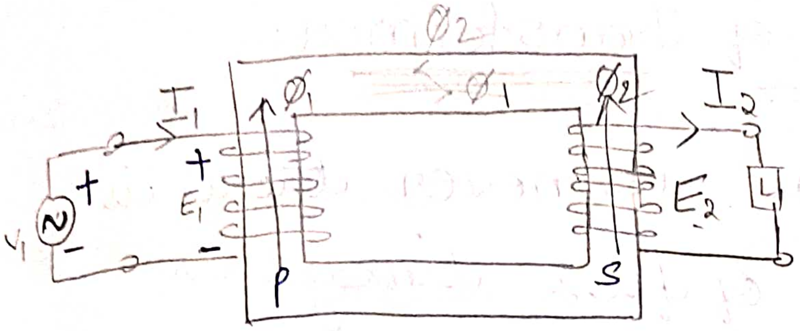
10/08/2022

TRANSFORMERS



E_1 = Self induced emf

∵ emf is induced due to the source;

The transformer just step up or down the voltage; but total power on either side remains same $\boxed{V_1 I_1 = V_2 I_2}$

Due to the flux developed in primary coil there is a flux developed in secondary coil; $\boxed{E_2 = \text{Mutually induced emf}}$

Principle: Faraday's law of Electromagnetic Induction.

E_1 is time dependent/ varying voltage.

Lenz Law: Effect should oppose the cause.

- Constant flux machine.
- Whenever; there is no load; the reduction in initial flux ϕ_1 due to ϕ_2; therefore, the source supplies a flux ϕ_2' equal to ϕ_2 but opposite in direction.

∴ Therefore, the overall flux in the

transformer is ϕ_1

*EMF equation of Transformer:

By Faraday's law; whenever there is a rate of change of flux linkage in a conductor; there is emf induced.

Avg emf/turn $= E_{avg}/turn = \frac{d\phi}{dt}$

$= \frac{\phi m - 0}{\frac{1}{4f}}$

$$\boxed{E_{avg}/turn = 4f\phi m}$$

$K_f = \frac{\text{Rms value}}{\text{Avg value}} = 1.11$

Rms value $= E_{rms}/turn = 4f\phi m(1.11)$

$$\boxed{E_{rms}/turn = 4.44 f\phi m}$$

$$\boxed{\begin{aligned} E_1 &= 4.44 f\phi m N_1 \\ E_2 &= 4.44 f\phi m N_2 \end{aligned}}$$

*Transformer Ratio (K) $= \frac{E_2}{E_1} = \frac{N_2}{N_1}$

$K > 1 \rightarrow$ Step-Up Transformer

$K < 1 \rightarrow$ Step-Down Transformer

$K = 1 \longrightarrow$ Isolation Transformer.

13/08/2022

* $E_1 = 3300V$ $E_2 = 250V$. $A = 125 cm^2$ $f = 50 Hz$.

$N_2 = 70$ $= 125 \times 10^{-4} m^2$

max.

$$B_m = \frac{\phi_m}{A} = \frac{E_2}{4.44 f N_2 A}$$

$$= \frac{250}{4.44 \times 50 \times 70 \times 125 \times 10^{-4}}$$

$$= \underline{\underline{1.289 T}}$$

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

$$N_1 = \frac{330\cancel{0}}{25\cancel{0}} \times 70$$

$$= 924.$$

* $N_1 = 800$ $N_2 = 200$ $V_{ac} = E_1 = 100V$.

