22/09/2022

* STEPPER MOTORS:

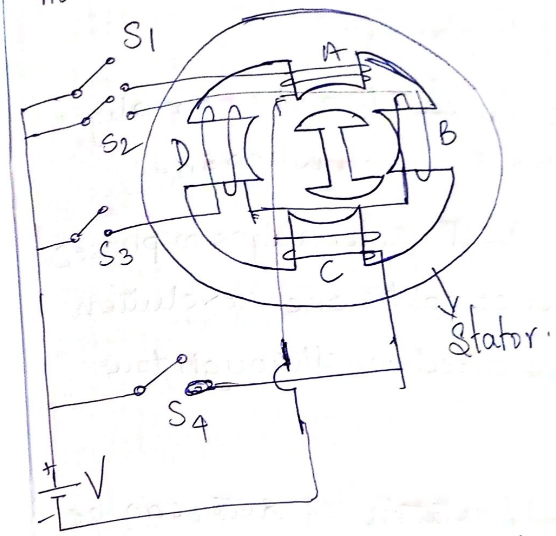
→ Rotor moves in discrete steps.

Types of motors:

1) Variable Reluctance type (VR)
2) Permanent magnet type (PM)
3) Hybrid type, a combination of VR & PM

⟹ VARIABLE RELUCTANCE (VR) TYPE: STEPPER MOTOR

- property of flux lines to occupy low reluctance path.
- Therefore, stator and rotor should be aligned such that magnetic reluctance is minimum.
- Stator has connected windings placed over the stator poles.
- Rotor carries no windings.
- Stator and Rotor are made up of high quality magnetic materials that have high permeability.
- Stator phases are excited in a proper sequence from a DC source using semi-conductor switches; there is a magnetic field generated.
- Rotor occupies the position which presents minimum reluctance to the stator field.



→ It is 4 phase 4/2 pole (4 poles in stator & 2 poles in rotor) single stack variable reluctance stepper motor.

→ Four phases A, B, C, D are connected to DC source with the help of semi conductor switches S_A, S_B, S_C, S_D.

→ Phase windings are energised in sequence.

A ⟶ B ⟶ C ⟶ D ⟶ A.

* A is excited; rotor aligns its position to the axis of phase A and cannot move until phase A is de-energised.

* Switch off S_A and on S_B: where rotor moves 90° in clockwise and aligns itself to phase B.

* Further C is excited and rotor aligns itself to phase C and when S_D is on and S_C is off; rotor aligns to phase D.

* In this rotor completes one revolution in clockwise direction through four steps.

* The direction of rotation of rotor can be reversed by reversing the sequence of switches i.e. A D C B A

* Direction of rotation depends only on sequence of switching the phase & independent of direction of current.

magnitude of step angle

$$\boxed{\alpha = \frac{360^\circ}{m_s N_r}}$$

$\alpha \rightarrow$ step angle

$m_s \rightarrow$ no. of stator phases

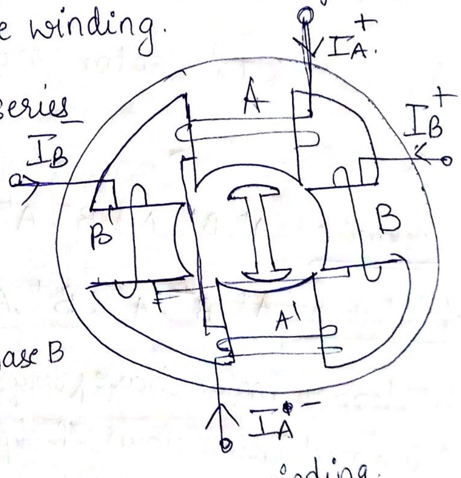
$N_r \rightarrow$ no. of rotor teeth poles.

⇒ PERMANENT MAGNET (PM) STEPPER MOTOR:

- Rotor is cylindrical and consists of permanent magnet poles made of high retentivity steel.
- The concentrated winding on diametrically opposite poles are connected in series to form 2 phase winding on stator
- Rotor poles align with stator poles depending on excitation of phase winding.

A-A' connected in series to form phase A winding.

B-B' connected in Series to form phase B windings.



when I_A^+ passes through phase A winding South pole of rotor is attracted by the stator so that magnetic axes of the stator & rotor coincide $\alpha = 0°$

$\alpha = 0°$

If current flows only in phase B winding rotor poles are attracted by stator & rotor moves by 90° in clockwise direction

$\alpha = 90° \Rightarrow I_B^+$

If current is I_A^-; rotor moves further by 90° i.e. $\alpha = 180°$

If current is I_B^-; rotor moves further by 90° i.e. $\alpha = 270°$

If current is I_A^+ rotor moves by 90° & $\alpha = 360°$

Clockwise: $A^+, B^+, A^-, B^-, A^+ \ldots$

Anticlockwise: $A^+, B^-, A^-, B^+, A^+, \ldots$

PM stepper motor have higher inertia & low acceleration than VR stepper motors.

*Brushless DC Motor:

- runs on DC source but don't have brushes and commutator.
- Superior efficiency, long life, smooth torque delivery and high speed operation

DC motor have excessive sparking and brush wear

∵ No brushes in BLDC ∴ no sparking & no brush wear and no need of replacement of brushes.

*→ Components of BLDC:

1) permanent magnet rotor
2) Stator with 3-4 phase windings.
3) rotor position sensor.
4) electric circuit to control phase of rotor winding.

* Working of BLDC:

- A BLDC motor functions by energizing one stator coil at a time using const. DC voltage.
- When coil is turned on it produces a stator magnetic field (Bs) and torque $T = KBr \times Bs$
  - aligns rotor with stator magnetic field.

  Br → stator magnetic field points up producing a counter clockwise torque on rotor.
  - Therefore, rotor turns left.

* The key to the operation of a BLDC motor is that; it includes a position sensor. So that control will know when rotor is

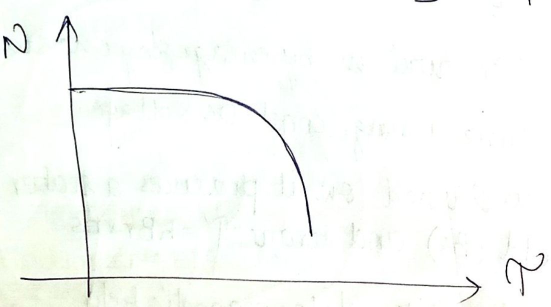
almost aligned with stator magnetic field.

* position sensor is used to switch the energized stator coil; when rotor is almost aligned; keeping the rotor rotating speed set by control electronics.

→ Salient pole rotors: /projected pole:

application with speeds from 100 to 1500rpm.

