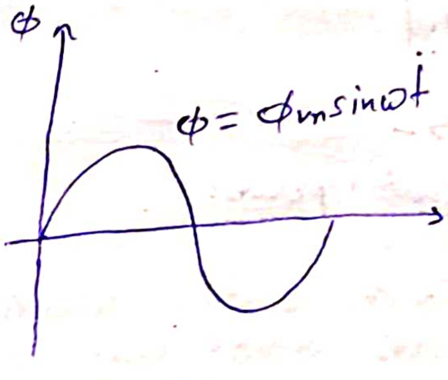
$E_2$ = Mutual induced emf

$N_1$ = No. of primary turns

$N_2$ = No. of secondary turns

$\phi_m$ = maximum flux (wb)

$f$ = frequency (Hz)




* According Faraday's law of electromagnetic induction.

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

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

$$E = -N\phi_m \omega \cos\omega t$$

$$E = N\phi_m \omega \sin\omega t(\omega t - \frac{\pi}{2})$$

$$E = E_{max} \sin(\omega t - \frac{\pi}{2})$$

$$\because E_{rms} = \frac{E_{max}}{\sqrt{2}}$$

$$E_{rms} = \frac{N \phi_m (2\pi f)}{\sqrt{2}}$$

$$E_{rms} = 4.44 \phi_m F N$$

- For primary side-

$$\boxed{E_1 = 4.44 \phi_m F . N_1}$$

- For secondary side-

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

# Transformation Ratio (K):

It is the ratio of secondary induced emf to the primary induced emf.

→ It is denoted by 'k'-

ie,

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

- For ideal transformer-

Input power = output power

$$V_1 I_1 = V_2 I_2$$

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

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

Ques: The maximum flux density in the core 250/3000V, 50Hz single-phase transformer is 1.5 Wb/m². If the emf per turns is 8V. Determine-

(i) No. of primary & secondary turns
(ii) Area of the core.

Sol: Given:

$$B_m = \frac{\phi_m}{A} \left(\frac{Wb}{m^2}\right)$$

$$B_m = 1.2\ Wb/m^2$$

$$E_1 = 250V,\ E_2 = 3000V$$

$$F = 50Hz,\ emf/turn = 8V$$

$$\therefore E_1 = emf/turns \times N_1$$

$$250 = 8 \times N_1$$

$$\therefore \boxed{N_1 = \frac{250}{8} = 31.25}$$ Ans

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

$$\boxed{N_2 = 375}$$ Ans

Since, $E_1 = 4.44\,\phi_m \cdot F N_1$

$$E_1 = 4.44 \times B_m \cdot A \cdot N_1 \cdot F$$

$$A = \frac{E_1}{4.44 \times B_m \times N_1 \times F} = \frac{250}{4.44 \times 1.2 \times 31.25 \times 50}$$

$$\Rightarrow \boxed{A = 0.03m^2}$$ Ans

Ques: A single phase transformer has 400 primary and 1000 secondary turns. The net cross-sectional area of the core is 60 cm². If the primary winding is connected to a 50 Hz supply at 520V. Calculate-

(i) The peak value of flux density at core.
(ii) voltage induced in the secondary winding.

Given: $N_1 = 400,\ N_2 = 1000$

$$A = 60cm^2,\ F = 50Hz$$

$$V_1 = E_1 = 520V.$$

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

$K = \frac{N_2}{N_1} = \frac{1000}{400}$

$\boxed{K = 2.5}$

Now,

$K = \frac{E_2}{E_1} \Rightarrow E_2 = K \times E_1 = 2.5 \times 250$

$\therefore \boxed{E_2 = 1300V}$ Ans 2

Now,

$E_1 = 4.44\, \phi_m \times F \times N_1$

$250 = 4.44\, \phi_m \times 50 \times 400$

$\phi_m = \frac{520}{4.44 \times 50 \times 400}$

$B_m \cdot A = \frac{8520}{4.44 \times 50 \times 400}$

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

$\boxed{B_m = 0.97 \text{ Tesla}}$ Ans 1

# Losses in Transformer:-

1. Iron loss or core loss (OR) Constant loss
   $P_i = V_1 I_0 \cos\phi_0$
   - Hysterisis loss: $P_h = K_h (B_m)^{1.6} \cdot F \cdot v$
   - Eddy current loss: $P_e = K_e \cdot B_m^2 \cdot F^2 t^2$
2. Copper loss (OR) Variable loss
   $P_{cu} = I_1^2 R_1 + I_2^2 R_2$

1. Iron loss-

The power loss taking place in winding core of transformer is known as iron loss or core loss or constant loss.

i.e. $P_i = V_1 I_0 \cos\phi_0$

There are two types of iron loss-

(I) Hysterisis loss
(II) Eddy current loss

(I) Hysterisis loss- This loss depends upon magnetic material used in winding of transformer, and therefore -

$$P_h = K_h \cdot (B_m)^{1.6} \cdot F \cdot v$$

where v is the volume of the core.

(ii) Eddy current loss – It depend on air gap b/w the winding of transformer.

therefore – $P_e = K_e \cdot B_m^2 \cdot F^2 \cdot f^2$

2. Copper loss –

The total power loss taking place in winding resistance of transformer is known as copper loss or variable loss.

→ It is denoted by $P_{cu}$.

i.e, $P_{cu} = I_1^2 R_1 + I_2^2 R_2$

# Phasor Diagram of Transformer:-

$$I_1 = I_0 + I_2'$$

and $\bar{I_0} = \bar{I_w} + \bar{I_\phi}$

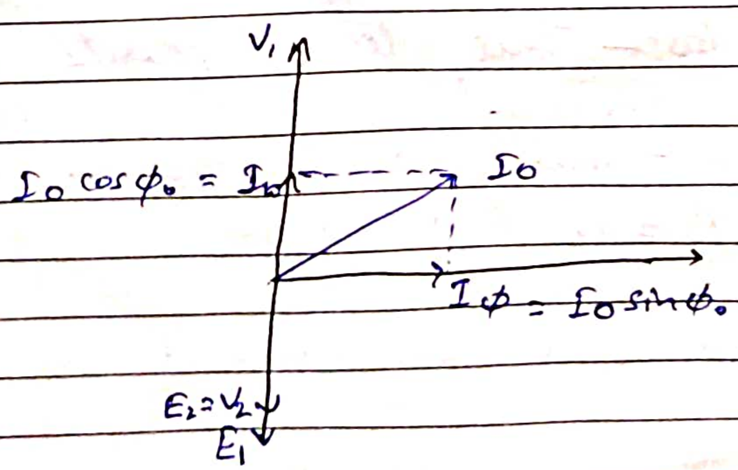
$$V_1 = E_1 + I_1 R_1 + j I_1 X_1$$

$$E_2 = V_2 + I_2 R_2 + j I_2 X_2$$

(a) At NO-LOAD :