$E_2 = ?$

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

$$= \frac{\cancel{100}^{25} \times \cancel{200}}{\cancel{800}} = 25V.$$

$$\text{Volts per turn} = \frac{V_1}{N_1} = \frac{\cancel{100}^{1}}{\cancel{800}_{8}} = 0.125.$$

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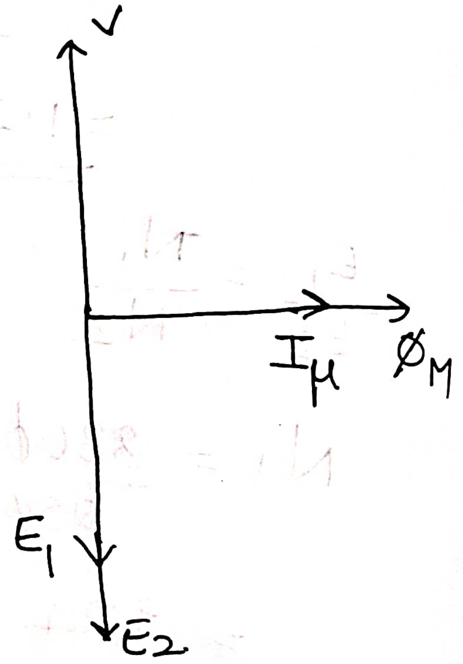
Volts per turn $= \frac{V_2}{N_2} = 0.125$.

* Ideal transformer:

Properties:

1) $\mu = \infty$: ability to produce flux with a min MMF (magnetomotive force)
2) Copper loss (I^2R) is neglected.
3) $R_1 = 0$; $R_2 = 0$ $\Rightarrow$ purely inductive.
4) No leakage flux
5) core loss $= 0$.



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

17/08/2022

~~* Magnetising & demag~~

* Magnetic reversal : magnetising & demagnetising of core : Heat loss developed due mechanical vibrations. is called HYSTERESIS LOSS.

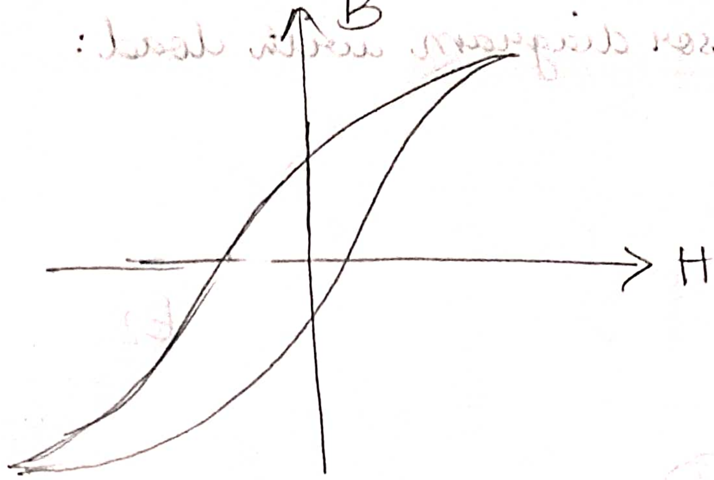
If the area of the loop is max. losses are more and vice versa

By using a proper material we

can reduce the Hysteresis loss.

$H \rightarrow$ Magnetic field density

$B \rightarrow$ Magnetic flux density



EDDYCURRENT LOSSES:

- Heat developed due to the eddycurrent developed in the core ($\because$ closed circuit) will cause eddy current losses.
  $\Rightarrow I^2R$ loss.
- Losses can be reduced using ~~co~~ thin laminated core.

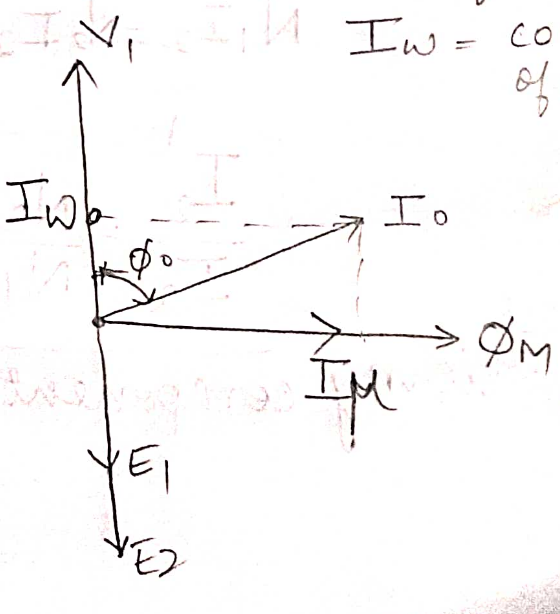
* Ideal transformer with no load but having core loss:

Phasor diagram:

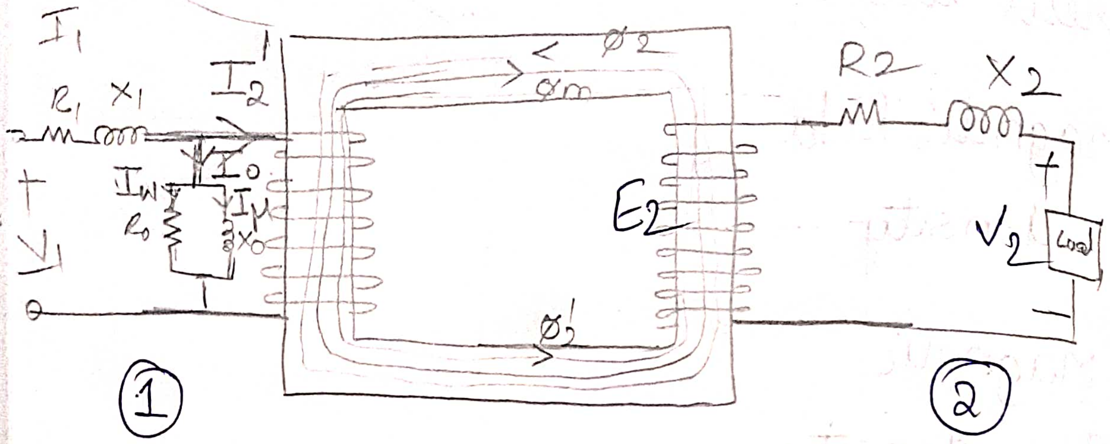
I_μ = Magnetising loss comp of current

I_w = core loss component of current

$I_o = \sqrt{I_w^2 + I_\mu^2}$ = No load ~~core loss~~ current.



* Phasor diagram with load:



Flux linking in the same coil : flux leakage.