→ Non salient pole rotors → application at higher speeds: 1500rpm & above



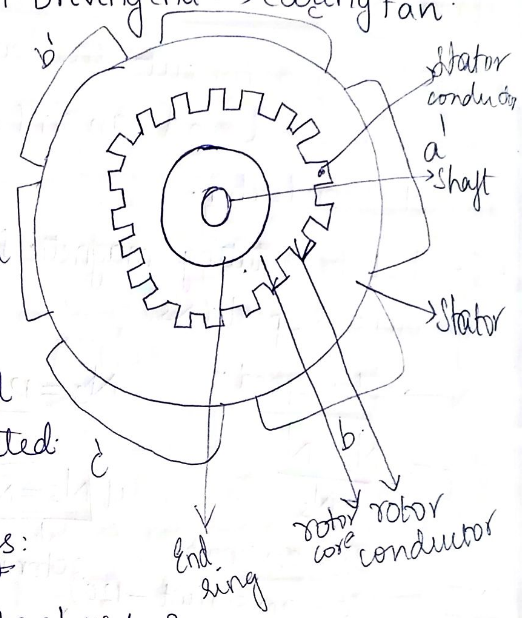
* 3 phase induction Motor:

Components:

Frame
Stator
Stator Winding
Rotor
Rotor winding

Cooling fan
Bearings.

- Frame → mechanical support to both stator & rotor.
- Stator → stationary part of induction motor.
- Rotor → • Driving end → mechanical load
  • Non-Driving end → cooling fan.



Stator windings:

- Star connected
- Delta connected

Rotor Windings:

wound as rotor bars & short circuited at both ends.

Types:

Squirrel Cage:

- Laminated cylindrical core consisting of parallel slots joined at each end using end rings

Slip-Ring:

- Laminated cylindrical core and carries a 3-phase winding.
- star connected rotor windings whose open ends are brought together using slip rings

Working:

* A Rotating Magnetic field is set up in the stator when a 3-phase supply is given.
* Stationary rotor cut the revolving magnetic field and an emf is induced in rotor conductor.
* Speed of the rotating magnetic field is called synchronous speed (Ns)

$N \rightarrow$ rotor speed. $N_s = \frac{120f}{P}$ $f \rightarrow$ frequency, $P \rightarrow$ poles.

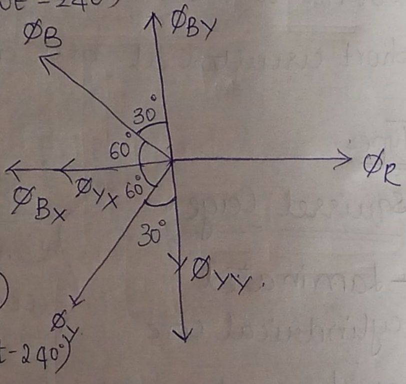
$$\text{slip} = \frac{N_s - N}{N_s}$$

if $\boxed{N_s = N}$ → rotor will not rotate.

RMF:
$$\phi_R = \phi_m \sin\omega t$$
$$\phi_B = \phi_m \sin(\omega t - 120^\circ)$$
$$\phi_Y = \phi_m \sin(\omega t - 240^\circ)$$

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

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



$$\phi_x = \phi_R - \frac{\phi_m}{2}\left[\sin(\omega t - 120^\circ) + \sin(\omega t - 240^\circ)\right]$$

$$\phi_x = \phi_m\left[\sin\omega t - \frac{1}{2}\left[\sin\omega t\left(\frac{-1}{2}\right) - \cos\omega t\,\frac{\sqrt{3}}{2} + \sin\omega t\left(\frac{-1}{2}\right) - \cos\omega t\left(\frac{-\sqrt{3}}{2}\right)\right]\right]$$

$$\phi_x = \phi_M\left[\sin\omega t + \frac{1}{2}\left[\sin\omega t\right]\right] = \frac{3}{2}\phi_M \sin\omega t$$

$$\boxed{\phi_x = \frac{3}{2}\phi_M \sin\omega t}$$

$$\phi_y = \frac{\sqrt{3}}{2}\left[\phi_M \sin(\omega t - 120^\circ) - \phi_M \sin(\omega t - 240^\circ)\right]$$

$$= \frac{\sqrt{3}}{2}\phi_M\left[\sin\omega t\left(\frac{-1}{2}\right) - \cos\omega t\left(\frac{\sqrt{3}}{2}\right) + \sin\omega t\left(\frac{1}{2}\right) + \cos\omega t\left(-\frac{\sqrt{3}}{2}\right)\right]$$

$$= \frac{\sqrt{3}}{2}\phi_M\left(+\sqrt{3}\cos\omega t\right) = \frac{3}{2}\phi_M \cos\omega t$$

$$\boxed{\phi_y = \frac{3}{2}\phi_M \cos\omega t}$$

$$\boxed{\phi_R = \frac{3}{2}\phi_M}$$

$\tan\theta = \cot\omega t =$

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

* Effect of slip on various rotor parameters:

- rotor frequency $\boxed{f_{2r} = s f_2}$
- rotor induced emf $\boxed{E_{2r} = sE_2}$
- rotor reactance $\boxed{X_{2r} = sX_2}$ $\boxed{Z_{2r} = \sqrt{R_2^2 + (sX_2)^2}}$
- Rotor power factor. $\boxed{\cos\phi_{2r} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}}$
- Rotor current $\boxed{I_{2r} = sE_2 / \sqrt{R_2^2 + (sX_2)^2}}$

* Power Stages:

- Input to Motor (P_i)
  - Rotor Input (P_2)
    - Mechanical Power (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 power:

$$P_2 = \omega_s T_d = \frac{2\pi N_s}{60} T_d$$

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

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

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

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

$$\frac{P_{cu}}{P_M} = \frac{N_s - N}{N} = \frac{SN_s}{N}$$

$$\frac{P_M}{P_2} = \frac{N}{N_s}$$

$$\boxed{\frac{P_M}{P_{cu}} = \frac{1-s}{s}}$$

$$\boxed{P_2 : P_M : P_{cu} = 1 : (1-s) : s}$$

* Torque in an induction motor:

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

$$= 3E_{2r} \cdot \frac{E_{2r}}{Z_{2r}} \cdot \frac{R_2}{\sqrt{R_2 + (SX_2)^2}}$$

$$\boxed{P = \frac{3E_{2r}^2 R_2 S^2}{R_2^2 + (SX_2)^2}}$$

I^2R losses:

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

$$S \times \text{rotor input} = \text{rotor copper loss}$$

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

$$\boxed{T_d = \frac{KSE_2^2 R_2}{R_2^2 + s^2 X_2^2}}$$

* Torque Slip characteristics:

$$\boxed{T_d = \frac{SR_2}{R_2^2 + (SX_2)^2}}$$

Low slip region:

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

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

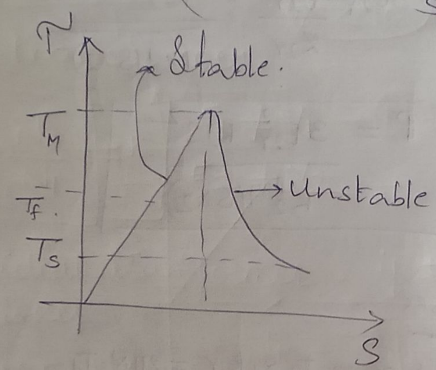
$T_d \propto S$

High slip region:

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

$R_2^2 + (S X_2)^2 \approxeq (X_2 S)^2$

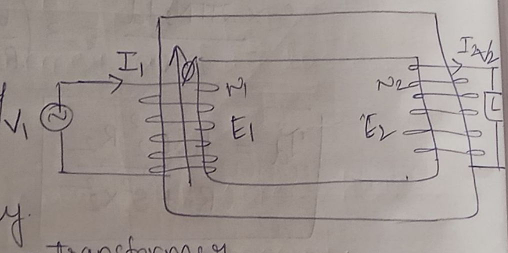
$T_d \propto \frac{1}{S}$



* TRANSFORMERS:

winding connected to load → secondary

winding connected to AC source → primary



$V_2 > V_1 \longrightarrow$ step-up transformer

$V_1 > V_2 \longrightarrow$ step-down Transformer

When an alternating emf V_1 is applied to transformer to the primary winding ~~and~~ flux is developed in the coil.

This flux links both the windings & induces emfs E_1 & E_2

where $E_1 = -N_1 \frac{d\phi}{dt}$

$E_2 = -N_2 \frac{d\phi}{dt}$

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

- Electromagnetic Induction.

flux remains constant in both windings

- Losses in transformer:
  - core losses ⇒ eddy current & hysteresis loss
  - copper losses ⇒ resistance of windings.

*→ Ideal Transformer:

(i) no winding resistance.

(ii) no leakage flux.

(iii) no iron losses. in the core.

* EMF Equation of a transformer:

$\phi = \phi_M \sin wt$

$e_1 = -N_1 \frac{d\phi}{dt} = -N_1 \frac{d}{dt}(\phi_M \sin wt)$

$= -N_1 \phi_M w \cos wt$

$= 2\pi f N_1 \phi_M \sin(wt - 90^\circ)$.

$E_{M1} = 2\pi f N_1 \phi_M$

$E_1 = \frac{E_{M1}}{\sqrt{2}} = \frac{2\pi f N_1 \phi_M}{\sqrt{2}}$

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

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

* Voltage Transformation Ratio (K)

$$K = \frac{V_2}{V_1} = \frac{E_2}{E_1} = \frac{N_2}{N_1} \Rightarrow \text{Ideal Transformer}$$

$E_1 = V_1,\ E_2 = V_2$

for any transformer

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = K} \quad \because E_1 \neq V_1,\ E_2 \neq V_2$$

In an ideal transformer, if there are no losses

$$V_1 I_1 = V_2 I_2$$

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

* Practical Transformer and its losses:

(i) Iron Losses:

Alternating flux in iron core; where eddy current & hysteresis loss occur.

Iron losses depend on magnetic flux density, supply frequency etc.

(ii) Winding Resistances:

Being made up of copper, the windings too generate a ~~less~~ power loss (I^2R)

(iii) Leakage Reactances:

The flux generated in the coil is called a mutual flux since it joins both primary & secondary coils.

- primary current produces flux ϕ_1
- secondary current produces flux ϕ_2

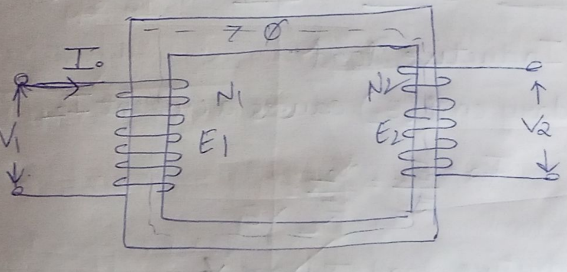
where these ϕ_1 / ϕ_2 link only one winding; either primary or secondary respectively.

These flux ϕ_1 and ϕ_2 are called leakage flux.

$\therefore$ primary leakage flux ϕ_1 introduces inductive reactance X_1 and secondary leakage flux ϕ_2, introduces inductive reactance X_2.

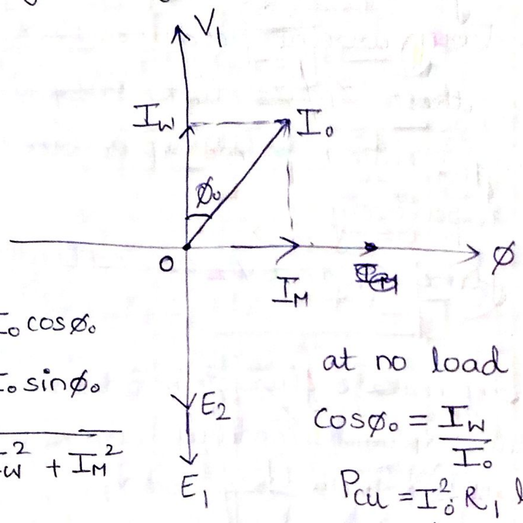
* Practical Transformer on no load:

No load $\Rightarrow$ secondary is open circuited.



Only a current I_0 flows in primary circuit where this I_0 is divided among I_w (iron loss component) & I_M (magnetising component).

$\therefore I_0$ lags V_1 by angle $\phi_0 < 90^\circ$



$\therefore I_W = I_0 \cos\phi_0$

$I_M = I_0 \sin\phi_0$

$I_0 = \sqrt{I_W^2 + I_M^2}$

at no load

$\cos\phi_0 = \frac{I_W}{I_0}$

$P_{cu} = I_0^2 R_1$ loss.

↓

$I_0 \to$ small

$\therefore$ loss can be neglected.

* Ideal Transformer On load:

$Z_L \to$ Inductive load

Secondary emf (E_2) causes a current I_2

$$I_2 = \frac{E_2}{Z_L} = \frac{V_2}{Z_L}$$

$\because$ Inductive load I_2 lags V_2

$\because$ flux in the coil should remain constant

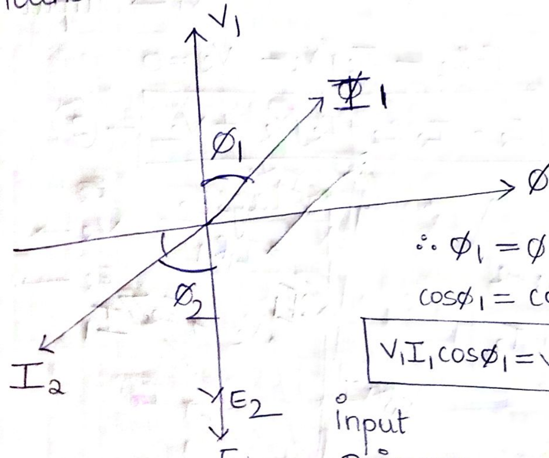
$\therefore$ current I_1 in primary should be:

* If capacitive load I_2 leads V_2

$N_1 I_1 = N_2 I_2$

$I_1 = \frac{N_2 I_2}{N_1} \Rightarrow \boxed{I_1 = k I_2}$

$\Rightarrow$ Primary must draw enough current to neutralise the demagnetising effect of secondary current so that mutual flux remains constant.