$I_2 = 0$

$\therefore E_2 = V_2$



(b) ON-LOAD:-

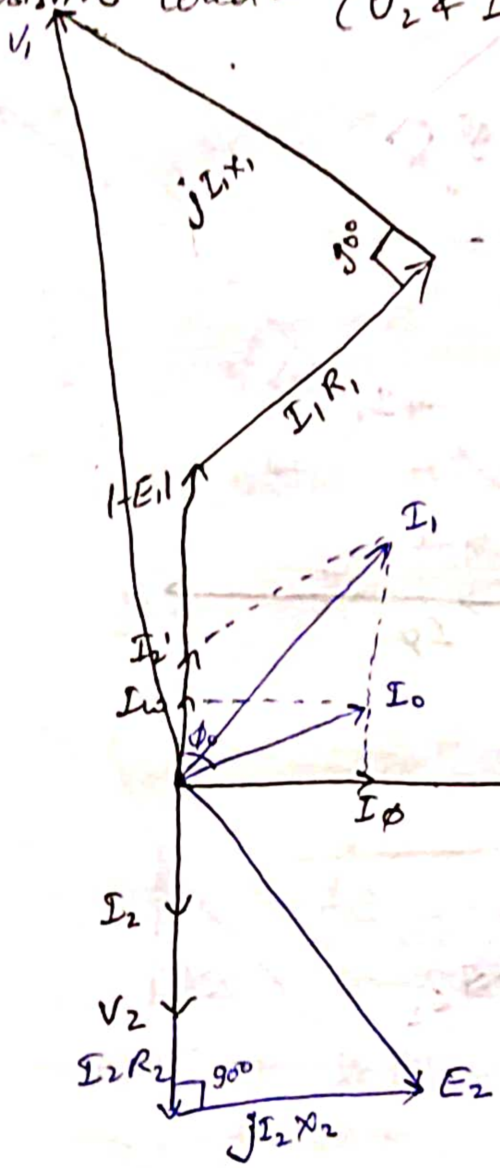
$$V_1 = E_1 + I_1R_1 + jI_1x_1$$

$$E_2 = V_2 + I_2R_2 + jI_2x_2$$

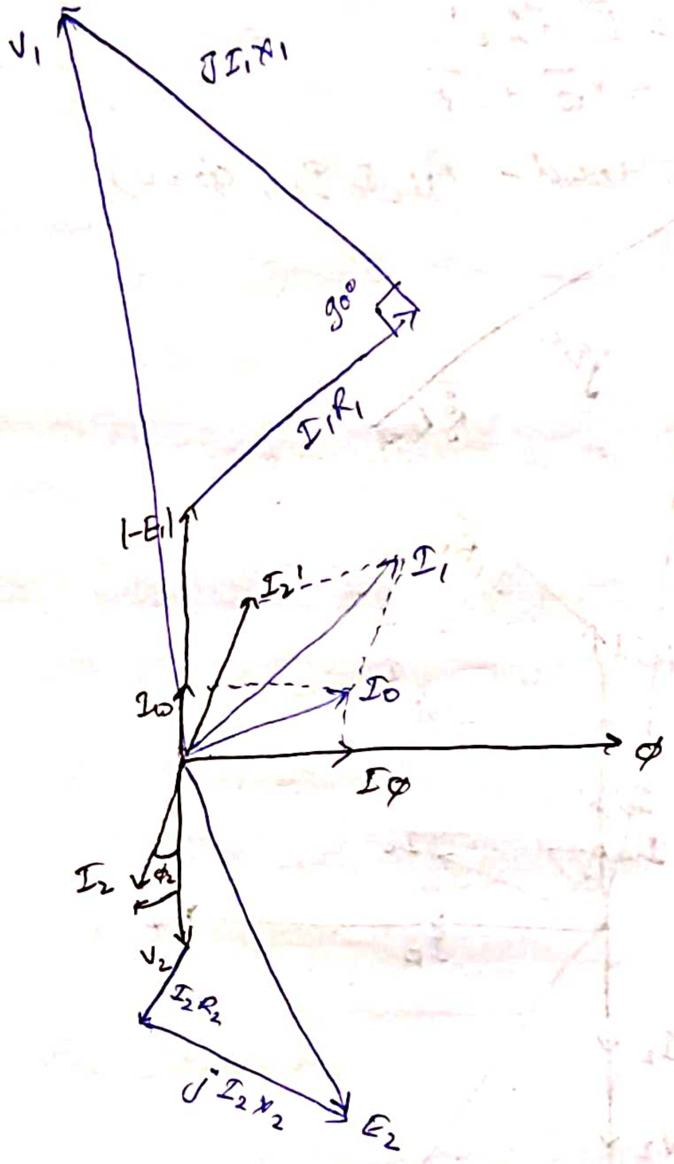
and, $I_1 = I_0 + I_2'$

$$\overline{I_0} = \overline{I_w} + \overline{I_\phi}$$

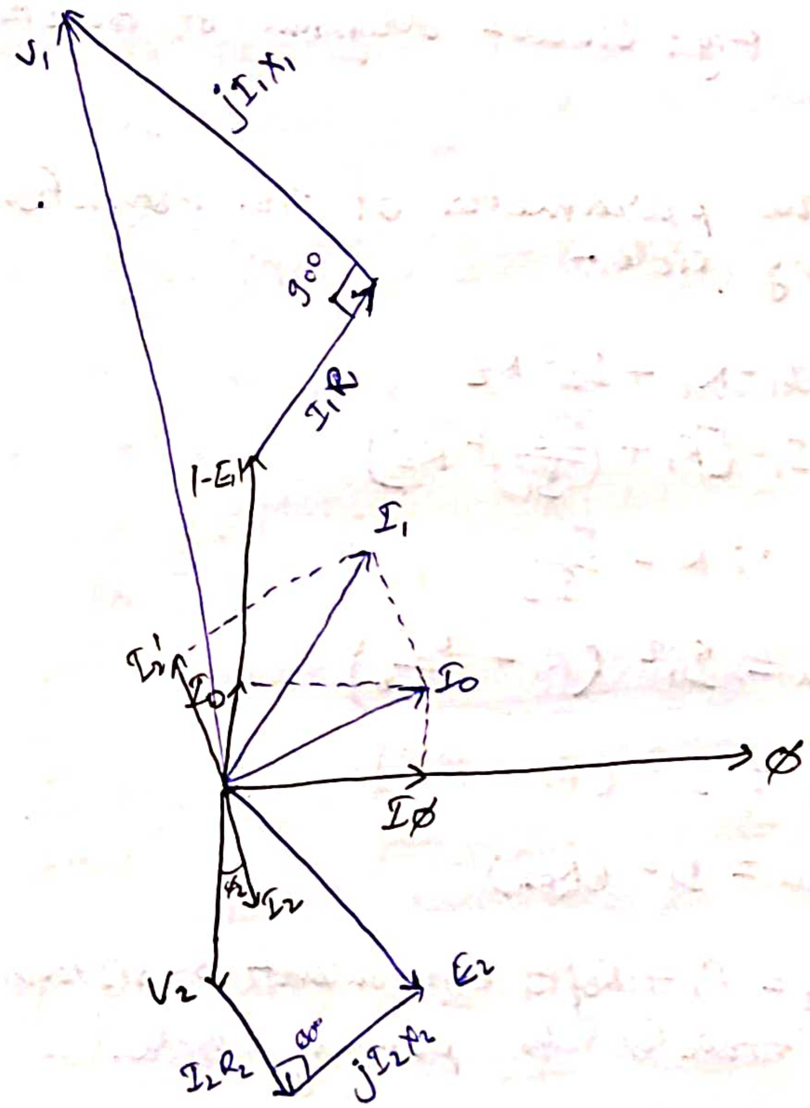
(i) At resistive load- ($V_2$ & $I_2$, $\phi = 0$)



(ii) Inductive load ($I_2$ lagg $V_2$ by $\phi_2$)



(iii) Capacitive load ($I_2$ lead $V_2$ by $\phi_2$)



# Equivalent circuit diagram of transformer -

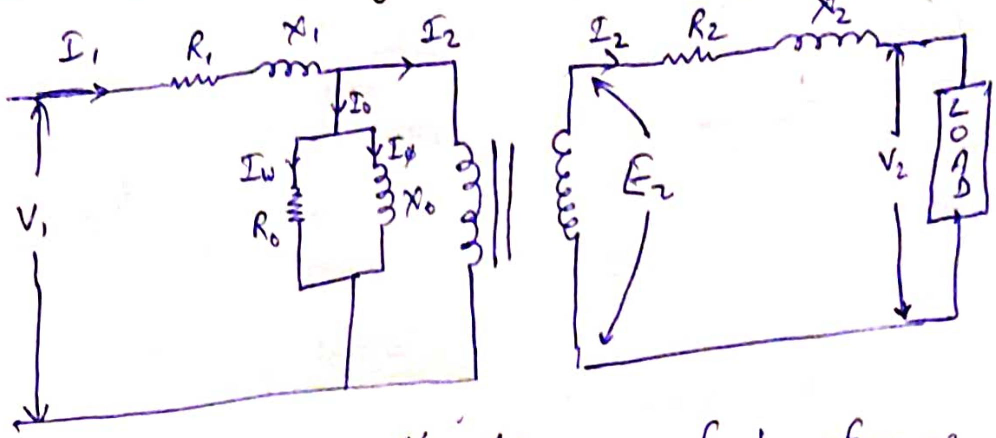



Fig: Circuit diagram of transformer

$\boxed{\text{Case - I:}}$