$\boxed{V_2 < E_2}$

①

$V_1 = E_1 + I_1(R_1 + jX_1)$ $\boxed{E_1 < V_1}$

E_1 lags V_1

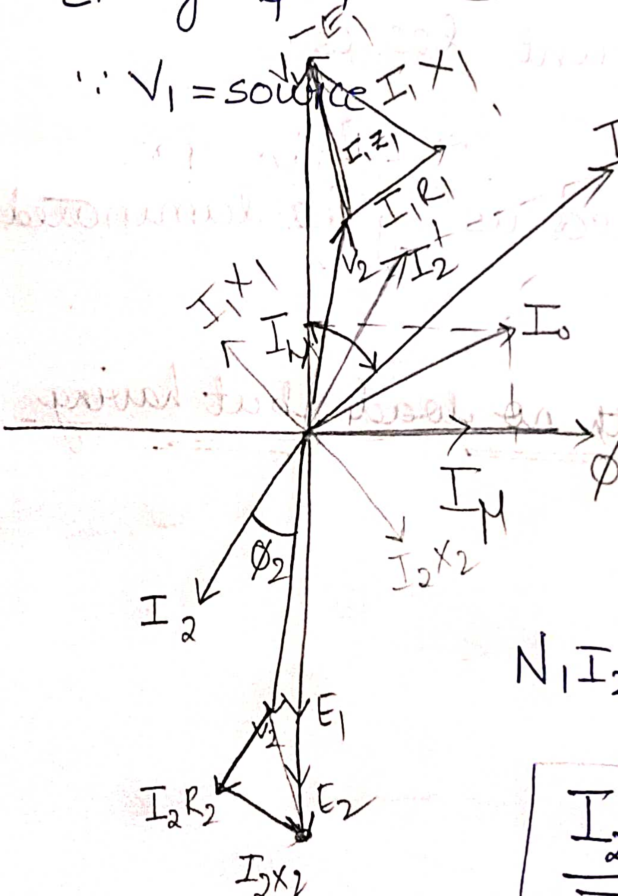
$\because V_1 = \text{source}$

$V_2 + I_2(R_2 + jX_2) = E_2$

V_2 lags E_2

~~E_2 lags V_2~~

$E_2 = \text{source}$



Loads

UPF : R

Lagging : RL

Leading : RC

current leads voltage $-X_C$

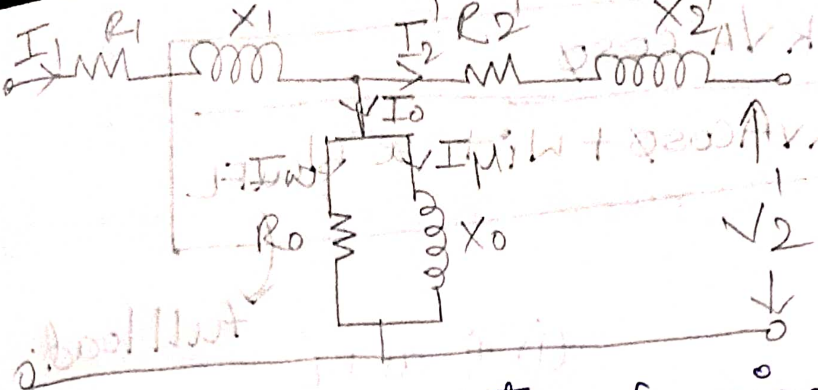
$N_1 I_2' = N_2 I_2$

current lags voltage $-X_L$

$$\boxed{\frac{I_2'}{I_2} = \frac{N_2}{N_1} \Rightarrow I_2' = K I_2}$$

$R_0 \rightarrow$ core loss

$X_0 \rightarrow$ magnetising component of current



Secondary to Primary.

* Even after transforming Power loss will be same.

$$I_2^2 R_2 = I_2'^2 R_2'$$

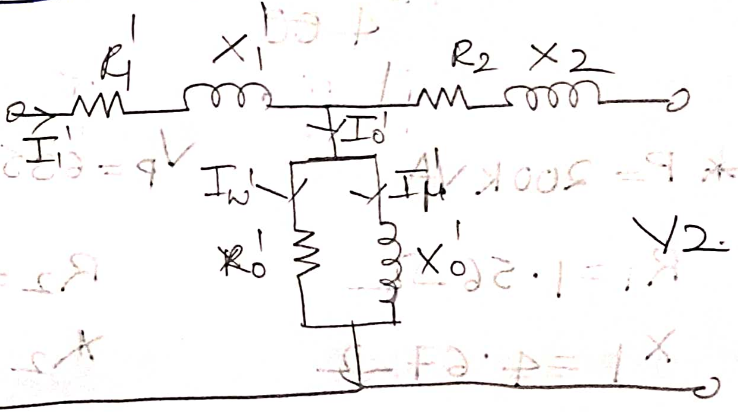
$$R_2' = \left(\frac{I_2}{I_2'}\right)^2 R_2 = \frac{R_2}{K^2}$$

$N_1 > N_2$
$R_1 > R_2$
$V_1 > V_2$.

high to low
R ↓ses
low to high
R ↑ses

$$\boxed{R_2' = \frac{R_2}{K^2}} \qquad \boxed{X_2' = \frac{X_2}{K^2}}$$

Primary to Secondary.



$$I_1^2 R_1 = I_1'^2 R_1'$$

$$R_1' = \left(\frac{I_1}{I_1'}\right)^2 R_1$$

$$\boxed{X_1' = K^2 X_1}$$

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

* **Efficiency:**

$x \rightarrow$ factor for operating load.

$$\eta = \frac{P_o}{P_i}$$

$$\boxed{\eta = \frac{x(KVA)\cos\phi}{xKVA\cos\phi + W_i + W_{cu}(x^2)}}$$

$W_i \longrightarrow$ const
W_{cu} = variable

$$\boxed{\eta = \frac{x\,kVA\cos\phi}{x\,kVA\cos\phi + W_i + x^2 \underbrace{W_{cuFL}}_{\text{full load}}}}$$

at Full load.