$\therefore \phi_1 = \phi_2$

$\cos\phi_1 = \cos\phi_2$

$\boxed{V_1 I_1 \cos\phi_1 = V_2 I_2 \cos\phi_2}$

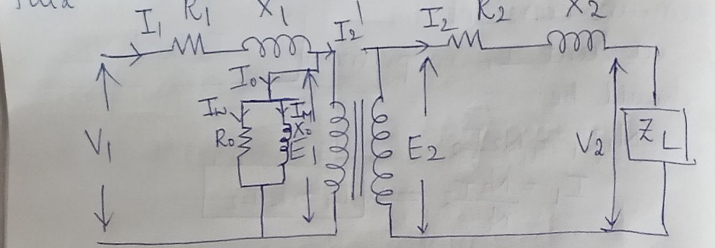
Input primary power = output secondary power.

* Practical Transformer on ~~no~~ load with resistance & leakage reactance.

Primary current I_1 being divided as

$I_0 \to$ for ironloss & magnetising loss

$I_2' \to$ demagnetise the effect of secondary flux.



$V_1 - I_1R_1 - I_1jX_1 - E_1 = 0$

$\boxed{V_1 = I_1R_1 + I_1jX_1 + E_1}$ — (1)

where E_1 lags V_1 $\quad E_1 \rightarrow$ source

$V_1 \rightarrow$ output

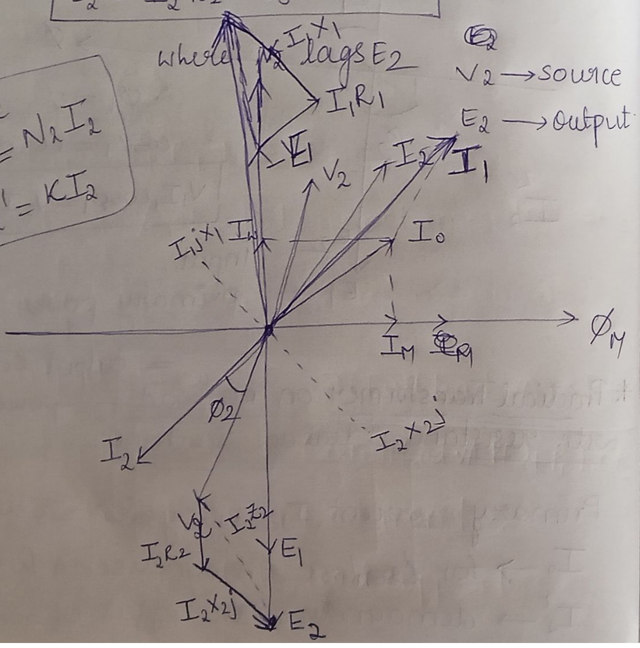
$E_2 - I_2R_2 - I_2jX_2 - V_2 = 0$

$\boxed{E_2 = I_2R_2 + I_2jX_2 + V_2}$ — (2)

where V_2 lags E_2 $\quad V_2 \rightarrow$ source

$E_2 \rightarrow$ output

where
$N_1I_2' = N_2I_2$
$I_2' = KI_2$



Impedance ratio:

$Z_2 = \frac{V_2}{I_2} \qquad Z_1 = \frac{V_1}{I_1}$

$\frac{Z_2}{Z_1} = \frac{V_2}{I_2} \times \frac{I_1}{V_1} = K \cdot K = K^2$

* Shifting Impedances in transformer:

* Primary to secondary reference

∵ primary has high resistance & reactance.

∴ when these are referred to secondary

$\cancel{R_1 = \frac{R_1}{K^2}}$ $\qquad R_{02} = R_2 + R_1'$

$= R_2 + K^2R_1$

$\boxed{Z_{02} = \sqrt{R_{02}^2 + X_{02}^2}}$ $\qquad X_{02} = X_2 + X_1'$

$= X_2 + X_1K^2$

* Secondary to primary reference:

∵ $R_{01} = R_1 + R_2'$

$= R_1 + R_2/K^2$ $\qquad \boxed{Z_{01} = \sqrt{R_{01}^2 + X_{01}^2}}$

$X_{01} = X_1 + X_2'$

$= X_1 + X_2/K^2$

If we shift all impedances to one winding: we can eliminate transformer and solve as equivalent electrical circuit.

* Losses:

Iron/ Core Losses (P_i) → Hysteresis Loss.
→ Eddy current loses.

Constant losses

Hysteresis loss can be minimised using steel of high silicon content.

Eddy Current losses can be reduced using core of thin laminations.

Copper Losses:

Losses in both the windings due to their ohmic resistances.

~~$P_{cu} = I_2$~~

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

↳ 90% of total transformer losses.

* Efficiency:

$$\eta = \frac{\text{Output Power}}{\text{Input Power}} = \frac{x(\text{Full load VA}) \times P.f}{(x \times \text{Full load VA} \cdot Pf) + P_i + x^2 P_c}$$

where P_i = Full Load iron loss

P_c = Full Load copper loss.

x → type of load

* Construction:

- core is made of silicon steel which has low hysteresis loss and high permeability.
  core is laminated to reduce eddy current loss.
- winding one half of each ~~limb on~~ winding on one limb: This ensures tight coupling and reduces leakage flux.
- R_1 & R_2 → reduced; rise in temp & high efficiency.

* Types → Core type
→ Shell type

* Power Factor Improvement:

∵ Most of the electronic devices used are LR circuits ∴ ~~To impro~~ the power factor lags due to which there is less power output in the device.

To improve the power factor and power output we should add a capacitor.

Active Power = $VI\cos\phi = P$

Reactive Power = $VI\sin\phi = Q$.

Apparent Power = $V*I = S$.

for Resistive load $\cos\phi = 1$

Inductive load $\cos\phi$ = Lagging

capacitive load $\cos\phi$ = Leading.

* Fuse:

A fuse is a short piece of metal inserted in the circuit; which melts when excessive current flows in the circuit and thus breaks the circuit.

Characteristics:

- Low melting point
- High conductivity
- Free from deterioration due to oxidation
- Low cost.

Materials used: tin, lead, tinned copper, Ag

Types:

(i) Re-wireable / Kit-Kat fuse:

- low values of fault current can be interrupted.
- simple, cheap; available upto current of 200A.
- Erratic in operation & performance deteriorates with time.

(ii) High Rupturing Capacity Cartridge Fuse:

- Consists of heat resisting ceramic body having metal end caps to which a silver current carrying element is welded. The space b/w surrounding elements is filled with chalk, POP etc.
- carries normal current without overheating
- Fault occurs, current increases and the fuse element melts and heat produced; vaporizes the melted silver element.
- Reaction b/w silver vapours and filling powder results in the formation of high resistance which is used in quenching the arc.