All the parameter of Tr. transfer to primary side -

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$

$$= I_1^2 \left[R_1 + \left(\frac{I_2}{I_1}\right)^2 R_2\right]$$

$$\because k = \frac{I_1}{I_2}$$

$$\therefore P_{cu} = I_1^2 \left(R_1 + \frac{R_2}{K^2}\right)$$

$$P_{cu} = I_1^2 (R_1 + R_2')$$

$$P_{cu} = I_1^2 (R_{01})$$

$\therefore R_{01} = R_1 + R_2'$ = equivalent resistance transfer to primary side.

& $X_{01} = X_1 + X_2'$, $X_2' = \frac{X_2}{K^2}$ = equivalent reactance transfer to primary side.

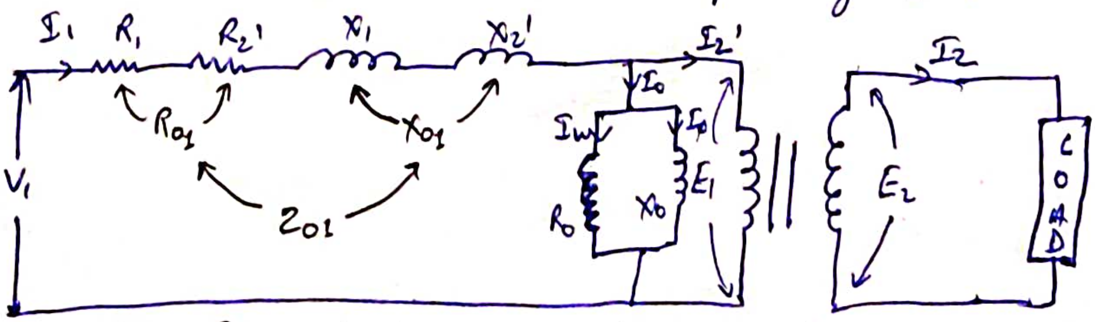



Fig. Equivalent circuit diagram of Tr. transfer to primary side.