$W_i = 400W$

$W_{cuFL} = 800W$

(i) η at FL

(ii) η at $\frac{1}{2}$ FL

(iii) η at $\frac{3}{4}$ FL.

22/08/2022

* $P = 25kVA$ $\quad V_p = 3300$ $\quad V_s = 400V$

$$I_p = \frac{25000}{3300} = 7.58A$$

$$I_s = \frac{250\cancel{00}}{4\cancel{00}} = 62.5A.$$

* $P = 200kVA$ $\quad V_p = 6350V$ $\quad V_s = 660V$

$R_1 = 1.56\,\Omega$ $\qquad R_2 = 0.016\,\Omega$

$X_1 = 4.67\,\Omega$ $\qquad X_2 = 0.048\,\Omega$

$$R_{01} = R_1 + R_2'$$
$$= 1.56 + \frac{R_2}{K^2}$$
$$= 1.56 + \frac{0.016}{(0.104)^2}$$
$$= 3.0392\,\Omega$$

$$K = \frac{660}{6350} = 0.104$$

$$X_{01} = X_1 + X_2'$$
$$= 4.67 + \frac{X_2}{K^2}$$
$$= 4.67 + \frac{0.048}{(0.104)^2}$$
$$= 9.107\,\Omega$$

* $P = 3KVA ; 50Hz \quad 1\phi$

$W_i = 600W \quad W_{cuFL} = 1600W \quad \cos\phi = 0.8$

Determine (i) η_{FL} ; (ii) $\eta_{1/2FL}$ (iii) $\eta_{3/4FL}$

(i) $$\eta = \frac{1 \times 3000 \times 0.8}{2400 + 1600 \times 1 + 600}$$

$= 0.52$

600×4

$\frac{1}{4} \times W_{cuFL} = 600$

(ii) $$\eta = \frac{\frac{1}{2} \times 2400}{1200 + \cancel{1600}^{400} \times \frac{1}{\cancel{4}} + 600} = \frac{1200}{2200}$$

$= 0.545$

(iii) $$\eta = \frac{\frac{3}{4} \times 2400}{1800 + \frac{9}{16}(1600) + 600} = \frac{1800}{1800 + 900 + 600}$$

1800
1500
$3\;000$

$= \frac{1800}{3300}$

$= 0.545$

* **Power factor Improvement:**

To improve power factor in a RL circuit we should add a capacitor;

We should improve power factor; to improve the power output and efficiency.

* Power factor for a
  - resistive load : 1 (unity)
  - inductive load : lagging
  - capacitive load : leading.

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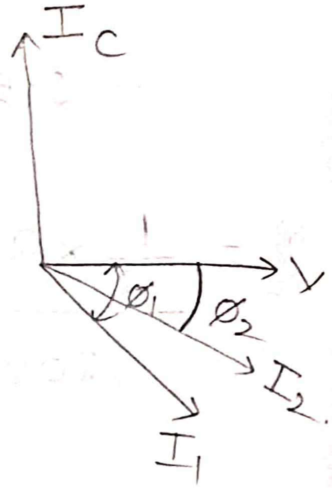
Causes of Low Power factor:

- Induction Motors
- Transformers
- Arc Lamps

} Inductive loads.

Disadvantages of low power factor:



- Size of conductor increases.
- Power loss increases
- Poor voltage regulation
- Efficiency decreases
- Overall cost increases.

* $\cos\phi \propto P_{out}$

- $\cos\phi$ ↑ses if ϕ ↓ses and P_{out} ↑ses.

