Machine "1" — 5/9 Mon

Magnatic field and circuit :

What ?! Magnatic field

Why ?! because magnatic field is fundemental for the operation of transform , Generatores and Motors as follow :

magnatic field مهم في transf, motor, Gener * ~~Mot Gen~~ G *

1. Any current (i) in the conductor generates magnatic field (ϕ) around it, direction of ϕ can be found by using RHR $\phi \Rightarrow i$
   ($\phi \propto i$).

2. Time varying magnatic field (AC , بيتغير) passing through a coil or a counductor will induced the voltage in this coil or counductor.

   * تيار اي سي بيمر ب Cond / Coil يولد Volt في الـ conduc/coil
   * اذا كان تيار DC مهما كان عدد لفات ب $\begin{bmatrix} + \\ - \end{bmatrix}$ ب $+$ $-$ بيموت V لا يعمل الـ Cond الـ V في = صفر

   This the concept of a transformer operation.

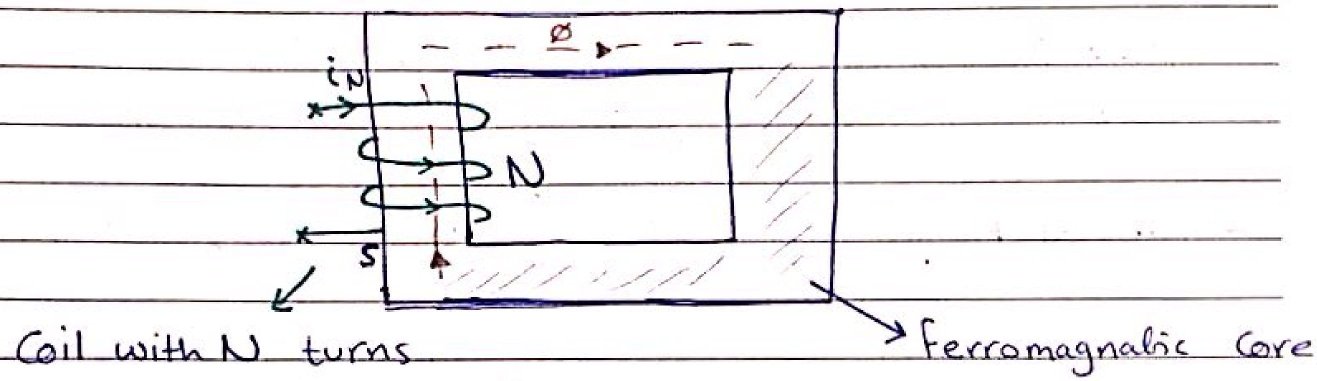
3. if conductor cut a magnatic field the voltage will be induced in it. This is the concept of generator operation.

4. A current calling conductor in a magnatic field will experience a force this is the concept of Motor operation.

Procedure:-

The problem is to find ϕ for a given i or find the required i for a given ϕ.

⇒ This can be solved by the concept of Magnatic circuits.



* Amper's law :-

$$\oint \bar{H} \cdot d\bar{l} = i$$

$H \equiv$ Magnatic field strength intensity
$l \equiv$ length of closed path.
$i \equiv$ current enclosed by the path.

* For a uniform magnatic field, ① can be expressed as follow :-

$$H l_c = N i$$

l_c : Mean length of flux path (m)
Unit of $H \equiv$ Amper-turns per meter.

* Relation ship between H and flux density B :-

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

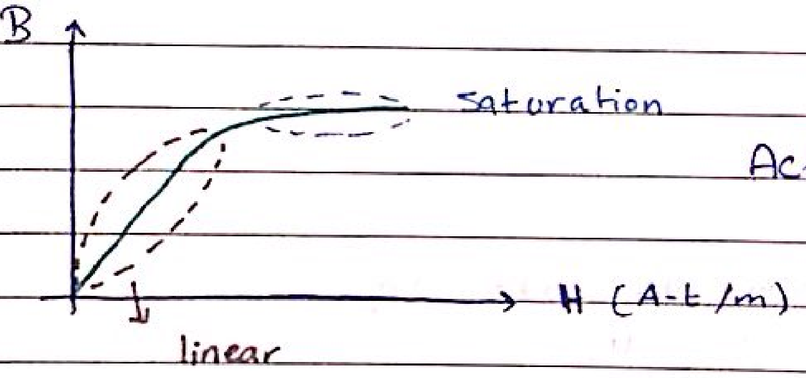
Unit of B is wb/m^2 or Tesla.

μ: Permability $\boxed{\mu = \mu_o \mu_r}$

μ_o : free space or air : $= 4\pi * 10^{-7}$
μ_r: relative permability of the material concerned

- typical Range $\boxed{2000 - 6000}$ unit of μ H/m

However Relation Between B and H is as follows



Actual curve is nonlinear

$B = \mu H$
$Ni = H\ell$
$Ni = \frac{B\ell}{\mu} = \frac{\emptyset}{A} \cdot \frac{1}{\mu} \ell$ $\qquad B = \frac{\emptyset}{A}$

A: cross section Area of the core.

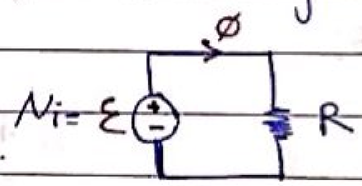
$Ni = \frac{l\phi}{A\mu}$ wher Ni is ~~magnetic~~ magnetomotive force mmf where.

$\frac{l}{A\mu}$ is called Reluctance.

$\mathcal{E} = R\phi \qquad R \propto \frac{1}{\mu} \Rightarrow R \propto \frac{1}{\mu_o \mu_r}$

since R for air is very high then in electrical machines, the space between rotor and stator should be as small as possible.

$\boxed{1}$ Can be represented by the following equivlent circuit.

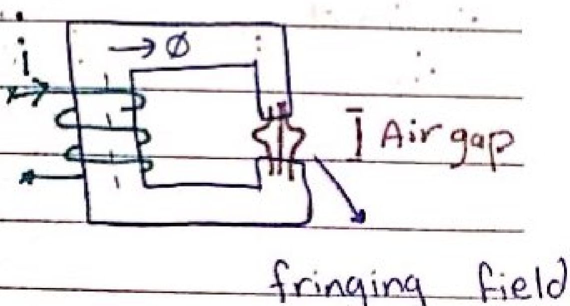


* There are an analog between electric circuit and magnatic circuit.

emf → mmf
i → ø
R → $\mathcal{R}$

* Hence all electrical laws are avaliable such as (ohms law, KVL, KCL).

* effect of air gap:



Due to fringing field $B_g = \frac{\varnothing}{A_g}$ $B_c = \frac{\varnothing}{A_c}$

g = gap , c = core.

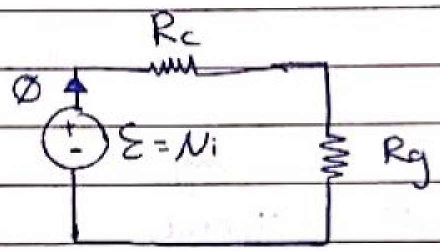
if fringing effect is neg then $\boxed{A_g = A_c}$ => $\boxed{B_g = B_c}$

* if fringing field be taken into account then $\Rightarrow$

[1] Add the length of the air gap to the side of core cross section in order to calculate A_g

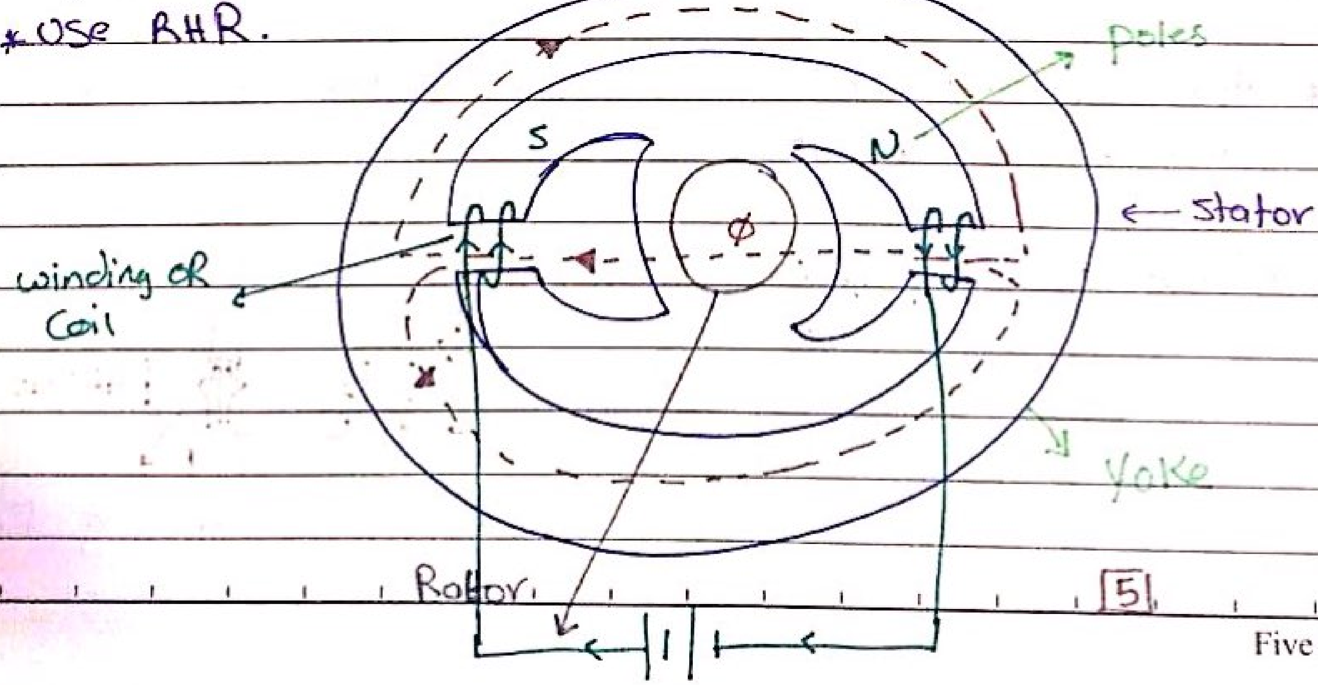
[2] OR Multiplied A_c by a certain given factor (e.g 1.05)

*



* illustration: Find the equivilent magnatic circuit of a 2pole machine.

* use RHR.



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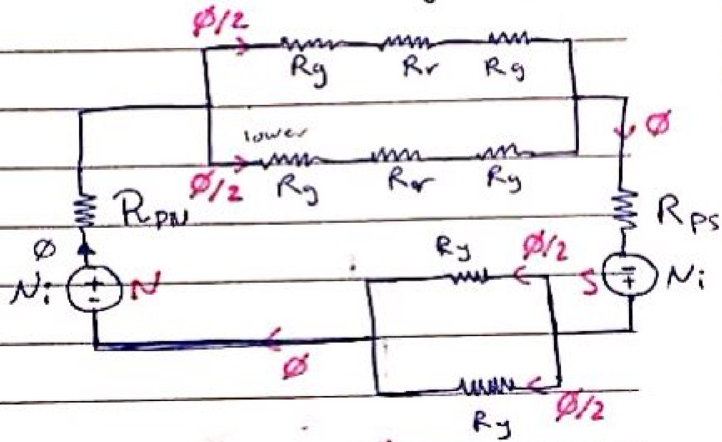
* Hence from the machin structure the following magnatic cct can be found :-



R_{PN}: Reluctance of North pole
R_g : " " : airgap.
R_r : " " Rotor
R_{PS} : " " South pole.
R_y : " " yoke.

By apply Mag. cct laws :-
By KVL :

$$\phi R_{PN} - Ni + \phi\left[(R_g+R_r+R_g) // (R_g+R_r+R_g)\right] + \phi R_{PS} - Ni + \phi\left[R_y // R_y\right] = 0 \quad \cdots (1)$$

Hence by using (1), one can calculate ϕ for a given Ni or Ni for a given ϕ

* see ex in book.

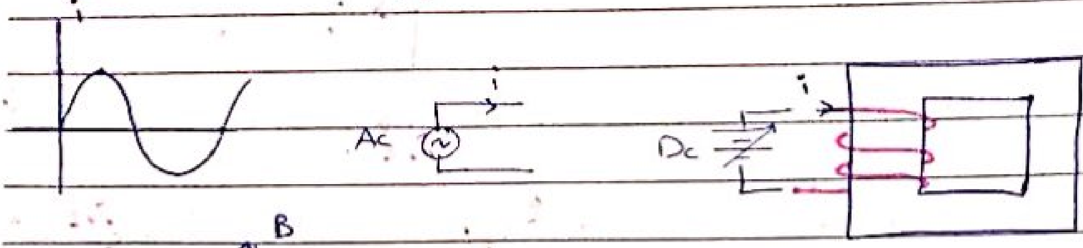
* Losses in Ferromagnatic (حديد) Materials :-

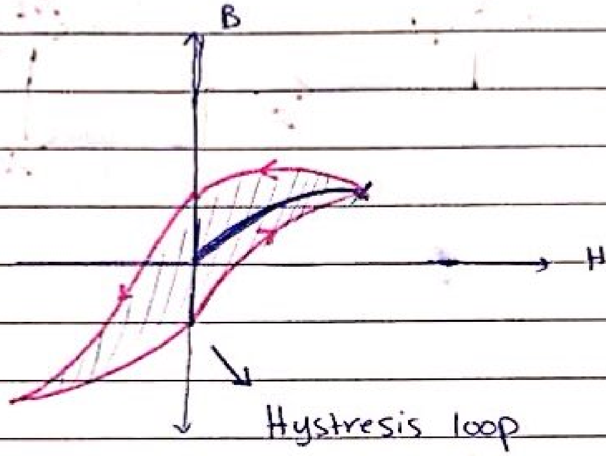
There are 2 types of such losses:

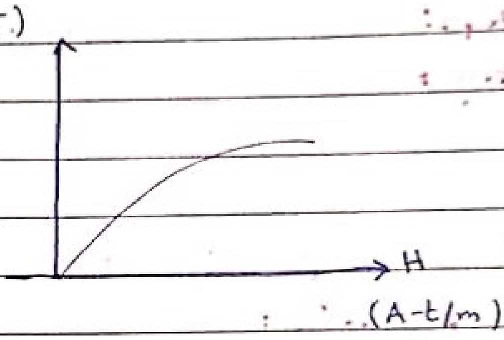
[1] Hysteresis losses, P_h

[2] Eddey current losses, P_e

* P_h :

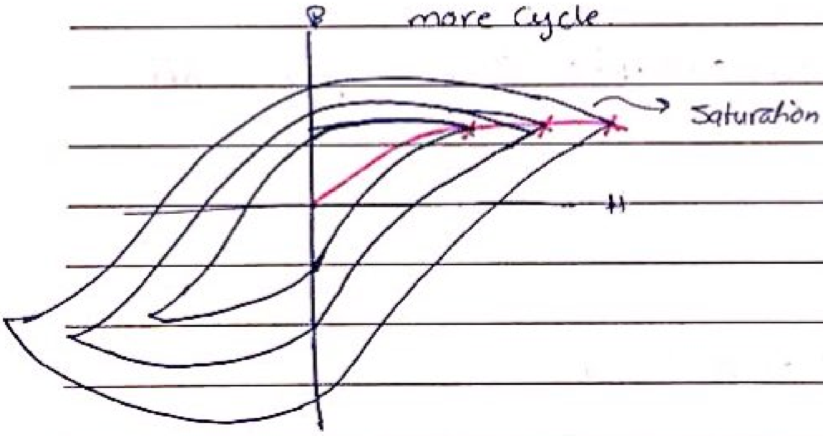






Hystresis loop for one cycle.

↑ i ↑ oruntation



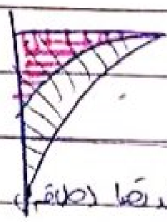
* The Area of H. loop $(B*H) = J/m^3$ This is called Energy density.

!? prove.

Hence: $F = B I L$

$N = B\, A.m$

$B = \frac{N}{A.m}$



مساحة إلي افرضنا (صفر)

Energy إلي ضفناه

الفرق بيظهر بتعطيني ال P_h

→ Area of H.loop, A_h = energy density per cycle.

$$A_h = \frac{\text{Total energy lost } (w) \text{ رمز w وليست watt } (J) \rightarrow \text{وحدة}}{\text{Total volume } (V) \text{ of material} * \text{Number of Cycle}}$$

$$\therefore A_h = \frac{W}{V * \text{Num of Cycle}} \qquad \therefore \rightarrow \boxed{P_h * \text{Time} = W}$$

P_h = power losses.

$$A_h = \frac{P_h}{V * \frac{\text{No. of cycle}}{\text{Time}}} = \frac{P_h}{V * f}$$

f: freqency of applied current.

↑f ↑losses.

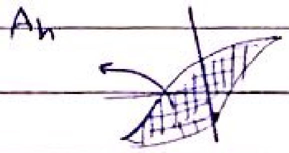
$$\boxed{\therefore P_h = A_h * V * f}$$

∴ 50HZ → 60HZ ↑f ↑P_h

∴ 60HZ → 50HZ ↓f ↓P_h

An emprical (تجريبي) formula was found for A_h:

$$A_h = K_h B_m^n$$



↓Ah ↓loss

K_h: Constant it's value depends on the time of material.

B_m: Maximum value of flux density.

n: Constant $1.5 \leq n \leq 2.5$

$$\therefore P_h = K_h B_m^n V f$$

$\boxed{\uparrow i \ \uparrow \text{airgap} \ \uparrow A_h}$

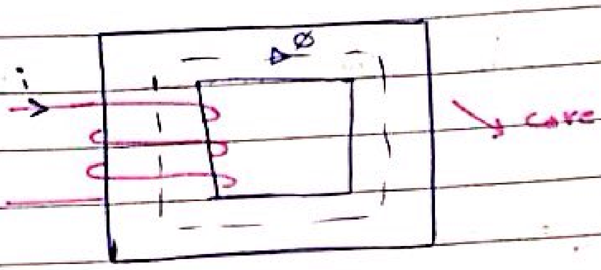
* 50 → 60 HZ ↑f ↑ph → ph عشان احافظ على
بقلل B_m ↓ عشان احافظ على نفس
P_h قيمة

2] P_e : ② Ac flux ① Ac current → voltage drop → يتولد current في conductor

magnitude ^ direction.

يتولد داخلياً في الـ conduc ← eddy

غير عن التيار الـ applied.



i will generate ϕ → $\phi \propto i$ →

since i is Ac then ϕ will be AC. →

ϕ will induce a voltage e_e in the core. →

since the core is conducting then a current i_e will flow due to e → i_e will flow in such a direction (acc. to lenZ's low) to generate ϕ_e oppssing ϕ →

Hence i_e flow in circular direction, hence it's called eddy current. → this i_e causing P_e

(i_e ≡ eddy current losses)

P_e is reduced by using Lamination for the core.

Since lamination are used then the total volume of the core is going to increase.

* Hence, Stacking factor $\triangleq \dfrac{\text{volume of the ferromagnetic material}}{\text{total volume of the core}}$

$= \dfrac{\text{Area of the ferromaterial}}{\text{Total area of the core}}$

* Expression of P_e:

$P_e \propto i_e^2$, since $i_e \propto e_e$

$\therefore P_e \propto e_e^2$

since $e_e \propto B_m \cdot f$

$\therefore P_e \propto B_m^2 f^2$

Hence, P_e can be expressed as:-

$P_e = K_e B_m^2 f^2 \tau V$

K_e: constant dependes on the type of ferromagnetic material
τ: lamination thickness
V: volume of the ferromaterial.

* Core losses, P_c:

$P_c \triangleq P_e + P_h$

Ex: The total core losses for a given magnetic Sheet Steel ~~...~~ is found to be 1800 W at 60 HZ. when the freq is increased by 50% the core losses is found to be 3000 Watt. [average power, Energy * time → watt hour energy / watt. power]

sol: $P_c = P_e + P_h$

$P_e = K_2 f^2 B_m^2$ [$\tau v K_m = K_2$ Constant]

$P_h = K_1 B_m^n f$ [$K_h V = K_1$ constant]

for the same flux density B_m

$K_2 B_m^2 = K_b$, $K_1 B_m^n = K_a$

$P_c = K_b f^2 + K_a f.$

$\therefore$ $1800 = K_b 60^2 + K_a 60$ .... ①

$3000 = K_b 90^2 + K_a 90$ .... ②

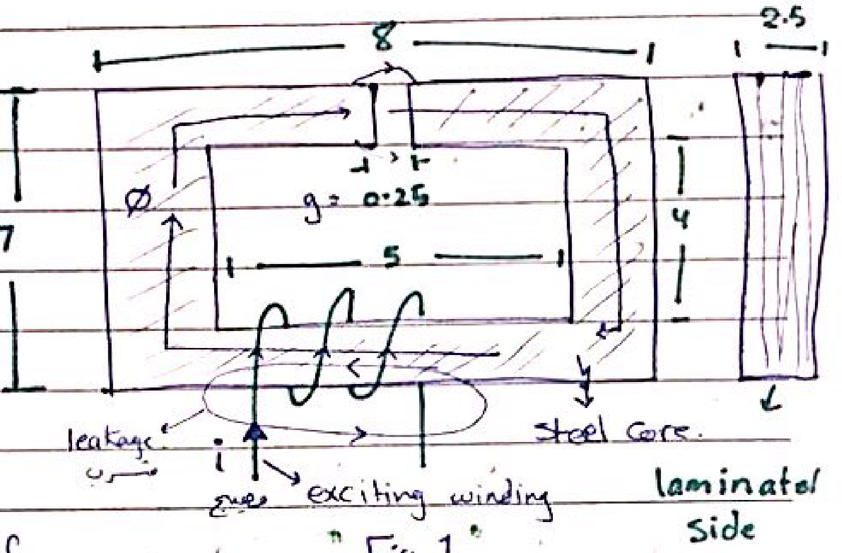
solving ① and ② it can be found:

$K_b = 1/9$ $\boxed{K_b = 70/3}$

f	P_e	P_h
60	$\frac{1}{9} * 3600 = 400$	$1800 - 400 = 1400$
90	$\frac{1}{9} * 90 * 90 = 900$	$3000 - 900 = 2100$

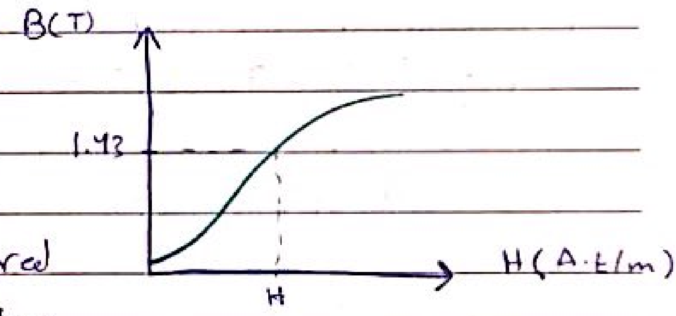
Ex:

The magnatic cct shown in Fig1 is composed of a laminated core of steel with air gap g and has an exciting winding of 350 turns.
The magnatization curve of steel is shown in "Fig 2". The pressence of lamination is taken into account by assuming stacking factor of 0.93.
Neglect leakage flux, but take into ~~acount~~ account fringing field, and calculate the required exciting current to produce a flux of $5*10^{-4}$ wb in the core.