**Case-II** All the parameters of transformer transfer to secondary side–

$$P_{cu} = I_1^2 R_1 + I_2^2 R_2$$
$$= I_2^2 \left[\left(\frac{I_1}{I_2}\right)^2 R_1 + R_2\right]$$
$$= I_2^2 \left[K^2 R_1 + R_2\right]$$
$$= I_2^2 \left[R_1' + R_2\right]$$
$$P_{cu} = I_2^2 R_{02}$$

where, $R_{02}$ = equivalent resistance transfer to secondary side $= R_2 + R_1'$

and, $X_{02} = X_2 + X_1'$, $X_1' = X_1 \cdot K^2$

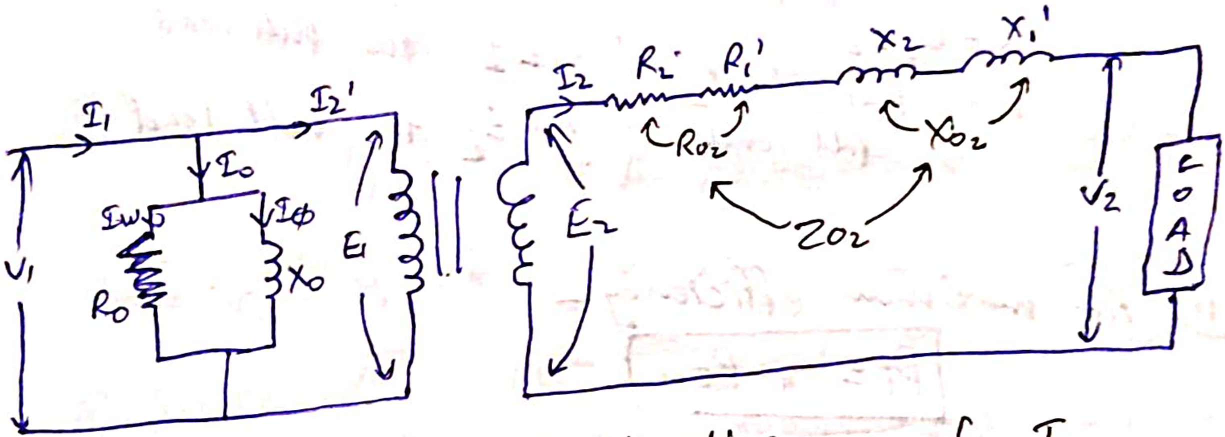



Fig: Equivalent circuit diagram of Tr. transfer to secondary side.

# Efficiency of Transformer ($\eta$):–

$$\eta = \frac{\text{Output power}}{\text{Input power}} = \frac{\text{Input power} - \text{losses}}{\text{Input power}} = \frac{\text{output power}}{\text{output power} + \text{losses}}$$

$\because$ Input power = output power + losses

and losses $= P_i + P_{cu}$

$$\eta = \frac{V_1 I_1 \cos\phi_1 - (P_i + I_1^2 R_{01})}{V_1 I_1 \cos\phi_1}$$

$$\eta = 1 - \frac{P_i}{V_1 I_1 \cos\phi_1} - \frac{I_1 R_{01}}{V_1 \cos\phi_1}$$

$$\frac{\partial \eta}{\partial I_1} = 0 \quad \text{for maximum}$$

so $$\frac{\partial \eta}{\partial I_1} = 0 + \frac{P_i}{V_1 I_1^2 \cos\phi_1} - \frac{R_{01}}{V_1 \cos\phi_1} = 0$$

$$\Rightarrow \frac{P_i}{\cancel{V_1} I_1^2 \cancel{\cos\phi_1}} = \frac{R_{01}}{\cancel{V_1 \cos\phi_1}}$$

$$\Rightarrow \boxed{P_i = I_1^2 R_{01}}$$ At maxm efficiency copper loss = iron loss

* Important formula to find '$\eta$':-

(i) $$\%\eta = \frac{x \cdot S \cdot \cos\phi_2}{x \cdot S \cdot \cos\phi_2 + P_i + x^2 P_{cu}} \times 100$$

$S = V_2 I_2$

$x = \frac{\text{Rated load}}{\text{full load}}$ | $x = 1$ for full load, $x = \frac{1}{2}$ for half load

(ii) At maximum efficiency -

$$\boxed{P_i = x^2 P_{cu}}$$

(iii) Load at maximum efficiency -

$$\boxed{= S \times \sqrt{\frac{P_i}{P_{cu}}}}$$

# Voltage regulation [VR]:-

Change in terminal voltage from no-load to full load is known as voltage Regulation.

i.e; $V.R = E_2 - V_2$

$$\boxed{\%V.R = \frac{E_2 - V_2}{E_2} \times 100}$$

Ques: A 25 KVA, 4000/200 V, 50 Hz single-phase transformer has $R_1 = 3.45\,\Omega$, $R_2 = 0.009\,\Omega$, $X_1 = 5.2\,\Omega$ and $X_2 = 0.051\,\Omega$. Calculate equivalent Resistance and equivalent ~~resi~~ reactance reffered to -

(I) Primary

(II) Secondary

(III) Also calculate net power loss due to winding resistance.

Sol: Given:

$S = 25\times10^3\,VA = V_1 I_1 = V_2 I_2$

$V_1 = 4000\,V$ | $F = 50\,Hz$ | $R_2 = 0.009\,\Omega$ | $X_2 = 0.051\,\Omega$

$V_2 = 200\,V$ | $R_1 = 3.45\,\Omega$ | $X_1 = 5.2\,\Omega$

Here, $K = \frac{V_2}{V_1} = \frac{200}{4000} = 0.05$

(I) In Primary -

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 3.45 + \frac{0.009}{(0.05)^2} = \boxed{7.05\,\Omega}$$ Ans

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K^2} = 5.2 + \frac{0.051}{(0.05)^2} = \boxed{25.6\,\Omega}$$ Ans

(II) In secondary -

$$R_{02} = R_2 + R_1' = R_2 + R_1\cdot K^2 = 0.009 + 3.45\times(0.05)^2$$

$$\boxed{R_{02} = 0.0176\,\Omega}$$ Ans

$$X_{02} = X_2 + X_1' = X_2 + X_1\cdot K^2 = 0.051 + 5.2\times(0.05)^2$$

$$\boxed{X_{02} = 0.064\,\Omega}$$ Ans

(III) $P_{cu} = I_1^2 R_{01}$

$\because V_1 I_1 = S$

$\Rightarrow I_1 = \frac{25\times10^3}{4000}$

$\Rightarrow I_1 = 6.25\,A$

So, $P_{cu} = (6.25)^2 \times 7.05$

$\Rightarrow \boxed{P_{cu} = 275.39\,W}$ Ans

Note: Why the rating of transformer in Volt-Ampere (VA) -

Ans: Because in transformer, there are two losses. One is constant loss and variable loss. Constant loss depend on voltage and variable loss depend on current.