* METHODS FOR POWER FACTOR CORRECTION:

- Static Capacitor
- Synchronous Condenser.
- Phaser advancer

27/08/2022

* 3-PHASE INDUCTION MOTOR:

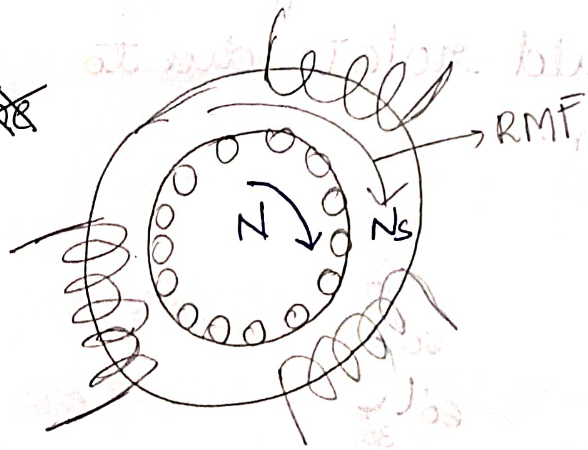
Frame
Stator
Stator Winding
Rotor
Rotor Winding
Cooling Fan
Bearings.

Types of Rotor:

- Squirrel cage rotor
- ~~Split ring~~
- slip ring rotor.

→ The wires of rotor in a squirrel cage rotor are placed in diagonal position so avoid locking of the flux.

* ~~Dia~~



Magnetically coupled ~~&~~ circuits are called inductive.

- AC supply is provided only to the stator

* The speed of the rotating magnetic field. is called synchronous speed.

* Rotor speed = N.

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

f → frequency
P → poles.

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* ~~The~~

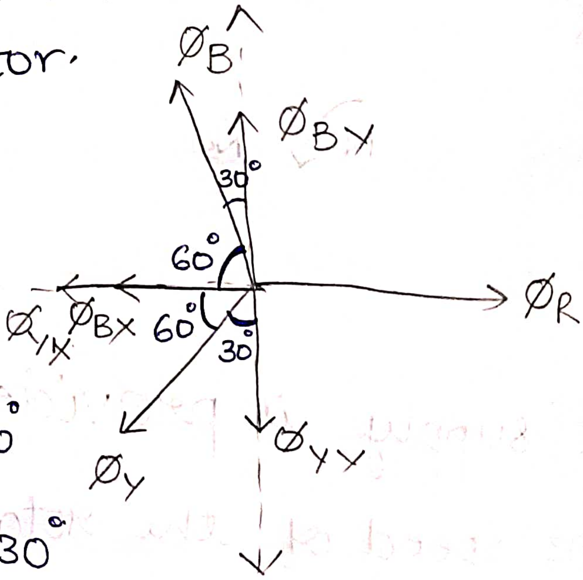
* There should be relative ~~sp~~ motion b/w conductor and flux generated.

If $N_s = N$ → the motor will not rotate; since relative motion and induction becom zero.

$$\boxed{Slip = \frac{N_s - N}{N_s}}$$

* **Rotating Magnetic Field (RMF)**

Due to the 3 inputs; the magnetic field generated should rotate due to motion in the rotor.



$$\phi_x = \phi_R - \phi_B \cos 60^\circ - \phi_y \cos 60^\circ$$

$$\phi_y = \phi_B \sin 60^\circ - \phi_y \sin 60^\circ$$

$$= \phi_B \cos 30^\circ - \phi_y \cos 30^\circ$$

$\phi_R = \phi_m \sin\omega t$

$\phi_y = \phi_m \sin(\omega t - 120^\circ)$

$\phi_B = \phi_m \sin(\omega t +$

$$\phi_x = \phi_m \left[\sin\omega t - \left[\sin(\omega t + 120^\circ) \cos 60^\circ + \sin(\omega t - 120^\circ) \cos 60^\circ \right] \right.$$

$$= \phi_m \left[\sin\omega t - \frac{1}{2} \left[2 \sin\omega t \cos 120^\circ \right] \right.$$

$$\phi_x = \phi m \left[\sin\omega t - \sin\omega t \left(\frac{-1}{2}\right)\right]$$