"Fig 1"

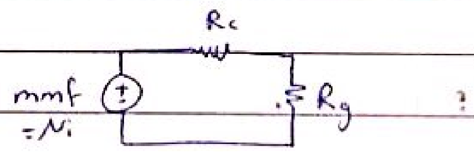
- all dimesion ~~in~~ are in cm



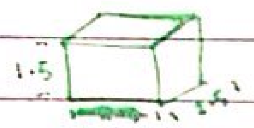
"Fig 2" [given]

* لما ما في lamination يعني Stacking factor = 1 .

Sol: Equivalent magnatic cct.



* Since leakage flux is neglected, then all the flux Ø flows in the core.



* Net Area of the steel core $= 1.5\times10^{-2} * 2.5\times10^{-2} * 0.93$
$= 3.49 \times 10^{-4}\ m^2$

→ Area of the core = ~~total are~~ Area of free * stacking factor

* Mean length of flux path in the steel core =

$$2\left(4+\frac{1.5}{2}+\frac{1.5}{2}\right)+\left(5+\frac{1.5}{2}+\frac{1.5}{2}\right)+\left(5+\frac{1.5}{2}+\frac{1.5}{2}-0.25\right)$$

$= 23.75\ cm = \boxed{0.2375\ m}$

* flux density in the core $= \frac{\phi}{A_c} = \frac{5\times10^{-4}}{3.49\times10^{-4}}$

$\boxed{B = 1.43\ T}$

∴ By using Fig 2 it can be found that for

∴ $B = 1.43 \rightarrow \boxed{H_{core} = 10^3}$ ✓

* Correction, air gap, add g to the sides of the gap

$A_g = (1.5 + 0.25)(2.5 + 0.25) \times 10^{-4}$

area air gap factor

$\boxed{A_g = 4.81 * 10^{-4}\ m^2}$

$B_g = \phi / A_g = \frac{5\times10^{-4}}{4.81\times10^{-4}} = \boxed{1.04\ T}$

$H_g = \frac{B_g}{\mu_0} = \frac{1.04}{4\pi\times10^{-7}} = \boxed{8.28 * 10^5}$ A-t

∴ By KVL:

Ni = core + gap

$F_{total} = F_{core} + F_{gap}$ $= H l_{c\ core} + H l_{c\ gap}$

$350\ i = 237.5 + 2070$ $0.2375 + (8.28\times10^5 * 0.25)$

$\boxed{i = 6.6A}$

* Inductance, L

Flux linkage $(\lambda) \triangleq N\phi$

$\lambda \triangleq L i$

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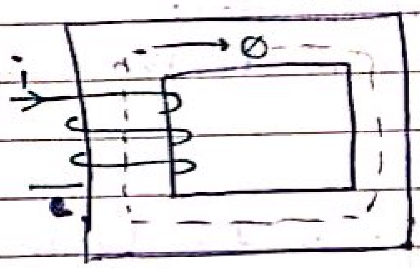
* Inductance $\mathcal{l}$ 8∆



Flux linkage, $\lambda \triangleq N\phi$ (magnetic cct)

$\lambda = L i$ (electrical cct)

$\therefore \quad L = \dfrac{N\phi}{i}$

since $Ni = R\phi$

$\therefore \quad L = \dfrac{N\phi}{\frac{R\phi}{N}} = \dfrac{N^2}{R} = \dfrac{N^2 \mu A}{\mathcal{l}}$

Transformer 8∆

*what?! Definition 8 It is a device or equipment which can be used to change the level of magnitude of AC voltage

*why?! . [↓PF, losses ↑, i↑] / i ↓ . voltage ↑

It is used the process of electrical energy transfer. by stepping up the voltage and ↓ reducing the current. Consequently

Hence power losses will be decreased.

*How?! Analysis 8∆

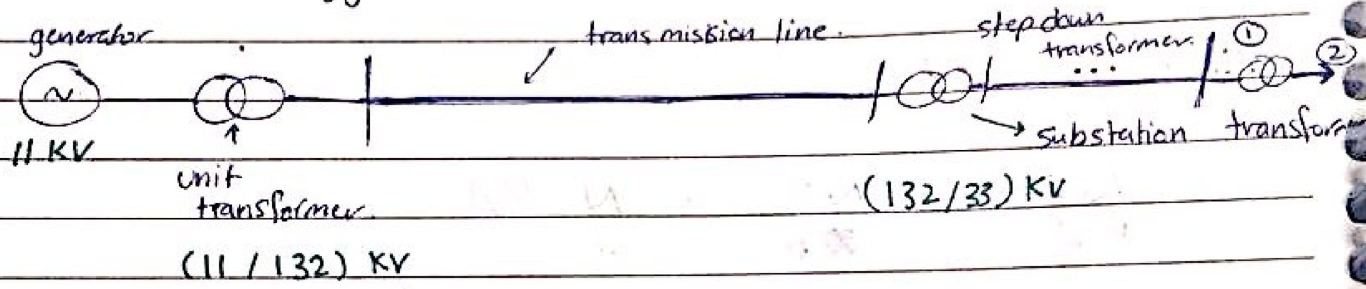
~~Classification of Trans~~

* Construction 8∆

Transformer consist of a core with 2 or more windings

تعريف * Classification:
according to thair application they can be classified into 8

[1] Power transformer: this is the one used in the process of generation, Transmission, and distribution of electrical energy.



① Distribution transformer (6.6 KV / 38 KV)
② Final Consumer. ↳ line voltage
220 phase voltage.

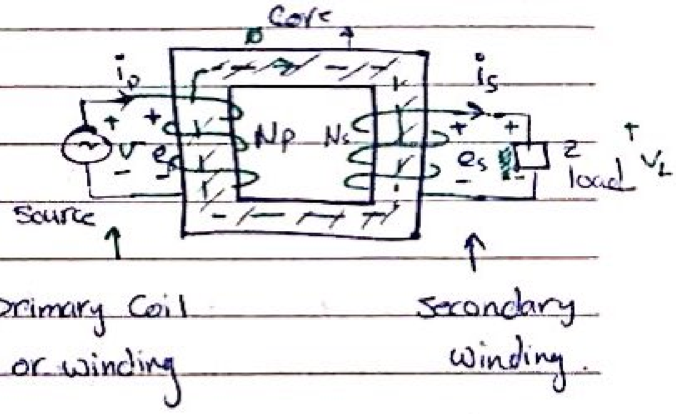
* Single line Diagram [read].

[2] Instrument Transformer: these are the ones which are used in the process of electrical measurment of voltage and current. :-

[A] Potenial transformer, PT
[B] Current transforme, CT.

This Course is concerned with power transformer:-

* Single phase transformer:
objective: to find voltage, current and power relationship.



*assume Ideal transformer: — linear transform ← طابوري غير core.

*assumtions :- — power transfe → core غير

1) No losses [electrical and core].

2) $\mu_r \to \infty$ (very high) all

3) No leakage flux: [i.e generated flux flow in the core]

i_p: applied primary current.

V: " " voltage

e_p, e_s: primary and secondary induced voltage.

V_L: loads voltage.

i_s:

* i_s مش eddy current لانه eddy بتولد داخل ال core.

* هي تيار بمشي داخل ال core eddy current

N_p, N_s: primary and secondary turns.

$$e_p = N_p \frac{d\phi}{dt}$$

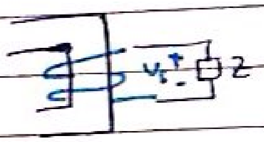
$$e_s = N_s \cdot \frac{d\phi}{dt}$$

$$\therefore \frac{e_p}{e_s} = \frac{N_p}{N_s} = a$$

$i_p N_p = i_s N_s$

$\therefore \dfrac{i_p}{i_s} = \dfrac{N_s}{N_p} = \dfrac{1}{a}$ (i_p, i_s inphase)
~~a maybe~~

since a is a real number . then e_p and e_s are inphase
Also i_p and i_s inphase



V_s : secondary terminal voltage.

* For ideal Transformer.
  $e_p = V_p$ and $V_s = e_s$

* The voltage and current relationship can be written in Phaser form as

$$\frac{V_p}{V_s} = \frac{I_s}{I_p} = a$$

$\therefore V_p I_p = V_s I_s$
apparent power of primary and secondary is the Same. (KVA)

HV → cross section area أقل.   ← Trans لل LV و HV بدي الحد *

Power:

P supplyied by primary $= P_p = V_p I_p \cos \Theta_p$ (rms)
$= \frac{1}{2}$ (peack value)

P taken by the secondary $= P_s = V_s I_s \cos \Theta_s$

for ideal transformer $\theta_p = \theta_s = \theta$.

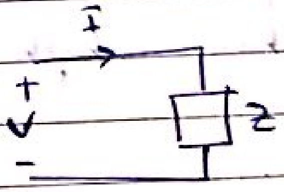
$$\therefore P_p = \underset{V_p}{(a V_s)} \cdot \underset{i_p}{\left(\frac{i_s}{a}\right)} \times \cos\theta$$

$$P_p = V_s\, i_s \cos\theta = P_s$$

$\therefore$ efficiency η of transformer $= 100\%$

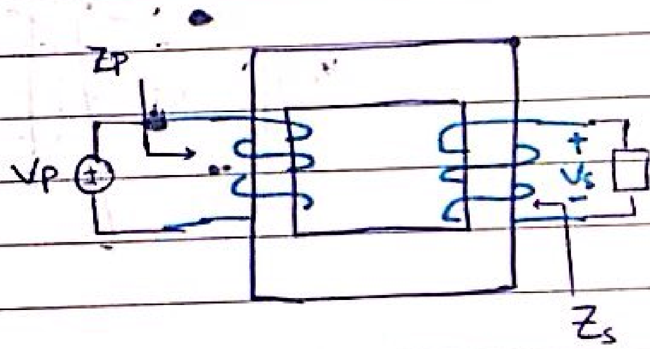
$$\text{efficiency } \eta \triangleq \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + P_{losses}}$$

Impedence:



$$Z = \frac{V}{I}.$$

for transformer.



$$Z_p = \frac{V_p}{I_p} = \frac{a V_s}{I_s / a}$$

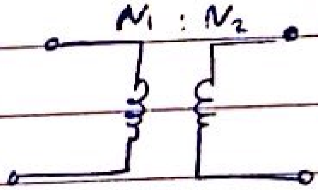
$$Z_p = a^2 \frac{V_s}{I_s} = a^2 Z_s$$

OR $Z_s = \frac{Z_p}{a^2}$

* نقل reflecting من circuit ل one circuit

To Reflect Z_s to primary $*$ by a^2

To " Z_p to secondary $\div$ by a^2



$1 : \frac{N_2}{N_1} = a_1$

OR $a_{21} = \frac{N_1}{N_2} : 1$

* إذا كان الـ a ← يضرب بـ a^2

" " الـ 1 ← تقسم على a^2

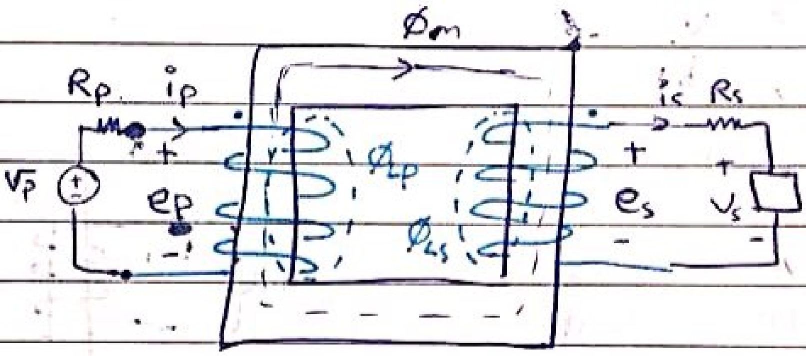
In general :
to reflect an impedence Z to the a side , multiply Z by a^2

to reflect an impedence Z to the 1 side , divide $\div$ Z by a^2

* Real OR Practical Transformer :

Here :

1. losses will be taken into accont.
2. leakage flux be taken into account
3. Mr has a high voltage.



$\emptyset_m$: mutual flux.

$\emptyset_{LP}$: leakage flux of primary.

$\emptyset_{LS}$: " " " secondary

$\emptyset_p = \emptyset_m + \emptyset_{LP}$

$\emptyset_s = \emptyset_m + \emptyset_{LS}$

$e_p = e_{m_p} + e_{LP}$

$e_s = e_{m_s} + e_{LS}$

$$\therefore\ e_p = N_p \frac{d\phi_p}{dt} = \underbrace{N_p \frac{d\phi_m}{dt}}^{e_{mp}} + N_p \frac{d\phi_{Lp}}{dt}$$

$$e_s = N_s \frac{d\phi_s}{dt} = \underbrace{N_s \frac{d\phi_m}{dt}}_{e_{ms}} + N_s \frac{d\phi_{Ls}}{dt}$$

$$\therefore\ \frac{e_{mp}}{e_{ms}} = \frac{N_p}{N_s}$$

for practical iron core transformer $\phi_m \gg \phi_L$

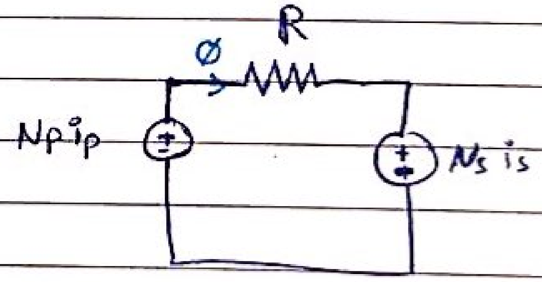
$\therefore\ \phi_m \simeq \phi$ [total flux]

$$\therefore\ \frac{e_p}{e_s} = \frac{N_p}{N_s}$$

If the resistance of the winding is neglected then $V_p \simeq e_p$ and $V_s \simeq e_s$

* Current Relationship :-

Equivalent cct.



$\therefore$ By KVL $\Rightarrow$ $N_p i_p - N_s i_s = R\phi$

Since R is very small $R \approx 0$

$N_p i_p = N_s i_s$

$$\therefore\ \frac{i_p}{i_s} = \frac{N_s}{N_p}$$ *

POWER UNIT

Machines 1

Dr.defallah dalabeeh

- Auto transformer :

These are usually used if the required voltage is very small (i.e. voltage ratio is around 1)

ex : (110/120) V or (12.8/13) KV

Construction :

Its construction can be understood by considering the winding of a conventional transformer Fig. 1 as follows :

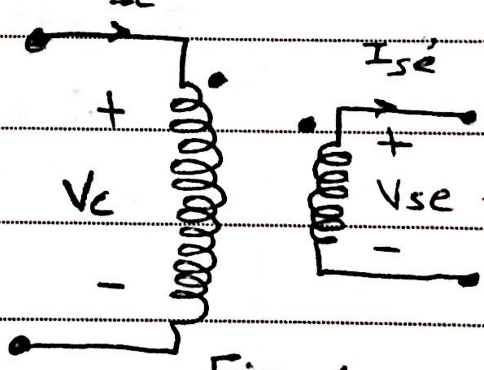
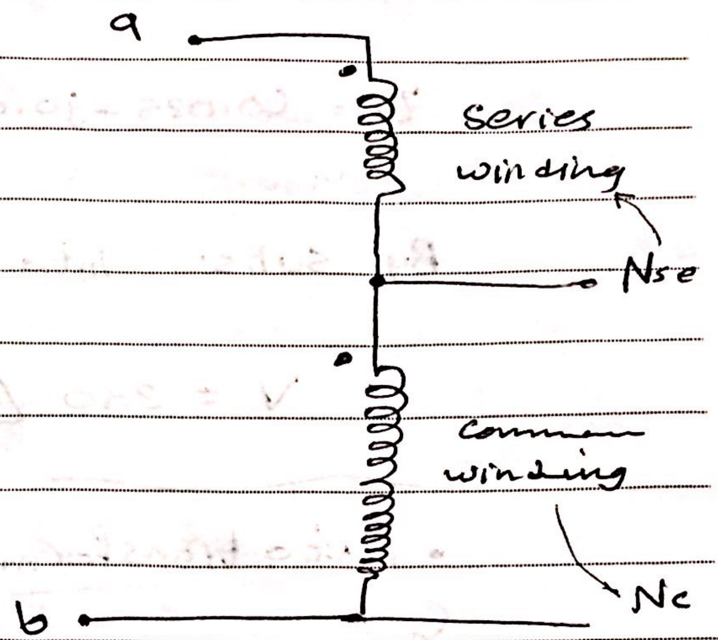


Fig. 1

Auto transformer can be constructed by connecting the two winding of fig. 1 in series aiding as follows :



$N_c, N_{se} \equiv$ Number of turns of common and series winding respectivily.

$V_c, V_{se} \equiv$ Voltage " " " "
" " " "

where $\frac{V_c}{V_{se}} = \frac{N_c}{N_{se}}$ --- $\boxed{1}$

$I_c, I_{se} \equiv$ Current of common & series winding

$$I_c N_c = I_{se} N_{se}$$

$\therefore$ OR - $\frac{I_c}{I_{se}} = \frac{N_{se}}{N_c}$ --- $\boxed{2}$

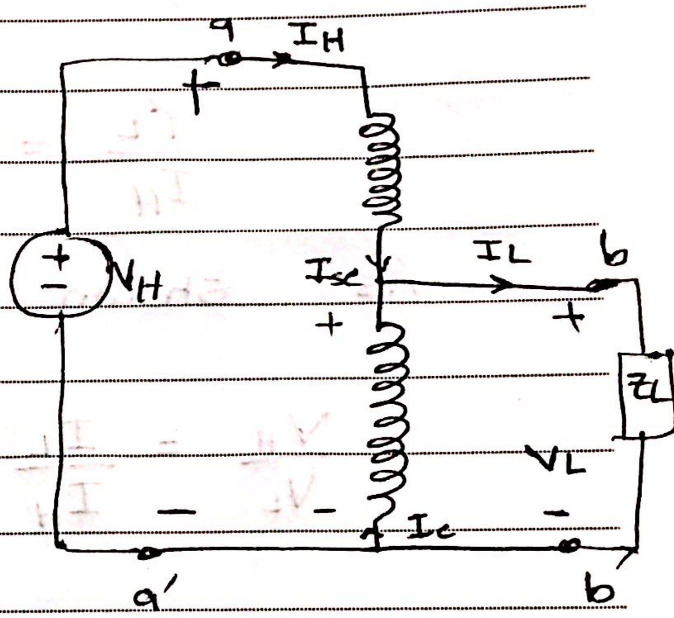
No.

Auto transformer can be used as stepup or step down, hence there are HV side and LV side

For ex: If supply connected to aa' then it is step down, with :-

$aa' \equiv$ HV side

$bb' \equiv$ LV side



Objective :

to find relationship of $\frac{V_H}{V_L}$ and $\frac{I_H}{I_L}$

Procedure

$$V_H = V_{se} + V_c \quad \text{---} \quad \boxed{3}$$

subs. $\boxed{1}$ into $\boxed{3}$

$$V_H = V_c \frac{N_{se}}{N_c} + V_c = V_c \left(\frac{N_{se} + N_c}{N_c} \right)$$

But $V_c = V_L$

No.

Current :

$$I_L = I_{se} + I_c \quad \text{—} \quad \boxed{5}$$

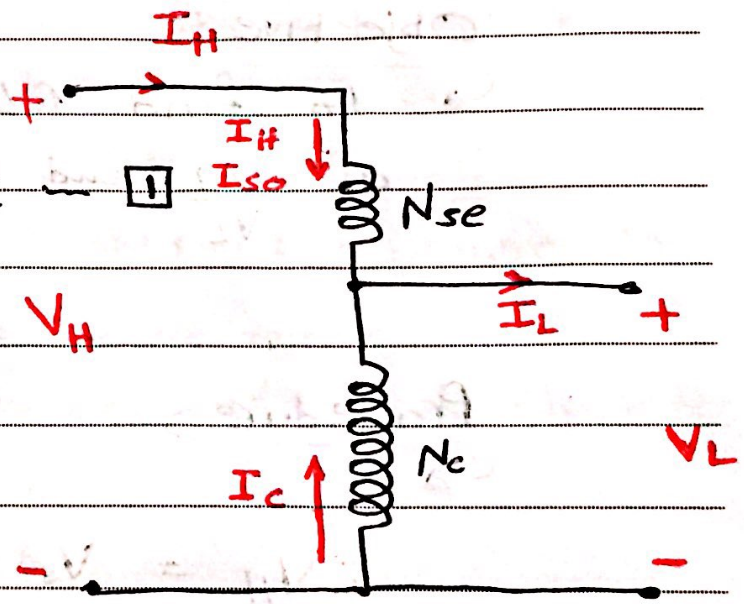
Subs. $\boxed{2}$ into $\boxed{5}$

$$I_L = I_{se} + I_{se}\frac{N_{se}}{N_c} = I_{se}\left(\frac{N_c + N_{se}}{N_c}\right)$$

$$\frac{I_L}{I_H} = \frac{N_c + N_{se}}{N_c}$$

As shown before :

$$\frac{V_H}{V_L} = \frac{I_L}{I_H} = \frac{N_c + N_{se}}{N_c} \quad \text{—} \quad \boxed{1}$$



Power relationship and power advantage of auto transformer :-

$$\text{Input Apparent power} = S_I = V_H I_H \quad \text{—} \quad \boxed{2}$$

Objective :-

To find relationship between input and output apparent power.

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No.