Ques. A 30 KVA, 2000/200 V, single phase transformer has a primary resistance of 3.5 Ω and reactance of 4.5 Ω. The secondary resistance and reactance are 0.015 Ω and 0.02 Ω respectively. Find -

(i) Equivalent resistance, reactance and impedance refered to primary side.

(ii) Equivalent resistance, reactance and impedance refered to secondary side.

(iii) The total copper loss in the transformer

Given -

$S = 30 \times 10^3 VA = V_1 I_1$

| | |
|---|---|
| $V_1 = 2000\,V$ | $R_2 = 0.015\,\Omega$ |
| $V_2 = 200\,V$ | $X_2 = 0.02\,\Omega$ |
| $R_1 = 3.5\,\Omega$ | |
| $X_1 = 4.5\,\Omega$ | |

(i) Primary side -

$\because K = \frac{V_2}{V_1}$

$K = \frac{200}{2000}$

$K = 0.1$

$R_{o1} = R_1 + R_2' = R_1 + \frac{R_2}{K^2} = 3.5 + \frac{0.015}{(0.1)^2}$

$\boxed{R_{o1} = 5\,\Omega}$ Ans

$X_{o1} = X_1 + X_2' = X_1 + \frac{X_2}{K^2} = 4.5 + \frac{0.02}{(0.1)^2}$

$\boxed{X_{o1} = 6.5\,\Omega}$ Ans

$Z_{o1} = \sqrt{R_{o1}^2 + X_{o1}^2} = \sqrt{5^2 + 6.5^2}$

$\boxed{Z_{o1} = 8.20\,\Omega}$ Ans

(ii) Secondary side -

$R_{o2} = R_2 + R_1' = R_2 + R_1 \cdot K^2 = 0.015 + (3.5 \times 0.1^2)$

$\boxed{R_{o2} = 0.05\,\Omega}$ Ans

$X_{o2} = X_2 + X_1' = X_2 + X_1 \cdot K^2 = 0.02 + (4.5 \times 0.1^2)$

$\boxed{X_{o2} = 0.065\,\Omega}$ Ans

$Z_{o2} = \sqrt{R_{o2}^2 + X_{o2}^2} = \sqrt{0.05^2 + 0.065^2}$

$\boxed{Z_{o2} = 0.082\,\Omega}$ Ans

(iii) $P_{cu} = I_1^2 R_{01}$

$\because S = V_1 I_1$

$\Rightarrow I_1 = \frac{S}{V_1} = \frac{30\times10^3}{2000}$

$\Rightarrow I_1 = 15A$

So, $P_{cu} = (15)^2 \times 5$

$\boxed{P_{cu} = 1125 W}$ Ans

Ques: In A 25 KVA, 2000/200 V, 50 Hz single phase transformer, the constant and variable losses are 350 watt and 400 watt respectively. Calculate the efficiency on unity power factor at

(i) Full-load

(ii) Half-load

Sol:

$S = 25\times10^3$

$V_1 = 2000V$

$V_2 = 200V$

$f = 50Hz$

$P_i = 350$ watt

$P_{cu} = 400$ watt

$\cos\phi_2 = 1$

(i) At full load, $n = 1$,

$$\eta = \frac{n \cdot S \times \cos\phi_2}{n \cdot S \times \cos\phi_2 + P_i + n^2 P_{cu}} \times 100$$

$$\eta = \frac{1\times25\times10^3\times1}{1\times25\times10^3\times1 + 350 + 1^2 \times 400} \times 100$$

$\boxed{\eta = 97.08\%}$

(ii) At half load - $x = \frac{1}{2}$

$$\eta = \frac{x \cdot S \cdot \cos\phi_2}{x \cdot S \cdot \cos\phi_2 + P_i + x^2 + P_{cu}} \times 100$$

$$\eta = \frac{\frac{1}{2} \times 25 \times 10^3 \times 1}{\frac{1}{2} \times 25 \times 10^3 \times 1 + 350 + (\frac{1}{2})^2 \times 400} \times 100$$

$$\eta = 96.52\%$$

Ques: Find the efficiency of a 150 KVA transformer at 25% of full-load at 0.8 power factor lagging. The copper loss at full-load is 1600 watt and the iron loss is 1400 watt. Ignore the effect of temprature rise and magnetising effect.

Sol:

$S = 150 \times 10^3$

$x = \frac{25}{100} = \frac{1}{4}$

$P_{cu} = 1600 \text{ watt}$

$P_i = 1400 \text{ watt}$

$\cos\phi_2 = 0.8$

$$\eta = \frac{x \cdot S \cdot \cos\phi_2}{x \cdot S \cdot \cos\phi_2 + P_i + x^2 \times P_{cu}} \times 100$$

$\boxed{\eta = 95.23}$ Ans

Ques: A 200 KVA single phase transformer has an efficiency of 98%. If the maximum efficiency occurs at 3 quater of full load. Find the efficiency at half load, assume power factor of 0.8 lagging for all load.