$$\boxed{\phi_H = \phi m \left(\frac{3}{2}\sin\omega t\right)}$$

$$\phi_y = \phi m \frac{\sqrt{3}}{2}\left[+2\cos\omega t \sin 120^\circ\right]$$

$$= \phi m \frac{\sqrt{3}}{2} \times \frac{\sqrt{3}}{\cancel{2}} \times \cancel{2} \cos\omega t$$

$$\boxed{\phi_V = \frac{3}{2}\phi m \cos\omega t}$$

$$\cancel{\phi = \sqrt{\left(\frac{3}{2}\right)^2 \phi m^2 + \left(\frac{3}{2}\right)^2 \phi m^2}}$$

$$\phi = \sqrt{\left(\frac{3}{2}\phi m\right)^2} = \frac{3}{2}\phi m$$

$$\boxed{\phi_R = \frac{3}{2}\phi m} \Rightarrow \text{Resultant flux.}$$

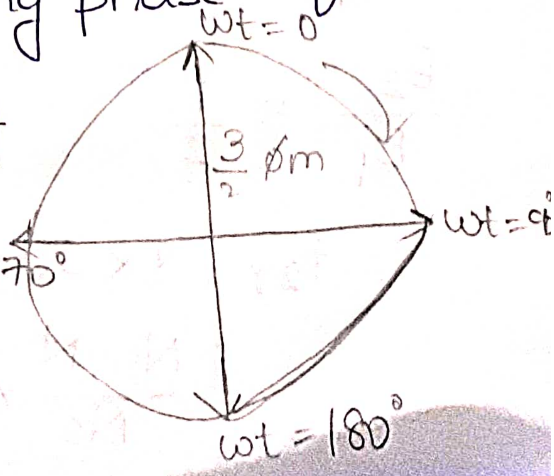
$$\cancel{\tan\phi = \frac{\phi_V}{\phi_H} = \tan\theta}$$

$$\tan\psi_R = \text{phase angle} = \frac{\phi_V}{\phi_H} = \cot\omega t = \cot\theta$$

$$\boxed{\psi_R = \frac{\pi}{2} - \theta}$$

* We can change the direction of flux generated by changing phase sequence.

- Interchanging any 2 terminals of input



* Effect of slip on various rotor parameters:

- → Rotor frequency (f_{2r})
- → Rotor induced emf (E_{2r})
- → Rotor ~~ind~~ reactance (X_{2r})
- → Rotor power factor ($\cos\phi_{2r}$).
- → Current (I_{2r})

* $\dfrac{N_s - N}{N_s} = \dfrac{f_{2r}}{f_2} = S$

* $E_2 \propto N_s$

$E_{2r} \propto N_s - N$

$\dfrac{E_2}{E_{2r}} = \dfrac{N_s}{N_s - N} = \dfrac{1}{S}$

$\boxed{E_{2r} = E_2 S}$

* $X_2 = 2\pi f_2 L_2$

$X_{2r} = 2\pi f_{2r} L_2.$

$\boxed{X_{2r} = S X_2}$

$Z_{2r} = \sqrt{R_2^2 + (SX_2)^2}$

* $\cos\phi_2 = \dfrac{R_2}{Z_2} = \dfrac{R_2}{\sqrt{R_2^2 + X_2^2}}$

$\cos\phi_{2r} = \dfrac{R_2}{Z_{2r}} = \dfrac{R_2}{\sqrt{R_2^2 + (SX_2)^2}}$

* $I_{2r} = \dfrac{E_{2r}}{Z_{2r}}$

$= \dfrac{SE_2}{\sqrt{R_2^2 + (SX_2)^2}}$

* $P = 4$ pole $\quad f = 50\text{Hz} \quad N = 1455$ rpm.