Procedure :-

Subs. $\boxed{1}$ into $\boxed{2}$

$$S_I = \left(V_L \frac{N_c + N_{se}}{N_c}\right) \cdot \left(I_L \frac{N_c}{N_L + N_{se}}\right) \quad - \boxed{3}$$

$$S_I = V_L I_L = S_o$$

$\therefore$ for Auto. transformer $S_I = S_o = S_{To}$ $- \boxed{4}$

- for the windings :-

$$V_c I_c = V_{se} I_{se} \quad - \boxed{5}$$

$$\therefore \underbrace{S_w}_{\text{winding}} = V_c I_c = V_L (I_L - I_H)$$

$$S_w = V_L I_L - V_L I_H \quad - \boxed{6}$$

Subs. $\boxed{1}$ into $\boxed{6}$

$$S_w = V_L I_L - V_L \left(\frac{N_c}{N_c + N_{se}} \cdot I_L\right)$$

$$= V_L I_L \left(\frac{N_c + N_{se} - N_c}{N_c + N_{se}}\right)$$

$$S_w = V_L I_L \left(\frac{N_{se}}{N_{se} + N_c}\right)$$

$$S_w = S_{To} \frac{N_{se}}{N_{se} + N_c}$$

No.

$$\therefore \frac{S_{IO}}{S_w} = \frac{N_{se} + N_c}{N_{se}} \quad \ldots \boxed{7}$$

Comment : 1. $\boxed{7}$ $S_{Io} = S_w \dfrac{N_{se} + N_c}{N_{se}}$

- By converting conv. transformer to auto then S of auto transformer will be > than S by a factor = $\dfrac{N_{se} + N_c}{N_{se}}$

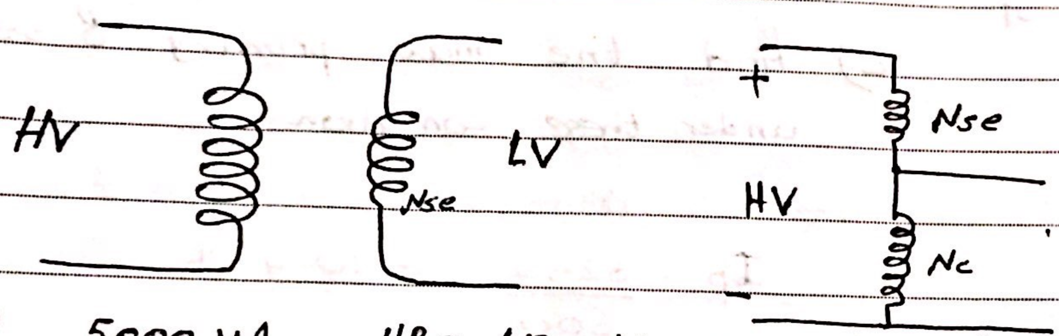
$\dfrac{N_{se} + N_c}{N_{se}}$ ≡ This is called apparent power advantage

2. To supply the same voltages Auto transformer will have a smaller size and cheaper.

No.

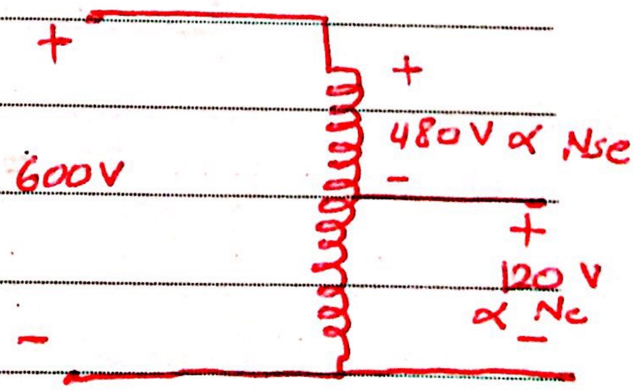
Disadvantages of Auto-transformer :-

1. It does not have electrical isolation between the primary and secondary ckts.
2. Its PU impedence will be reduced by a factor = recisrical of app. power advantages



Ex : A 5000 VA , 480 / 120 V conv. transformer is to be used to supply power from 600 V source to 120 V load. Consider transformer to be ideal and assume that all Insulation can handel 600 V.

a) Sketch the auto transformer connection that will do the Job required.



No.

b) find the KVA rating of this transformer configuration

$$\frac{S_{IO}}{S_W} = \frac{N_C + N_{SE}}{N_{SE}}$$

$$S_{IO} = S_W \frac{N_C + N_{SE}}{N_{SE}}$$

$$= 5000 \cdot \left(\frac{120 + 480}{480}\right) = 6250 \text{ VA}$$

c) find the max. primary & secondary current under these condition

$$I_P = \frac{6250}{600} = 10.4 \text{ A}$$

$$I_S = \frac{6250}{120} = 52.1 \text{ A}$$

d) If the PU impedence of the conv. = Z = 0.01 + j0.0...
find the corresponding PU impedence of auto.

$$Z_{Auto} = \frac{Z_{conv.}}{\text{App. pwr Adv.}} = \frac{0.01 + j0.08}{(6250/5000)}$$

$$= 0.008 + j\,0.064$$

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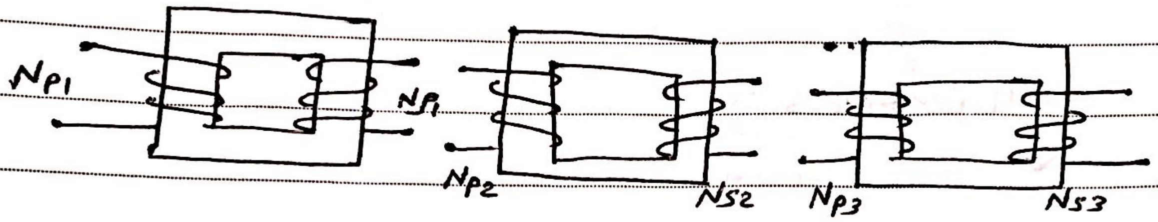
No.

- 3 Phase transformer :-

Construction :-

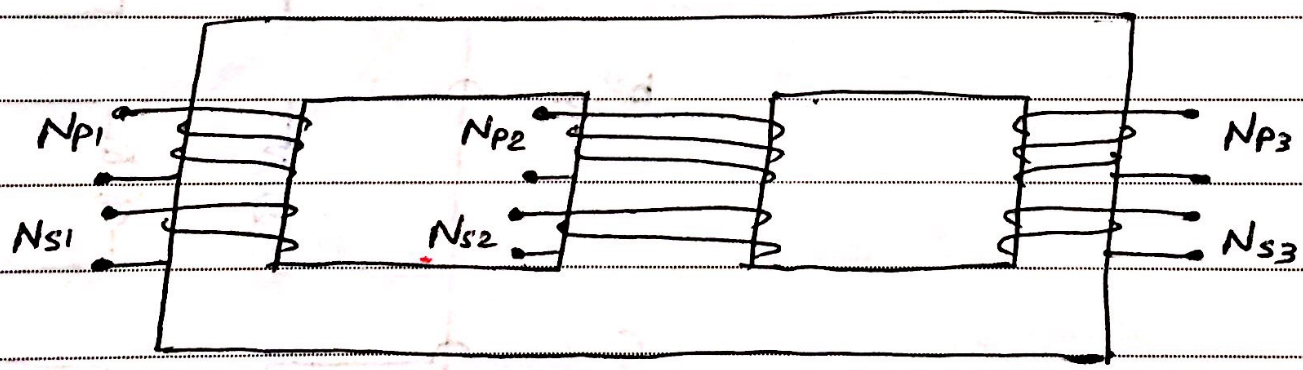
It could be of 2 types :-

1. Using 2 single phase transformers



Sometimes it is called a bank of 3-phase transformer.

2. A single-core with 3-pairs of winding on its limbs



- Smaller in size
- cheaper
- More efficient.

- Types of connections in 3-phase transformer :-

Y Y

Y Δ

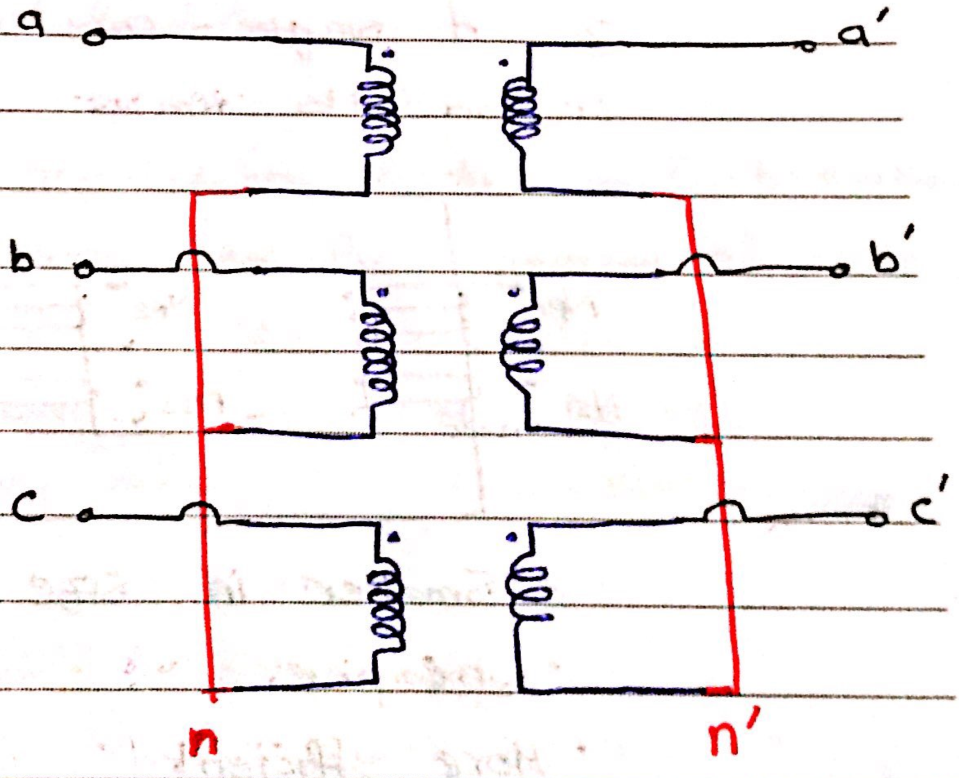
Δ Y

Δ Δ

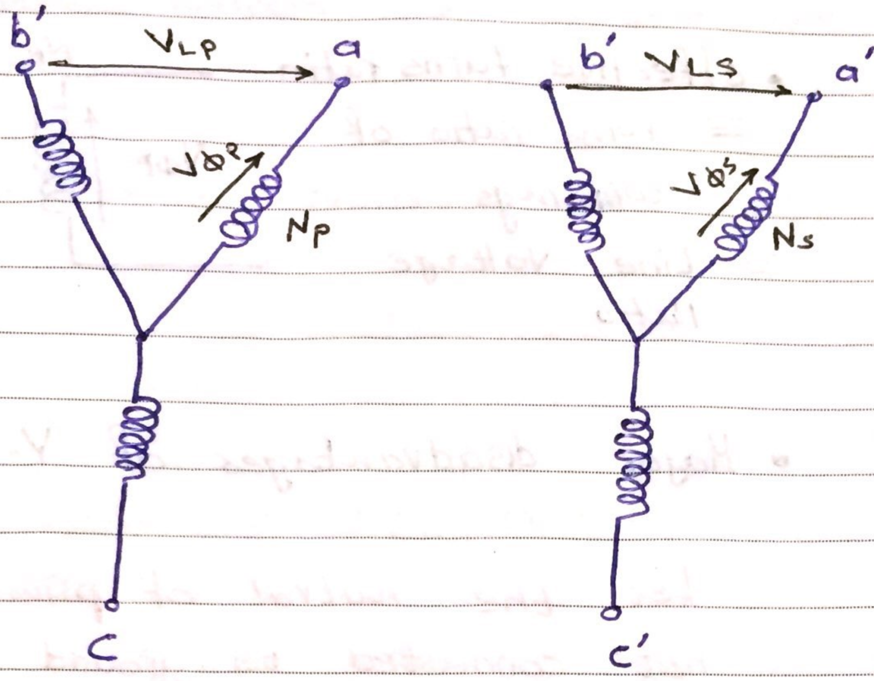
Objectives :-

1. Voltage Ratio
2. Major disadvantage
3. Characteristics.

Y-Y connection



Connection or wiring diagram



N_P, N_S ≡ Number of turns of primary & secondary windings

$V_{\phi P}$, $V_{\phi S}$ ≡ Phase voltage of " " " "

V_{LP}, V_{LS} ≡ Line voltage of " " " "

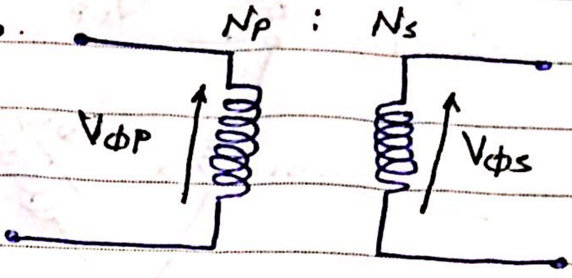
- Let $a = \frac{N_P}{N_S}$ ≡ Turns Ratio.

- Voltage Ratio :-

$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}\, V_{\phi P}}{\sqrt{3}\, V_{\phi S}} = \frac{V_{\phi P}}{V_{\phi S}} = \frac{N_P}{N_S} = a \quad \text{--- } \boxed{I}$$

$\boxed{I}$ can be used to find per-phase equv. ckt of Y-Y connection.

- effective turns ratio
  ≡ turns ratio of windings
  ≡ Line Voltage ratio



- Major disadvantages of Y-Y connection:

Let the nutral of primary isolated not connected to ground

1. Exciting current iext is as shown before, non-sinusoidal and periodic

2. By using fourier series, iext can be written as the sum of fundumental

Since 3rd harmonic is dominant the other harmonics are neglected

Line current can be written as :-

$i_a = I_{m1} \sin(\omega t) + I_{m3} \sin(3\omega t)$

$i_b = I_{m1} \sin(\omega t - 120) + I_{m3} \sin(\overset{3\omega t - 360}{3(\omega t - 120)})$

$i_c = \underbrace{I_{m1} \sin(\omega t - 240)}_{\text{Fundamental}} + \underbrace{I_{m3} \sin(\overset{3\omega t - 720}{3(\omega t - 240)})}_{\text{3rd harmonics}}$

equal phasor ≡ same mag.

- Fundamental component of i_a, i_b, i_c are balanced

- 3^{rd} harmonics of i_a, i_b, i_c are equal phasors.

$$i_a + i_b + i_c = 0$$

$$\text{Balanced Component} + 3 I_{m_3} \sin(3\omega t) = 0$$

- In This case 3^{rd} harmonic component do not flow in the line

- Hence I_{ext} is pure sinusoidal

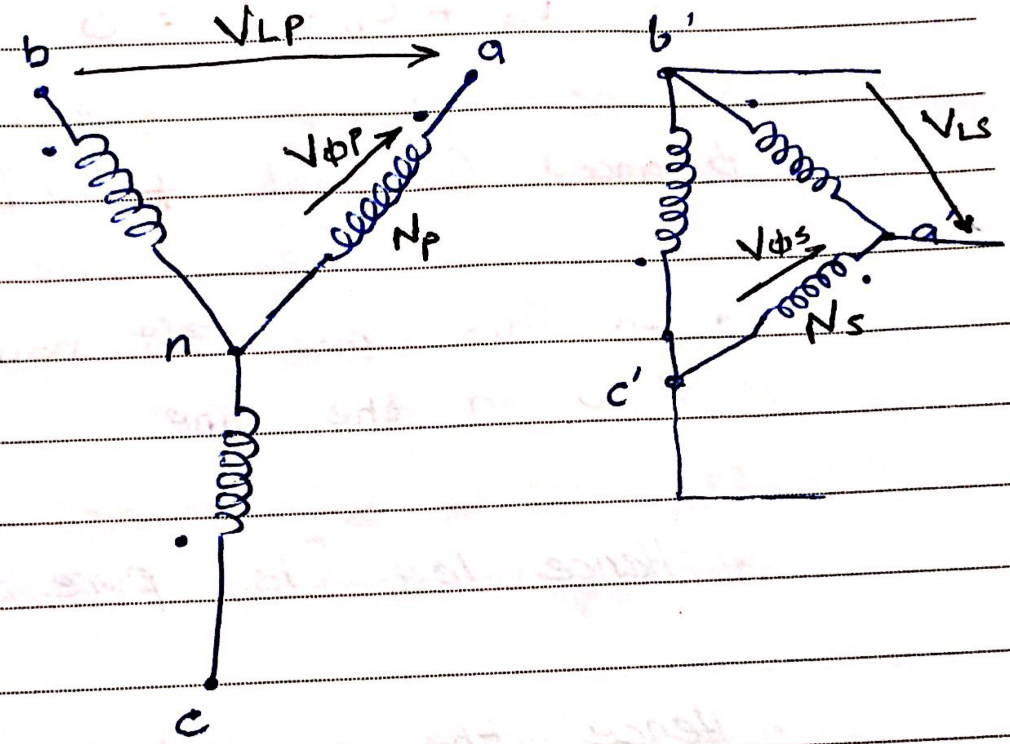
- Hence the generated flux is non sinusoidal and consequently induced Voltage non-sinusoidal Hence it has harmonic

- Hence solution, let 3^{rd} harmonic current flow by :-

  1. Grounding the neutral of the primary winding So 3^{rd} harmonics can flow back to the neutral of source

Cont. 1. OR add a 3^{rd} winding, called teritiary winding, Connected in Δ, Consequently 3^{rd} harmonic induced voltages will cause 3^{rd} harmonic current to flow

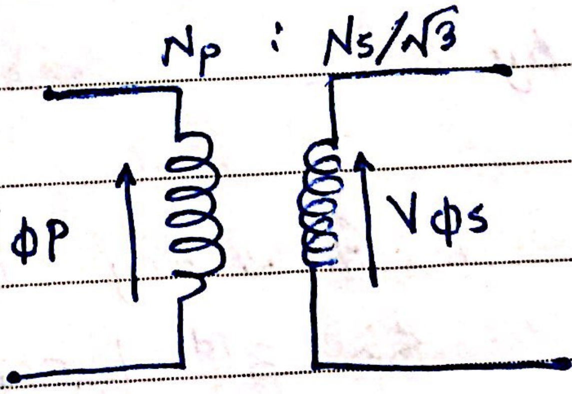
- Y – Δ Connection



$$\frac{V_{LP}}{V_{LS}} = \frac{\sqrt{3}\ V_{\phi P}}{V_{\phi s}} = \sqrt{3}\ \frac{N_p}{N_s} = \sqrt{3}\ a$$

$$= \sqrt{3}\ \frac{N_p}{N_s} \doteq \frac{N_p}{N_s/\sqrt{3}}$$

$N_p : N_s/\sqrt{3}$: effective turns ratio



_ major disadvantage :-
phase shift between primary and secondary as follows :

* assume +ve phase sequence :-

if $\angle V_{ab} = 30° \rightleftarrows \therefore \angle V_{an} = 0°$

it can be shown that $\angle V_{a'b'} = 0° = \angle V_{an}$
usually this transformer is used as step down.
$\therefore$ H.V leads L.V by $30°$
(V_{ab} for H.V, $V_{a'b'}$ for L.V)
$\therefore$ in parallel connection should take into account the $30°$ phaseshift

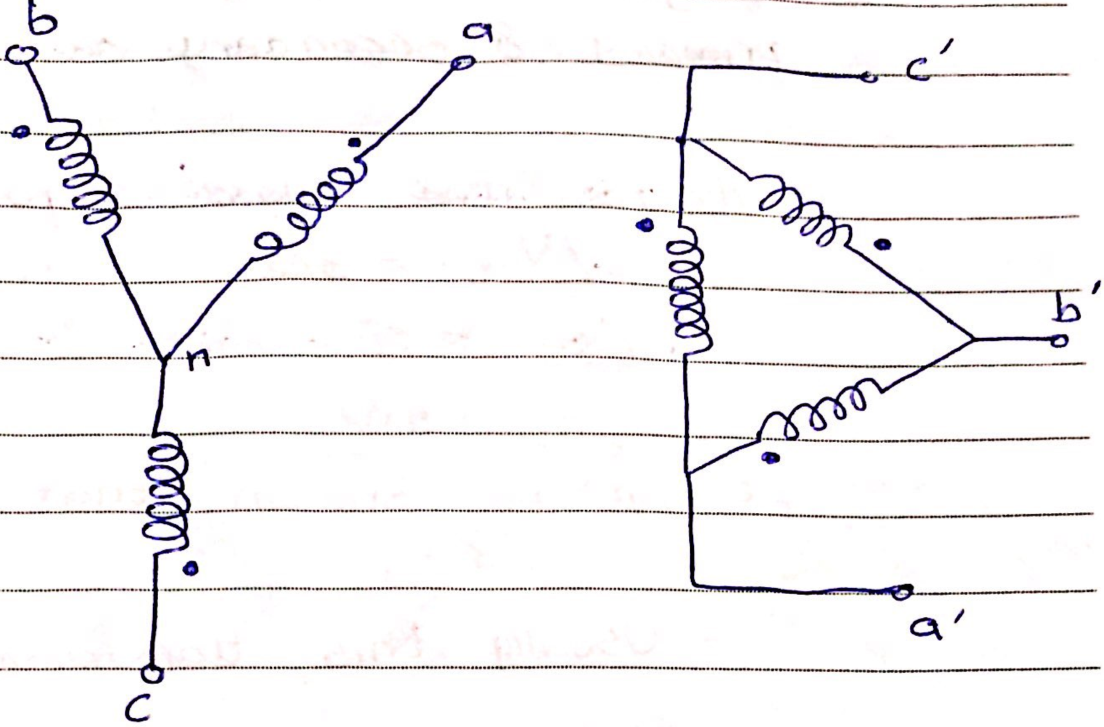
_ For Δ-Y connection :- (step up)
(Δ = L.V, Y = H.V)

$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{V_{\phi s}} = \frac{N_P\sqrt{3}}{N_s}$$

_ For Δ-Δ :-

$$\frac{V_{LP}}{V_{LS}} = \frac{V_{\phi P}}{V_{\phi s}} = \frac{N_P}{N_S}$$

Cont.



Assume +ve phase seq.

HV–LV: $Y-\Delta$ is used for step down

Let $\angle V_{an} = 0^\circ$

$\therefore \angle V_{ab} = 30^\circ$

$V_{a'b'}$ is in phase with V_{an}

$\therefore \angle V_{a'b'} = \angle V_{an} = 0^\circ$

High voltage V_{ab} leads LV $V_{a'b'}$ by 30°

the same result can be found by $\underset{LV}{\Delta} - \underset{HV}{Y}$ connection (i.e. step up)

No.

Ex : A 3-phase transformer bank is to handle 400 KVA and have (34.5/13.8) KV Voltage ratio. Find the rating of each individual transformer (HV, LV, turns ratio and apparent power) if the transformer bank is connected as :-

a) Y-Y

b) Y-Δ

c) Δ-Y

d) Δ-Δ

find $V_{\phi h}$, $V_{\phi L}$, $\frac{V_{\phi h}}{V_{\phi L}}$ = turns ratio = a

a) $V_{\phi h} = 34.5/\sqrt{3} = 19.92$ KV

$V_{\phi L} = 13.8/\sqrt{3} = 7.97$ KV

$a = \frac{19.92}{7.97}$

Note:

$S_{1\phi} = \frac{S_{3\phi}}{3}$

in ex:-

$S_{1\phi} = \frac{400}{3}$

b) $V_{\phi h} = 34.5/\sqrt{3} = 19.92$ KV

$V_{\phi L} = 13.8$ KV

$a = \frac{19.92}{13.8}$

c) $V_{\phi h} = 34.5$ KV

$V_{\phi L} = 13.8/\sqrt{3}$ KV

$a = 34.5 * \sqrt{3} / 13.8$

d) $V_{\phi h} = 34.5$ KV

$V_{\phi L} = 13.8$ KV

$a = \frac{34.5}{13.8}$

3-Phase Transformation by using two transformers:

Two transformers can be connected in various ways to supply 3-phase power. Among these is the so called open-Δ or V-V connection.