* Circuit Breaker:

Switching device which can be operated manually / automatically for controlling and protection of electrical system.

- Consists of fixed and moving contacts called electrodes.
- These contacts remain closed until and unless a fault occurs.
- When a fault occurs; the trip coils of the breaker get energized and moving contacts are pulled apart; thus opening circuit

Types:

→ Miniature CB
→ Residual current CB.
→ Air Blast CB.
→ Vaccum CB.

*Miniature Circuit Breaker:

→ Switching function: On/off.

Protection from overloads & short circuits.

- Electromechanical device to protect an electrical circuit from over current which may lead to shortcircuits/overload.
- MCB is better than fuse; since it need not be replaced once overcurrent is detected.
- A switch which turns off automatically when the current flowing in the circuit is more than rated value.

- When current exceeds the limit; the solenoidal forces the moveable contact to open & MCB turns off breaking the circuit

*Advantages:

- Simple to resume supply
- Better interface
- electrically safer.
- Reusable.
- less maintaince & replacement cost.

*Applications:

- Home electrical panels.
- lights.
- Heaters

*Earthing:

Process of connecting metallic bodies of all electrical equipment to a huge mass of earth by a wire of negligible resistance is called earthing.

- Discharge of electrical energy takes place smoothly without any danger.

Purpose:

- To avoid electrical shock/death.
- To protect buildings & machinery from fault conditions.
- To provide safe path to dissipate lightning or short circuit currents.

Methods of Earthing → Maintainence Free Earthing
→ Conventional Earthing.

Maintainence Free Earthing:

- No need to pour water at regular interval
- Maintain stable & consistent earth resistance.
- More surface area for peak current dissipation.

Conventional Earthing:

Digging a large pit which a GI pipe or copper plate positioned in middle layers of charcoal & salt.

- Requires maintainence & regular pouring of water.

*→ Methods of conventional Earthing:

1) Plate Earthing:

- Copper or GI plate is embedded in alternative layer of coke & salts for min. thickness.
- Earth wire is securely bolted to an earth plate with bolt nut & washer.

2) Rod Earthing:

- Copper/GI/steel rods are driven vertically into earth.
- We need to ↑se the embedded length of electrode under the ground which is necessary to reduce the earth resistance.
- Very cheap.

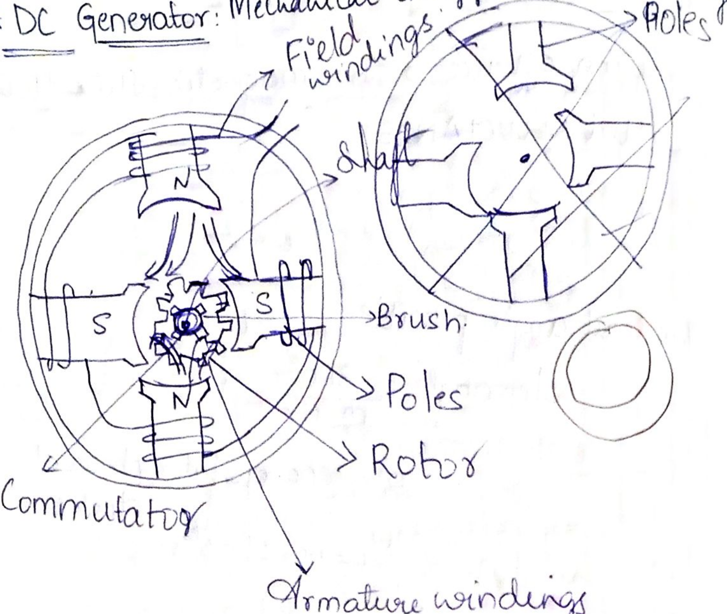
3) Pipe Earthing:

- Earthing a GI pipe vertically in ground to work as earth electrode & depth depends upon soil conditions.
- Wire is embedded upto wet soil.
- Can take heavy leakage current compared to Plate earthing.

* Applications:

- Telecommunication
- Transmission
- Power Generations
- Residential Building
- Water Treatment plants.

* DC Generator: Mechanical Energy to Electrical energy



When current starts flowing; magnetic field is produced.

In all rotating machines; ~~d~~ dynamically induced emf is seen.

When the rotor starts rotating; there is an emf induced.

- Supply is given → current starts flowing
- Magnetic field is produced → Relative motion in b/w
- Emf is induced in rotor conductor
- Current starts flowing.

* ~~An~~ DC emf is induced in the circuit due to an AC source.

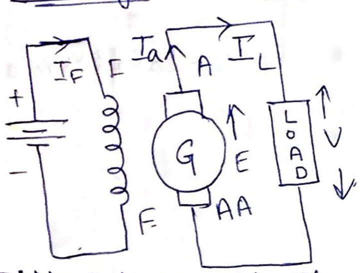
Principle: Whenever there is a change in flux linkage; an emf is induced in the circuit.

Stator:
- Magnetic frame
- Pole cores & pole shoes.
- field windings
- Brushes & Brush holders
- End covers

Rotor:
- Armature Core
- Armature winding
- Commutator
- Shaft.

TYPES → Separately excited
TYPES → Self Excited → DC shunt, DC series, DC compound.

Separately excited DC Generator:



∵ field is supplied from external DC source. and the excitation to the field & armature are separate

- Field winding consists of large no. of turns.

resistance of field is high: in order to limit the field current.

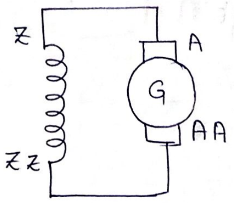
$I_a = I_L$.

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

$$E = V + I_a R_a + V_{Brush}$$

↳ Brush contact drop

* Sey excited DC generator:

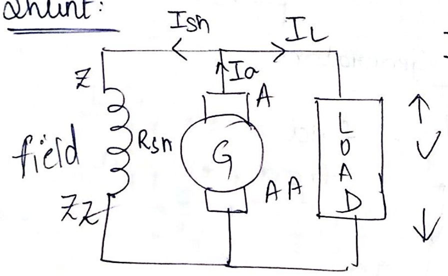


Residual Magnetism

When the generator is started; the field poles possess some procedural flux.