Sol:

$$\frac{1 \times 200 \times 10^3 \times 0.8}{(1 \times 200 \times 10^3 \times 0.8) + P_i + 1 \times P_{cu}} = 0.98 \quad \text{--- (2)}$$

and, $P_i = x^2 P_{cu}$ for maximum efficiency

$\Rightarrow P_i = (\frac{3}{4})^2 P_{cu}$

$\Rightarrow P_i = \frac{9}{16} P_{cu}$ --- (1)

Put (2) in (1) -

$$\frac{200\times10^3\times0.8}{(200\times10^3\times0.8)+\frac{9}{16}P_{cu}+P_{cu}} = 0.98$$

$$200\times10^3\times0.8 = 0.98(200\times10^3\times0.8)+0.98\times\frac{25}{16}P_{cu}$$

$$\frac{25}{16}P_{cu} = \frac{200\times10^3\times0.8-0.98(200\times10^3\times0.8)}{0.98}$$

$$P_{cu} = \frac{16}{25}\times\frac{(200\times10^3\times0.8)-0.98(200\times10^3\times0.8)}{0.98}$$

$P_{cu} = 2089.79$ watt

$\boxed{P_{cu} = 2.08 \text{ Kwatt}}$

Now,

$P_i = \frac{9}{16}\times 2.08 \Rightarrow \boxed{P_i = 1.17 \text{ K watt}}$

Now,

$$\eta = \frac{\frac{1}{2}\times200\times\cancel{10^3}\times0.8}{(\frac{1}{2}\times200\times\cancel{10^3}\times0.8)+1.17+\frac{1}{4}\times2.08}\times100$$

$\boxed{\eta = 97.9}$ Ans

# Magnetic Circuits

(1) MMF (Magneto motive force) -

It is the product of flux and reactance is known as MMF.

i.e, $\boxed{MMF = \phi \times S} = NI \; (AT)$

$A \rightarrow$ Ampere, $T \rightarrow$ Turns

(2) Reluctance -

Offered by the substance which oppose the flow of magnetic flux.

i.e, $\boxed{S = \frac{l}{\mu A}}$

(3) Magnetic flux density -

It is the flux per unit area and therefore -

$$B = \phi / A \; (Wb/m^2)$$

(4) Permeability -

It is the product of absolute permeability and relative permeability.

$$\therefore \mu = \mu_0 \mu_r$$

(5) Magnetic field intensity -

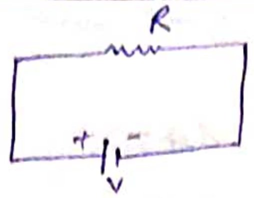
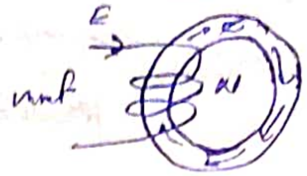
It is the ratio of flux density to the permeability.

$$\therefore \boxed{H = \frac{B}{\mu}}$$

Ques. 1: Analogy b/w electric and magnetic circuit.

OR

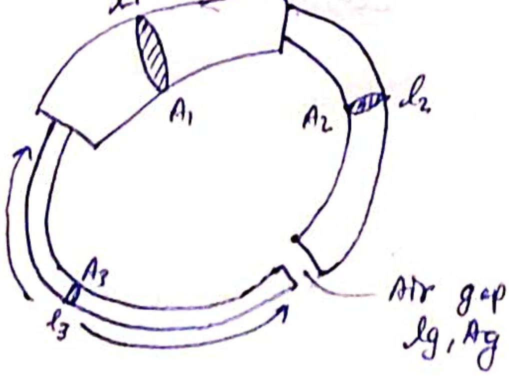
Difference b/w OR comparison b/w

| | Electric circuit | Magnetic circuit |
|---|---|---|
| (1) Circuit |  |  |
| (2) Definitions | The closed path followed by the current is known as electric circuit. | The closed path followed by the magnetic flux is known as magnetic circuit. |
| (3) Driving force | EMF | MMF |
| (4) Response | $I = E/R$ | $\phi = \frac{mmf}{S}$ |
| (5) Impedence | $R = \rho l/A$ | $S = \frac{l}{\mu A}$ |
| (6) Density | $J = I/A$ | $B = \phi/A$ |
| (7) Field Intensity | $E = V/l$ | $H = \frac{mmf}{l}$ |
| (8) Droop | $IR$ | $\phi \times S$ |

# Dissimilarities -

Flux can flow in air but current cannot flow in it.

# Analysis of Series magnetic circuits -



$$mmf = \phi \cdot S = N \times I \text{ (AT)}$$

$$= \phi (S_1 + S_2 + S_3 + S_g)$$

$$= \phi \left( \frac{l_1}{\mu_0 \mu_{r_1} A_1} + \frac{l_2}{\mu_0 \mu_{r_2} A_2} + \frac{l_3}{\mu_0 \mu_{r_3} A_3} + \frac{l_g}{\mu_0 A_g} \right)$$

$$= \frac{B_1 l_1}{\mu_0 \mu_1} + \frac{B_2 l_2}{\mu_0 \mu_2} + \frac{B_3 l_3}{\mu_0 \mu_3} + \frac{B_g l_g}{\mu_0}$$

$$\boxed{mmf = H_1 l_1 + H_2 l_2 + H_3 l_3 + H_g l_g = N \times I \text{ (ATs)}}$$

(6-7 times) VVI

Ques: An electromagnet has an air gap of 4 mm length and flux density of the gap is 1.3 wb/m². Determine the ampere-turns for the gap.

Sol:

$$\therefore AT = mmf = \phi \times S_g$$

$$= \phi \times \frac{l_g}{\mu_0 A_g}$$

$$= \frac{B_g l_g}{\mu_0} = \frac{1.3 \times 4 \times 10^{-3}}{4\pi \times 10^{-7}} = 4138$$

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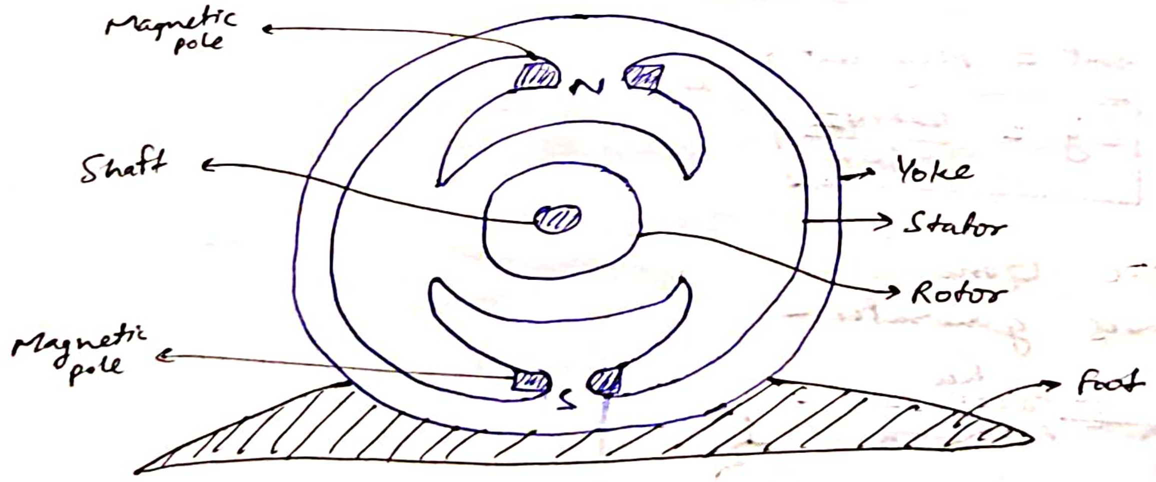
# Unit - IV