Among the application of these connection are :-

1. If one phase in Δ-Δ connection in a 3-phase bank transformer fail, then this failed phase can be removed, and one can still supply 3-phase Voltage.

2. for a new electrified area, one can use 2 transformers (V-V) to supply 3-phase power, and the 3rd transformer can be added when the load grow.

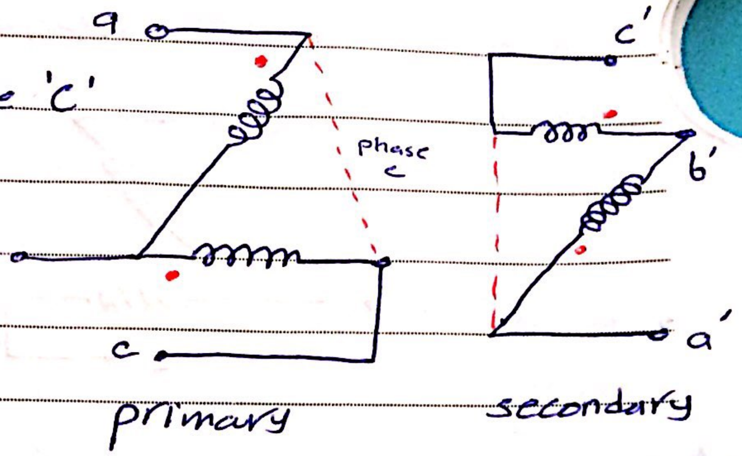
3. V-V connection can be used to supply 1-phase and 3-phase loads simultanewsly.

Objective:

Show that V-V Connection can supply balanced 3-phase voltages:-

In this illustration it could be fault on phase 'c'

Sometimes in this phase c is called ghost phase



Assume +ve phase seq.

V_{ab}, V_{bc}, V_{ca} are Balanced 3-phase supply

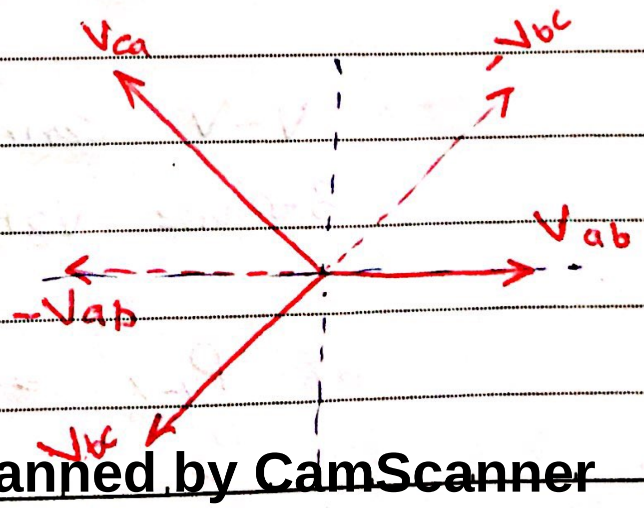
Let $V_{ab} = V\angle 0^\circ$ -- $\boxed{1}$

$V_{bc} = V\angle -120$ --- $\boxed{2}$

$V_{ca} = V_{cb} + V_{ba}$

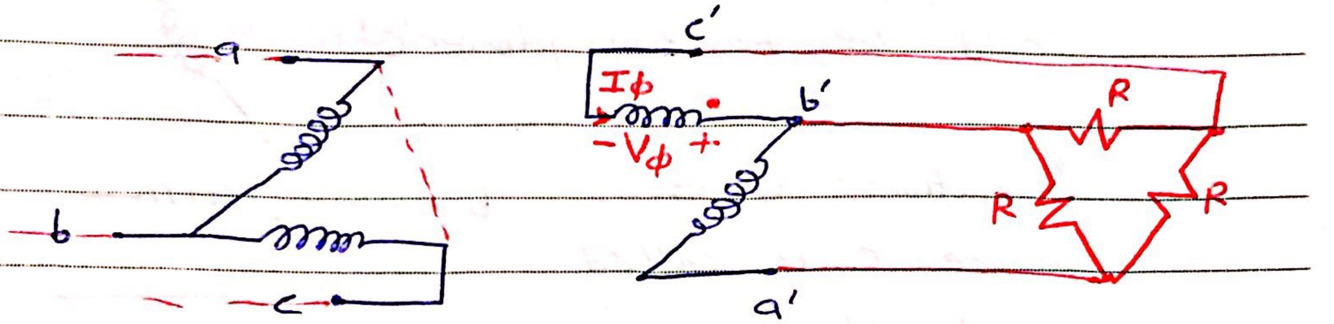
$= -V_{bc} - V_{ab}$ -- $\boxed{3}$

by subs. $\boxed{1}$ and $\boxed{2}$ into $\boxed{3}$ it can be found $V_{ca} = V\angle -240^\circ$



Objective : Find the power supplied by V-V connection.

Procedure : Assume that V-V is supplying power to a balanced Δ - connected resistive load



let the rating of each phase in the secondary by V_ϕ and I_ϕ respectively

$\therefore$ It can be deduced that in the case of $\Delta - \Delta$ the power supplied by transformer $= 3 V_\phi I_\phi$

However it can be shown in the case of open Δ, V-V, " " " "
" $= \sqrt{3}\, V_\phi I_\phi$

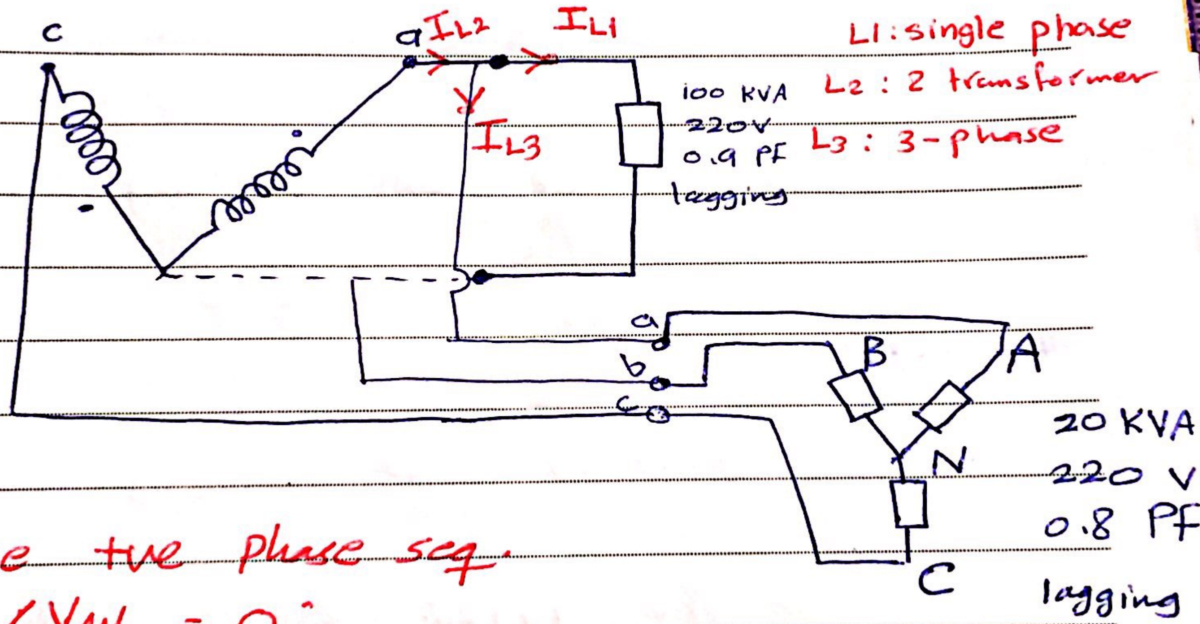
- V-V connection can still supply balance 3-phase voltage but with reduced power

$$\frac{P_{V-V}}{P_{\Delta-\Delta}} = \frac{\sqrt{3}\, V_\phi I_\phi}{3 V_\phi I_\phi} = \frac{1}{\sqrt{3}} = 0.57$$

Cont. OR

$$\frac{P_{V-V}}{\text{Rating of the 2 transformer}} = \frac{\sqrt{3}\, V_\phi\, I_\phi}{2 V_\phi\, I_\phi} = 0.86$$

Ex: A small industry requires 100 KVA of a 1-phase power at 0.9 PF lagging and 220 V. In addition its building has an air-condition comperssor driven by 20 hp, requiring 20 KVA, 220 V, 3-phase at 0.8 pf lagging.
The combined load is to be supplied by 2 transformers connected in V-V. what current will flown in the secondary of each transformer.



Assume +ve phase seq.

let $\angle V_{AN} = 0°$

$\therefore \angle V_{AB} = \angle V_{ab} = 30°$

$$|I_{L1}| = \frac{100 * 10^3}{220} = 454.55\ A$$

$\angle I_{L1} = 30° - \cos^{-1}(0.9) = 30 - 25.84$

$I_{L1} = 454.55 \angle 30-25.84 = 453.35 + j\,32.97\ A$

$$|I_{L3}| = \frac{20 * 10^3}{\sqrt{3} * 220} =$$

$$\angle I_{L3} = \angle V_{AN} - \cos^{-1}(0.8) = -36.87$$

$$I_{L3} = 52.49 \angle -36.87 = 41.99 - j\,31.49 \text{ A}$$

$$I_{L2} = I_{L1} + I_{L3}$$

$$= 495.3 \angle -0.17^\circ \text{ A}$$

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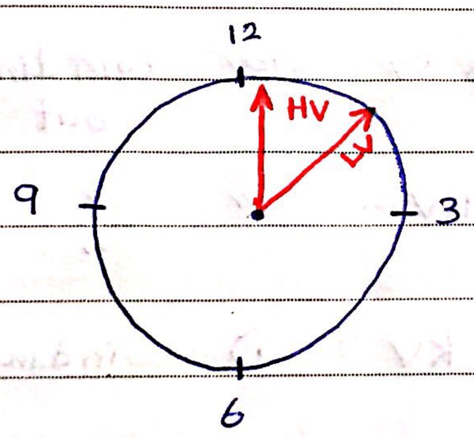
3-phase connection Designation :

Usually capital letters are used for HV and small letters are used for LV as follows :-

Connection	HV	LV
wye	Y	y
Delta	D	d
Neutral	N	n
Terminals	A,B,C	a,b,c

- Phase shift between HV and LV quantities are represented by clock hour figure as follows:-



1. The voltage vector of the HV is used as a Ref. pointing at the 12 o'clock

where the hour arm

2. The next lower voltage is represented by the minute arm.

The phase shift of the LV is written with respect to HV.

Ex : A 3-ph trans. with 2 winding is as follows :-

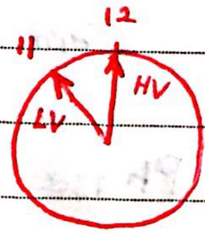
[1] 2000 V delta winding
400 V star (Y) winding with neutral brought out → neutral يوجد

The voltage on the star leads the other voltage by 30°.

Find the connection Designation.

Dyn11
HV LV o'clock

ذكر بالسؤال إنه موجود



[2] 123 KV star winding with neutrall brought out

36 KV : " " " " " "

7.2 KV : D winding

The Voltages of star windings are in phase and the voltage on the delta leads the other voltages by 30°

YNyn0 or 12 d11 → lead by 30
1 → lag " "

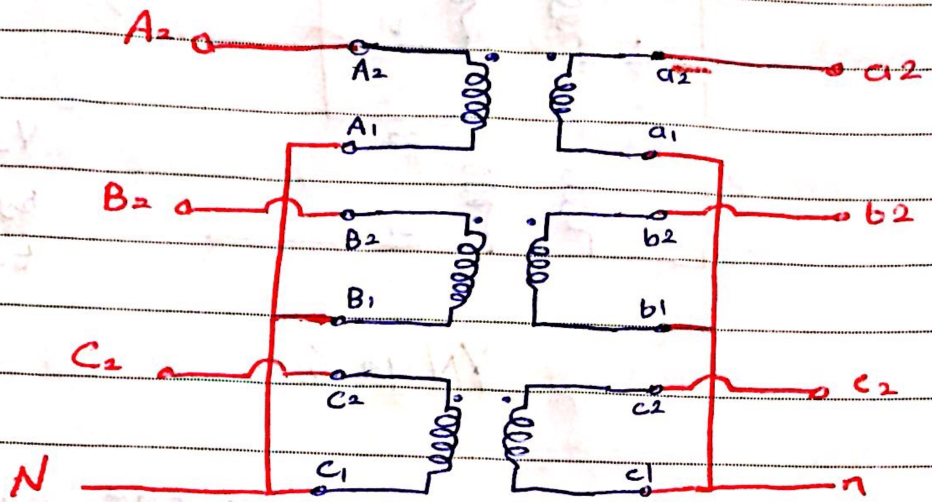
No.

Group Number :

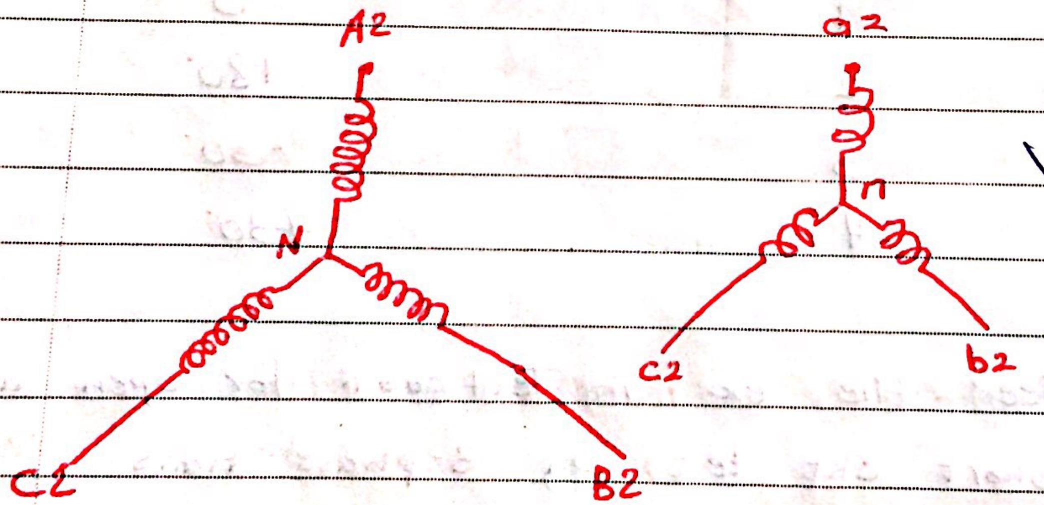
This is illustrated by the following illustration :

I

Group 1



This winding connection can be represented as follows :

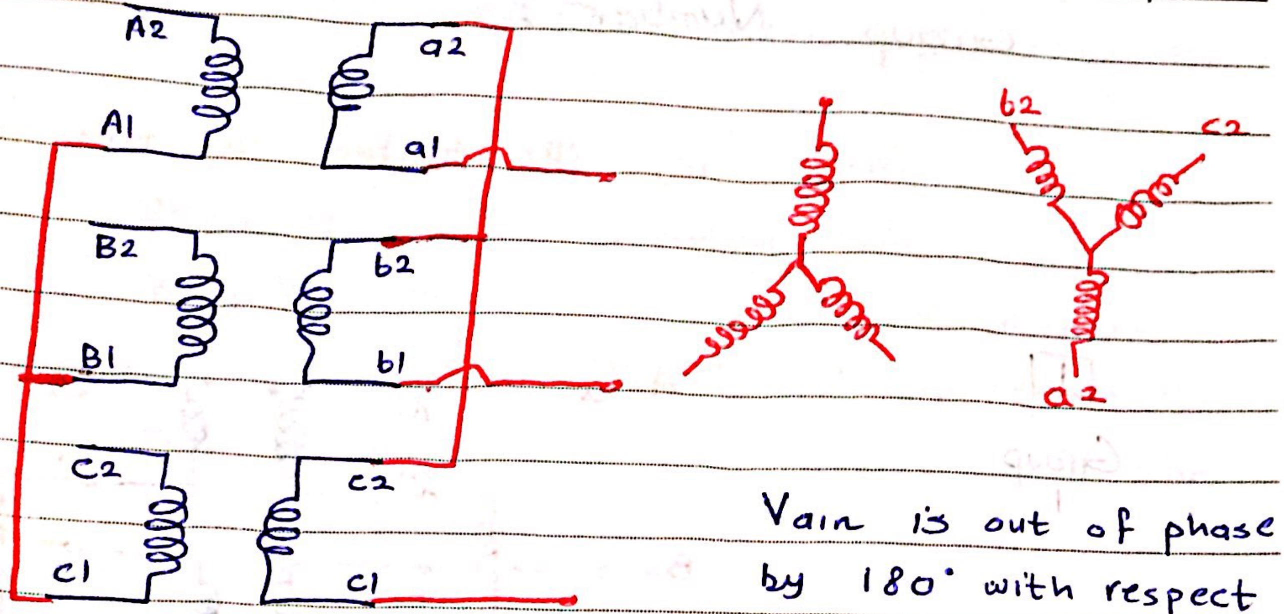


V_{A2N} in phase V_{a2n}.

YNyn 0

2

Group 2



V_{a1n} is out of phase by 180° with respect to V_{A2N}

YNyn 6

group number give the phase shift and defined as follows :-

Group No	Phase shift
1	0°
2	180°
3	-30°
4	+30°

See the ex in Textbook for open and short ckt test on 3-phase trans.

DC Machines :

Construction :

Electrical machines, generator motor, DC or AC consists of 3 major items :-

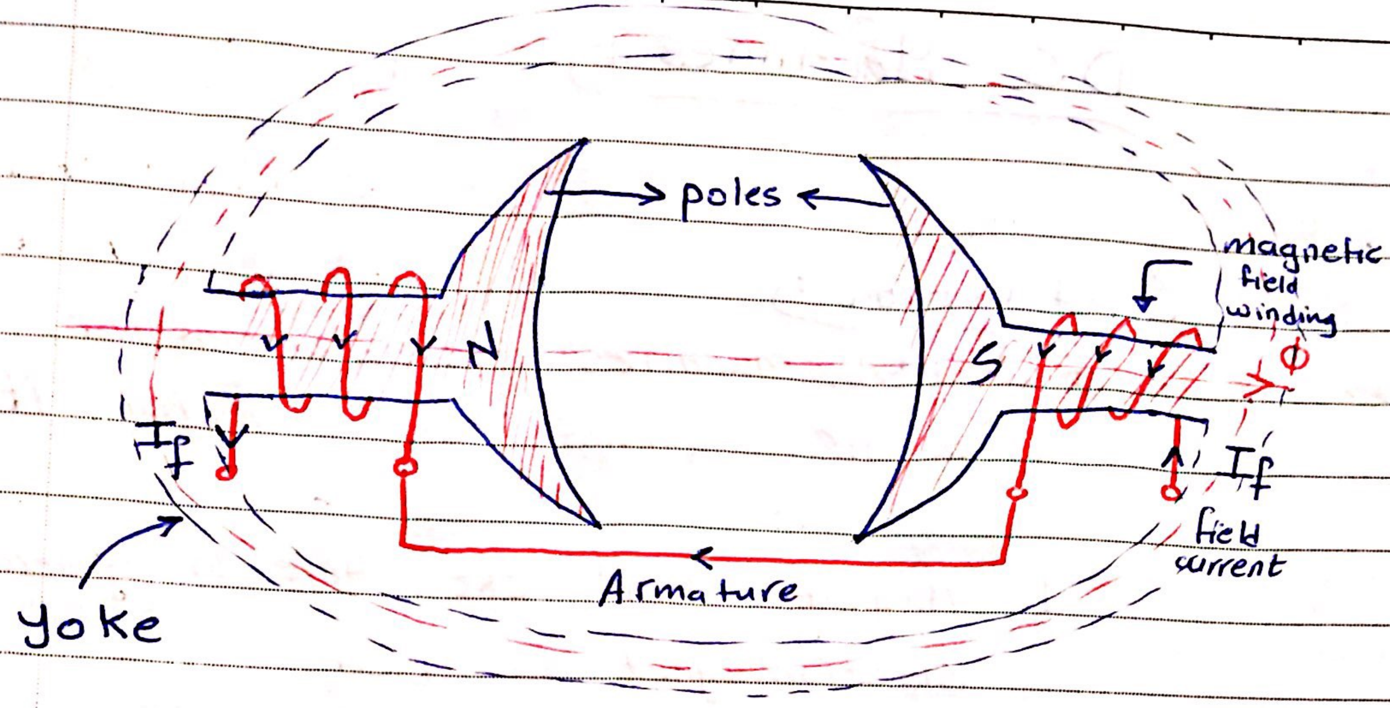
1. Magnetic field ckt. Here in general electromagnet is used

2. Conductors in which voltages are induced in case of generators or conductors in which a current is applied to it in case of motors.
'These are called Armature conductors.'

3. Relative motion between '1' & '2'. hence it could be magnetic field stationary and the Armature conductors rotating or vis-versa.

Stationary component is called Stator
Rotating " " " Rotor

In DC machines, magnetic field winding or ckt is the stator and Armature winding are the Rotor as follows :

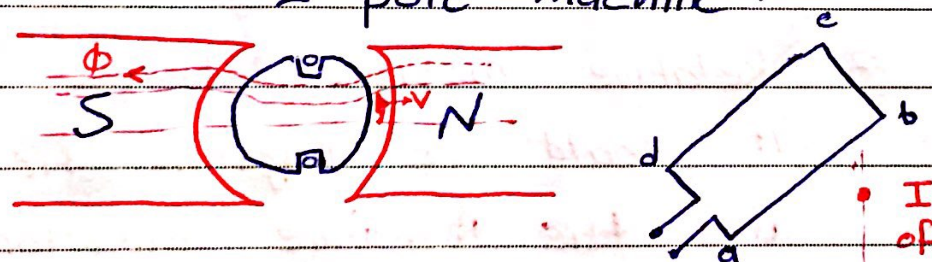


$\Phi \equiv$ generated magnetic field by I_f

- Voltage induced in the Armature coils:

- Consider a single turn coil:
- " " 2-pole machine.