- flux is generated and small currents are produced by the armature in field winding

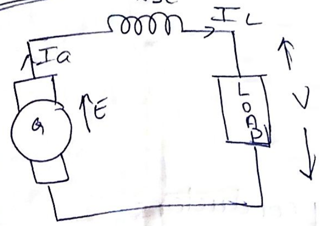
Shunt:



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

$$E = V + I_a R_a + V_{b.rush}$$

Series:



resistance of series field winding is very small with less no. of turns & thick cross section area.

$$I_a = I_L = I_{se}$$

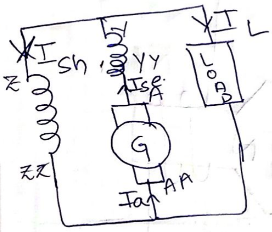
$$E = V + I_a R_a + I_{se} R_{se} + V_{brush}$$

↓ armature resistance drop

↳ series field resistance drop

* Compound:

Long Shunt:



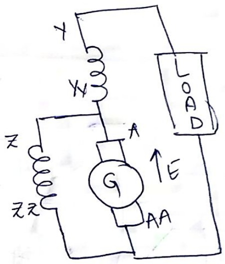
$I_a = I_{se}$.

$I_a = I_{sh} + I_L$

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

$E = V + I_a R_a + I_{se} R_{se} + V_B$ ⟶

Short Shunt:



$I_L = I_{se}$

$I_a = I_L + I_{sh}$

$$I_{sh} = \frac{E - I_a R_A}{R_{sh}}$$

EMF equation

$$e = \frac{d\phi}{dt} = \frac{P\phi N}{60} \times \frac{Z}{A}$$

where ϕ = flux

P = No. of poles

Z = total no. of conductors

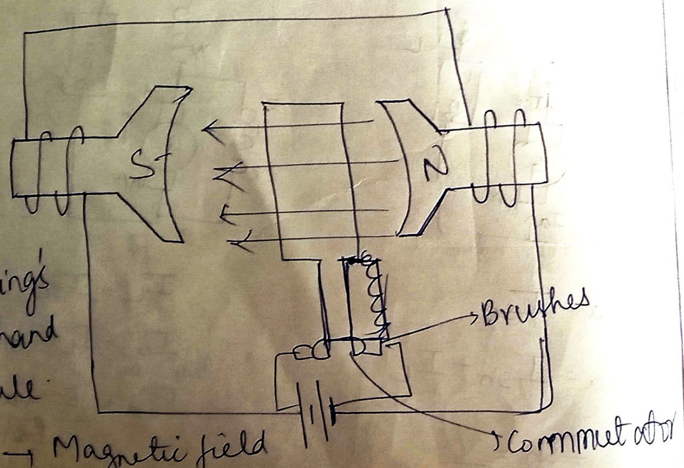
N = speed of armature

A = No. of parallel paths $\propto$ current

Lap windings: $A = P$

Wave windings: $A = 2 \Rightarrow$ constant

*DC Motors: Electrical to Mechanical



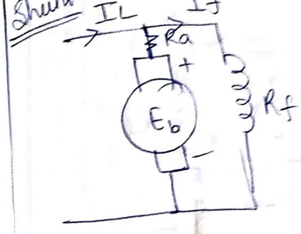
Fleming's Left hand Rule

Index $\rightarrow$ Magnetic field

Midfinger $\rightarrow$ current

Thumb $\rightarrow$ force

Shunt:



armature flux

$\rightarrow$ conductor flux

field flux

$\downarrow$

actual flux

$I_L = I_a + I_f$

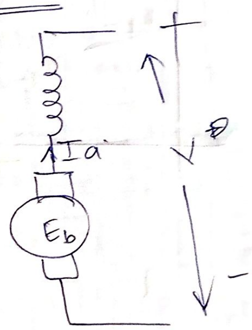
$V = I_a R_a + E_b \rightarrow$ back emf $\rightarrow$ opposes the source voltage

E_b controls the current I_a

Starter is used to limit the starting current (I_a); we need to limit the starting current to avoid damage to the circuit

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

Series:

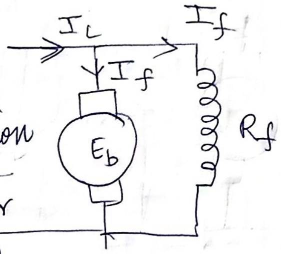


$I_L = I_{sc} = I_a$

$E_b - V = I_a R_A$

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

* Torque in DC Motor:



$P_m = E_b I_a$.

$$\text{Power} = \frac{\text{Workdone/Revolution}}{\text{time taken for one revolution}}$$

$$= \frac{F \times 2\pi r}{60/N} = Fr\left(\frac{2\pi N}{60}\right) = Fr(2\pi f) = \underline{\underline{Fr\omega}}$$

$$\boxed{P = T\omega}$$

$E_b I_a = T\omega$

$$\frac{\phi Z \cancel{N}}{\cancel{60}} \cdot \frac{P}{A} \cdot I_a = T \cdot \frac{2\pi \cancel{N}}{\cancel{60}}$$

$$T = \frac{P\phi Z}{2\pi A} I_a$$

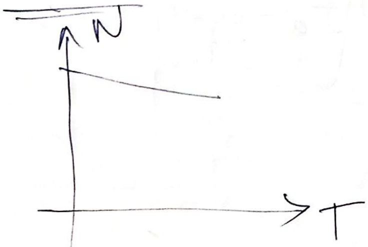
$$\boxed{T \propto I_a}$$

$E_b = \dfrac{\phi Z N P}{60A}$

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

$N \propto V - I_a R_a$.

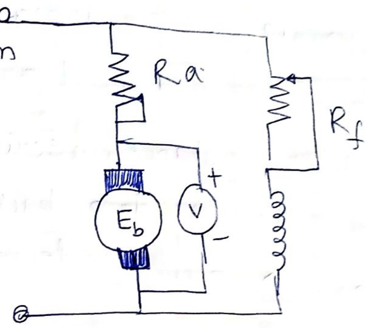
N V/s T



* Speed control of DC shunt motor:

Speed shd be minimum at beginning

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



~~Va → armature~~
~~varies Ra~~

Va can be varied with Ra at max and R_f at min. to start the circuit.

→ Varying flux per pole: Flux control method

→ varying armature resistance: armature control method.

* Flux control:

variable resistance is placed in series with field winding.

rheostat reduces shunt field current I_{sh} & hence the ~~current~~ flux ϕ.

- raise the speed of motor above rated speed.

Only above rated speeds are obtained ; ∵ Shunt field winding resistance cannot be below Rsh

* ## Armature Control :

Vary voltage across armature : hence backemf and ~~are~~ speed are changed.

Controller resistance in series with armature

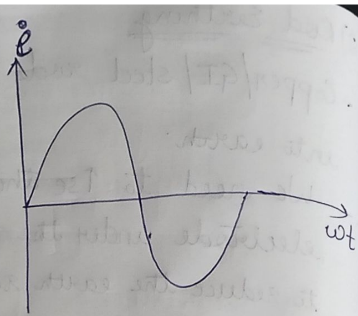
$\because$ there is a voltage drop, back emf is $\downarrow$sed

$\because N \propto E_b \Rightarrow$ speed also decreases.