# Electrical Machines

Electrical Machines

- D.C Machines
  - D.C Generator
  - D.C Motor
- A.C Machine
  - 1-ϕ IM (Induction motor)
  - 3-ϕ IM
  - Synchronous machine

## # DC Machines -



## * EMF Equation of DC generator –

let $\phi$ = flux in wb

$P$ = no. of poles

$N$ = speed in rpm

$A$ = no of parallel path

$Z$ = total no of conductor

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

$d\phi$ = change in flux $= \phi \times P$

1-revolution $= N/60$

$dt$-revolution $= \frac{1}{1\text{-revolution}} = \frac{60}{N}$

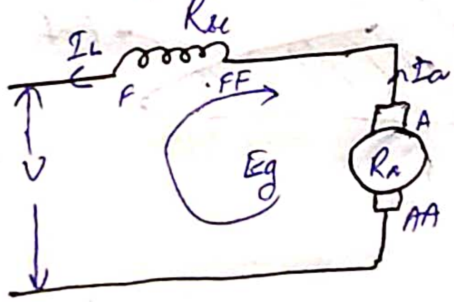
$$\text{Average emf} = \frac{d\phi}{dt} = \frac{\phi P N}{60}$$

$$\text{Total emf} = \text{Avg emf} \times \frac{Z}{A}$$

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

## * Types of D.C Generator –

① DC series generator –



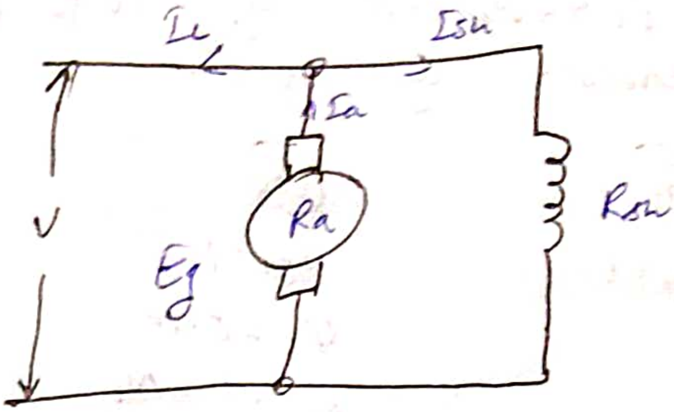

$$\boxed{I_L = I_a}$$

$$\boxed{I_L = \frac{P_L}{V} = \frac{V}{R_L}}$$

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

$$\boxed{P_g = E_g I_a}$$

② DC shunt generator -

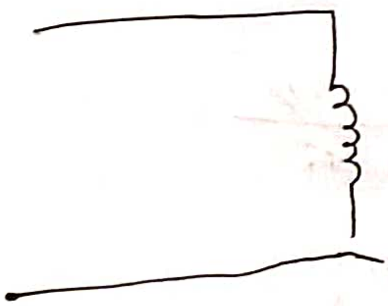



$I_a = I_L + I_{sh}$ , $I_{sh} = \frac{V}{R_{sh}}$

$E_g = V + I_a R_a + BDV$

③ DC compound generator -

a) Long sheet d.c compound generator:



Ques: In a DC generator what is the change in emf if flux is reduced by 20% and speed is increased by 20%.

Sol

$G_1$ $\qquad$ $G_2$

$E_{g1} = ?$ $\qquad$ $E_{g2} = ?$

$\phi_2 = 0.8\phi_1$

$N_2 = 1.2 N_1$

Now, $E_{g1} = \frac{\phi_1 Z N_1 P}{60A}$ , $E_g = \frac{\phi_2 Z N_2 P}{60A}$

Now,

$$\frac{E_{g2}}{E_{g1}} = \frac{\phi_2 N_2}{\phi_1 N_1}$$

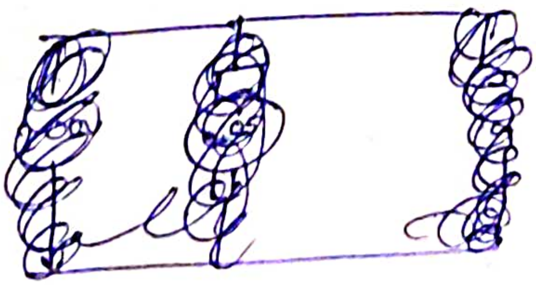
$$\frac{E_{g2}}{E_{g1}} = \frac{0.8\cancel{\phi_1} \times 1.2\cancel{N_1}}{\cancel{\phi_1} \times \cancel{N_1}}$$

$$\boxed{E_{g2} = 0.96 E_{g1}}$$

reduce by 4%.

Ques: A 20 KW, 200V DC shunt generator has an armature resistance of 0.05 Ω and field resistance of 200Ω, calculate armature current, generated emf and power developed.