By design flux lines are $\perp$ on the armature surface.



ba, dc ≡ coil side

- In the case of single turn coil each side has one conductor
- Each turn has 2 conductors

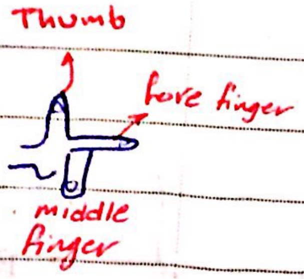
- Induced voltage / conductor $= (B * V) \cdot L = e$

$B \equiv$ flux density (wb/m^2) or Tesla.

$V \equiv$ linear velocity of the conductor (m/s)

$l \equiv$ length of conductor.

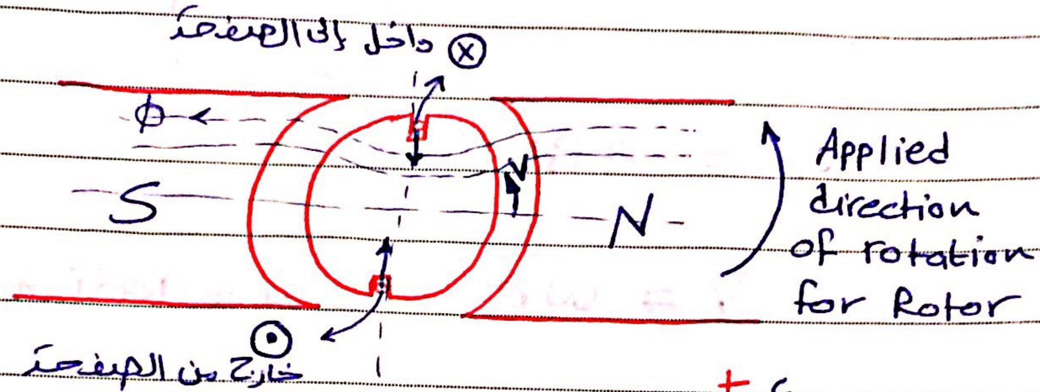
e can also found by Right hand Rule.

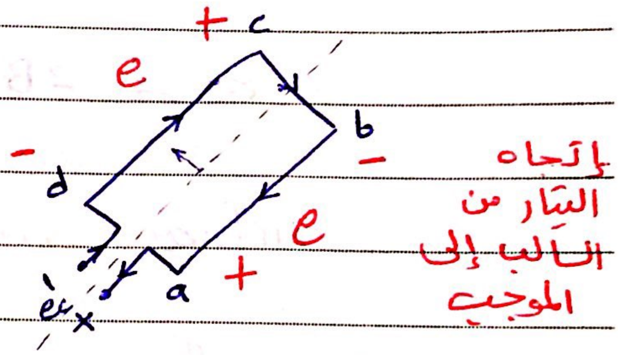


Fore finger ≡ Direction of magnetic field.

Thumb ≡ " " applied force or motion

middle finger ≡ " " induced voltage.





∴ Voltage induced in the coil $= e_{ad} = e + e = 2e$

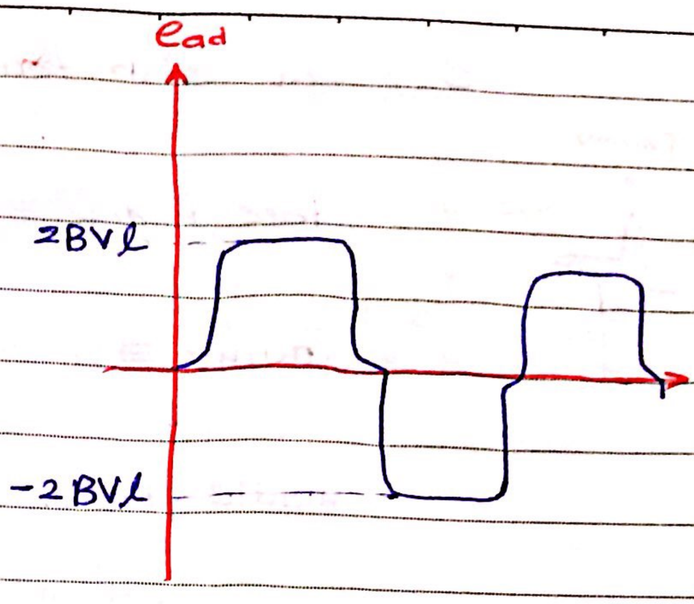
Note: there is no induced voltages in bc and ad

$\therefore\ e_c = e_{ad} = 2e = 2B\ell V$ for the first 180°

for the next 180° coil sides will interchange locations.

$\therefore\ e_{ad} = -2e = -2B\ell V$

- The internal generated voltage within the armature coil is <u>AC</u>



$$e_c = 2BVl$$

$V = \omega r$; $\omega \equiv$ radian speed.

$\therefore e_c = 2Bl\omega r$ ~ $\boxed{1}$

surface area of armature (Rotor) $= 2\pi r l$ ... $\boxed{2}$

$\therefore$ Surface area under one pole, $A_p = \frac{2\pi r l}{2} = \pi r l$

Beacuse we have 2 pole.

$\therefore r l = \frac{A_p}{\pi}$ ~ $\boxed{3}$

Subs. $\boxed{3}$ into $\boxed{1}$

$$e_c = 2B\omega \frac{A_p}{\pi} = \frac{2}{\pi}\omega B A_p$$

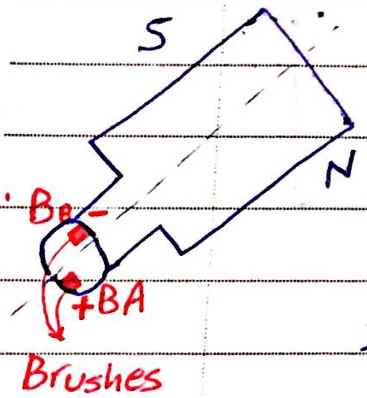
$\phi = BA \longrightarrow e_c = \frac{2}{\pi}\omega\phi$, $\phi \equiv$ flux per pole.

No.

- e_c depends on :-
  1. $\frac{2}{\pi}$ which represent the structure of the machine.
  2. speed.
  3. Magnetic flux

- Commutation :-

This is the process of converting the internal generated AC Voltage to DC Voltage as follows :-

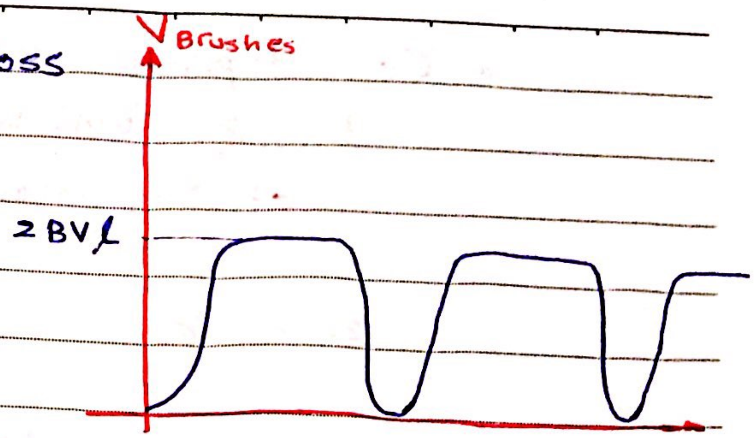


1. Each terminal of a coil is connected to a semi circular disc (copper conductor). called commutator. In general it consists of a set of segments.

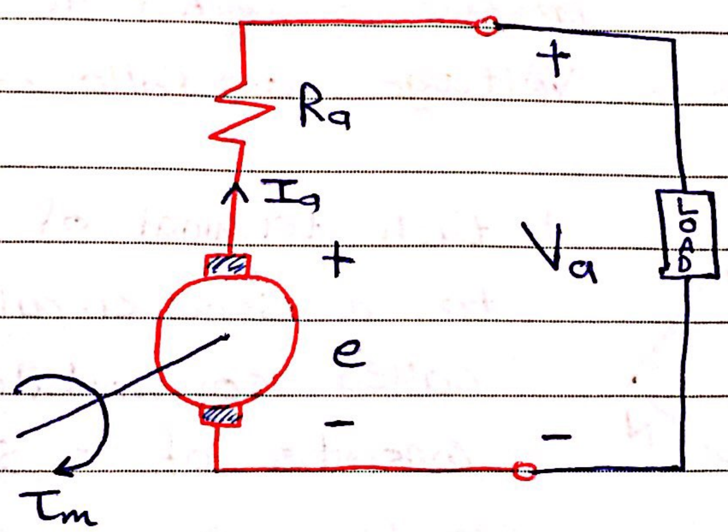
2. Commutator is always in contact with fixed contacts called <u>Brushes</u>. where B_A is always in contact with coil side under 'N' pole, and B_B is contact with coil side under 'S' pole.

No.

The Voltage across the Bruches will be as follows :



• Equivalent electrical circuit :-



$e \equiv$ generated voltage

$R_a \equiv$ Armature resistance.

$V_a \equiv$ Armature terminal Voltage

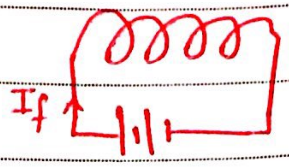
$I_a \equiv$ Armature current

$\tau_m \equiv$ Applied mechanical tourq.

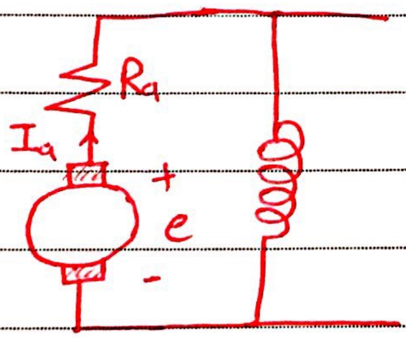
No.

Sources of field current applied to field windings :

1. External source separately excited DC machine.



2. Self - excited dc machine. Here field windings are connected to Armature circuit. This depend on the existance of Residual flux.



- Generated Voltage (E) and Torque (τ_{ind}) in Real DC machines:-

E : Voltage per conductor, $e = BLV$

E = Voltage across the Brushes

$$E = \frac{Z}{a} e = \frac{ZBLV}{a} = \frac{ZBlwr}{a} \quad \cdots \boxed{1}$$

$$\frac{2\pi r L}{P} = A_P \quad , P \equiv \text{Number of poles.}$$

$$rL = \frac{P A_P}{2\pi} \quad \cdots \boxed{2}$$

sub. $\boxed{2}$ into $\boxed{1}$

$$E = \frac{ZBw}{a} \cdot \frac{PA_P}{2\pi}$$

$$\therefore E = \frac{PZw\phi}{2\pi a} \quad , \phi = BA_P \equiv \text{Flux per pole.}$$

if the rotational speed of the gen. = n r.p.m

$$w = \frac{2\pi n}{60} \quad \cdots \boxed{4}$$

sub. $\boxed{4}$ into $\boxed{3}$

$$E = \frac{PZ\phi}{2\pi a} \cdot \frac{2\pi n}{60} = \frac{PZn\phi}{a\, 60}$$

No.

$\therefore$ For a given generator :-

$$E = K\phi n \quad , \quad K = \frac{PZ}{60a}$$

$Z \equiv$ Total number of Armature conductors.

- τ_{ind} OR $\tau_{developed}$

$$\tau_{cond} = B\, I_{cond}\, \ell\, r$$

$\tau_{cond.} \equiv$ Torque developed per conductor

$I_{cond} \equiv$ Conductor's current

$$= B\left(\frac{I_A}{a}\right)\ell r$$

$$= B\left(\frac{I_A}{a}\right)\frac{P A_P}{2\pi}$$

$$= \frac{I_A P}{2\pi a} . B A_P = \frac{I_A P \phi}{2\pi a}$$

$I_A \equiv$ Armature current.

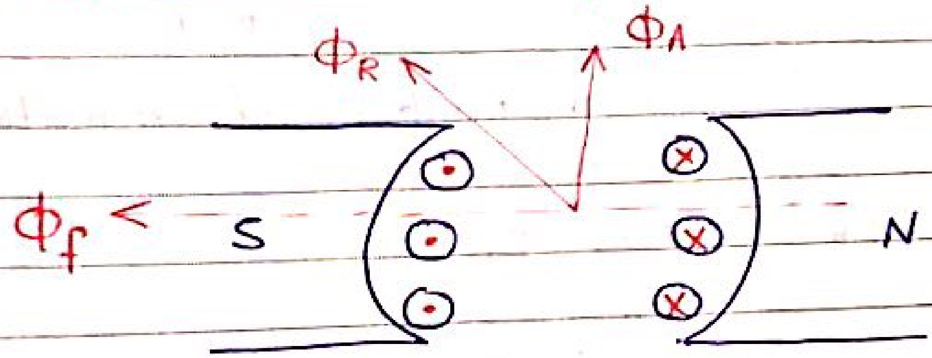
$$\therefore \tau_{ind} = Z\, \tau_{cond.} = \frac{Z I_a P \phi}{2\pi a}$$

$$= \underbrace{\frac{ZP}{2\pi a}}_{K_1} . I_a \phi = K_1 I_a \phi$$

No.

- Armature Reaction :

Consider the following DC machines :



Φ_R المحصلة تقلل من Φ_f

$\Phi_A \equiv$ flux produced by Armature current.

$\Phi_R \equiv$ Resultent of Φ_f and Φ_A

$\otimes$ $\odot$ $\equiv$ current in Armature conductors

Armature Reaction : it is the interaction between main magnetic field (Φ_f) and the flux generated by Armature current (Φ_A).

No.

Analysis of DC Machines:-

efficiency, $\eta = \frac{P_{out}}{P_{in}}$

$= \frac{P_{in} - P_{Losses}}{P_{in}}$

P_{Losses} it consists of the following:-

1. Electrical losses, (I^2R)

Ex : Armature losses $= I_A^2 R_A$

$R_A \equiv$ Equivalent resistance of parallel paths.

field losses $= I_f^2 R_f$

2. Brush losses.

3. Core losses

4. Mechanical losses

"Pulley friction + friction of Air with rotor

5. Stray load losses

These can be illustrated by the so called power flow diagramy as shown :-

cont

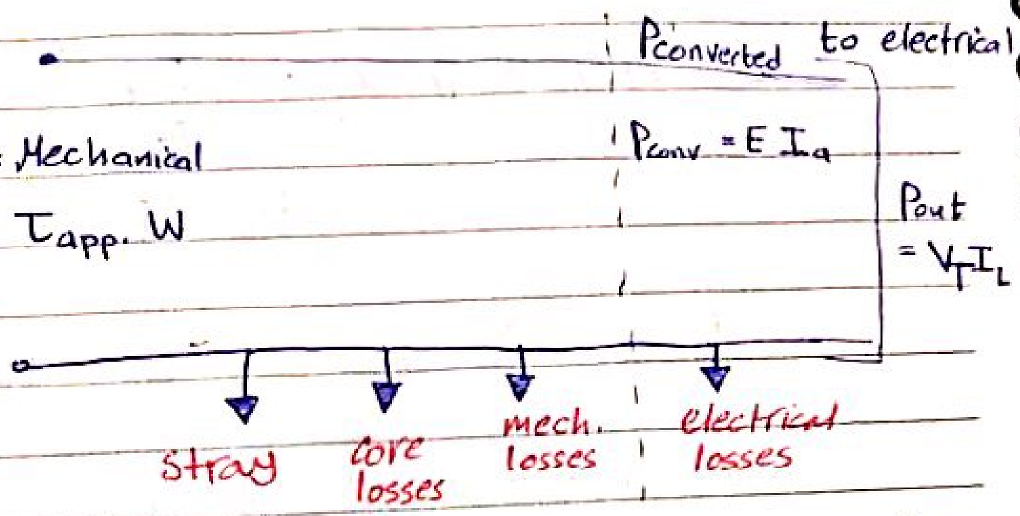
No.

Generator :

V_T = Terminal Applied Voltage to Armature

P_{in} = Mechanical

$= \tau_{app} \cdot W$



A Similar power flow diagram can be produced for DC motor.

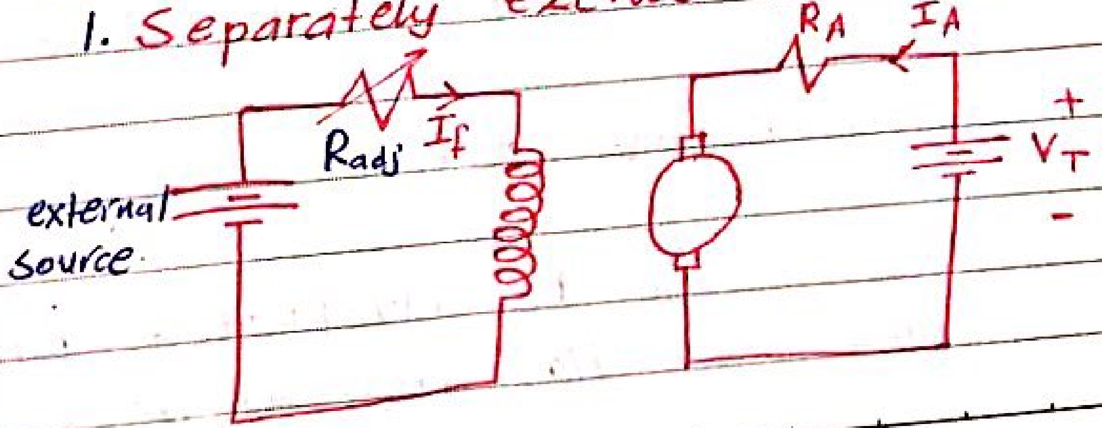
• Analysis of DC motors :

* Speed Regulation, $SR = \frac{n_{nL} - n_{FL}}{n_{FL}} * 100\%$

* Speed - Torque charasteiristics :

DC Motors can be classified into :-

1. Separately excited



No.

$R_F \equiv$ Resistance of field ckt.

OR

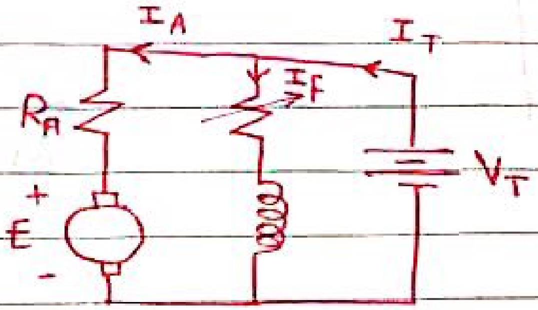
Resistance field windings + variable resistance

2. Self - excited :- a- shunt

b- series

c- compouned

Shunt :-



By KVL :

$$V_T = E + I_A R_A$$

$$\therefore V_T = K\phi\omega + I_A R_A \quad \text{---} \boxed{1}$$

Since $\tau_{ind} = K_1 \phi I_A$ --- $\boxed{2}$

$$\therefore I_A = \frac{\tau_{ind}}{K_1 \phi} \quad \text{---} \boxed{3}$$

Sub. $\boxed{3}$ into $\boxed{1}$

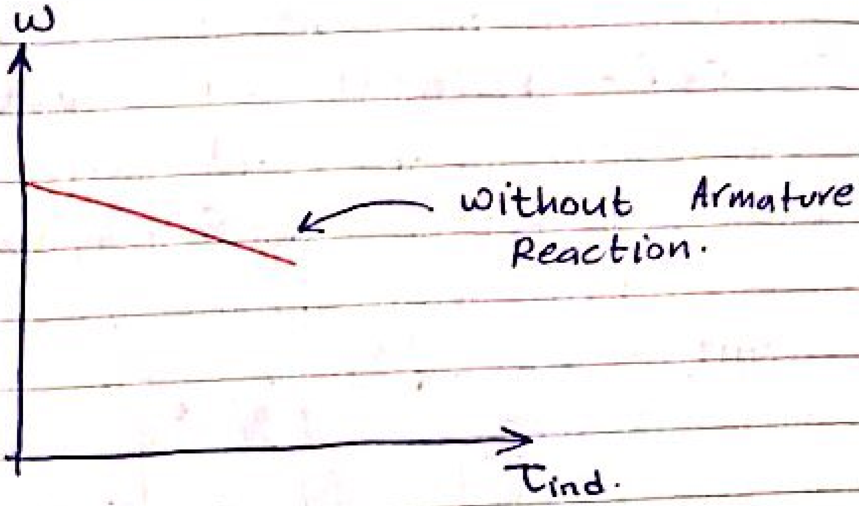
$$V_T = K\phi\omega + \frac{\tau_{ind}}{K_1\phi} R_A$$

cont. →

No.

كل ما زاد ال τ_{ind} تقل ω

$$\boxed{\omega = \frac{V_T}{K\phi} - \frac{\tau_{ind}}{K K_1 \phi^2} R_A}$$



No.

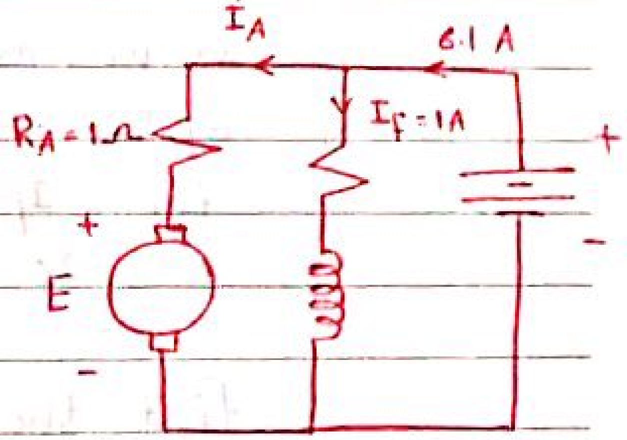
Ex: When connected to a source at rated voltage, a 25 hp, 230 V shunt motor draws 6.1 A at no-load, at a speed of 1300 rpm. The Field current is 1 A at no-load. The Armature ckt has a resistance of 1 Ω.

1. Find the speed of the motor when Armature current is 80 A (rated)
2. Speed regulation.

$I_A = 6.1 - 1 = 5.1\,A$

Sol. 1. $E = V - I_A R_A$

$E = K\phi n$



$$n = \frac{V - I_A R_A}{K\phi}$$

Since the flux ϕ is constant for shunt motor.