* AC CIRCUITS :

$e = \hat{I}_m \sin\omega t$

$E_{max} =$



$E = E_m \sin\omega t$

E_{max}

flux linkage of coil = no. of turns × flux linking

$= n\,\phi_{max} \cos\omega t$

$e = -\dfrac{d\phi}{dt}$

$= -n\phi_m \cdot -\sin\omega t \cdot \omega$

$e = +n\phi_M \omega \sin\omega t$

$$\boxed{E_{max} = n\phi_M \omega}$$

→ Value of alternating quantity at any instant is called instantaneous value.

→ Time taken to complete one cycle of an alternating quantity is called time period.

→ No. of cycles that occur in one second.

→ Maximum value attained by an alternating quantity is called its peak value.

$\boxed{T = \dfrac{1}{f}}$ $\boxed{\omega = \dfrac{2\pi}{T}}$

$\boxed{f = \dfrac{PN}{120}}$ N ⟶ speed
P ⟶ poles.

* Average Value of Sinusoidal Current:

$I = I_m \sin\theta$

$I_{av} = \dfrac{\text{Area of half cycle}}{\text{Base length}} = \dfrac{I_m\int_0^{\pi} \sin\theta\, d\theta}{\pi}$

$= \dfrac{I_m\left[-\cos\theta\right]_0^{\pi}}{\pi}$

$= \dfrac{-I_m}{\pi}(-2) = \dfrac{2I_m}{\pi}$

$\boxed{I_{av} = \dfrac{2I_m}{\pi}}$ $\boxed{E_{av} = \dfrac{2E_m}{\pi}}$

* RMS Value of Sinusoidal Current:

$I = I_m \sin\theta$

$I_{rms} = \sqrt{\dfrac{\text{Area of half-cycle squared wave}}{\text{Half-cycle base}}}$

$= \sqrt{\dfrac{\int_0^{\pi} I_m^2 \sin^2\theta\, d\theta}{\pi}}$

$= \sqrt{\dfrac{I_m^2}{\pi}\int_0^{\pi} \dfrac{1-\cos 2\theta}{2}\, d\theta}$

$$= \frac{I_m}{\sqrt{\pi}} \sqrt{\int_0^{\pi} \frac{1}{2}\, d\theta - \int_0^{\pi} \frac{\cos 2\theta}{2}\, d\theta}$$

$$= \frac{I_m}{\sqrt{\pi}} \sqrt{\frac{\pi}{2} - \frac{1}{2} \cdot \frac{1}{2} \left[\sin 2\theta\right]_0^{\pi}}$$

$$= \frac{I_m}{\cancel{\sqrt{\pi}}} \cdot \sqrt{\frac{\cancel{\pi}}{2}} = \frac{I_m}{\sqrt{2}}$$

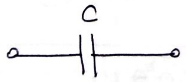
$$\boxed{I_{rms} = \frac{I_m}{\sqrt{2}}} \qquad \boxed{E_{rms} = \frac{E_m}{\sqrt{2}}}$$

* Form Factor: $\frac{\text{RMS value}}{\text{Avg value}} = \frac{\frac{E_m}{\sqrt{2}}}{\frac{E_m}{2}} = \frac{\frac{I_m}{\sqrt{2}}}{\frac{I_m}{2}}$

$= 1.11$

* Peak Factor: $\frac{\text{Max Value}}{\text{RMS. value}} = \frac{I_m \times \sqrt{2}}{I_m} = \frac{E_m \times \sqrt{2}}{E_m}$

$= 1.414$

* Capacitor:  (passive)

— 2 metallic plates separated by a dielectric which stores energy in the form of charge / electric field.

$q \propto V \Rightarrow \boxed{q = CV}$

$\boxed{i = C\frac{dV}{dt}}$ $\qquad W = \int P\, dt$

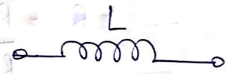
$W = \int VI\, dt = \int V C \frac{dV}{\cancel{dt}} \cancel{dt}$

$\boxed{W = \frac{CV^2}{2}}$ $\qquad \boxed{V = V_0 + \int_{0+}^{t} i\, dt}$

* When we apply DC ; capacitor acts as open circuit.

→ capacitor do not allow sudden changes in voltage.

→ Capacitor acts as voltage source initially and act as open circuit at the end.

* Inductor:  (passive)

→ Faraday's law: Rate of change of flux will generate an emf.

→ Stores energy in the form of flux or magnetic field.

$L = \frac{N^2 \mu A}{l}$

- Active elements provide energy for infinite time
- Passive elements provide energy for short interval of time.

N → turns
A → area } of bar.
l → length }

$L = \frac{\text{Flux linkage}}{\text{Ampere}}$

$\boxed{L\frac{di}{dt} = V}$ $\boxed{I = I_0 + \int_{0+}^{t} V\,dt}$

$\boxed{V = \frac{d\phi}{dt} N}$

* Inductor acts as a current source initially and acts as short circuit at the final conditions.

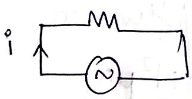
Inductor do not allow sudden changes in current

$L = L_1 + L_2$, $C = \frac{C_1C_2}{C_1+C_2}$, $R = R_1 + R_2$ } Series

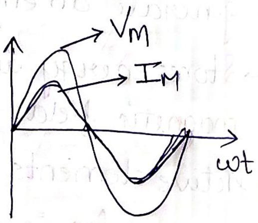
Parallel { $L = \frac{L_1L_2}{L_1+L_2}$, $C = C_1 + C_2$, $R = \frac{R_1R_2}{R_1+R_2}$

* Rotating vector is called a phasor.

* AC through pure resistance:



$V = V_m \sin\omega t$



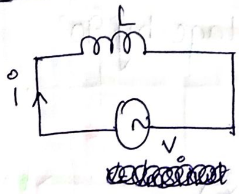
$I = I_m \sin\omega t$

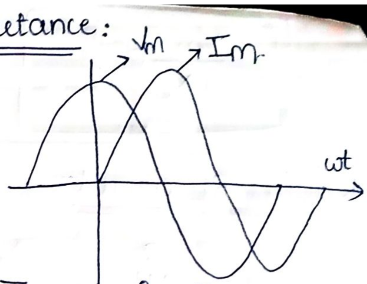
$P_{av} = \frac{V_mI_m}{\pi}\int_0^{\pi} \sin^2\theta \, d\theta$

$= \frac{V_mI_m}{2\pi}[\pi - 0] = \frac{V_mI_m}{2}$

$\boxed{P = V_{rms} \times I_{rms}}$

* AC through pure inductance:





$V = L\frac{di}{dt}$

$I = I_m \sin\omega t$

$\cancel{\frac{V}{L}dt = di}$

$V = L I_m \omega \cos\omega t$

$\boxed{V = V_m \sin(\omega t + 90^\circ)}$

$P_{av} = 0 \Rightarrow$ Inductor will not consume any power.