Ans



$I_L = \frac{P_L}{V} = \frac{20\times10^3}{200}$

$\boxed{I_L = 100}$

$I_{sh} = \frac{V}{R_{sh}} = \frac{200}{200} = 1$

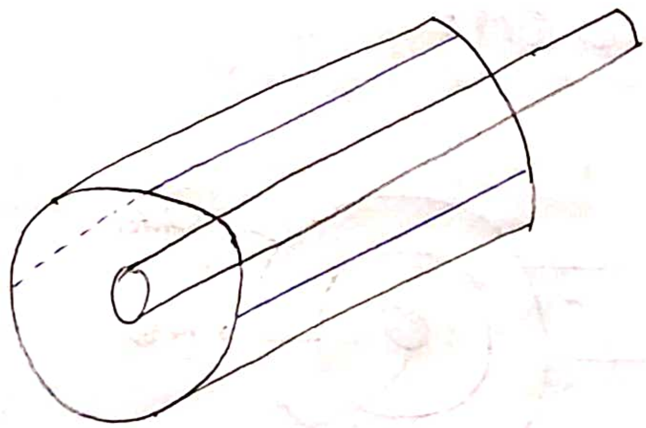
So, $I_a = I_L + I_{sh} = 100 + 1 = 101$

$\boxed{I_a = 101}$

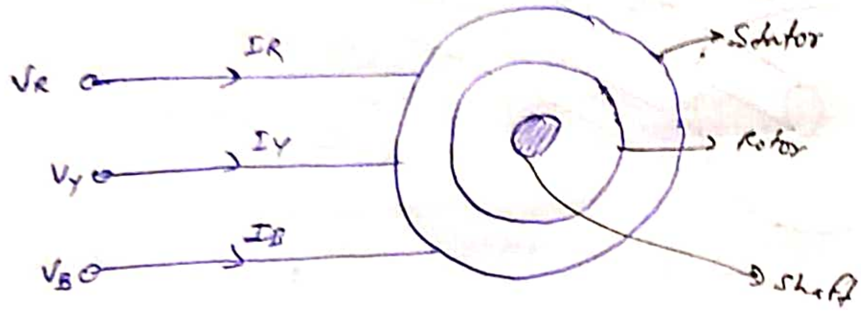
# Three Phase Induction motor -

* Types of $3\phi$ IM:

① Single squared cage $3-\phi$ IM -



## *Operations of 3-$\phi$ IM:




Realtime speed $\begin{pmatrix}\text{Slip}\\\text{Speed}\end{pmatrix} = N_s - N_r$

$$\text{Slip},\ S = \frac{N_s - N_r}{N_s}$$

* Torque Developement in 3-$\phi$ IM -

$$P_m = \omega_r \cdot T_e$$

$$(1-s) P_g = (1-s)\omega_s \cdot T_e$$

$$T_e = \frac{P_g}{\omega_s} = \frac{60}{2\pi N_s} \cdot P_g$$

$$T_e = \frac{60}{2\pi N_s} I_2^2 \frac{r_2}{s}$$

$$T_e = \frac{60}{2\pi N_s} \cdot \frac{E_2^2}{\left[\left(\frac{r_2}{s}\right)^2 + x_2^2\right]} \cdot \frac{r_2}{s}$$

For 3-$\phi$

$$\boxed{T_e = \frac{3\times 60}{2\pi N_s} \cdot \frac{E_2^2}{\left[\left(\frac{r_2}{s}\right)^2 + x_2^2\right]} \cdot \frac{r_2}{s}}$$

$$\frac{\partial T_e}{\partial s} = 0 \Rightarrow \frac{r_2}{x_2} = s$$

$$\Rightarrow \boxed{r_2 = s x_2}$$

$$\boxed{T_{e\,max} = \frac{3\times 60}{2\pi N_s} \cdot \frac{E_2^2}{2x_2}}$$

** # Draw the Slip/Speed/Torque characteristics of 3-$\phi$ Induction motor.

$$S = \frac{N_s - N_r}{N_s} \quad \text{—(i)}$$

At starting $N_r = 0$

$$\boxed{s = 1}$$

$$N_r = (1-S)N_s \quad \text{—(2)}$$

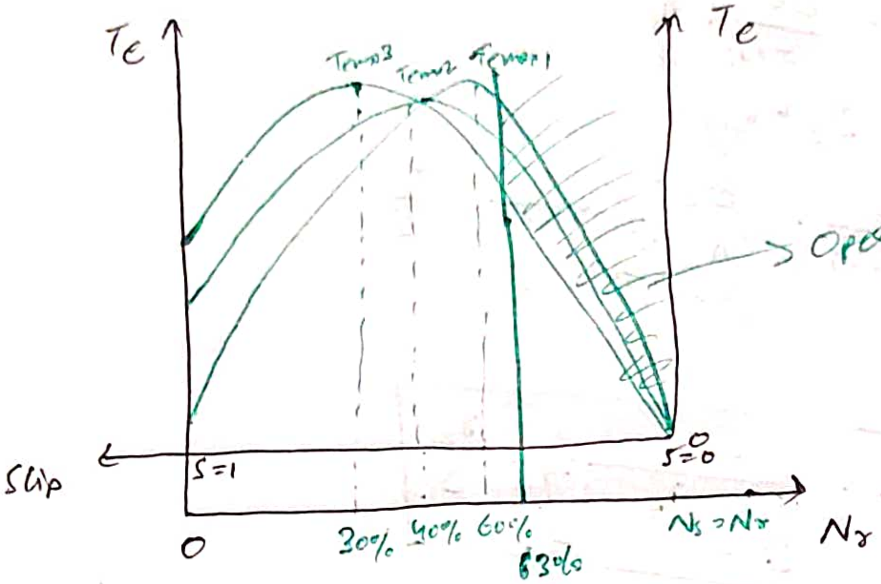
$$T_e = \frac{3\times 60}{2\pi N_s} \cdot \frac{E_2^2}{\left[\left(\frac{r_2}{s}\right)^2 + x_2^2\right]} \cdot \left(\frac{r_2}{s}\right)$$

$$T_{e\,max} = \frac{3\times 60}{2\pi N_s} \cdot \frac{E_2^2}{2x_2}$$

S=1 starting

$$T_{e\,st} = \frac{3\times 60}{2\pi N_s} \left[\frac{E_2^2}{r_2^2 + x_2^2} \cdot r_2\right]$$

Mode of motoring operation region from 0 to 1.




Ques: A 3-$\phi$, 4-pole, 50Hz I.M runs at 1460 rpm Determine the slip.

$$N_s = \frac{120f}{P} = \frac{120 \times 50}{4} = 1500$$

$$S = \frac{N_s - N_r}{N_s} = \frac{1500 - 1460}{1500} \times 100$$

$\boxed{S = 2.66}$ Ans