$\boxed{1\ hp = 0.746\ Kw}$

$$\frac{n_1}{n_2} = \frac{V - I_{A1} R_A}{V - I_{A2} R_A}$$

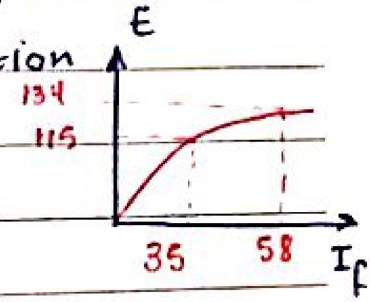
$$\frac{1300}{n_2} = \frac{230 - 5.1 * 1}{230 - 80 * 1}$$

$n_2 = 866.7$ rpm

2. $SR = \frac{n_{NL} - n_{FL}}{n_{FL}} * 100\% = \frac{1300 - 866.7}{866.7} * 100\%$

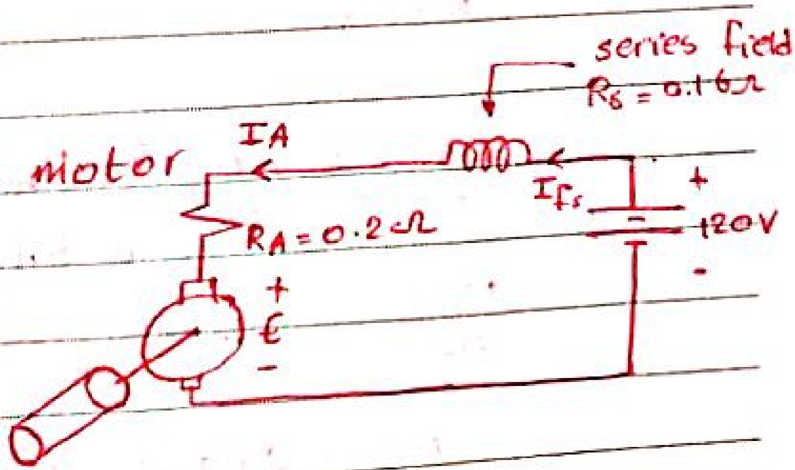
Ex: A 7.5 hp, 120 V series dc motor has $R_A = 0.2\,\Omega$ and series field resistance $R_s = 0.16\,\Omega$. At full load the current input is 58 A at the rated speed equal 1050 rpm. The core losses are 200 W and mech. losses are 240 W at full load. Assume that mech. losses vary as the cube of motor's speed and core losses are constant.

Given Also the Magnetization curve which is taken at speed = 1300 rpm from which
for $I_f = 35\text{ A}$, $E = 115\text{ V}$
$I_f = 58\text{ A}$, $E = 134\text{ V}$



Find the speed and η of the motor if it is operating at Armature current 35 A.

Sol. for series motor
$I_A = I_{fs}$



$E = K\Phi n$ ← 1300 rpm

$I_A = I_f$, $R_A = 0.2\ \Omega$, $R_S = 0.16\ \Omega$

$\therefore$ E at $I_A = 35\,A$ is $E_1 = 120 - 35(0.2 + 0.16) = 107.4V$

E at $I_A = 58A$ is $E_2 = 120 - 58(0.2 + 0.16) = 99.1V$

$E_1 = K\phi_1 n_1$; $\frac{E_1}{E_2} = \frac{\phi_1 n_1}{\phi_2 n_2}$ ---- $\boxed{1}$

$E_2 = K\phi_2 n_2$;

Now from magnetization curve.

$I_A = 35\,A$, give $E_1' = 115\,V$ at $n = 1200$ rpm

$I_A = 58A$, give $E_2' = 134\,V$ at $n = 1200$ rpm.

$E_1' = K\phi_1 \cdot 1200$

$E_2' = K\phi_2 \cdot 1200$

$\frac{E_1'}{E_2'} = \frac{115}{134} = \frac{\phi_1}{\phi_2}$ ---- $\boxed{2}$

subs. $\boxed{2}$ into $\boxed{1}$

$\frac{E_1}{E_2} = \frac{107.4}{99.1} = \frac{115}{134}\,\frac{n_1}{1050}$

$n_1 = 1326$ rpm.

$\eta = \frac{output}{Input} * 100\%$ $\Rightarrow$ Input $= 120 * 35 = 4200\,W$

cont

No.

Output = $P_{conv.} - (P_{core} + P_{mech.})$

$P_{conv.} \equiv$ Amount of mech. power which is converted from the electrical input

$= E I_A$

Back emf

From the equv. ckt.

$(E = V - I_A(R_A + R_S)) * I_A$

$E I_A = \underbrace{V I_A}_{\text{input}} - \underbrace{I_A^2 (R_A + R_S)}_{\text{electrical losses}}$

$P_{conv.} = 107.4 * 35 = 3759$ W

$P_{core} = 200$ W

$P_{mech.} \propto n^3$

P_{mech} at $n = 1326$ is $240 \cdot \left(\frac{1326}{1050}\right)^3 = 483.4$ W

output $= 3759 - (200 + 483.4) = 3075.6$ W

$\eta = \frac{3075.6}{4200} * 100\% = 73.2\%$

proof $P_{conv} = E I_A$ for all types of dc motors and prove it for shunt motor

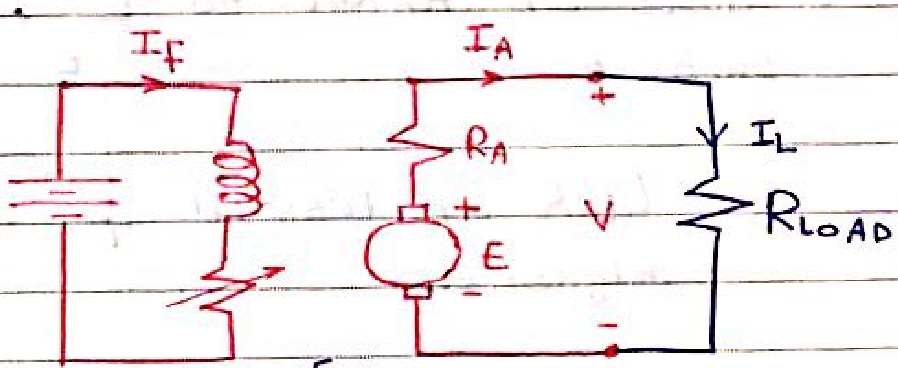
No.

Introduction to DC generator :

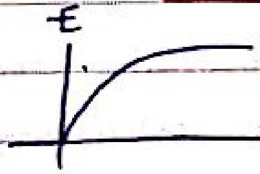
Classification : It is the same as DC motors separately excited and self excited.

Equivalent ckt :

I) Separately excited.



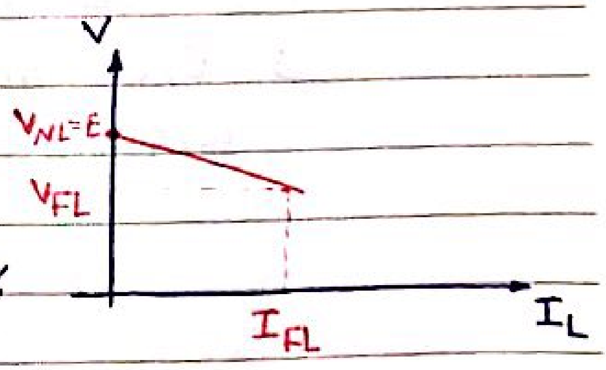
$E = K\phi S$



output chara. :

$V = E - I_L R_A$

$$VR = \frac{V_{NL} - V_{FL}}{V_{FL}} * 100\%$$

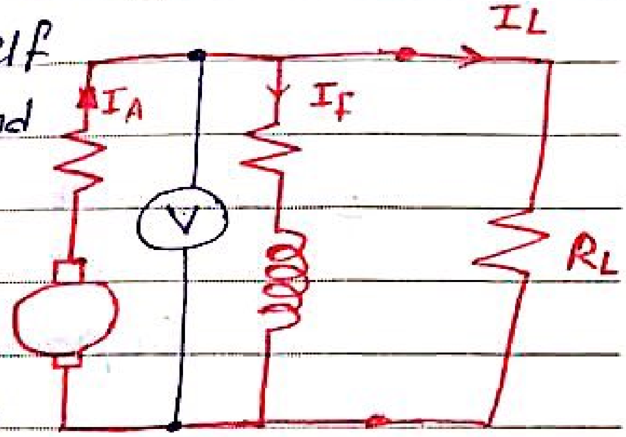


No.

2 Self excited

Take for ex. shunt generator

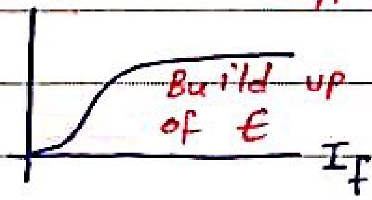
- The operation of self excited generator depend on the existance of Residual Magnetizm



$I_A = I_f + I_L$

- Causes of failure to build up :

E



1. lack of residual magnetizm.

2. field winding connection w.r.t Armature winding are reversal (i.e. cancel any residual magnetizm)

3. O/C in the armature or field winding.

Scanned by CamScanner

3 phase synchronous generator :

- This is basically used in conventional power station for the generation of 3-phase electrical voltage and energy

- Construction : It consists of :

Stator

It carries 3-ϕ winding, in slots, in which 3-ϕ Voltages are induced.

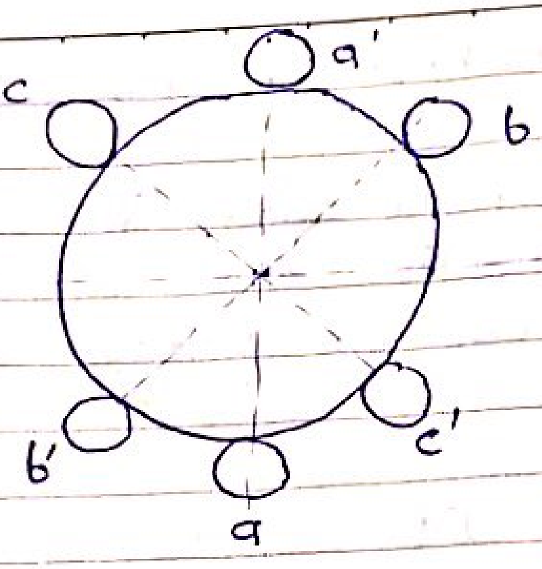
Rotor

It carries the field windings, into which dc current is supplied from external source through Brushes which make contact with 2 rotating slip-ring

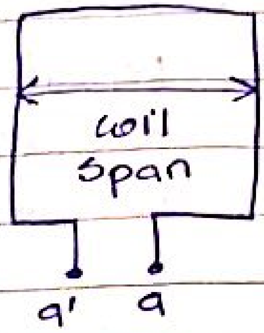
- Rotating magnetic field :

* A Balanced 3-ϕ current applied to the 3-ϕ windings of the stator, will generate a rotating magnetic field within the stator. As explained as follows :

No.



As a convention :
let +ve current = $\otimes$
" -ve " = $\odot$



- There are 3-ϕ windings aa', bb', cc' where the coil span = 180°

- let the applied balanced 3-ϕ currents be :

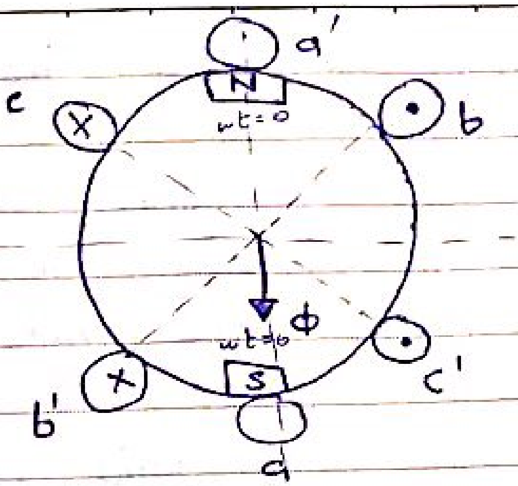
$$i_{aa'} = I_m \sin(\omega t)$$
$$i_{bb'} = I_m \sin(\omega t - 120)$$
$$i_{cc'} = I_m \sin(\omega t - 240)$$

- Next let the applied current change over one cycle

	ωt	$i_{aa'}$	$i_{bb'}$	$i_{cc'}$	ϕ 이동
1.	0	0	-ve	+ve	$\downarrow$
2.	90				$\rightarrow$
3.	180				$\uparrow$
4.	270				$\leftarrow$
5.	360				$\downarrow$

No.

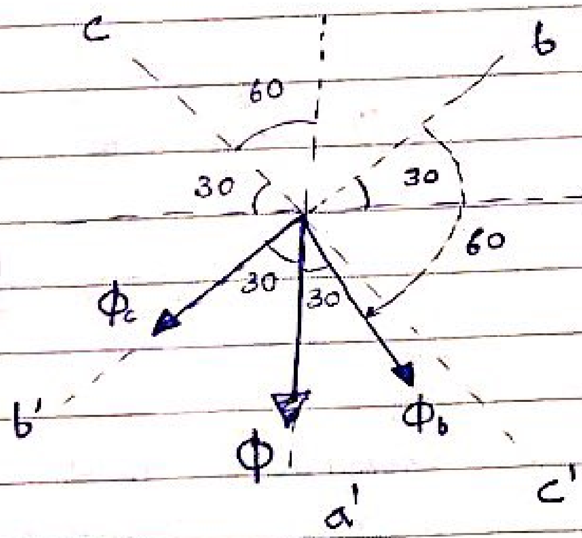
$\phi \equiv$ Resultant flux.

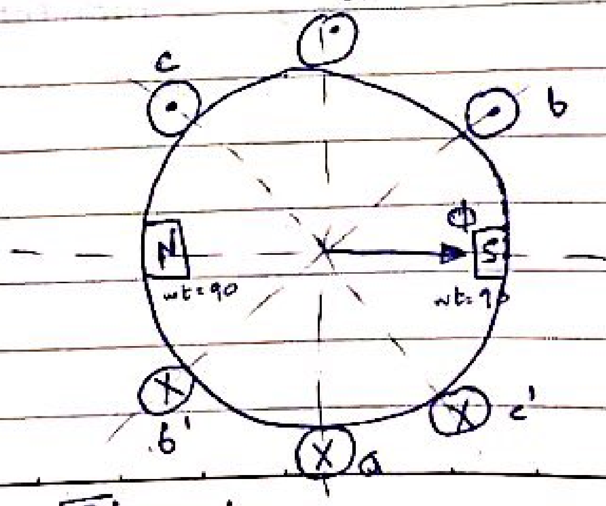


$\boxed{1} \to wt = 0$

1. Apply RHR

2. by finding the resultant flux of ϕ_b and ϕ_c as follows :





$\boxed{2}$ $wt = 90$

No.

It can be deduced :-

1. When the current makes one cycle, the generated magnetic flux ϕ make one mechanical rotation.

2. This type of armature winding (i.e. coil span = 180°). can be represented by a 2 pole magnet.

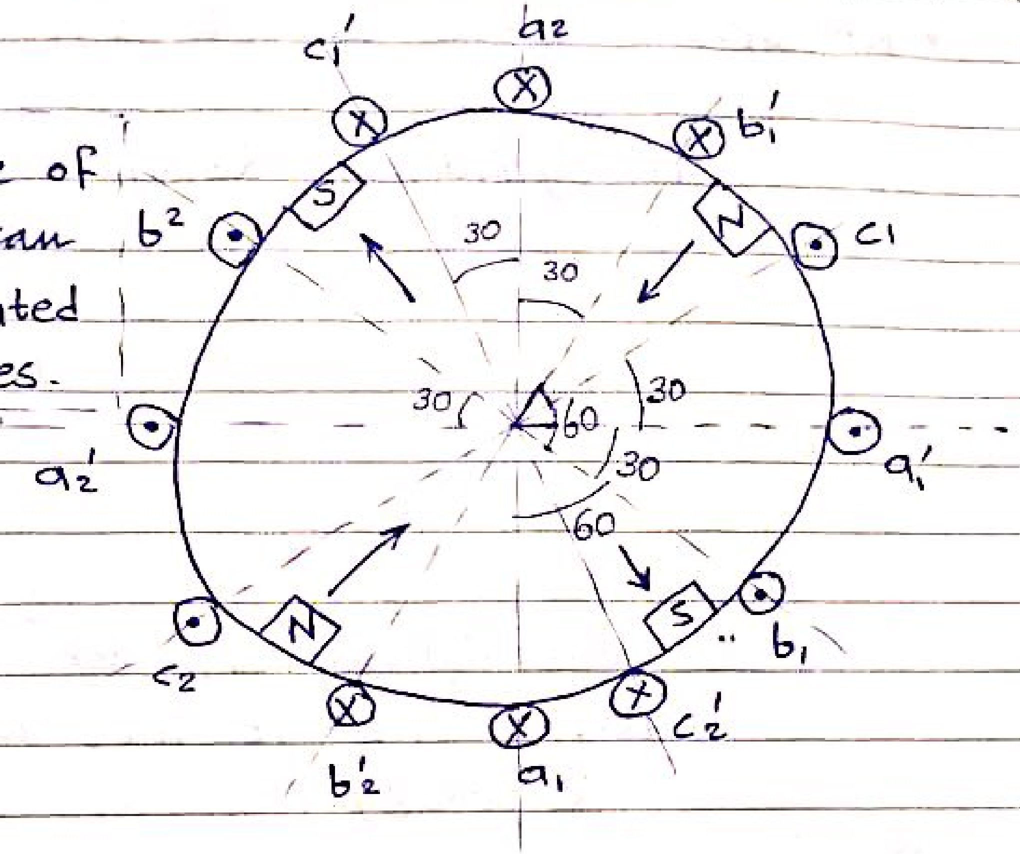
∴ For this case : $\omega_e = \omega_m$
electric = mechanical

① can be rewritten as :

$$\omega_e = \frac{P}{2}\,\omega_m \quad , \; P \equiv \text{Number of poles.}$$

Consider now the following Armature winding connection :

This type of winding can be simulated as 4 poles.



Phase $a = a_1 \; a_1' \; a_2 \; a_2'$

" $b = b_1 \; b_1' \; b_2 \; b_2'$

" $c = c_1 \; c_1' \; c_2 \; c_2'$

∴ for this structure of armature windings :

$$W_e = 2 W_m$$

$$W_e = \frac{P}{2} W_m \quad , \quad P = 4$$

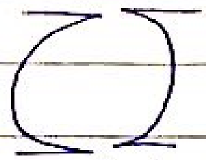
In general , $w_e = \frac{P}{2} w_m$

$n_e = \frac{P}{2} n_m$, $n \equiv$ r.p.m
r.p.s

No.

- Rotor :- There are 2 types :

    1. Cylindrical Rotor : it has only 2 poles OR non - salient rotor



    2. Non - cylindrical or Salient rotor (i.e. it has more than 2 poles).

$$n_e = \frac{P}{2} n_m$$

$f = Pn$, P= Number of pole pair

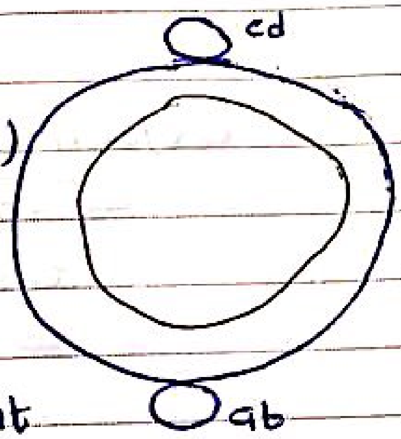
if $f = 50\,Hz$

$50 = 1 \times 50$, 2 poles.

Voltage induced in 3 phase synch. generator :

Consider the following :

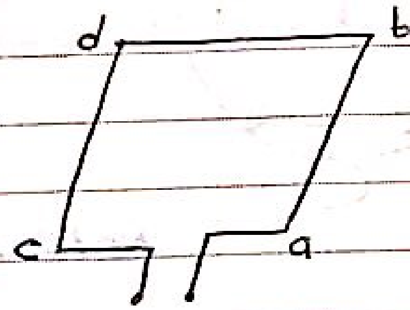
1. Consider a single turn coil on the stator (abcd)



2. The rotor windings are designed in such a way that when DC field current is applied to, then it generates a sinusoidal flux within the stator

- Stator,
- Rotor

This flux can be expressd as



$B = B_m \cos \alpha$ ---- $\boxed{1}$

abcd ≡ stator armature winding.

$B_m \equiv$ max. value.

$\alpha \equiv$ Angle measured from direction of B_m

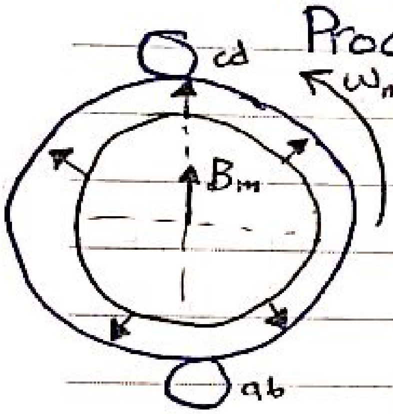
where, as a Ref. , B_m is taken along +ve y-axis. Where acc. to $\boxed{1}$, B is always directed outward from the rotor

Since the rotor is running at a mechanical speed W_m, Then $\boxed{1}$ can be expressd as:

$$B = B_m \cos(\underbrace{\omega_m t - \alpha}_{\text{displacment}}) \quad \cdots \boxed{2}$$

Objective :-

To find the voltage induced in the single turn coil (abcd) due to rotating B



Procedure :-

find the voltages induced in the side ab and cd; by using the concept of Right hand rule (RHR).

Note : In apply RHR, magnetic field should be stationary.

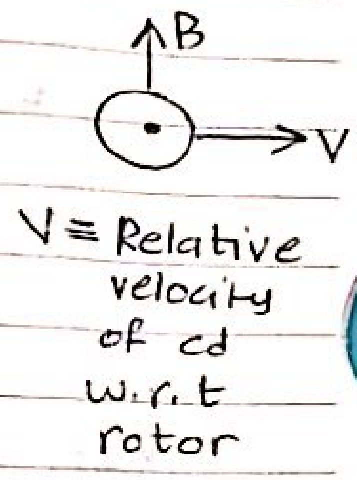
Hence to apply it to the rotating field, then it is assumed that the observer is riding on the rotor.

Hence to the observer the armature windings appear to him as moving away. as follows :-

No.