$\boxed{X_L = \omega L 2\pi}$

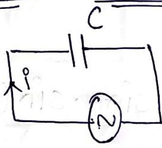
$i = I_m e^{j\omega t}$

$V = I_m \omega j L e^{j\omega t}$

$\boxed{V = jX_L I_m e^{j\omega t}}$

current lags voltage by 90°.

* AC through pure capacitance:



$i = C\frac{dv}{dt}$

$= CV_m \cos\omega t \cdot \omega$ $V = V_m \sin\omega t$

$\boxed{i = I_m \cos\omega t}$

$\boxed{i = I_m \sin(\omega t + 90^\circ)}$

$\boxed{X_C = \frac{1}{2\pi f C}}$

$i = -jX_C V_m e^{-j\omega t}$

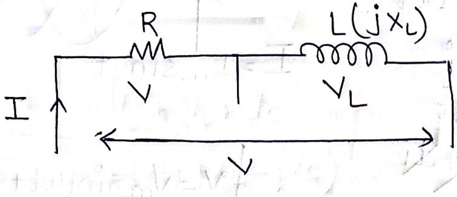
$V = V_m e^{j\omega t}$

$i = -V_m j\omega e^{-j\omega t}$

$$\boxed{i = \frac{V_m}{jX_C} e^{-j\omega t}}$$

current leads voltage by 90°

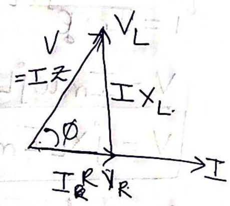
* Series RL circuit:



$$\bar{V} = \bar{V}_R + \bar{V}_L \qquad \boxed{Z = R + jX_L}$$

$$V = IR + IjX_L$$

$$\boxed{I = \frac{V}{R + jX_L}}$$



Phasor $V = V_m \sin\omega t$

$$I = I_m \sin(\omega t - \phi)$$

$$P = \int_0^{\pi} \frac{P}{\pi} \, d\theta$$

$$P = \frac{1}{\pi} \int_0^{\pi} V_m I_m \sin\theta \cdot \sin(\theta - \phi) \, d\theta$$

$$= \frac{V_m I_m}{\pi} \int_0^{\pi} \sin\theta \left[\sin\theta\cos\phi - \cos\theta\sin\phi\right] d\theta$$

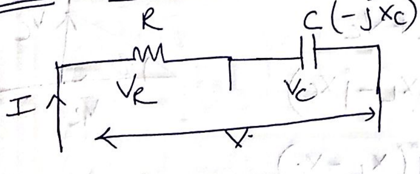
$$= \frac{V_m I_m}{\pi} \int_0^{\pi} \left[\sin^2\theta \cos\phi - \frac{1}{2}\sin 2\theta \sin\phi\right] d\theta$$

$$= \frac{V_m I_m}{\pi} \left[\frac{\cos\phi}{2}(\pi) + \frac{\sin\phi}{2} \cdot \frac{1}{2}(1-1)\right]$$

$$P = \frac{V_m I_m}{\cancel{\pi}} \cdot \frac{\cancel{\pi}\cos\phi}{2}$$

$$\boxed{P = \frac{V_m I_m \cos\phi}{2}} \qquad \boxed{P = V_{rms} I_{rms} \cos\phi}$$

* Series RC circuit:

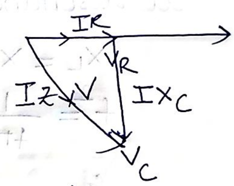


$$\bar{V} = \bar{V}_R + \bar{V}_C \qquad \boxed{Z = R - jX_C}$$

$$V = I(R - jX_C)$$

$$\boxed{I = \frac{V}{R - jX_C}}$$

Phasor



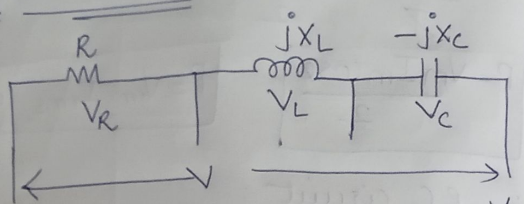
$$V = V_m \sin(\omega t)$$

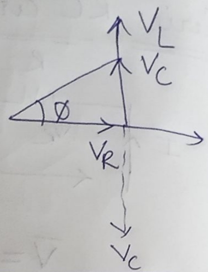
$$I = I_m \sin(\omega t + \phi)$$

$$P = \frac{1}{\pi} \int_0^{\pi} V_m I_m \sin\omega t \sin(\omega t + \phi)$$

$$\boxed{P = \frac{V_m I_m}{2} \cos\phi}$$

* Series LCR circuit :





$V = V_R + V_L + V_C$

$= I(R + jX_L - jX_C)$

$V = IR + Ij(X_L - X_C)$

$\boxed{I = \frac{V}{Z}}$ $\boxed{Z = R + j(X_L - X_C)}$

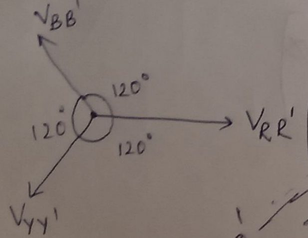
$X_L = 2\pi f L$ $X_C = \frac{1}{2\pi f C}$

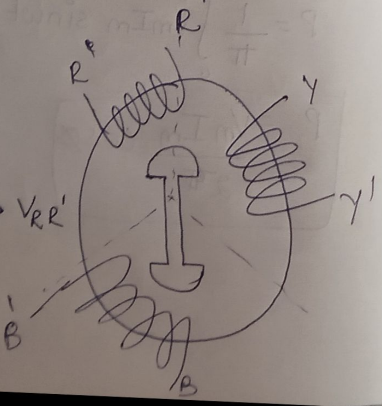
at resonance condition

$X_L = X_C$

$f^2 = \frac{1}{4\pi^2 LC} \Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{LC}}}$

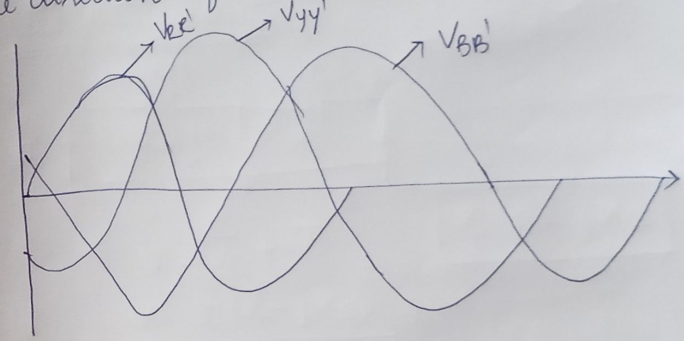
* Three Phase Circuits :





The order in which the phases attain their maximum / reference value is called phase sequence.

By changing the phase sequence; we can change the direction of current.



$V_{RR'} = V_m \sin\omega t$

$V_{YY'} = V_m \sin(\omega t - 120°)$

$V_{BB'} = V_m \sin(\omega t - 240°)$

* STAR AND DELTA CONNECTIONS :