$\dfrac{E_2}{E_1} = \dfrac{1}{2}$

$f_r = ?$

$E_2 = ?$

$E_{2r} = ?$

$f_{2r} = S \times 50$

$= \dfrac{N_s - N}{N_s} \times 50$

$N_s = \dfrac{120f}{P} = 1500$

$$f_{2r} = \frac{45 \times 50}{1500} = 1.5\,Hz.$$

$$E_{2r} = S \cdot E_2$$

$$\frac{E_2}{E_1} = \frac{1}{2}$$

$$E_2 = \frac{415}{2\sqrt{3}}$$

$$= 1198\,V.$$

$$= \frac{45}{1500} \times 1198$$

$$= 3.59\,V$$

* POWER STAGES IN INDUCTION MOTOR:

Input to Motor. (P_i)

- Rotor input (P_2)
  - Rotor output (or) Mechanical Power developed. (P_m)
    - Motor Output (P_o)
    - Windage & Friction losses.
  - Rotor copper losses. (P_{cu})
- Stator copper & iron losses.

* Relation b/w Rotor Copper Loss & Rotor: T_d, N_s & N

$$P_2 = \omega_s T_d$$

$$= \frac{2\pi N_s}{60} T_d \quad \text{(Input Power to rotor)}$$

$$P_{in} = \omega_r T_d = \frac{2\pi N}{60} T_d$$

$$\boxed{P_{cu} = P_2 - P_m}$$

$$P_{cu} = \frac{2\pi}{60}(N_s - N) T_d$$

$$\frac{P_{cu}}{P_2} = \frac{N_s - N}{N_s} = S$$

$$\boxed{P_{cu} = S P_2}$$

$$P_m = P_2 - P_{cu}$$

$$\boxed{P_m = (1-S) P_2}$$

$$\boxed{\frac{P_m}{P_{cu}} = \frac{1-S}{S}}$$

$$\boxed{\frac{P_m}{P_2} = 1 - S}$$

$$P_2 : P_m : P_{cu} = \frac{P_{cu}}{S} : \frac{1-S}{S} P_{cu} : P_{cu}$$

$$\boxed{P_2 : P_m : P_{cu} = 1 : (1-S) : S}$$

* Torque in an Induction motor:

Electrical power generated in rotor under running condition.

$$= 3 E_{2r} I_{2r} \cos\phi_{2r}$$

$$= 3 E_{2r} \cdot \frac{E_{2r}}{Z_{2r}} \cdot \frac{R_2}{\sqrt{R_2^2 + (S X_2)^2}}$$

$$\boxed{P = \frac{3 E_{2r}^2 R_2 S^2}{R_2^2 + (S X_2)^2}}$$

→ I^2R (copper Losses).

input power to rotor $= \frac{2\pi N_s T_d}{60}$

$S \times$ rotor input = rotor copper Loss (P_{cu})

$$\frac{S \times 2\pi N_s T_d}{60} = 3\left(\frac{E_2^2 s^2}{R_2^2 + s^2 X_2^2}\right) R_2$$

$$\boxed{T_d = \frac{K S E_2^2 R_2}{R_2^2 + S^2 X_2^2}} \quad \therefore \frac{3}{\left(\frac{2\pi N_s}{60}\right)}$$

* Torque Slip Characteristics :

$$T_d = \frac{K S E_2^2 R_2}{R_2^2 + S^2 X_2^2}$$

$$T_d = \frac{S R_2}{R_2^2 + (S X_2)^2}$$

E_2 = supply voltage

region.

$$\cancel{R_2^2 >>> (S X_2)^2}$$

$$\cancel{T_d \propto \frac{S R_2}{R_2^2}}$$

$$\cancel{\boxed{T_d \propto \frac{S}{R_2}}}$$

Low slip region:

$$R_2^2 >>> (S X_2)^2$$

$$R_2^2 + (S X_2)^2 = R_2^2$$

$$\boxed{T_d \propto S}$$

High slip region:

$$(S X_2)^2 >>> R_2^2$$

$$R_2^2 + (X S_2)^2 = (X_2 S)^2$$

$$\boxed{T_d \propto \frac{1}{S}}$$