Let the rotor rotates in ccw :

1- Coil side cd :



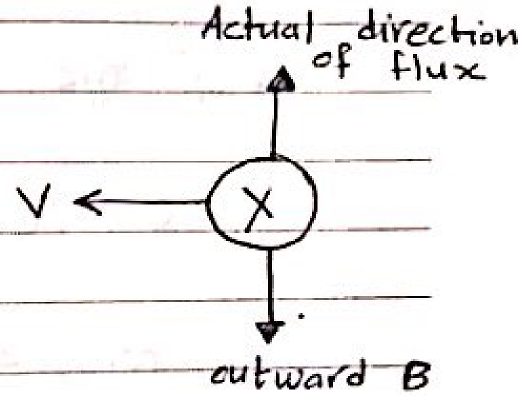
Hence $\alpha = 0$

$\therefore e_{cd} = B \ell V$

$= B_m \cos(\omega_m t - \alpha)$

$= B_m \ell V \cos(\omega_m t)$

2- Coil side ab :

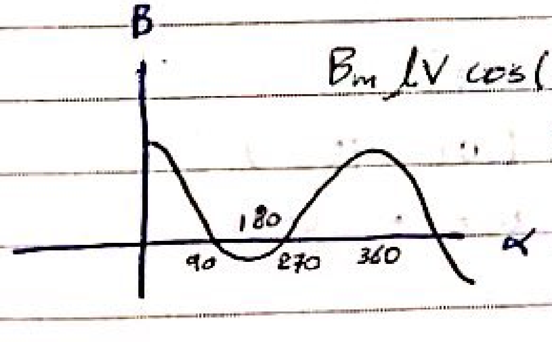


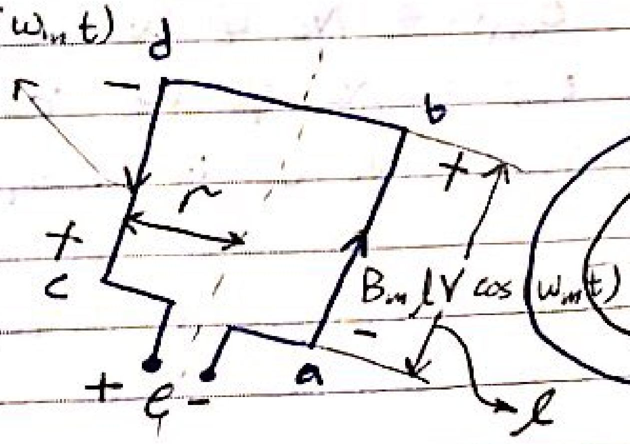
Hence $\alpha = 180$

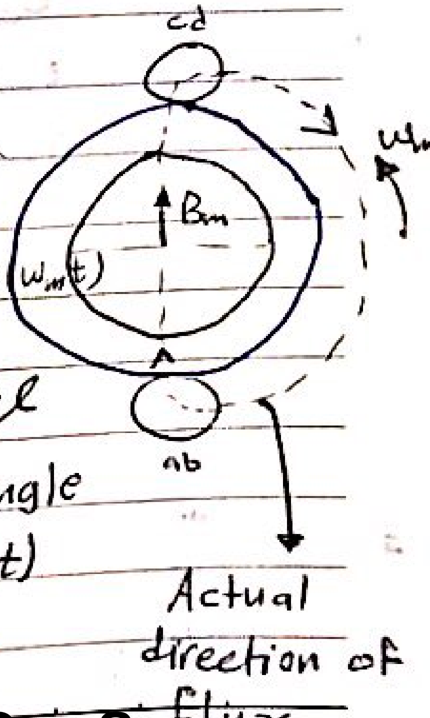
$\therefore e_{ab} = B \ell V$

$= - B_m \cos(\omega_m t - 180) + \ell V$

$= B_m \cos(\omega_m t) \ell V$







$\therefore$ The voltage induced in single turn coil $= e = 2 B_m \ell V \cos(\omega_m t)$

No.

$\therefore \; e = 2 B_m \, l \, (\omega_m r) \cos(\omega_m t)$, since $V = \omega_m r$

$$e = \omega_m B_m (2 r L) \cos(\omega_m t)$$

$e = \omega_m \phi \cos(\omega_m t)$, ϕ (magnetic flux) $= B_m * 2rL$

- If the coil has N_c turns, then

$$e = N_c \omega_m \phi \cos(\omega_m t)$$

- If the machine has 2 poles, then $\omega_m = \omega_e = \omega$

$$e = N_c \, \omega \, \phi \cos(\omega t)$$

$\therefore$ for 3-phase generators:

$$\begin{aligned} e_{aa'} &= \overbrace{\boxed{N_c \phi \omega}}^{E_m} \cos(\omega t) \\ e_{bb'} &= \boxed{N_c \phi \omega} \cos(\omega t - 120^\circ) \\ e_{cc'} &= \boxed{N_c \phi \omega} \cos(\omega t - 240^\circ) \end{aligned}$$

. Max. or peak value of generated voltage :

$E_m = N_c \phi \omega$, $\therefore E_{rms} = \dfrac{E_m}{\sqrt{2}} = \dfrac{N_c \phi \omega}{\sqrt{2}}$

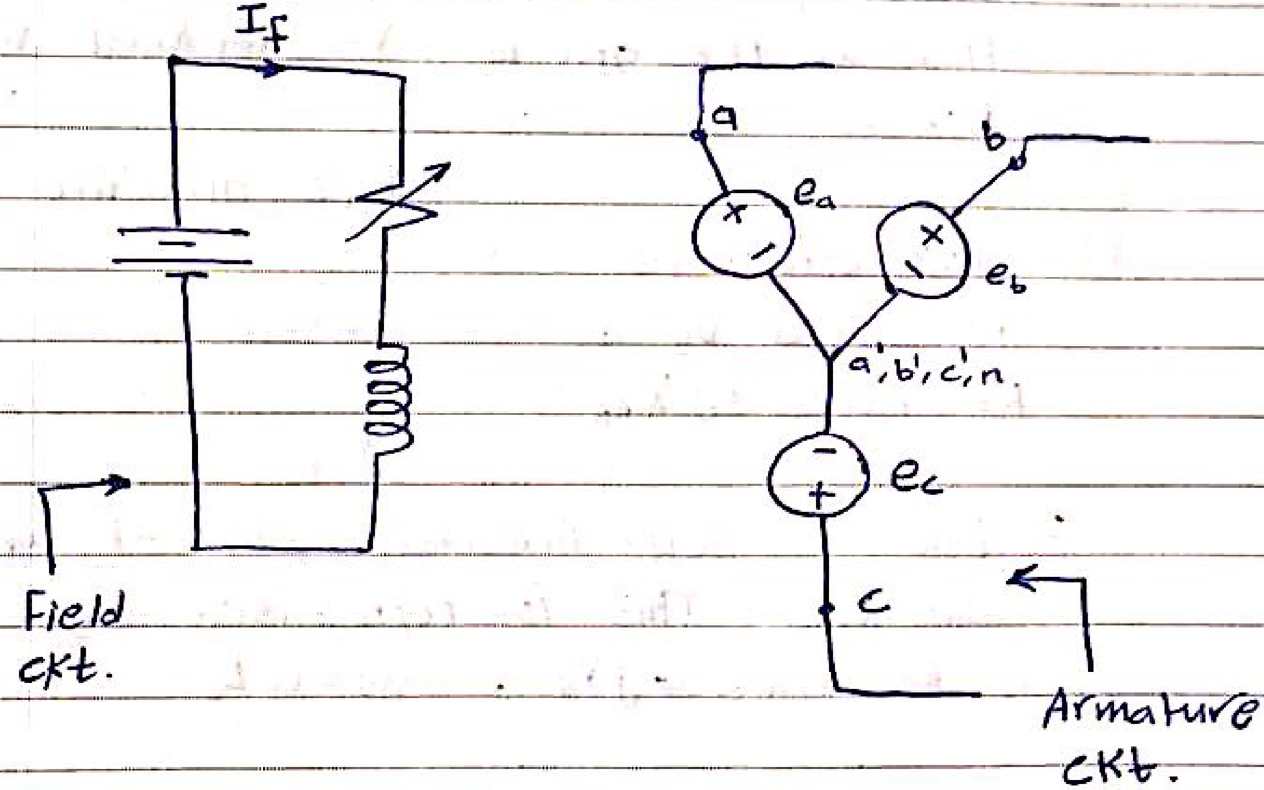
No.

$$E_{rms} = \frac{N_c \, \phi \, 2\pi f}{\sqrt{2}} \quad , \quad f \equiv \text{freq. (Hz)}$$

$$E_{rms} = \sqrt{2}\,\pi N_c \phi f$$

$$E_{rms} = 4.44 \, N_c \, \phi \, f$$

- Equv. ckt :
  Usually 3 phase generator is Y-connected

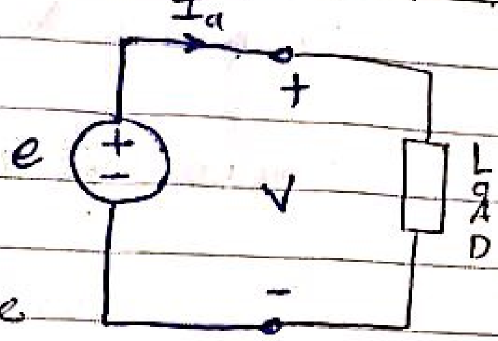


- In practice the generated line voltage could be in the range of (11 - 25) KV

- Since the generator voltages are balanced, then the ~~pole~~-phase ckt. is used

No.

- At no-load,
  $V = e$



- At load,
  $V \neq e$ due to the followings:

$e \equiv$ generated phase Voltage

$V \equiv$ Terminal Voltage.

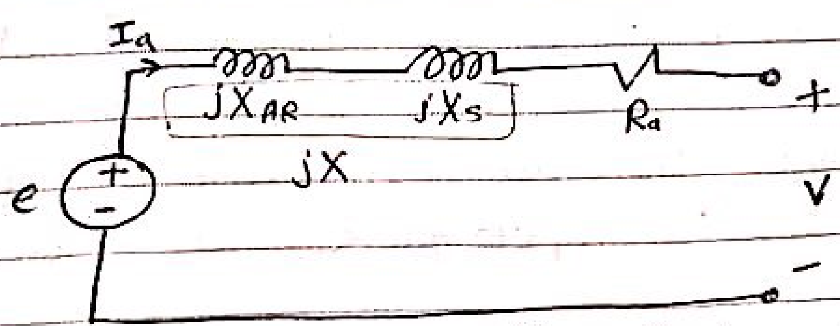
$I_a \equiv$ Armature current

1. Due to armature reaction. Hence the flux in the gen. is Reduced.

   This effect is represented by a Reactance $= jX_{AR}$

2. Due to self inductance, L, of armature windings. This is represented by a Reactance $= jX_s$, $X_s = \omega L_s$

3. Resistance, R_a of Armature windings.



where $X = X_{AR} + X_s$, it is called synchronous Reactance.

No.

Voltage Regulation :

- $VR = \frac{|V_{NL}| - |V_{FL}|}{|V_{FL}|} * 100\%$

where $V_{NL} = E$

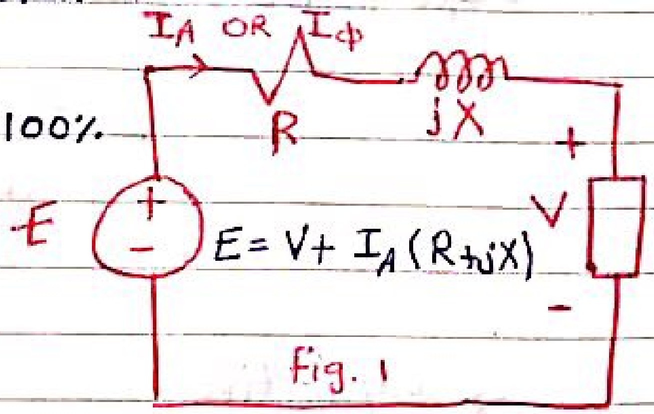


fig. 1

To see significance of VR, let us see the phasor diagram under various loading condition.

- Here it is assumed that $|V|$ and $|I_A|$ remain constant while the load PF is changing

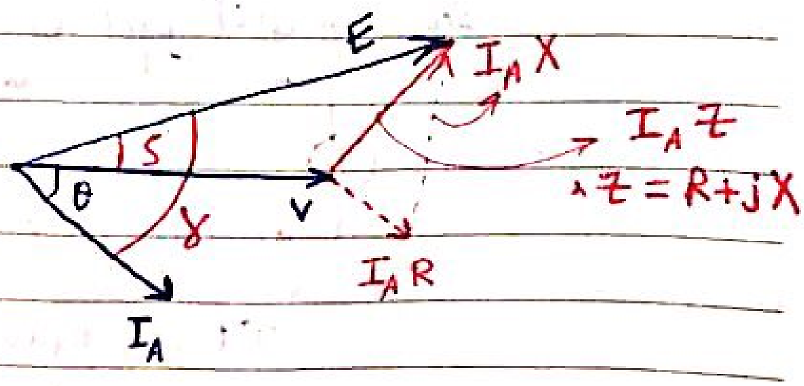
→ from fig 1.

$E \equiv$ generated voltage $= K\phi\omega$.

$V \equiv$ Terminal voltage

$I_A, I_\phi \equiv$ Armature OR phase current

→ lagging :



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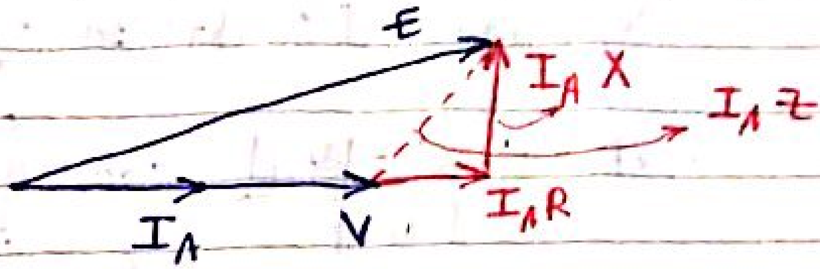
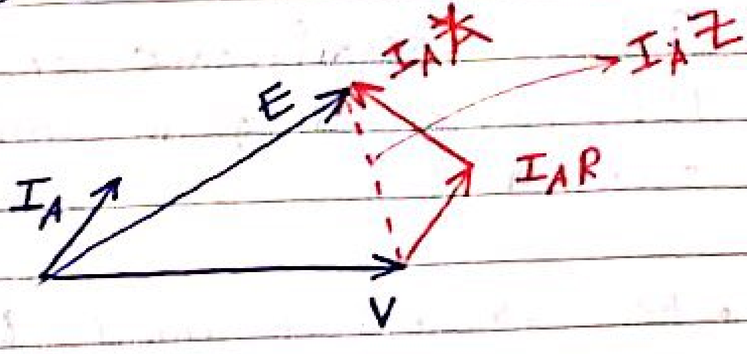
No.

→ Resistive :



→ Capacitive :



Hence it can be observed that

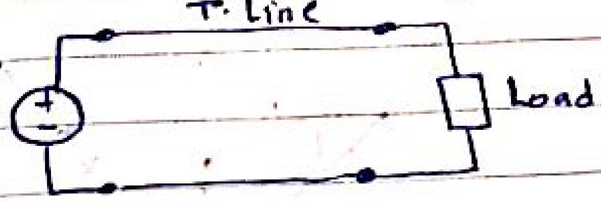
1. $E_L > E_R > E_c$

2. At same PF, it could be

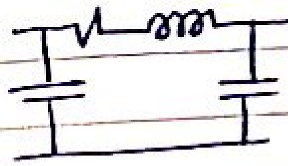
$|E_c| < |V|$

$\therefore$ VR is −ve

معلومة إضافية : تفسير أن الفولتية على out أعلى من In



T. Line Equv. ckt



ترتفع الفولتية بسبب وجود Capacitor

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No.

- Measurment of Generator parameters: (R & X)

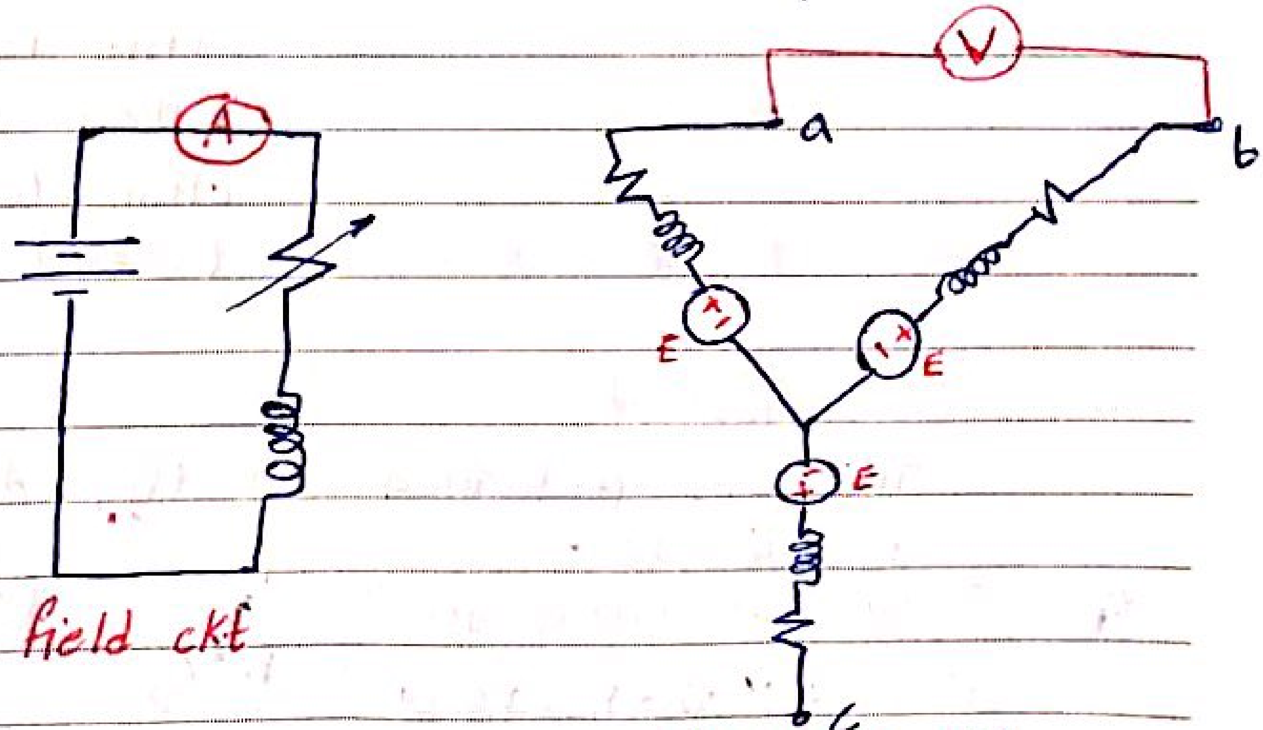
These are required in order to see the performance of the generator such as VR and η.

Procedure :-

The following tests are performed :-

O/C Test. :

1. With the terminals of the generator O/C, run it at rated speed.



field ckt

Armature ckt

2. Vary the field current, I_f, and record the corresponding terminal voltage.

$\therefore V \equiv$ generated voltage at NO-LOAD

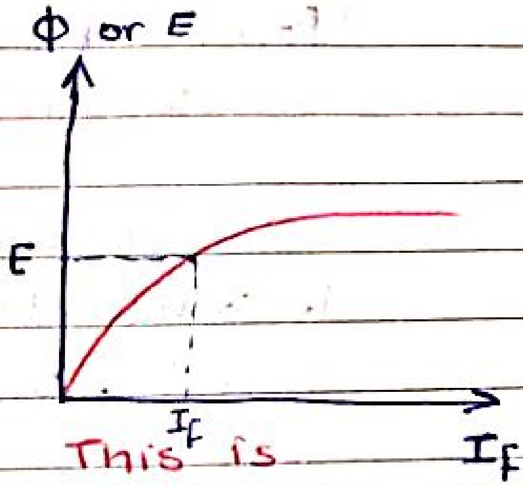
A	V, $E = \frac{V}{\sqrt{3}}$
I_{f1}	E_1
I_{f2}	E_2
$\vdots$	$\vdots$
I_{fN}	E_N

Since $E = k\phi\omega$

Since ω is constant

$\therefore E = K_1 \phi$

$\phi \propto I_f$



This is called open circuit characteristic of gen. (OCC)

DC Test :

This is performed on the Armature ckt as follows :

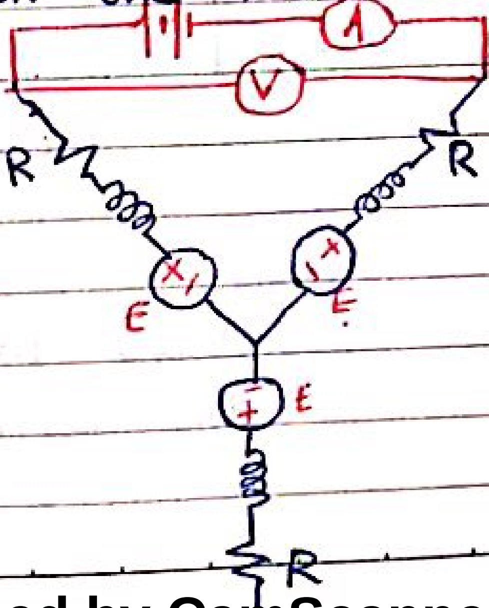
"without running gen."

في هذه الحالة لا يوجد E

بنحذفه من الـ ckt

ولا يوجد inductor

نحط مكانهم short ckt.



Since it is DC ckt, ∴ X will be SC

by KVL : $V = 2RI$

DC Resistance $R = \frac{1}{2}\frac{V}{I} = \frac{\text{Voltmeter Reading}}{\text{Armature Reading}}$

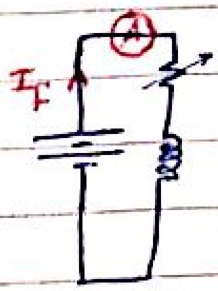
However R_a (i.e Armature resistance) is AC resistance

$R_a = R_{DC} * \text{factor}$ ↳ (1 - 1.5)

S/C Test :

1. With generator running at rate speed
2. S/C the terminals of the Armature
3. Vary the field current I_f and record I_A

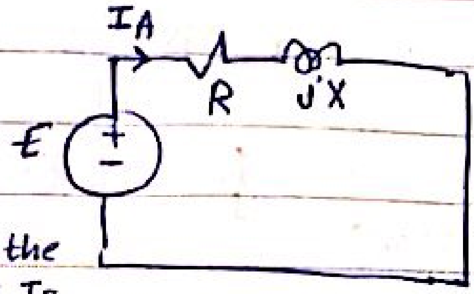
I_F	I_A
I_{f1}	I_{A1}
I_{f2}	I_{A2}
⋮	⋮
I_{fN}	I_{AN}



No.

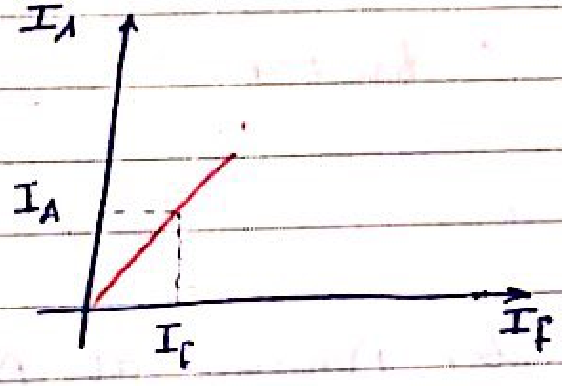
The only load on the gen., it is internal impedence.

$$E = I_A (R + jX) = I_A Z$$



$$|Z| = \frac{|E| \to O/C}{|I_A| \to S/C} \to \text{for the same } I_F$$

In the S/C test one plot I_A Vs I_F



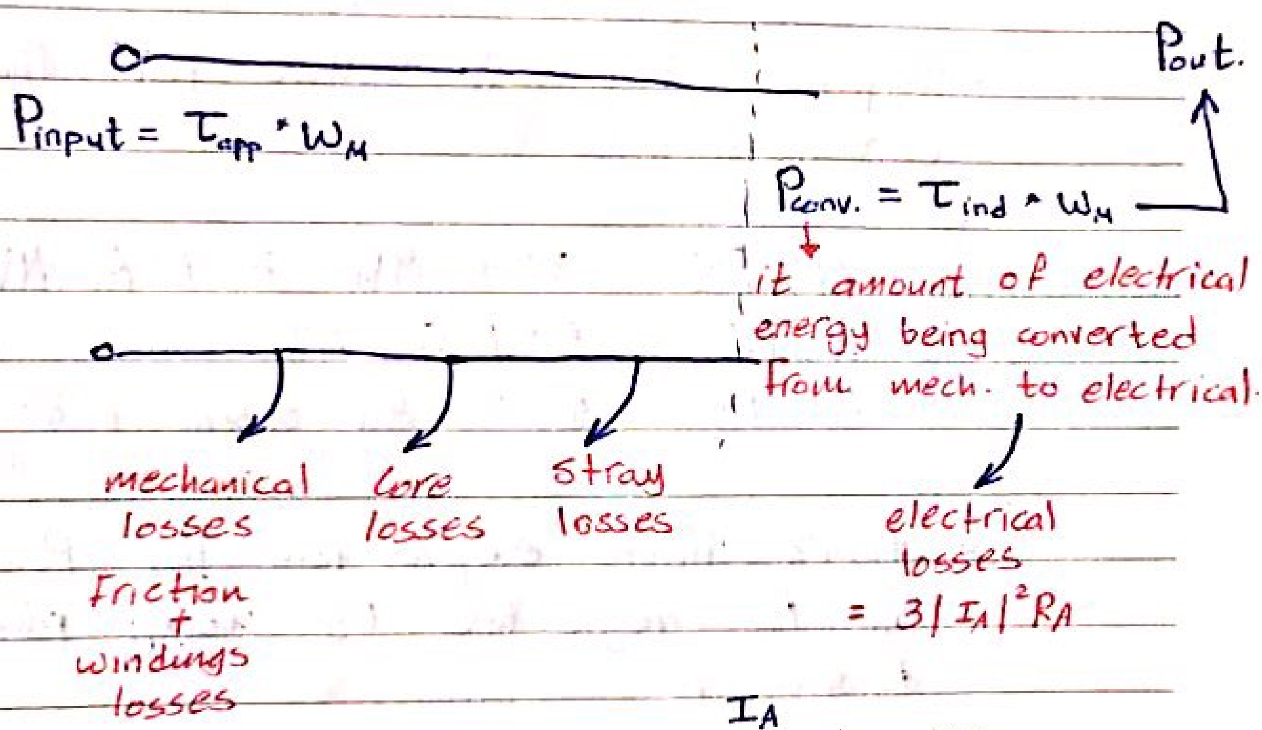
$$|Z| = \sqrt{R^2 + X^2}$$

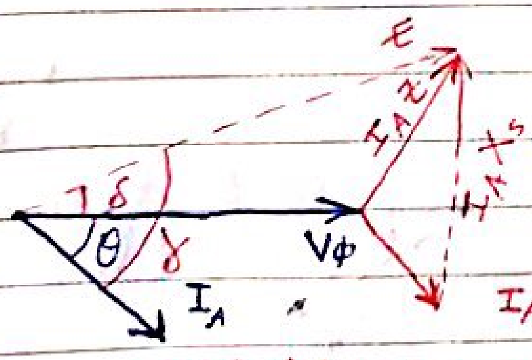
$$\therefore X = \sqrt{|Z|^2 - R^2}$$

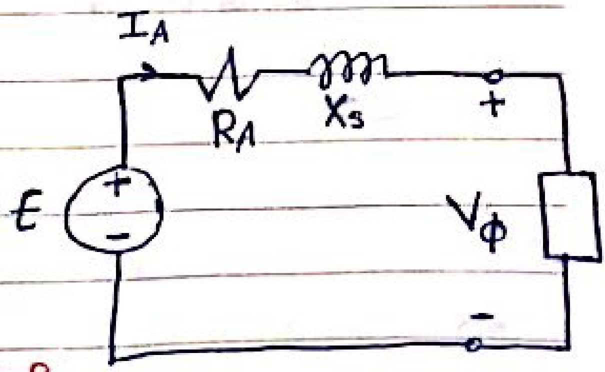
Power flow in 3-ϕ generator:

- The rotor is driven by a prime mover could be: steam, gas or hydro turbine, ... etc.

$\therefore$ P_{input} is mechanical







$$P_{conv} = 3\,|E|\,|I_A| \cos\gamma = \tau_{ind} * \omega_m$$

$$\therefore \tau_{ind} = \frac{3\,|E|\,|I_A| \cos\gamma}{\omega_m}$$

No.

$$P_{out} = 3|I_A||V_\phi| \cos\theta \quad \text{"W"}$$

Also $\quad Q_{out} = 3|I_A||V_\phi| \sin\theta \quad$ "VAR"

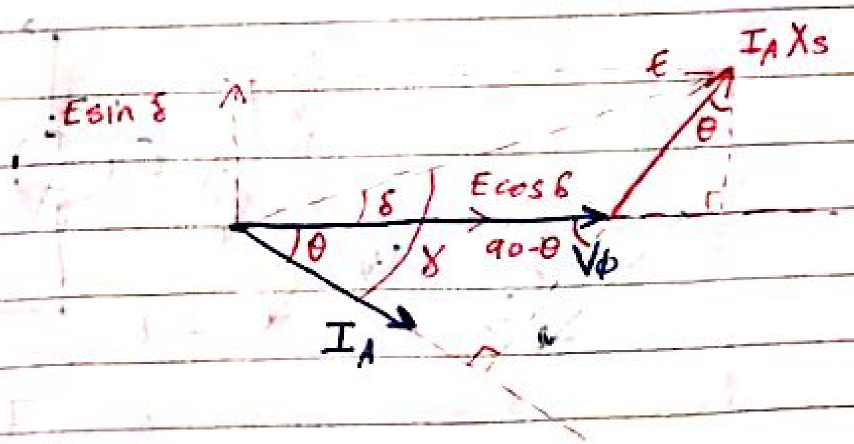
$\therefore \quad S = P_{out} + jQ_{out} \quad$ 'Complex pwr.' "VA"

$$\eta = \frac{P_{out}}{P_{in}} = \frac{P_{out}}{P_{out} + \text{losses}}$$

- Typical Practical value for P_{out} in Jordan :

1. HTPS $\quad 3 * 33$ MW + $4 * 66$ MW
2. ATPS $\quad 5 * 135$ MW
3. SCCPS $\quad 4 * 100$ MW steam + $8 * 100$ MW gas turbine.

- Approximate expression for P_{out} if R_A is neglected, by using phasor diagram :-



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No.

$E \sin\delta = I_A X_s \cos\theta$

$I_A \cos\theta = \frac{E \sin\delta}{X_s}$ ... $\boxed{1}$

Since $P = 3V_\phi I_A \cos\theta$ ... $\boxed{2}$

Subs. $\boxed{1}$ into $\boxed{2}$.

$\therefore P_{out} = \frac{3V_\phi E \sin\delta}{X_s}$ ... $\boxed{3}$

Comment:

1. Since R_A is neglected, then electrical losses are neglected.

2. P_{out} in $\boxed{3}$ $= P_{conv.}$

3. P_{out} depends on the Angle "δ" which is called Tourqe or power angle.

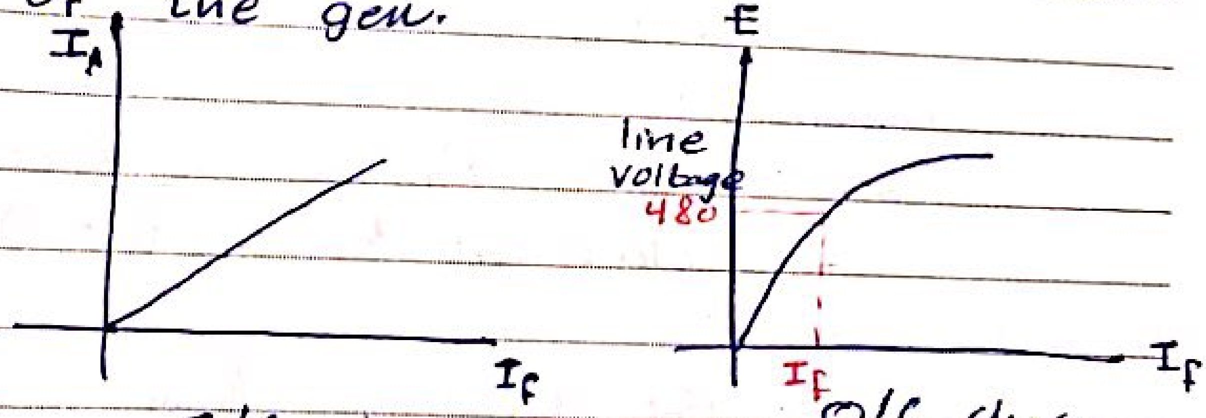
4. P_{out} is max. when $\delta = 90^\circ$.

$\therefore P_{max} = \frac{3V_\phi E}{X_s}$, This is called static stability limit

- In practice P_{out} never reach P_{max}. because δ is usually in the range (20-30)

No.

Ex : A 480 V, 200 KVA, 0.8 PF lagging, 2 pole Y-connected synch. generator has $X_S = 0.25\ \Omega$ and $R_A = 0.04\ \Omega$. At 60 Hz Friction + winding losses = 6 KW, core losses = 4 KW, stray losses are neglected. The field ckt. has a dc voltage of 200 V and max. value of $I_f = 10$ A. The field ckt. resistance is adjustable over the range (20 – 200) Ω. Also given the O/C and S/C charac. of the gen.



S/C charac.   O/C charac.

1. How much field current is required to make V_T (i.e. terminal voltage) equal to 480 V when the gene. is running at no-load.

$V_T = E = 480$ V, ∴ from the give O/C char. it can be found that $I_f = 4.55$ A

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No.

2. What is the internal gen. voltage of the gen. at rated condition from the eq. ckt. $E = I_A(R_A + jX_s) + V_\phi$ ⁓ $\boxed{1}$

$$V_\phi = \frac{480}{\sqrt{3}} \angle 0° \text{ V} \sim \boxed{2}$$

$$I_A = \frac{200 * 10^3}{\sqrt{3} * 480} \angle -\cos^{-1}(0.8) = 240.6 \angle -36.87 \text{ A} \quad \boxed{3}$$

By subs. $\boxed{2}$, $\boxed{3}$ and using given data into $\boxed{1}$, it can be found

$$E = 322.7 \angle 7.4° \text{ V}$$

3. How much I_f is required to make $V_T = 480$ V when the gen. is running at rated conditions

$$|E_L| = \sqrt{3} * 322.7 = 559 \text{ V}$$

from the o/c char., $I_f = 7A$

4. How much power and torque must the gen. prime mover be capable of supplying.

$$P_{\substack{prime \\ mover}} = P_{input} = losses + P_{out}$$

$$= 4 * 10^3 + 6 * 10^3 + 3|I_A|^2 R_a + P_{out}$$

$$= 176.9 \text{ KW}$$

$3 * (240.6)^2 * 0.04$

cont →

[illegible] 0.8)

No.

cont. 4 : $P_{in} = T_{app} * W_{in}$

$f = nP$, $f \equiv Hz$., $n \equiv rps$, $P =$ no. of pole pairs

$60 = n \cdot 1$

$n = 60$ rps

$w = 2\pi n = 120\pi$

$\therefore T_{app} = \dfrac{176.9 * 10^3}{120\pi} = 469.5$ N.m

5. find η

(200k * 0.8)
4 من

$\eta = \dfrac{P_{out}}{P_{in}} = \dfrac{160 * 10^3}{176.9 * 10^3} = 90.4\%$

No.

Short ckt. Ratio (SCR) of 3-ϕ Sync. gen. :—

This parameter is defined as follows:

$$SCR \triangleq \frac{\text{Field current required to generate rated voltage at } o/c}{\text{" " " " " " armature current at } s/c}$$

$$= \frac{I_{fV}}{I_{fI}}$$

Significance of SCR :

It can be found that :

$$SCR = \frac{1}{X_s(PU)} \quad , \quad X_s \equiv \text{sync. reactance in per unit.}$$

$\therefore$ As $X_s \downarrow$ then $SCR \uparrow$, It will be shown later that SCR is related to the reluctance of the 3-ϕ gen.

No.

Cont. Significance of SCR :-

$$SCR \triangleq \frac{1}{X_s\,(PU)}$$

at S/C

RMS Voltage.

$$X = \frac{E}{I_a} = \frac{(4.44\, f N \phi)}{I_a}$$

Since $Ni = R\phi$, R : Reluctance.

$$\phi = \frac{Ni}{R} = \frac{\digamma}{R} \quad \digamma \rightarrow \text{mmf}$$

$$\therefore \; X = \frac{4.44\, f N \digamma}{I_a R}$$

$$X \propto \frac{1}{R}$$

large SCR ⟶ small X ⟶ large R

⟶ large air gap between Rotor and stator

⟶ Hence large mmf is required from the field windings ckt

⟶ Consequently a larger size for the machine size (i.e. larger volume per KVA at the machine)

⟶ Hence higher cost.

No.

Operation of sync. generator :

This could be one of two :-

1. Generator is operating alone.
   This is rarely being used, except in certain conditions, such as :-
   a. Emergency gen. in hospital.

   b. Black start gen. in power stations.

   Its performance and analysis was described before by using phasor diagram for inductive, resistive, and capacitive.

2. Generator is operating in parallel with other generators :

Parallel operation of 3-ϕ sync. gen.

What ?

Why ? :(

How ?

No.

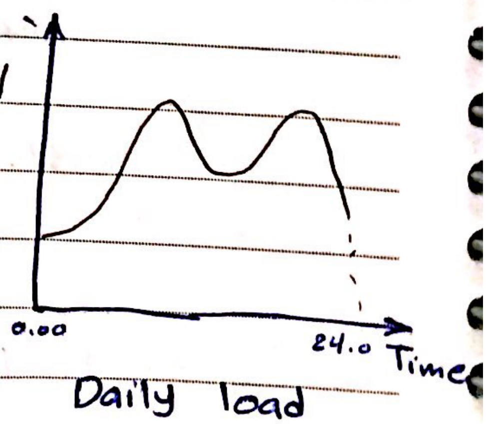
Advantages of Parallel operation :

1. A set of parallel gen. can supply more load than a single gen.

2. More Reliable, because failure of one or more generators, does not cause complete load loss. Also small cost for the reserve unit required

3. One or more units can taken for preventive maintenance

4. Units will be loaded at or near its rated capacity, hence higher efficiency.

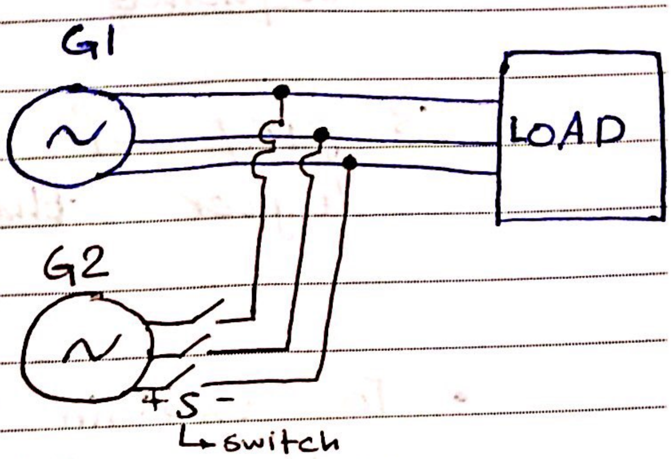


Daily load curve

No.

Procedure :-

- Initially G_1 is supplying the load.



- Nown another generator say G_2 is to be connected in parallel with G_1. G_2 is called "On Coming" generator.

Conditions for parallel connection:-

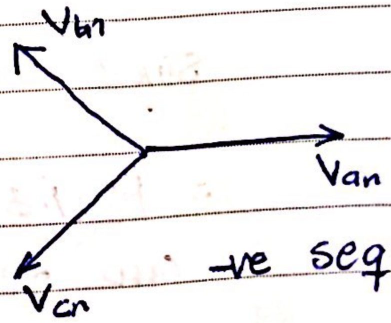
1. The Two generator must have the same voltages

$V_{an} = V_{a'n}$

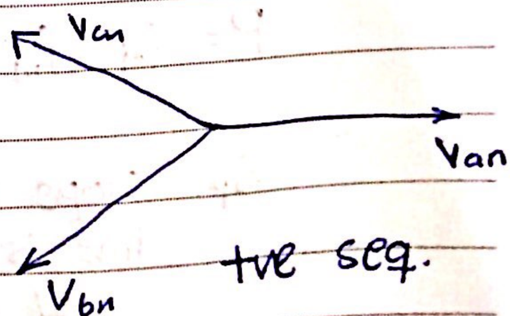
$V_{bn} = V_{b'n}$

$V_{cn} = V_{c'n}$

G_1 ← (unprimed) ; (primed) → G_2



-ve seq.



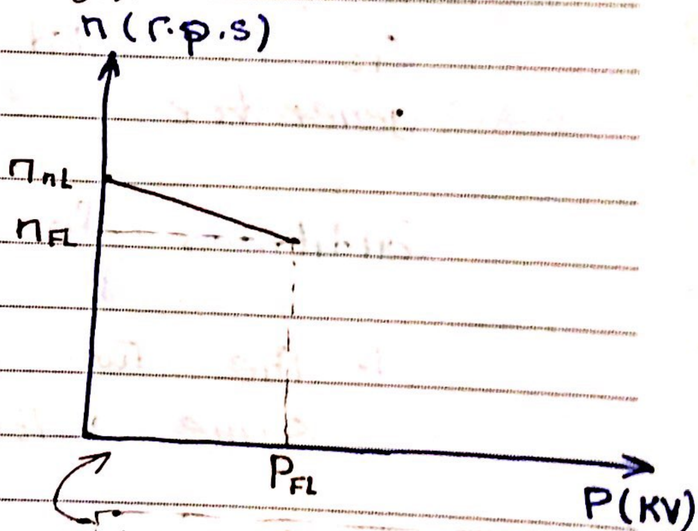
+ve seq.

No.

2. Should have the same phase sequence.

3. freq of G_2 should be slightly higher than freq. of G_1

- To explain the process of parallel operation. Consider the following Block diagram of 3-ϕ gen.



Hence there is what is called speed drop (SD)

$$SD \triangleq \frac{n_{nL} - n_{FL}}{n_{FL}}$$

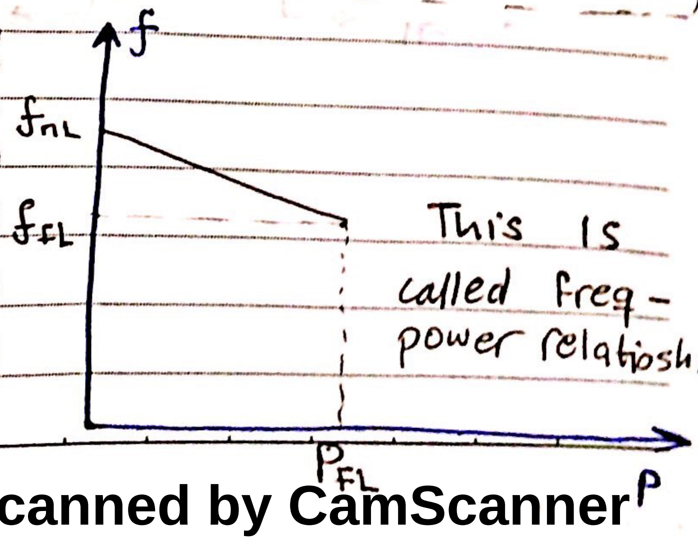
since $f = nP$

$\therefore$ P (i.e P_{out} of gen.) can be expressed as:

by using governor the drop in speed is must linear.

$$P = S_P \left(\frac{f_{nL} - f_{sys} \text{ OR }}{f_{FL}}\right)$$

S_P: slope of the line is (KW or MW / HZ)



This is called freq - power relationship

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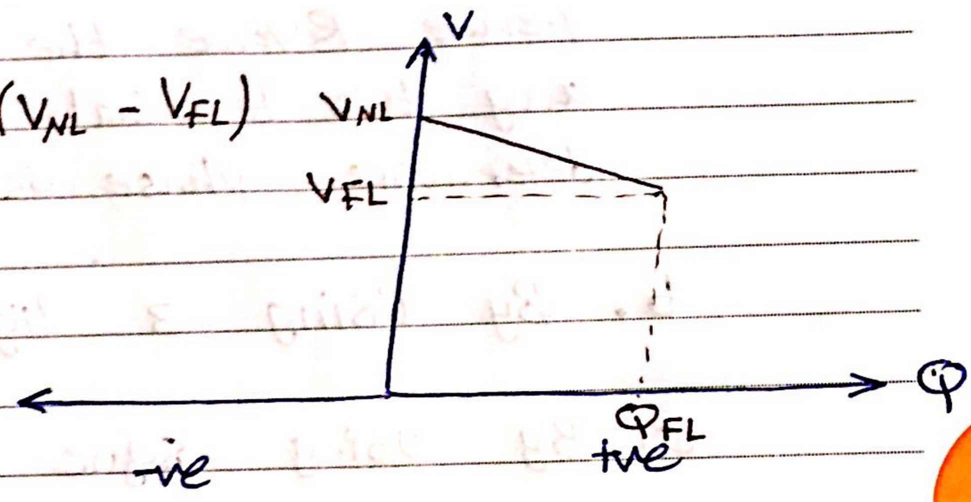
No.

- Regulator is used to control I_f ... ... $\rightarrow \phi \rightarrow E$

Hence there is a relationship between Q and V (terminal voltage)

$$Q = S_Q (V_{NL} - V_{FL})$$



Practical steps for achieving parallel operation (OR synchronization):-

1. By using a voltmeter and adjusting I_f by means voltage regulator, make $V_{RMS}(G_2) = V_{RMS}(G_1)$.

2. To check the phase sequence one of the followings is used :-

   a. By connecting a 3-ϕ induction motor, first to G_1 and observe its direction of rotation. Then reconnect it to G_2 and observe direction of rotation :-

No.

i - If direction is the same, Hence G_1 and G_2 have the same phase seq.

ii - " " is not the same, Hence Reverse the connection of any two terminals In order to determine phase seq.

b. By Using 3 light bulbs method

c. By using sync device